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Research Articles

Dual-Use and Emerging Space Technologies: Drivers of Militarization and the Governance Deficit

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Abstract

The rapid diffusion of space technologies, both established dual-use systems (e.g., GNSS, Earth observation, and launch vehicles) and emerging technologies (e.g., autonomous on-orbit servicing, robotic satellites, and AI-enabled space systems), is reshaping strategic competition in outer space and exposing fundamental weaknesses in extant governance regimes. This paper investigates how the technical affordances of dual-use and emerging space technologies facilitate militarization, and why existing legal and normative instruments are ill-equipped to prevent their progressive weaponization. The analysis identifies three mechanisms linking technology to militarization: functional convergence (civilian systems repurposed for military ends), capability diffusion (commercial innovations lowering thresholds for military use), and operational opacity (limited transparency and verification enabling strategic ambiguity). It further maps governance gaps, exploring the arenas for cooperative space governance. The study adapts methodological foundations from secondary sources and theoretical ground from neorealism, neoliberalism, and security studies.

Keywords Dual-use, emerging technologies, space militarization, governance, verification, space policy.

Introduction

States have historically exploited the domain of outer space to pursue their interests, both civilian and military, and the Cold War period witnessed the dramatic use of outer space as a competitive domain. Even so, scientific advancements and space innovations drove the competition. American celestial accomplishments are considered to have outpaced those of the Soviets during the period, primarily due to the development of more sophisticated space technology, with private entities contributing to the innovation and development of space technology (Brown, 2011). By the 21st century, more states have ventured into outer space to explore the vast cosmos, and competition has taken a different dimension. Commercial entities have increased in number and contribution level. The state-centric model of exploring and exploiting outer space has now evolved into a mixed model involving private entities, primarily to stay ahead in technological innovation. This mixed model has led to the emergence of new technologies apart from the existing dual-use systems and has accelerated the utility of the outer space domain. The rapid advancement in technological progress in outer space, while accelerating progress on one hand, also surpasses existing governance mechanisms by militarizing the domain. This paper is built to address two major questions: how do dual-use and emerging space technologies facilitate the militarization and potential weaponization of outer space? And why are current governance frameworks failing to address this challenge?

The paper argues that functional convergence, capability diffusion, and operational opacity link militarization and technology and are systematically lowering the barriers to and increasing the incentives for space militarization, thereby exposing critical vulnerabilities in a governance regime designed for a bygone era.

The paper proceeds by first reviewing the discourse on militarization and weaponization before looking at the theoretical perspectives. It then develops an analytical framework centered on three mechanisms linking technology to militarization, and subsequently maps the corresponding governance deficits before conclusion.

1. Discourse on Space Militarization and Weaponization

Even before the launch of the Sputnik satellite by the Soviet Union, which marked the beginning of the space age, the United States had plans to build a world-circling spaceship with potential military applications (Hays, 2011).The development of photo-reconnaissance and intelligence-gathering satellites by the US was a way to monitor the Soviet Union and their developments (Hays, 2011, p. 3). Later, the heightened tensions of the Cold War were not limited to the Earth alone; they extended far up into space. Similar to the arms race on Earth, the space race was initiated by the Cold War powers. It was never limited to scientific advancements but to military applications as well. They developed and deployed satellites to be used for meteorology, communication, and early warning, among others (Mowthorpe, 2004). Assets based in space could provide information regarding activities of national concern, including military communications, position-navigation-timing, missile early warning systems, missile targeting, movement of military troops and fleets, and intercept signals from adversaries, apart from civilian necessities. Satellite deployments and exploration activities have contributed to the military power of respective countries, particularly in intelligence gathering, reconnaissance, and understanding capabilities of the adversary, and thus need a focus. In this way, space assets could ensure overhead surveillance over a state's territory as well as over that of an adversary. It can be seen that the Cold War, through the deployment of military-spy satellites, had a significant role in assigning space as a military domain (Muszyński-Sulima, 2023).

The Cold War and early post-Cold War years could demonstrate the military uses of space assets as in the Gulf War of 1991, the Kosovo War of 1999, the Afghanistan intervention in 2001 and Iraq intervention of 2003 which demonstrated the space-enabled warfare abilities including GPS-enabled precision strikes, weather calculations for attack, battlefield coordination and target acquisition through intelligence, surveillance and reconnaissance (ISR) (Cheng, 2012). It also demonstrated the changing nature of warfare, which demanded information domination over the adversary to have a complete battlefield picture and situational awareness (Cheng, 2012, p. 58). Thus, space militarization was necessary to ensure battlefield intelligence and to secure a win in warfare. That said, there are diverse arguments regarding the militarization of space, with some scholars asserting that its initial phases were predominantly defensive, whereas contemporary developments indicate a shift toward more offensive capabilities, while others argue that space has always been militarized. Others argue that space was not just militarized but has been weaponized. The source of these diverse arguments stems from the ambiguity in defining what space militarization is and how it is different from space weaponization. Matthew Mowthorpe defines space militarization as "the use of assets based in space to enhance the military effectiveness of conventional forces or the use of space assets for military purposes" (Mowthorpe, 2004, p. 3) and space weaponization as "weapons based in space or weapons based on the ground with their intended targets being located in space" (Mowthorpe, 2004, p. 3). However, the principles of the OST are not complementary to Mowthorpe's definition. It limits certain activities in space, predominantly weaponization. It calls upon "states to refrain from placing in orbit around the earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction or from installing such weapons on celestial bodies" and "the establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military maneuvers on celestial bodies shall be forbidden" (UNOOSA, 1967).

It can be seen that the 1967 Outer Space Treaty (OST) categorizes only weapons of mass destruction (WMD) and nuclear weapons in orbit as weaponization, leaving loopholes for states to exploit the same (UNOOSA, 1967). All these would have adequately captured the military uses of space, except for the changes in warfare, technology, and the military potential of space. Over the past two decades, warfare has evolved significantly. The objective is no longer just physical dominance, but information superiority through space assets as well as denying the adversary's access (Berge, 2024). Achieving this increasingly depends on space-based systems such as satellites, as well as the ground infrastructure that supports them. Thus, the scope of what constitutes a 'space asset' has broadened. Today, space assets can be space-based (satellites, spaceships, space stations, etc) and ground-based (control and tracking centers, ground stations, launching facilities, etc). The military use of these assets, whether for surveillance, navigation, communication, or coordination, clearly falls under the realm of militarization. These are tools that support military effectiveness without necessarily being weapons themselves. However, as rivalries intensify and states seek to deny adversaries access to space, a new set of technologies has emerged - counterspace weapons. These are specifically designed to disrupt, disable, or destroy an opponent's space systems (Moltz, 2024, p. 138). These can be hard-kills, causing physical destruction to assets, and soft-kills, where it does not physically damage assets but can disable, disrupt, and damage satellite functioning, causing reversible damage (Bowen B. E., 2022, p. 250). In the soft-kill case, technology is used as a military tool, essentially militarizing technology. Bowen categorizes space weapons into three operational domains: earth-to-space, space-to-space, and space-to-earth.

Earth-to-space weapons: These are ground-based systems, such as kinetic kill vehicles, anti-satellite (ASAT) missiles, and directed energy weapons, which target satellites or other objects in space (Bowen B. E., 2022, p. 246). While these weapons are launched from Earth, their intended targets are in orbit, which technically makes them part of space weaponization under Mowthorpe's definition. However, the OST does not explicitly prohibit such ground-based systems, allowing states to exploit this legal gap.

Space-to-space weapons: These include soft-kill technologies like lasers, microwave weapons, jammers, robotic arms, and cyber tools installed on orbiting platforms (co-orbital) (Bowen B. E., 2022, p. 258). Though they are capable of disabling or disrupting other satellites, they are often embedded within dual-use systems and can be framed as part of a satellite's defensive or operational functions. Because the OST only bans nuclear weapons or weapons of mass destruction in space, soft-kill weapons remain in a legal grey area. Their presence blurs the line between military support and actual weaponization.

Space-to-earth: This is the most speculative category and refers to hypothetical systems capable of launching attacks from orbit toward targets on Earth. Examples 4 include kinetic orbital strike systems like orbital bombardment (Bowen B. E., 2022, p. 277). No state has deployed such systems, and they would almost certainly violate OST provisions if developed.

The OST, while foundational, is limited in its scope. It prohibits the placement of nuclear weapons or other weapons of mass destruction in orbit and bans military activities on celestial bodies, but it says little about non-nuclear, dual-use, or ground-based systems (Ferreira-Snyman, 2015). As a result, many states have continued to develop and test counter-space capabilities without breaching the treaty's letter, if not its spirit. This loophole enables nations to field advanced technologies designed for hostile purposes while technically maintaining a non-weaponized stance in space. For example, a satellite carrying a laser jammer can be described as a communications or navigation satellite, depending on its mission profile, even if it holds the potential to disable adversary assets. Given the complexity of the current space environment, the definitions of militarization and weaponization require updating. Militarization today encompasses the integration of both space-based and ground-based assets for military advantage as well as denying the adversary's access. Weaponization, by contrast, implies the active deployment of weapons of hard-kill nature in space against space-based assets or against ground-based assets. Here, direct-ascent ASAT weapons, although offensive and hard-kill in nature, would not fall under weaponization since OST implicitly provides a gray area. Also, ASAT tests by countries have only been employed against their assets, but with the potential to do the same against other assets. Thus, they can be considered as part of space militarization, aimed at strategic deterrence, because the lines between space militarization and weaponization are increasingly becoming blurred. While we have not yet reached a fully weaponized space environment (since no space-to-Earth or space-to-space hard kill systems have been deployed), we are witnessing a strategic and technological convergence, a blend of militarization with latent weaponization capabilities.

While scholars agree on the blurring of militarization and weaponization of outer space and acknowledge the role of dual-use space technology in facilitating the same, this paper offers a systematic analysis of the causal mechanisms through which dual-use and emerging technologies accelerate the militarization of space. Additionally, the paper explores the governance deficit as a causal factor, as well as a stage for enhanced governance.

2. Theoretical Lenses

2.1. Neorealism

The neorealist argument of space militarization is grounded in the structural anarchy of the international system. Since outer space is also a domain governed by anarchy, i.e., the absence of a hierarchy to bring order, states are primarily concerned with survival and will seek to maximize their relative power and security. In an anarchic world where no central authority exists to enforce rules and bring order, states cannot be certain about one another's intentions (Mearsheimer, 2014). As a result, they are compelled to act in ways that maximize their power and security, even if it means taking assertive actions. This logic fits well within the space domain, where dual-use technologies, such as satellites capable of both civilian and military applications (Cannon, 2023), further complicate understanding of the actual motive. Since no state can be fully confident about the purpose of another's space capabilities, mistrust and competition naturally follow. The ambiguity surrounding space systems reinforces the basic tenets of offensive realism: the pursuit of power, the centrality of survival, and the impossibility of fully knowing others' objectives (Hudson, 2022). Hence, in space, states would seek to maximize their capabilities, leading to the militarization of space. For defensive realists, security-seeking motives gain an upper hand over power maximization that leads to security. For this reason, the logic of the security dilemma from Security Studies applies with defensive realism, whereby a state's efforts to enhance its own security unintentionally generate a sense of threat in other states, prompting them to strengthen their own security measures. These responses then feed back into the original state's threat perceptions, resulting in a cycle of mutual insecurity. In outer space, where the intent and motive of other states are unknown, and where dual-use and emerging technologies have an upper hand, the security dilemma can be traced.

3.2 Neoliberalism

Neoliberalism, while accepting the condition of anarchy, offers a more optimistic view regarding the potential for cooperation. Neoliberals argue that institutions, regimes, and norms can mitigate the security dilemma by reducing transaction costs, increasing transparency, and facilitating repeated interactions that build trust. Neoliberal institutionalism argues for the establishment of institutions to increase cooperation (Jervis, 1999). However, for institutions to be established, actors would need to have cooperation as the desired outcome. Neoliberal approaches assume that by lowering transaction costs and increasing transparency, states and other actors will naturally move toward cooperation. In practice, however, the rapid commercialization of space has made this more difficult. As private and state-linked actors gain uneven access to information and advanced capabilities, mistrust grows rather than diminishes, weakening confidence-building efforts instead of reinforcing them. Governance deficits, therefore, emerge because existing institutions, largely inherited from Cold-War-era treaties, cannot monitor or verify the proliferating constellation of dual-use technologies, leaving the domain susceptible to militarization (Burke-White & Williams, 2025). Hence, the challenge of governance deficit can be met with transparency and confidence-building measures that align the interests of the actors with cooperative outcomes. Neorealism predicts that rising dependence on space assets and ambiguous intent will produce security-seeking or power-seeking countermeasures, and neoliberal institutionalism predicts that where credible transparency and verification exist, cooperative restraint is possible. While existing literature capably describes the symptoms of space competition and critiques governance shortfalls, there is a need for a more systematic, mechanism-driven analysis of the causal links between modern technology and militarization. This paper seeks to fill that gap. It moves beyond stating that dual-use technologies are problematic to explain how and why they drive militarization through specific, identifiable mechanisms. By grounding these mechanisms in current technological case studies, this paper attempts to analyse a core challenge in space security.

3. Methodology

This paper uses a qualitative, theory-guided process-tracing approach to link technological affordances to observed patterns of militarization. The method is used to assess whether the cases follow a sequence, beginning with uncertainty about intent and ending with observable militarization-oriented responses. Three purposively selected cases are analyzed, including Global Navigation Satellite Systems (GNSS), commercial Earth observation, and autonomous on-orbit servicing, chosen to capture possible variations in technological maturity, actor type, and publicly available evidence. Sources include peer-reviewed articles, books, official government statements, strategy documents, and technical reports. Limitations include reliance on open sources and the focus on illustrative cases.

4. Mechanisms Of Space Militarization

4.1. Functional Convergence

Functional convergence refers to the inherent ability of a system designed and operated for civilian or commercial purposes to perform military functions with minimal to no physical modification. Outer space systems are designed with respect to functional convergence properties to repurpose them for military effect. In an anarchic space environment marked by uncertainty over intentions, functional convergence blurs the civilian–military boundary in ways that intensify security dilemmas, as states increasingly view civilian space assets or non-military capabilities as potential threats, thereby encouraging defensive protection, denial strategies, and countermeasures. Navigation satellite systems, earth observation systems, and potential multi-functional systems are all examples of the same. Systems like GPS (USA), Galileo (EU), GLONASS (Russia), and BeiDou (China) are public goods providing critical timing and positioning data for global transportation, finance, and communication. Militarily, however, GNSS is a force multiplier. Its civilian signals also enable military precision, synchronization, and situational awareness (Larsen, 2001). It is fundamental for the navigation of troops, the guidance of precision munitions, and the synchronization of military operations. The 2022 conflict in Ukraine has starkly illustrated this, with both sides heavily reliant on GNSS for drone operations and artillery targeting, while simultaneously engaging in jamming and spoofing attacks (Jhanjhi, et al., 2025). The civilian infrastructure is, de facto, a core military infrastructure. Similarly, earth observation systems, particularly those employed for commercial applications, resonate with the mechanism. The revolution in high-resolution, high-revisit-rate satellite imagery, led by companies like Maxar Technologies, Planet Labs, and Airbus, has democratized access to strategic intelligence. During the Ukraine conflict, commercial EO from entities like Maxar, Starlink, etc., provided near-real-time imagery of Russian troop buildups, battlefield damage assessments, and evidence of alleged war crimes, which were used by Ukrainian forces and publicized by governments (Kostenko & Manzhula, 2025). This represents a direct, functional convergence where a commercial commodity becomes a pivotal tool for strategic intelligence, surveillance, and reconnaissance (ISR), erasing the line between commercial remote sensing and military spy satellites.

5.2 Capability Diffusion

Capability diffusion describes the process by which commercial innovation, economies of scale, and market competition dramatically lower the cost and technical barriers to acquiring advanced space capabilities. Innovations favouring small satellites, mega constellations, commercial launches, and reusable rockets are contributions to capability diffusion. While capability diffusion has contributed to the democratization of space-access with more and more actors engaging in the frontier, it also raises the question of who genuinely has this expanded access.

Commercial innovation, market competition, and reduced technical barriers have allowed a greater number of states and private entities to participate in space activities, especially through small satellite deployment and new launch options, suggesting a trend toward broader inclusion and equity in space access. Such trends underlie the narrative that space is becoming more accessible to emerging space nations and non-traditional players beyond the historic space powers (Peeters, 2025). The problem is not simply that more actors are present in orbit, but that capabilities once associated with high-end military systems are now embedded in commercial platforms with ambiguous intent and dual-use functionality. The CubeSat standard and advances in miniaturization have reduced the cost and time for the development of satellites. This shift has enabled commercial actors to operate constellations consisting of hundreds of small satellites, providing continuous Earth-observation capabilities that were previously associated with government-run programs (Hallex & Cottom, 2020). Reduction in launch costs driven by reusability and modest investment, even for the deployment of dedicated ISR constellations, has made space faring affordable and reliable, but it has also increased the complexity of the space environment. They make it easier to put military systems into orbit as well. Capabilities such as direct-ascent anti-satellite weapons, on-orbit inspection spacecraft, or coordinated satellite swarms become simpler to deploy when access to space is cheaper, more frequent, and less technically demanding. The same technological advances that underpin a thriving commercial space sector can also, unintentionally, intensify military competition by reducing the practical and economic barriers to escalation in space (Bowen, 2020). Capability diffusion complicates neoliberal institutionalist assumptions, as expanded access through markets increases the salience of governance and verification while simultaneously producing asymmetries that undermine transparency and erode the cooperative dynamics institutions are meant to foster. At the same time, it creates and reinforces security dilemmas since it deepens uncertainty about intentions, prompting actors to take reciprocal measures, which fuel militarization. The increased number of actors tends to create insecurity and multiply threat perception. The lowered costs of launches and development of space systems equally lowered the cost of competition. This could make ASAT weaponry cheaper and therefore preferable.

5.3 Operational Opacity

Operational opacity stems from the technical characteristics of emerging technologies that create ambiguity in intent. It becomes difficult or impossible for an external observer to distinguish between peaceful and hostile activities, thereby complicating attribution, eroding trust, and enabling 'grey zone' aggression below the threshold of armed conflict. On-orbit servicing, assembly, and manufacturing (OSAM) technologies illustrate one of the most striking dual-use dilemmas in space security today. A servicer equipped with a robotic arm, grappler, or refueling nozzle may be designed for benign purposes such as life-extension, debris removal, or in-space assembly, like the rendezvous and proximity operations, but the same physical capabilities can enable close approaches, inspection, grappling, or even interference with another satellite's operations (Porras, 2019). Capabilities developed for servicing or active debris removal could, if misused or repurposed, degrade or disable space assets and thus blur the line between peaceful and threatening activity. The inherent ambiguity of such systems is evident in contemporary orbital behavior. For example, Russia's so-called 'nesting doll' satellites, Cosmos-2542 and its deployed sub-satellite Cosmos-2543, have performed extended close approaches near a U.S. reconnaissance satellite (Jenkins, 2024). Also, Shijian-21(SJ-21), launched in 2021, successfully exhibited rendezvous and proximity operations (RPO) by docking with an out-of-service BeiDou-2 G2 navigation satellite, flying it to a temporary disposal graveyard orbit, and 40 returning to GEO. A similar robot grappling feature was reportedly exhibited by SJ-17 as well (US Department of Defense, 2024). Similarly, the digitization of satellite command and control and the use of internet-protocol-based links create vulnerabilities and opacity, resulting in fields for cyber and electronic warfare. Soft-kill weapons such as lasers, jammers, and cyber-attacks are employed in this dynamic. These are as lethal as kinetic-kill weapons but are usually non-collidable in nature and can be used to destroy and disable space systems, with the advantage of deniability in cases of accusations. This opacity provides a permissive environment for constant, low-level testing of an adversary's defenses and resilience without triggering overt retaliation. Operational opacity deepens insecurity in space by obscuring intent and making even routine actions appear threatening. When states cannot reliably verify what others are doing, they are more likely to assume worst-case scenarios and take precautionary measures to protect themselves. This uncertainty strengthens the security dilemma, as actors respond not to confirmed threats but to perceived vulnerabilities. At the same time, opacity erodes the very conditions that neoliberal cooperation depends upon, like transparency, information sharing, and trust. Without credible insight into others' behavior, institutions lose their ability to reassure, and cooperative frameworks struggle to function as intended.

5. The Governance Deficit

The 1967 OST remains the cornerstone of space law. While its principles, such as the non-appropriation of celestial bodies and the freedom of exploration, are enduring, its utility for managing contemporary security threats is severely limited. Key terms like 'peaceful purposes' are subject to weaker interpretations, permitting militarization to an extent, while neither distinguishing nor banning weaponization (M.Cervino & Davolio, 2003). Its narrow focus on weapons of mass destruction does not properly define that space weapons, ASATs, and soft-kill weapons are undefined (Ferreira-Snyman, 2015). The treaty is crafted for states as actors, leaving the regulatory status of private entities ambiguous.

The three mechanisms listed above adequately map the governance gaps in international laws concerning outer space. The governance deficit in outer space cannot be understood simply as a gap in law or an absence of institutions. Rather, it reflects the deeper structural pressures created by security dilemma dynamics that are intensified by dual-use and emerging technologies. International law struggles to regulate a technology based on its potential use. Export control regimes like the Missile Technology Control Regime (MTCR) are slow to update, can be circumvented via globalization, and often fail to capture commercial components. There is no legal instrument to prevent a nation from using globally available, high-resolution commercial imagery for military targeting, as it is a passive use of a commercial product. Also, there are no international limits on the number of satellites launched, the size of constellations, or the frequency of launches. While the UN Committee on the Peaceful Uses of Outer Space (COPUOS) focuses on long-term sustainability guidelines, these are non-binding (Ancona, 2025). The commercialization of key technologies means they are sold on the open market, effectively diffusing potential military capabilities to any entity with the capital to purchase them. Similarly, there is currently no comprehensive international agreement that defines safe and responsible behavior in orbit, particularly for rendezvous and proximity operations (RPO). While RPOs have become more common due to on-orbit servicing, inspection, and debris-removal technologies, there is no universally accepted set of keep-out zones, mandatory notifications for close approaches, or clear rules distinguishing passive from active inspections in Earth orbit (Johnson, 2020). The vulnerability exposed by cyber and electronic warfare does not possess any regulatory mechanisms, alarming the heightened deficit in space governance. Although new initiatives like Artemis Accords, EU-led International Code of Conduct, etc. emerges, the geopolitics rooted in specific national interests brings in question the authenticity of viewing space as a global common. Hence, the current landscape is fragmented and has the potential to exacerbate terrestrial geopolitical divides.

6. Conclusion

This paper has argued that the ongoing militarization of space is being driven systematically by the intrinsic affordances of dual-use and emerging technologies. Through functional convergence, capability diffusion, and operational opacity, these technologies are lowering the barriers to entry, increasing the incentives for military use, and creating a strategically ambiguous environment ripe for miscalculation and conflict. The existing governance regime, anchored in the outdated Outer Space Treaty, is fundamentally ill-equipped to manage these challenges, resulting in a dangerous governance deficit that lags far behind the pace of innovation. The findings strongly support a neorealist interpretation of space security dynamics across all three mechanisms - functional convergence, capability diffusion, and operational opacity. States respond to technological ambiguity by engaging in security-seeking behavior consistent with the security dilemma. Dual-use and emerging technologies intensify uncertainty regarding intent, increase insecurity with an increased number of players, and blur standards of ambiguity, causing escalation to a security dilemma. To address these challenges, a pragmatic approach to governance is needed. This does not imply that cooperation via neoliberal institutionalism is impossible; rather, it suggests institutionalism as the solution. Governance efforts must be mechanism-specific, technologically informed, and capable of reducing uncertainty at the operational level. Apart from building norms and transparency through confidence-building measures, diplomatic engagements like sanctions and moratoriums by governance institutions are necessary on kinetic-kill tests. The role of non-state actors has to be managed along with the management of commercial space situational awareness. Ultimately, progress will likely require a combination of binding measures that are politically feasible and incorporated through a structured international regime.

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