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Conflicts in Orbit: Constraints and Possibilities in Anti-Satellite Warfare

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TABLE OF CONTENTS

INTRODUCTION

On October 4th 1959 - the first time in human history - one man-made object, a curious-looking spherical contraption made mostly of aluminium, breached the lower layers of the atmosphere and managed to reach orbit . The ball maintained that orbit for barely a couple of months, and by January it had already re-entered the atmosphere, flickering across the sky as it was consumed by heat and friction. The name chosen for that auspicious but unassuming sphere by its Soviet inventors was *Sputnik-Odin*, or *Satellite-One,* both the Russian and English words being used to describe celestial objects that orbit another, bigger object, and both sharing the same etymology: that of likening these objects to travellers[1] and companions. Aptly so, as asters such as the Moon, the Sun, Mars and Venus and stars like Sirius and the North Star have been "following" humanity since its first steps. Space has been a constant companion and source of wonder throughout the history of our species, providing key guidance in both navigational and spiritual matters (Rappenglück, 2011); yet only recently (at least in historical terms) has humanity been able to truly tap into the scientific, economic and strategic potentials of outer space. Ever since the launch of Sputnik-1 space has slowly but surely entered numerous facets of our societies and economies, reaching a point of fundamental relevance in most aspects of our daily lives (ESA, 2005; OECD, 2007): space transmits our television programmes, tells us which way to go in an unfamiliar city, gives us the ability to predict the weather, forecasts droughts and floods, helps us manage events and crises, allows us to access the Internet in the middle of a desert or the Amazons and so much more. As both the size of humanity's collective space infrastructure and its economic weight

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[1] Specifically, *спутник* (*sputnik*) was coined in the 19th century to refer to astronomical satellites, and literally means "fellow traveller", while *satellite* has its origin in the latin *satelles*, meaning "attendant", or "follower".

burgeon like never before, its importance does as well, not just to the private individual or the firm, but to international organisations and to states.

A now key domain in strategic matters (Starling, Massa, Mulder & Siegel, 2021), standing side by side with the traditional (land, sea and air) and the novel (cyberspace), space is more than ever a matter of national security for powers great and small, and as it is more and more "filled" with infrastructure and assets, most of them extremely expensive and sophisticated, questions of security are pushed to the fore: do countries need to actually defend their space assets from more than errant debris, meteorites and solar flares? The continued development - starting from just a couple of years after Sputnik 1's flight - of so-called ASAT (antisatellite) weapons, meant to either discourage attacks or preemptively strike, suggests that indeed governments and firms have reasonable cause to doubt the physical security of the satellites and constellations they own and operate. While the typology of ASAT attacks will be presented later in more detail, suffice to say that there's a significant breadth of vectors that countries at conflict can use to disable or destroy each other's space assets. While a number of historical processes put a damper on the development and implementation of ASAT capabilities, with the increasing multipolarity (and accompanying instability and competitiveness) that seems to characterise the current international system (Peters, 2022) security and resilience of space assets has become a foremost concern for most international actors. Demonstrations of physical destruction of space assets have only been done by a small set of countries on their own satellites (Bugos, 2022) – by using, for the most part, repurposed ballistic weapons– resulting in certain cases in international backlash; all the while, attacks of the non-destructive or cyber variety are entering centre-stage as a paramount security issue, and there's an increased call for revamping space governance on a security basis from the US, its allies (Ortega & Cesari, 2022) and to a certain extent the international community at large (UN General Assembly, 2023). The ease with which the US, Russia, China and India have shot down their own satellites in tests -often publicised and dramatised- of military might raises a series of questions in terms of international security and the future of mankind in outer space. These questions tell us that events in the space domain are taking us into uncharted waters, where safe navigation is difficult and demanding on the captains and the ships involved. Since Sputnik first breached orbit, more than seventy years have passed and no country has ever attacked another in space. Is this about to change? If so, why, how and when?

This thesis hopes to answer a question that is becoming more and more relevant by the day: what are the chances we will witness attacks on space infrastructure in our lifetimes? What forms will it take if conflict is brought to the one realm of human progress still untouched by violence and war? By employing a pluralist and analytically eclectic (Sil & Katzenstein, 2010) approach, taking into account various theoretical frameworks and contributions to the literature of International Relations, such as geopolitics, the analytical tradition of bounded rationality, we shall examine the factors that can influence the emergence of hostilities, physical or otherwise, in space. We will endeavour to prove that a series of important factors, such as the intrinsic characteristics of the space environment, the public perception of outer space as peaceful and collaborative, the heterogeneity of weapons available and the interconnectedness of space infrastructure actively discourage destructive or strongly disruptive actions in space between great powers, as well as between great and smaller powers. Our analysis will find that most countries have a remarkably charged and non-neutral view of space as an inherently pacific and tightly enmeshed domain, and their decision making process as well as the way space craft is distributed geographically, pushes them towards a preference for space remaining relatively untouched by military escalation. The only countries interested in changing this somewhat stable status quo will be smaller, isolated "rogue nations" that don't have a lot to lose (materially and politically) from the ensuing retaliation.

This thesis will be divided into seven parts, beginning with a small chapter on the methodology employed. We will then move to define a typology of ASAT systems, and a brief history of their testing and deployment. In the second chapter we shall look at space as a physical environment and how it shapes conflict, as well as the "human" part of the space environment and the targets of ASAT weapons: satellites and constellations, their characteristics and how the latter might influence conflict in space. Our third chapter will analyse the international legal framework surrounding space activities as an additional constraint on state action, the economic environment of space and the public perception of both outer space and conflict therein as additional constraints on state action. The fourth chapter will collate our previous findings into a model which will provide the answer to the research question presented in our introduction: what form will anti-satellite warfare take, if any at all? Lastly, we will look at the EU as a case study to apply our model and analyse European agency and relevance in ASAT warfare. Conclusions and an appendix containing an agent-based toy model implementation of our framework will follow.

ON METHODOLOGY

It is not a secret that International Relations, and to a lesser degree social sciences in general, are often embroiled in methodological spats. It is often taught that IR studies have had no less than three (or four, depending on whom you're asking) major theoretical debates since their birth as a proper academic subject, and the discipline and its adherents have frequently been accused of being mired in "-isms", theories and paradigms that contradict and fight with each other on the most basic of operational definitions (Lake, 2013). This thesis wholeheartedly embraces pluralism as an effective research tool for IR studies, and does so by employing a methodological framework developed by Peter Katzeinstein and Rudra Sil (Sil & Katzenstein, 2010) called "analytical eclecticism" (ANEC). The basic principles underlying ANEC can be summed up as follows:

1. The most apt use of ANEC should be to develop a "pragmatic" knowledge base, tackling practical issues of policy.
2. The problems addressed should be wide in scope, making use of the "narrower" past discoveries and insights more beholden to a particular analytical framework.
3. Each of the frameworks and theories commonly employed in IR tends to prefer a series of causal mechanisms over others. Analytical eclecticism doesn't wish to settle the debate on who is right and wrong on these mechanisms, but rather incorporate them into a pragmatic body of knowledge that accepts multi-causal relationships between its components. The aim of ANEC is to make a concerted use of causal mechanisms that have been traditionally used in isolation from each other.

In this sense, ANEC is closely related with what Barkin (2015) defines as heuristic, Weber-inspired models which do not look to discover absolute rules of political conduct and human behaviour in a deterministic sense, but rather provide "insights" (*ibid.*) and to highlight and discover constraints to state behaviour in the international arena. I believe this to be the best approach to the subject matter for two reasons:

1. As a domain with a relatively short history and a paucity of legal instruments and precedents to aid in framing issues and solutions, space presents a challenge similar to

cyberspace in being novel, different in one or more key aspects with respect to more traditional strategic domains and still open. States have simply less to go on when it comes to deciding what approach might best serve them, and may employ different kinds of decision-making or framing practices, or may feel less constricted in their actions due to the novel nature of the domain. If this is the case, sticking to a singular theoretical framework would probably not be reflective of reality, less so than it already is.

2. As pointed out by Stroikos (2022), with space being still a comparatively new avenue of research in IR studies, a researcher would be better served by integrating different perspectives and disciplines, as using a singular theory may lead to missing out on some unique characteristics of the subject matter.[2]

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[2] A comparable approach, justified on analogous grounds, is present in Pekkanen, Blount *et al.* (2024) for space related studies in the IR discipline.

CHAPTER 1 - HISTORY AND TYPOLOGY OF ASAT SYSTEMS

This chapter will first outline a brief history of counter-space weapons and their political relevance throughout the 20th and 21st century. Secondly, it will provide the reader with a comprehensive typology of ASAT weapons and methods of attack, employing a classification system based on three distinguishing factors: the ease of development, operation and maintenance of a given ASAT weapon, its ability to interfere with a satellite's operations, and the type of political fallout that is bound to await the user back on Earth . This classification of possible ASAT vectors will constitute the basis for our subsequent analysis of the constraints and determiners of state action in counter-space warfare, defining what we can -and cannot- reasonably expect from hostile countries when it comes to attacks on space infrastructure.

1.1 A BRIEF HISTORY OF WAR IN SPACE

When - on December 17 1903 - the Wright brothers managed to achieve flight for the first time in human history, lifting off the ground for less than three hundred meters, on a contraption made of timber and powered by a modest twelve horsepower gasoline engine, it is doubtful they could have imagined that not even seventy years after their momentous accomplishment people would have been walking on the moon, having done so with the fundamental aid of a technology - digital computing - that had also made its first headway relatively recently (in historical terms at least). In fact, the 20th century is unprecedented not only in the breakneck technological and social developments that it brought mankind, but also as for the creation of three new strategic domains in the span of fifty or so years. To our knowledge, conflict has been a significant part of human interaction since well before recorded history, and war sits as one of the most unfortunate and influential constants of social and historical change. War has been a companion to mankind for a long time, and the way it is waged has changed and adapted to the challenges posed by environment, culture, and technology. Even so, for most of our species' history opponents could only fight each other in two broad domains: land and sea, with a significant body of knowledge associated with the two having been developed, revised and refined over millennia of warfare. We have to wait for the 20th century to see mankind take conflict to additional and unprecedented stages: first in the sky, then into space, both cyber and outer. But unlike the aerial and cyber domains, which both started as peaceful endeavours of which the strategic implications were quickly realised, spaceflight had a different origin altogether.

While the idea of reaching space was initially a dream for a select few engineers and scientists - mostly in Germany and the US - the first object to breach the Kármán line[3] in 1944 was not the result of peaceful research, but rather the work of an authoritarian, aggressive regime set on weaponising outer space to reverse the fortunes of a losing war: specifically an experimental prototype of the V2 ballistic missile series, one of the *Wunderwaffe* developed by the besieged Nazi regime to turn the tides of the war. While the V2 had essentially no impact on the outcome of the war, the advantages it had over other contemporary missiles was clear: by striking with astounding speed, it was essentially beyond the reach of any anti-air system employed at the time. More importantly, the way it achieved such a speed and reach presented an incredible opportunity: if the V2 had managed to push through the atmosphere and at least partly win against the pull of Earth's gravity, how far and how high could one go if the technology behind it was developed even further? For the two countries who were set to become the superpowers of the next half of the century, realising this ambition and capturing the lead engineer behind the V2 rockets Wernher Von Braun and his team of experts became a chief concern. Only partly realising his importance to both the US and the USSR, Von Braun fled the island of Peenemunde in which he had designed and built his V2s and evaded both the SS (who were under strict orders to eliminate all key scientific personnel of the Reich) and the Soviets, managing to surrender himself and most of his team to American troops in Austria (Krige & Russo, 2000). As Truman had publicly disavowed the possibility of any former affiliate of the Nazi Party working for the United States' government, an obfuscating exercise - Operation Paperclip - had been put in motion by the American intelligence services to capture and transfer German scientific know-how and personnel to prevent it from falling into Soviet hands (Webb, 2009). While the Soviets had lost the race in acquiring Von Braun and his expertise, they had managed to loot Nordhausen, the main manufacturing facility for the V2 rockets and had managed to capture a small group of German engineers who had worked on the project. Determined not to be left behind, the USSR had already invested a significant amount of time and money into weaponising rockets

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[3] The Kármán line, named after Hungarian physicist Theodore von Kármán, is a commonly used convention to define where the lower atmosphere ends and outer space begins, and is defined as 100 km above the mean sea level. It is based mostly on the nature of aerodynamics, as above this altitude air becomes too rarefied to be able to sustain conventional flight.

well into the 30s, eventually developing and implementing the Katyusha rocket batteries which, unlike the V2s, proved instrumental to the war effort.

All of this comes to show that spaceflight in its earliest iterations was essentially borne out of military and strategic interests, unlike regular flight and cyberspace, which had their start as civilian and scientific endeavours. What is all the more peculiar then, is the trajectory that space followed in the decades after the end of the 2nd World War: what started as an exercise in rocketry to deliver nuclear ordnance morphed into a different beast altogether with the successful launch of Sputnik in 1957. The USSR had awed the world (and caused a profound crisis of confidence in the US) with its technological achievements, and it had nothing to do with ICBM and nuclear bombs and all to do with science and its possibilities for mankind[4]; the race to space had acquired a public face that apparently excluded weapons entirely and shifted the persuasiveness of the two political and economic systems espoused by the USSR and the USA from the destructive capabilities of the respective countries to their scientific and technological potential in outer space. The Space Race was not a competition of destruction but rather one of creation and discovery, with efforts by both the US and the USSR in creating a façade of peaceful competition to their space programmes, not just through their scientific missions but also with their legislative efforts in regulating the international use of outer space (Buono, 2020). However behind the scenes the countries which had the know-how and the material capabilities to reach space realised that -as a domain- it offered an unparalleled strategic advantage, the ultimate high ground from which one could surveil, control and possibly dominate the surface[5]. While the world was dazzled by the epoch-defining exploits of the Moon landing or by the stunning pictures of Venus' surface provided by the Venera missions, governments and military commands moved more or less covertly to take advantage of the new strategic frontier that had opened above their heads.

One key issue faced immediately by both superpowers was the possibility that the other could place nuclear ordnance in orbit, which was partly defused by the international regulatory

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[4] Case in point, Sputnik regularly pinged its presence in a wide band radio frequency, making it possible to track it across the sky as long as one had even rudimentary radio equipment. It was, in a sense, a further spectacularisation of an already incredible achievement: a classroom could easily tune into the frequency and listen to Sputnik beep away as it crossed the skies.

[5] See for example the often quoted speech held by Air Force General Thomas D. White in 1957: "Whoever has the capability to control the air is in a position to exert control over the land and seas beneath. I feel that in the future whoever has the capability to control space will likewise possess the capability to exert control over the surface of the Earth" (Stares, 2021). This sentiment is maintained to this day by the US and is often echoed by the Chinese military (Weeden & Samson, 2019)

efforts of the Outer Space Treaty of 1966, which prohibits the placement of weapons of mass destruction in orbit. While the strategic advantage of placing nuclear ballistic missiles in orbit (i.e. space-basing) is minor if nonexistent[6], satellites for the purpose of surveillance or signal interception (SIGINT) provide an important strategic advantage to any country that operates them (Early & Gartzke, 2021), being far more consistent and resilient as information gatherers than any other method, which led to the general decline of other forms of aerial surveillance (*ibid.*). As imaging and surveillance technologies improved, spy satellites proliferated, and with the expansion of intelligence gathering to orbit, the strategic relevance of space became more and more paramount for the countries which employed these satellites in the first place. Eventually, spacecrafts acquired more military uses than "just" surveillance, early warning or intelligence gathering: navigation, weather forecasting and communication (Palmer, 2023), all key activities necessary to successfully conduct military operations, became increasingly dependent on space assets, and the need to protect them became pressing, leading to the development of anti-satellite weapons as the most prominent type of counter space capabilities (Webb, 2009); all the while the early fears of WMDs pointed at the surface of our planet were assuaged by both legislative efforts such as the Outer Space Treaty, and the significant drawbacks and engineering challenges faced by space-to-ground and space-to-space weapon systems, be they conventional explosives, nuclear devices or kinetic weapons (Wright, Grego & Gronlund, 2005).

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[6] There are several drawbacks to orbital ICBMs (Wright, Grego & Gronlund, 2005), both from the material as well as strategic point of view:

1. For starters, while it may seem counterintuitive, a missile placed in orbit requires a lot of energy to re-enter the atmosphere. Maintaining a stable orbit around the Earth calls for a significant amount of speed, which has to be reduced in order for the missile to fly "down" towards the ground. This means carrying additional fuel, which would weigh down the rocket carrying the ICBMs to orbit and limit the amount of missiles one can put in orbit
2. Since regular maintenance is not possible in orbit, missiles would have to be tailor-made to be sufficiently durable as to not require repairs for prolonged periods of time. Additionally the missiles and their control systems would have to be hardened against cosmic radiation. This would add weight and development costs to the ICBMs.
3. Rockets have a very high failure rate compared to most other vehicles, and an explosion or mechanical failure while the missiles are being brought to orbit could cause the ICBMs and their fissile cores to break up into the atmosphere, showering large areas on the ground with radioactive materials.
4. Placing ICBMs in space takes away a critical advantage that many conventional ground vehicles possess: covertness. It's essentially impossible to hide a satellite in space, meaning that these orbital
5. missile platforms would be easily targetable in a nuclear exchange, unlike submarines, stealth bombers or underground silos which are more difficult to track down.

Both the US and the USSR had a series of development phases when it came to anti-satellite systems, stretching from the 60s to the current day with several gaps between these phases, roughly matched with periods of *detente* or heightened competition between the two superpowers. Originally, ASAT systems were mostly being developed for ground defence, rather than destroying permanent space assets. In other words, ASAT weapons were being developed from stopping objects which would've reached space for a limited amount of time -i.e. ICBMs- while still in transit. In the first half of the Cold War, the USSR had a relative advantage over the US in terms of ASAT warfare due to its -at the time- more advanced long-range missile programme (Grego, 2012), having deployed a ballistic shield around Moscow made up of nuclear missiles, tasked with saturating the portion of the high atmosphere above the city with atomic ordnance and intercept oncoming American ICBMs before they could land[7]. This "saturation" approach was also initially followed by the Americans, who were concerned about the possible orbital placement of nuclear weapons by the Soviet and had to wrestle with technological limitations of the time: guidance systems were not sophisticated enough to accurately intercept ballistic missiles, leading to the use of nuclear ordnance which wouldn't need to be particularly precise, as its destructive range would be enough to destroy incoming missiles. As the years went by and the technological gap between the US and the USSR shrunk considerably, different priorities emerged from both superpowers: on the one hand the US had expanded its constellation of imaging satellite, which had even been able to produce irrefutable evidence of Soviet installations on Cuba during the Cuban Missile Crisis. Recognising both their intelligence gathering potential[8] and the apprehension it could cause to both enemies and allies, the US was eager to create a legal framework that could legitimise their military satellites. On the other hand, the USSR was cognizant that the relative advantage it had enjoyed in long-range ballistic technology since the launch of Sputnik was rapidly being eroded, especially after the Kennedy administration had publicly[9] thrown its whole weight behind the Space Race. The USSR had also been experimenting with a "co-orbital" ASAT system[10] (US Congress, 1985) with a certain amount of success, but the

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[7] Although with different specifications, this system is still employed today.

[8] Spy and imaging satellites had become even more important after the realisation that the USSR had become capable of downing American reconnaissance aircraft, as demonstrated by the U-2 incident of 1960 that had soured the Paris Summit scheduled for that year.

[9] See the famous Rice University Address of 1962, commonly known as "We choose to go to the Moon" speech: "we choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organise and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too." available at (last opened 02/07/2024): https://www.jfklibrary.org/archives/other-resources/john-f-kennedy-speeches/rice-university-19620912

[10] Specifically, this system consisted of a small satellite filled with conventional explosives. It would be put on the same orbital plane as the target satellite, made to approach it and then detonate, destroying it with shrapnel.

technology had a series of drawbacks (Grego, 2012) that made the Soviet leadership less sure of its capabilities as a deterrent in space; the case that the US had been making for a international legal framework for regulating space activities -especially those of a military nature- seemed to the *nomenklatura* a useful artifice to make the competition more predictable and less volatile. The aims and hopes residing in a new international legal instrument regulating space were divergent, but the desire to bring it to fruition was the same, resulting in the creation of the Outer Space Treaty of 1967, which laid down the basic rules of international space law, allowing for both recognition for American satellites and the general slowing down of ASAT escalation that the Soviets feared.

While the Outer Space Treaty - and successive instruments like the Treaty on the Limitation of Anti-Ballistic Systems (ABM Treaty) of 1972 - did slow down the development of anti-satellite systems, it didn't prevent it completely, with research in the US shifting towards directed energy weapons like lasers, either ground or air-based. However, we have to wait for the 80s to see a public resurgence in space warfare, owing to the Strategic Defense Initiative (SDI) pushed by the Reagan administration. The SDI proposal was for the US to set up a series of interlocking defence systems that would shield American territories from the threat of Soviet ICBMs. While the SDI wasn't specifically meant for destroying satellites, it could easily be repurposed as such easily, and coupled with the development by the US of its ALMV system[11], it was enough to create apprehension in Soviet circles and to spur additional development and testing of their co-orbital platform, as well as doubling down on their own missile research program, combining it with diplomatic efforts to ban space-based weapons entirely and a self-imposed moratorium on ASAT weapons testing, which was partly mirrored by a general restraint on part of the US, with Congress banning further ALMV testing in 1985. The ban was not extended in 1988, but Congress still refused to fund initiatives pertaining missile-based ASAT systems, forcing the Army and the Air Force to switch to a different kind of weapon: ground-based lasers, which could target satellites directly and dazzle or damage permanently their sensors, or the even the satellite bus itself[12]. This pivot

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[11] Air Launched Miniature Vehicle, which consisted of a two-stage missile which could be launched by a regular fighter jet cruising at high-altitude. The ALMV would then reach the target satellite and impact it directly. The ALMV, while not without its own shortcomings, was able to eliminate several of the drawbacks of the Soviet co-orbital ASAT platform, which had to wait for the target to fly above it to launch and then wait again for it to reach its target. The ALMV, on the other hand, while much more demanding from a technical point of view, could be launched from any capable fighter jet with more freedom as to the starting point and was significantly faster in reaching his target.

[12] The satellite bus is the main body of the spacecraft, the structural frame which houses most of its systems and sensors (i.e. the payload).

towards directed energy weapons was also due to intelligence reports, later revealed to be exaggerated in their warnings, that the Soviet had developed a fully functioning optical laser which could target and destroy spacecraft in orbit. An official American visit to the main laser research facility in the USSR, requested specifically by Soviet leadership to prevent what was looking to be a new laser-themed arms race, later revealed that the dreaded Soviet laser lacked guidance systems to keep it locked in on the target satellite and adaptive optics to prevent the laser beam from scattering in the atmosphere, making its value as an actual ASAT weapon doubtful to say the least. As the Soviet regime reached its limits - both human and budgetary - by the end of the 80s, the USSR had little to show considering it had once been the main contender of the Space Race: a series of laser weapons that weren't able to keep a steady lock on their targets, a co-orbital weapon that - while successfully tested and vetted - had severe strategic and practical limitations and was eventually decommissioned in 1993 and a series of missiles that could theoretically work as ASAT weapons but which had not being properly tested due to a self-imposed moratorium.

On the other side of the Atlantic the US was facing similar difficulties: the ground based laser ASAT MIRACL, pushed by the Air Force, and the KE-ASAT project, directed by the Army, had both run into issues of funding by Congress and had been discontinued by the second half of the 90s; unsurprisingly, considering the relatively hopeful prospects of the solidity of the Pax Americana and the success of the wave of democratisation that followed the break up of the USSR. It seemed that now that history had "ended" (Fukuyama, 1992), interstate conflicts and wars would gradually become a thing of the past as more and more countries became part of the club of liberal democracies; a club that for a long time had seemed fairly exclusive, but that now seemed on the verge to encompass large swathes of the globe. This period of optimism found its end fairly quickly, and by the beginning of the 2000s, the US found itself embroiled in several conflicts across the world, facing a resurgent Russia helmed by Vladimir Putin and a new fearsome contender in China, and with them a renewed American interest on the strategic value of space. The Bush Jr administration was the first to push, budgetary wise, on a series of projects meant to enhance American capabilities in space, by bolstering its expenditure on energy weapons, testing new ASAT ballistic systems, satellite manoeuvring systems, unmanned space planes like the X37-B and expanding its satellite jamming capabilities. It was also in these years that the American government publicly reaffirmed its own security framework for space activities by publishing its *Introduction to US National Space Policy* in 2006. It was in this document that the need for the US to aggressively maintain its dominance in the space sector was declared (Webb, 2009), and it is with this in mind that one must frame its unilateral withdrawal from the ABM Treaty in 2002 (Grego, 2012). Since then, the US has oscillated between more conciliatory efforts towards regulating what could prove to be a runaway arms race to space and a more hardline stance that seeks to maintain its strategic independence at the risk of potentially alienating international partners and alarming rivals. An example of this inconsistent approach is the provision inserted in the official Space Policy in 2006 against any international effort that could restrict American access or its use of space assets, like arms control regimens[13]; however, while the US government was rather cold towards the Russo-Chinese draft treaty on Weapons in Outer Space of 2008, the Obama administration openly allowed for the possibility of a different (and in its opinion, more equitable) type of international accord regulating the use of outer space weaponry and supported the EU-led initiative - which ultimately ended in failure (West & Azcárate Ortega, 2022) - of an International Code of Conduct for Outer Space Activities. However, the US isn't the only actor to have shown a renewed interest in space security: with outer space becoming a keystone of global society, and not just the US[14], more and more countries are cognizant of the vulnerability of space infrastructure, the need to defend it and the place it has in both national and international security.

The EU, while not possessing ASAT capabilities, is one of the world's foremost space powers - owing to its close partnership with the European Space Agency - and the European Commission has openly declared that it considers space as not only an economic and scientific domain, but a strategic one as well. A key example of this is the Galileo navsat system, which was built specifically to provide the EU and its member states strategic autonomy[15] from the GPS system (which is owned by the US) and the GLONASS system (which is owned by Russia). As mentioned above, the EU is also hoping to harness its purported regulatory influence through the *Brussels effect* (Bradford, 2020) for the benefit of its space policy, although for now with limited success.

China has caught the attention (and the rebuke) of the international community in 2007 for its successful test of an ASAT ballistic missile system - which created a significant amount of

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[13] See NSDP 49 of the 2nd Bush Administration, available here: https://irp.fas.org/offdocs/nspd/space.html

[14] It's important to note that there's a significant material gulf in terms of space infrastructure between the United States and other relevant actors in the space domain, with the US possessing more satellites on its own that the rest of the world combined (see https://www.statista.com/statistics/264472/number-of-satellites-in-orbit-by-operating-country/)

[15] See "Why Europe needs Galileo", ESA, available here: https://www.esa.int/Applications/Satellite_navigation/Galileo/Why_Europe_needs_Galileo

long lasting debris - reigniting the debate over the possibilities of runaway impact cascades and the consequences of an escalation if warfare is actually taken to orbit. China shares with the US the view of space as a key domain for its national security (Weeden & Samson, 2019) and is investing significant amounts of manpower and money to bridge the technological gap with the US, while being outwardly against the militarisation of space (Spacewatch, 2019).

Russia has also been expending more of its efforts into regaining its prominence in the space domain, with consistent rumours of testing for a new, unknown space weapon (Beard, 2017) and it is assumed that state-sponsored hackers are behind the cyber attack on the Viasat satellite network of February 2022, which was concurrent with the invasion of Ukraine. The US' Department of Defense has also recently accused Russia of launching a counter-space weapon meant to destroy satellites in LEO (Lukiv, 2024) and that this weapon may be nuclear in nature (Harpley, 2024).

Lastly, India has recently joined the fairly exclusive club of countries who have successfully tested a kinetic ASAT system: in 2019 a small target satellite was destroyed by a missile interceptor, creating a similar cloud of debris to the 2007 Chinese test, although far smaller in size and at a much lower altitude, which should guarantee that most if not all the debris created in the exercise would've degraded and burnt up in the atmosphere after a couple of months (Tellis, 2019). What this spell in terms of the mounting tensions between India and China is still to be seen, but can be read more broadly as part of a trend towards a general militarisation of space (Grego, 2019)

1.2 WHY A TYPOLOGY OF ASAT CAPABILITIES IS NEEDED

Our cursory overview of space warfare has given us a sense of the evolution and developments of counter space weapons throughout the years; as outlined above, these developments weren't linear, with different technologies acquiring relative prominence, fading into obscurity and then returning to the fore as advancements in various scientific domains such as material engineering, propulsion, optics and aerodynamics opened up new avenues for weaponisation and securitisation of space, as well as the growing dependence of the global economy, civilian and military alike, creating new and powerful incentives for both increasing one's resilience and offensive capabilities. The rest of this chapter will be dedicated to providing a comprehensive account of all types of ASAT systems either developed, employed (purely in tests, as we've already established) or designed, to give a pragmatic and solid analytical base from which to consider current counter-space capabilities. While the debate on the influence of technology over warfare is not settled in the least (Cohen, 2019), it's clear that the capabilities of weapons provide not "just" the tactical and strategic makeup of battles and wars, but influence the processes through which conflict is framed, analytically and ideationally[16]. For example, the enormously destructive capabilities of nuclear weapons caused the birth of an hitherto field of policy analysis, nuclear deterrence, which inverted[17] (Mueller, 2013) millennia's old conventions on what constitutes an offensive or defensive policy, and presented mankind with the possibility of its own - and self-inflicted - destruction. During the Cold War, it is posited that the enormous nuclear arsenals of the United States and the USSR created a strong policy constraint, in the sense that neither country could directly face the other lest risk a nuclear exchange, leading to a series of proxy conflicts around the world for the better part of fifty years. While the consequences of nuclear annihilation were material in nature, one should not forget the normative aspects of deterrence (Tannenwald, 1999). The material characteristics of the atomic bomb put in place strict limitations on the freedom of foreign policy and caused normative constraints against the use of nuclear weapons to spring into being; these new norms borne of the horrors of Hiroshima and Nagasaki then retroactively acted on the material endowments through non-proliferation treaties. testing bans and bilateral agreements (*ibid.*).

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[16] While I don't wish to enter the well known debate on material vis a vis ideational factors, I do not subscribe to the neorealist concept of material factors being the key determiner of state action, with ideas and concepts as mere manifestations of the objective, physical reality of power politics. However, I also do not agree with the "hard" constructivist approach of simply reversing the relation in favour of ideas. Rather than considering either material factors or ideational factors as prominent causes of the other - a sort of IR-themed chicken and egg debate - I believe we would be better served for our model by considering the relation between the two as reciprocal and non-hierarchical. A cursory but persuasive argument for this approach in general terms is given by Branch (2018).

[17] Specifically, nuclear deterrence is characterised by the inversion of offence and defence, meaning that policies that are normally seen as defensive and therefore de-escalatory, like building a series of fortifications at the border of one's own country become destabilising and offensive in nature when viewed through the lens of nuclear deterrence: building an interception system to shield country A from nuclear missiles launched from country B can be seen as an offensive, aggressive action from the perspective of country B, as it breaks down the deterrence borne of mutually assured destruction. Country A could theoretically attack with impunity as country B would not be able to retaliate due to the presence of the interception system. Conversely, country A enhancing its nuclear arsenal is signalling to country B that they are committed to the mechanism of mutually assured destruction, which implies reluctance to attack. In any other strategic domain, augmenting one's arsenal would be seen as an aggressive action and would signal the intention to attack, but in the nuclear domain this becomes defensive posturing.

We can affirm that space, with its intrinsic physical and material characteristics, selects for certain weapons and systems (much like any other domain), following a series of principles and processes[18]. These systems will have a number of capabilities, and will be able to only achieve certain effects and not others: this will in turn inform both the strategic and tactical implementation of these weapons, as well as partly frame the boundaries of what constitutes aggression, war and conflict in outer space, although one should not consider this relation as uni-directional, as briefly touched upon in the above paragraph and as I hope to highlight in the second chapter of this thesis. Since this plethora of characteristics - technical, legal, political and ideational - would be far too wide to be addressed in exacting details in this thesis, we will employ a more systematic and synthetic approach, as we shall collate the numerous factors influencing the use of ASAT weapons into three macro-categories which we will then apply to all the systems examined in the rest of this chapter.

The first category is the ease of development, operation or maintenance (or EDOM for short) of an ASAT system. Not all weapons are born equal: some require a lengthy and difficult gestation process, as well as significant human and financial capital, while others are much more “accessible” from a technological and budgetary point of view. We will divide this category into three sublevels: high, medium or low EDOM. High EDOM signifies that this weapon is relatively easy to manufacture and operate and is fairly inexpensive; a great deal of countries would be able - if willing - to field it. Medium EDOM tells us that our ASAT system calls for a non-trivial amount of capital (both human and financial) to be developed, used and maintained. Specialised facilities may be required, as well as trained personnel. This would limit the group of countries able to field such weapons: strong education systems, a relatively ample military budget and facilities to store and operate the weapons would put these weapons out of reach of less developed countries, as well as small developed countries. Low EDOM requires highly advanced facilities, a significant budget for all stages of development, operation and maintenance, a strong base of know-how and scores of highly educated or trained professionals. Only a handful of countries would be able to afford the monetary costs or would possess the human capital and the resources to build and use such

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[18] Cohen (2019) presents a cursory look at some of these principles as they have been presented in the literature: for example, a weapon A may be developed but takes a long time to see deployment, the reason being there is already a pre-existing weapon B that works well enough. Until weapon B shows its limits, weapon A will not see widespread use. This mechanism is called “form follows failure”.

weapons. Effectively, these systems are out of reach of the vast majority of countries today, and only the most affluent would be able to afford them.

Our second category is the interference capability of the ASAT system in question, i.e. its ability to interfere with the regular operations of a satellite, which we shall divide into high, medium and low capability. Depending on the weapon taken into consideration, "interference" can be taken literally, or as a euphemism: some ASAT weapons can physically destroy a satellite or a part of it, rendering it permanently inoperable, which we consider as high interference capability. Other systems can temporarily commandeer a satellite, or render it inoperable for a limited amount of time without permanently damaging it, and these systems we will consider as having medium interference capability. Lastly, when what is attacked is not the satellite directly, but its ability to communicate with the ground and other space assets, we are faced with low interference ASAT systems.

Our last category is the political "impact" of a given counter-space weapon: it is understood that the political fallout of using weapons on Earth depends heavily on the characteristics of the weapon itself as well as the context in which it is used, and the same goes for ASAT weapons. It is logically sound that the more outwardly destructive a weapon is, the more political and diplomatic headaches will be waiting for the decision maker back on Earth, but since space as an environment is extremely different from the surface, adjustments have to be taken into consideration when assessing the political impact of counter-space attacks. Much like the two categories before, political impact is divided into three levels: high, which would justify immediate retaliation either in space or on the surface; medium, which would create a major diplomatic incident but not necessarily an answer in kind; low, which would would strain relationships between the affected countries but would not lead to lead to prolonged political consequences for any of them.

1.3 ASAT SYSTEMS CURRENTLY IN USE OR DEVELOPMENT

There are a number of typologies of ASAT capabilities present in the literature, but a common trait shared by all of them is a division between kinetic weapons and directed energy weapons (DEWs). Kinetic systems attack satellites by delivering a physical projectile sufficiently close and with sufficient energy to damage, disable or destroy the target. Common examples are ballistic missiles, co-orbital attack satellites and space mines. Directed energy systems, on the other hand, impact satellites with beams of energy, usually in the form of electromagnetic energy, either in the visible light range (lasers) or microwaves. DEWs can dazzle (temporarily incapacitate) sensors, damage them or even permanently disable the satellite in its entirety, if fired with sufficient power and for a certain amount of time. Together, kinetic and energy weapons are commonly grouped together as physical ASAT weapons, as they aim to degrade the functioning of a satellite through physical contact.

On the opposite side of the spectrum, we have cyber ASAT and electronic ASAT weapons: these systems degrade, disable or commandeer space assets without physical intervention. Cyber ASAT weapons attack the underlying computing architecture of the satellite or of its ground segment, much like it is commonly done on regular computers and networks. Electronic ASAT weapons instead work by interfering with the signal of the satellite, and consist of two main techniques: spoofing and jamming. Cyber and electronic ASAT systems also distinguish themselves from physical systems in another manner: unlike the latter, which are specifically meant to either disable or destroy a satellite, cyber-digital ASAT can also be used to turn the space asset against its owner, either by taking control of it or by taking advantage of it covertly (data theft and wiretapping). It’s important to note that the distinction between physical and non-physical systems is purely on the basis of how they operate when interacting with a satellite, not on the outcome of the interaction: in other words, you can use non-physical ASAT weapons to achieve actual damage or destruction of the target, as we shall see in a following section of this subchapter. For now, let’s begin our typology with physical ASAT systems.

1.3(A) KINETIC WEAPONS

As mentioned above, kinetic ASAT weapons (K-ASAT) work by directing a physical projectile to their target and destroy it or damage it. There are two main types of K-ASAT weaponry:

1. Direct ascent, in which the projectile takes off to directly strike its target, with no intermediate steps and without entering an orbit. The most common form of direct ascent weapon is the ballistic missile, which can be a dedicated system or a different one repurposed for such use, usually ABM interceptors. Direct ascent weapons can be

shot from the ground or from an aircraft, and usually carry either kinetic kill vehicles (KKV)[19], nuclear warheads or conventional explosives (Wright, Grego & Gronlund, 2005). They may operate by either directly impacting the target, detonating an explosive warhead in close proximity to the target, or releasing a cloud of pellets to shred the target. Direct ascent weapons may be required to have a way to track and follow their target once they reach outer space, which is the main technological barrier to their development: however, as pointed out by Grego, Wright and Gronlund (*ibid.)*, homing systems are not a complex endeavour for any space-faring country, and even states without a presence in space should be able to manufacture simple - but effective - homing devices from commercially available components. An homing system is not a *conditio sine qua non*, as a direct ascent weapon could approach the general position of the satellite and then release a cloud of pellets over a vast area; however this method is unlikely to be employed if alternatives are available due to its unreliability.

2. Co-orbital, in which the weapon system first reaches a stable orbit, moves closer to its target and then either impacts the target directly or fires a projectile at it, such as a missile or a group of pellets and debris. Co-orbital weapons can be prepared for a launch and impact with an operational window of days, or can be placed in orbit and remain dormant for years (CSIS, 2019); in the latter case, co-orbital weapons are usually called *space mines*. If manoeuvred sufficiently close to its target, co-orbital weapons could be developed to be relatively small in size and weight: a device similar to a Claymore anti-personnel mine could reasonably damage most satellites above one metre in diameter by detonating at a distance of one kilometre, all while weighing around 100 kilogrammes (US Congress, 1985). A co-orbital weapon could also manoeuvre itself into the same orbit of its target, but in the opposite direction, significantly augmenting its destructive potential (Wright, Grego & Gronlund, 2005).

Starting with our ease of operation, development and maintenance metric (EDOM), kinetic weapons present an interesting conundrum: they are obviously not instantaneous, and require factoring in the travel times from the ground or from a fighter jet to orbit. This creates the need for facilities with round-year personnel making sure the weapons are ready to launch at a moment's notice and this obviously adds to the cost of maintenance and operation (Chun, 2003). On the other hand development, especially if we consider direct ascent weapons, could

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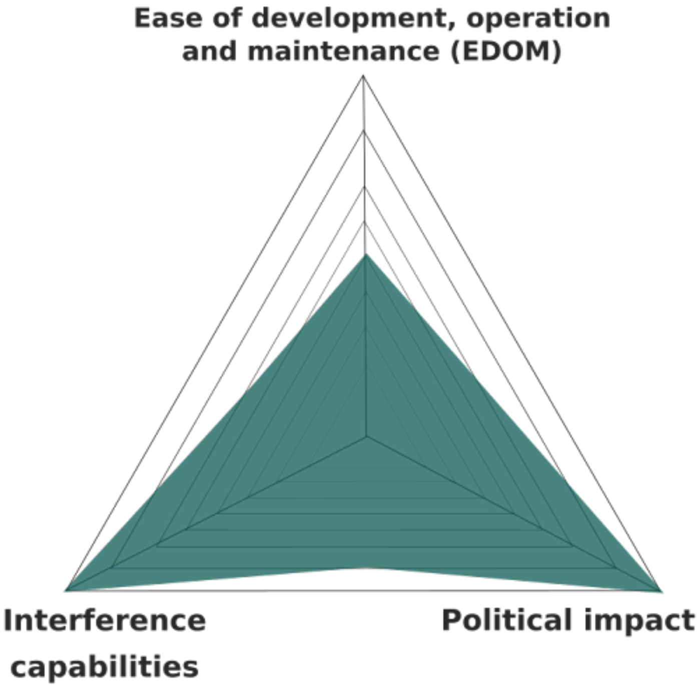
[19] Kinetic kill vehicles are weapons that deal damage exclusively through the kinetic energy - the square of the velocity of an object multiplied by half of its mass - it acquired in transit, without using explosives.

potentially be fairly inexpensive: any country with space faring capabilities, or in possession of ballistic or ABM systems could repurpose them into an effective ASAT weapon without much difficulty (Wright, Grego & Gronlund, 2005). Moreover, as outlined above, a direct ascent weapon does not necessarily need to directly impact its target, as it can release a cloud of debris on the orbital path of the satellite to damage or destroy it, such that a complex navigation and tracking system wouldn't be needed, at least on board the missile itself, further cutting down potential costs. Taking these factors into consideration, we can classify kinetic weapons as a medium-class weapon under our EDOM metric, as weapons relatively accessible for a determined country, as long as the initial entry barrier of possessing a ballistic or ABM system is cleared. Moving on to our interference capability metric, kinetic weapons are obviously the most conventionally destructive ASAT option as long as they are able to hit their target (Chun, 2003); while there are ways of avoiding a collision through manoeuvring the spacecraft out of the way, this is not easy to accomplish, especially if the weapon is sufficiently sophisticated or works by interdicting a part of the orbit with a cloud of debris. The operator also needs to know that an attack is imminent and must have the time to react.



Graph 1 - Characteristics of kinetic weapons as radar plot

One additional point to raise is that most types of fortifications or armouring used on the surface are not feasible on satellites[20]. It shouldn't therefore be surprising that we rate kinetic weapons as high on our interference capability metric: as weapons designed for physical destruction, and with very few countermeasures available to protect space assets,

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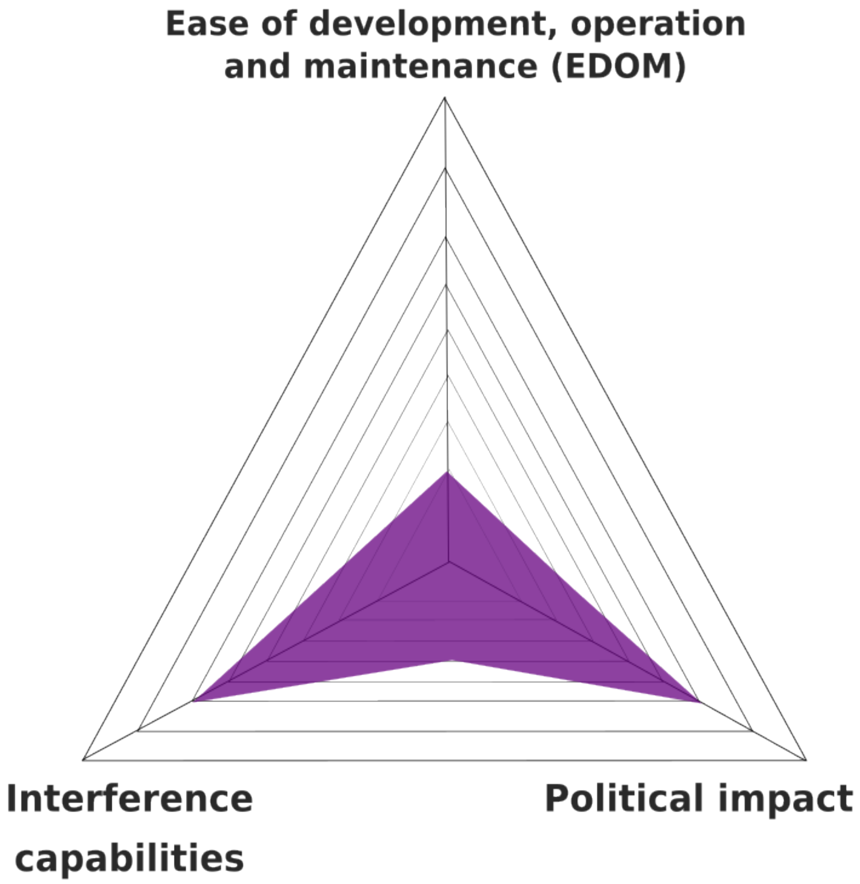
[20] Defensive countermeasures have been proposed over the years to defend key satellites from kinetic weapons: ablative armour, bodyguard satellites (Wright, Grego & Gronlund, 2005) and interceptor weapons mounted on the satellite itself are some examples, but they all present significant technical and economic challenges. For example, ablative armour raises the cost of the satellite by virtue of weighing it down significantly. A solution can be to selectively protect the most statistically likely areas of impact (Williamsen, 2008).

it’s clear that a successful hit by a kinetic weapon will result in the destruction of the targeted spacecraft. As for political impact, kinetic weapons are the only type of ASAT system that has seen relatively widespread testing from multiple countries. These tests have invariably resulted in diplomatic fallout for the “offending” countries, although the extent of the negativity can vary according to the specifics of the tests; e.g. India was able to present itself as a more “responsible” power vis a vis China (Sönnichsen & Lambach, 2020) as it chose a target satellite orbiting sufficiently low that its debris would reenter the atmosphere in “just” a couple of months instead of the years projected for the 2006 ASAT test it underwent. Specifically, the way India tailored Mission Shakti to make an effective show of force and present to the world -and its own citizens- the government’s technical achievements makes a compelling point as to just how much “impressive” kinetic weapons can be, and the political clout they can generate. They are big, fast, dramatic, and immediately understandable by the public compared to the more “esoteric” alternatives we will examine below; they also generate significant amounts of debris, which can impact spacecraft that were not the intended target, or even assets of third countries, severely complicating diplomatic efforts . Nuclear weapons are no exception as they achieve a similar effect by the nature of their operation: the intense radiation produced by a nuclear detonation would render large swathes of orbital “real estate” extremely hazardous, if not unusable, for several years. These factors come together to form a picture of a weapon with a significant amount of political weight attached to its use: their dramatic mode of operation, the risks they pose not just for the target, but for every spacecraft around it, and the irreversibility of their effects is such that kinetic weapons have high levels of political impact.

1.3(B) DIRECTED ENERGY WEAPONS

Directed energy weapons (DEWs) work by utilising a focused beam of energy or particles to directly strike the satellite in question, without using a projectile. DEWs developed for anti-satellite capabilities usually employ electromagnetic energy, usually in the form of infrared or visible light lasers and microwaves. A laser DEW could be used to dazzle (i.e. temporarily blind) a sensor, blind it or even damage the structure of the satellite itself. It’s important to note that both physics and engineering play a key role in defining the effectiveness of a laser DEW. For starters, to both dazzle or damage a sensor, the laser must sit in the field of view of the sensor itself, otherwise the light from the laser has no way of reaching the sensor;

depending on the sophistication and purpose of the targeted satellite, this area can be as as be as wide as tens of square kilometres. Once the laser has made contact with the sensor, it will be able to saturate part or all of it (depending on the size of the sensor and its construction quality), degrading the quality of the image and causing a series of visual artefacts on the final image. Dazzling requires relatively low power applied for a comparatively long period of time, as the laser needs to fully saturate the pixels of the sensors. On the other hand, permanently damaging the sensor requires more power (proportional to how much of the sensor the aggressor wants to disable: increasing the ground area obscured to the detector by ten times calls for around a hundred times more power), but even commercial-grade lasers have sufficient wattage to damage a satellite image detector enough to obscure the surface equivalent of tens of metres. In any case, dazzling requires less intelligence on the satellite, as all that is needed is to calculate the amount of light that bounces off the Earth onto the sensor and exceed it, while physically damaging the sensor requires having in-depth knowledge of the optical system of the satellite and what type of filters it uses (Wright, Grego & Gronlund, 2005). In short, this means that when faced with the decision on whether to dazzle or blind the spacecraft of a rival state, the attacking country may have to consider more factors than just the immediate tactical value of the attack: blinding a sensor on a military satellite requires acquiring classified knowledge, and the attacker may either be incapable of acquiring said knowledge or unwilling to tip off the attacked that it does, in fact, have an



Graph 2 - Characteristics of directed energy weapons as radar plot access to high level military intelligence. As we mentioned in the introduction to this subchapter, the technical specifications and the physical limitations behind a weapon allow us to glean motivations and constraints on state actors. While both methods - dazzling and blinding - require a high degree of technological know-how, the reasons why a country would choose one over the other may not be technical in nature, but political and strategic: a country may be placing more value into plausible deniability, and could choose to employ a low-intensity dazzling attack rather than raise the chance of a confrontation, or revealing its acquisition of classified military knowledge.

Microwave weapon can be used to damage both electronic and electrical components of the satellite, and can follow a front-door approach, whereas the weapon targets the satellite's antenna as the way to reach its internal components, or back-door approach, which exploits small gaps in the satellite's shielding to gain entry (CSIS, 2019). As the atmosphere is partially opaque to highly energetic microwaves, the microwave DAW needs to get relatively close to its target to be effective. Microwaves are less energetic than visible light or infrared lasers, meaning that they cannot directly damage structural components of a satellite, but they can interfere with the functioning of electronic components, resetting the onboard computer or wiping the internal memory, as well as burn out the electrical circuits of the satellite, if sufficiently powerful. Much like lasers, this would render the spacecraft unusable without generating any debris.

DEWs are a relatively recent development in counter-space technologies, with initial R & D efforts starting in the late 70s. Nowadays DEWs see deployment in a wide variety of tactical scenarios, with their ASAT application being a relatively small fraction of a wider whole. An example of a DEW developed for ASAT scenarios is the US Navy MIRACL (Mid Infrared Advanced Chemical Laser) system, which was tested for its counter space capabilities in 1997 and deemed a partial failure due to the damage sustained by the laser itself when it opened fire on the decommissioned satellite chosen for the test (Bull, 1997).

Employing our tripartite framework again, it's clear that DEWs are probably pound-by-pound the most expensive ASAT system in our typology. Directed energy weapons are extremely complex, require exotic materials and manufacturing processes, large amounts of electrical power, significant budgetary commitments and high quality human capital. DEWs are therefore the prerogative of the most affluent and technologically advanced countries in the world, earning them a place in the low-class of our EDOM metric as the least accessible and most expensive class of ASAT systems. As for their interference capability, we've argued that DEWs are scalable, meaning that their output can be adjusted to achieve different effects. Directed energy weapons also move at the speed of light, meaning evasive manoeuvres are not possible, and are extremely precise, such that they could potentially target a singular part of the spacecraft, leaving every other component intact (Cannin, 2021). However, there are some significant limitations to the use of DEWS: as straight, concentrated beams of electromagnetic energy, they have to be sitting right below the part they want to damage or dazzle, which limits their possible uses and flexibility unless they're mounted on a flying platform. DEWs are also affected by the weather in a way that kinetic weapons aren't: they are much less powerful in cloudy weather, and are not usable when raining, due to the scattering effects of raindrops. Lastly, mitigation against directed energy weapons is simpler.

Overall, while DEWs are capable of physically damaging a satellite, the technical and physical restrictions that they face, as well as ease with which operators and designers may defend against their use, make this an unlikely prospect. It is much more likely for DEWs to be used as dazzlers, preventing the use of a satellite temporarily. For these reasons we are going to consider directed energy weapons at medium level of interference capability. The political impact of DEWs is less straightforward to analyse compared to that of kinetic weapons, owing to their scarcity and the fact that they've never been used. One point to keep in mind is that DEWs do not produce debris, which reduces the diplomatic difficulties in assessing who has and could potentially be wronged. Furthermore, the fact that directed energy weapons are much more precise in their targeting as well as scalable in their output also opens the possibility of selective retaliation, varying the response as the situation changes. For there reasons, I argue that DEWs do not have the same political impact levels as kinetic weapons do and much of this difference is unaffected by the flexibility they afford to the country in question: when used offensively and destructively, the lack of generated debris would probably help moderate the tensions in the international community and keep the crisis "contained" between the affected countries. In other circumstances (such that no permanent damage is done) it's unlikely that the dazzling of a sensor, be it offensive or retaliatory, would cause a strong, violent response on the part of the affected country and the rebuke of the international community. For these reasons, I think it best to classify DEWs as having medium levels of political impact.

1.3(C) CYBER AND ELECTRONIC WEAPONS

It is no secret that in the present day cyberspace is both ubiquitous and pivotal, with many social and economic activities having been subsumed into it, as well as acquiring an increasingly important role as critical infrastructures and for security applications; space assets form a significant part of this cybernetic environment, posited to increase in scope and relevance as satellites are increasingly becoming integrated into a globe-spanning communication and navigation network (Salim, Moustafa & Reisslein, 2024). It is no wonder then that space assets have been targeted with increasing frequency and sophistication (Kaczmarek, 2024) by malicious actors. While there's a growing realisation inside the sector as to just how much damage a determined group of hackers could cause to a country if it decides to target their space infrastructure (Peeters, 2022), space systems are still particularly vulnerable to cyberwarfare due to a variety of technologic, economic and geographical factors (Manulis, Bridges, Harrison, Sekar & Davis, 2020):

1. Protocols used in satellite communication are simple and lightweight, owing to the need for speed in download and upload between the air and ground segment. This has meant that in the past security was not considered of particular importance when developing communication protocols[21], and to this day security measures are often still seen as a secondary concern, instead of being implemented in the development process from the ground up. For certain industrial sectors of the space economy (such as satcom) the need to shore up their cybersecurity may directly impact the viability of their business model, as security countermeasures consume bandwidth destined for paying customers and adds latency, degrading the services.
2. Communication protocols used by satellites are often tailor-made for a specific mission, and while there are certain standard solutions employed by space agencies across the board, a sector-wide set of rules and best practices when it comes to cybersecurity has not been firmly established, although headway has been made by some institutions such as the US' National Institute of Standards and Technology,

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[21] Additionally, the space industry has enjoyed a reprieve from attacks due to its relative obscurity and attacker interest in other, more lucrative sectors of the economy (NSR, 2022). This may have contributed to the relaxed outlook that many space companies and agencies tend to have had until recently on cybersecurity

which has made available a series of its influential NIST Handbooks dedicated to the cybersecurity of commercial space systems (NIST, 2023).

3. More generally, many firms develop components and payloads by following a unique inhouse process, banking on the fact that not following widely known best practices and guidelines will give an additional layer of protection against attacks, a method called *security by obscurity* that is demonstrably ineffective at preventing cyber attacks (Matei, 2021).
4. A significant portion of operational satellites do not employ authentication processes of any kind, meaning that a malicious actor familiar with the communication protocols and the architecture of the satellite can send commands and take control of the spacecraft. While this state of affairs is not due to negligence (Matei, 2021), it still constitutes a key weakness in the space infrastructure of many countries and firms.
5. Owing to the complex nature of space missions, there are several points of entry that attackers can exploit: cyberattacks can target both the satellite (air segment), the ground control station (ground segment) and the final user (user segment). This inherent weakness is exacerbated by the nature of modern satcom constellations like Starlink, which are comprised of dozens of satellites, each vulnerable to exploitation.
6. Removing cyber vulnerabilities is a complex technical endeavour even on the ground, doubly so when dealing with custom-made operating systems, software or protocols. Heavily customised software and hardware require time to close gaps in their cyber defence: arrays have to be reprogrammed, producer patches have to be adapted to custom architectures and operational or administration practices have to be updated in light of the changes. Satellites, being for the most part purpose-built from the ground up with very specific - and often outdated - components due to the need to harden them against cosmic radiation, as well as the time elapsed from the original proposal of a mission to its launch (ENISA, 2024), are even more difficult to upgrade than regular, earthbound computer systems. One should also consider that after its launch most spacecraft will be beyond the possibility of any physical repair or adjustment[22] (Kazcmarek, 2024).

Having established the numerous challenges faced by firms and governments in keeping their space assets secure from cyber-intrusion, one can wonder what exactly could a sufficiently

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[22] A famous exception is the Hubble Space Telescope, which launched with faulty optical instruments that had to be substituted in orbit - a feat only possible thanks to the Space Shuttle.

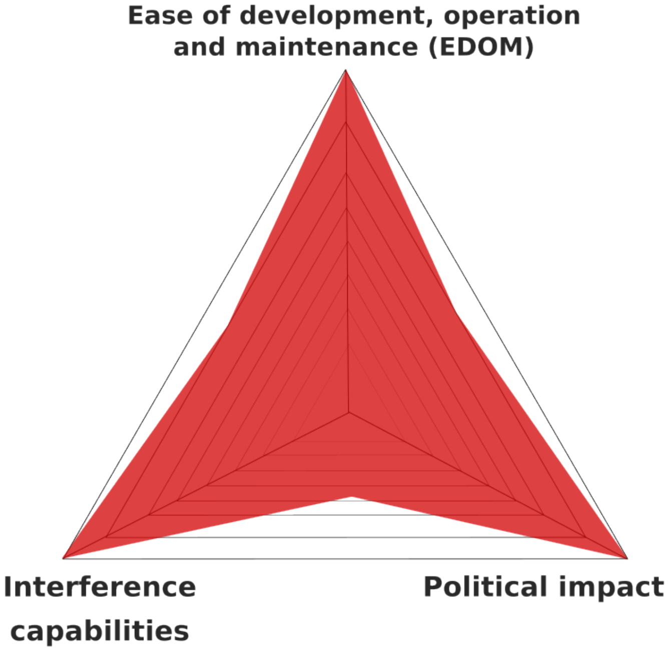
capable group of cyber-assailants gain from attacking a satellite and the entity of the damage they could wreak. A report by ENISA (2024) gives us a compendium of possible outcomes which we shall briefly summarise below, ranging in severity from service degradation all the way to physical damage to the spacecraft:

1. Service degradation: the end user is unable to access or make use of the services offered by the satellite
2. Command & Control degradation: the administrator is unable to properly manage the satellite, which is partly or totally controlled by the attacker
3. Damaging the asset: the attacker can use their control of the system (partial or full) to cause physical damage to the satellite
4. Data theft: data produced, stored or redirected through the satellite is stolen by the attacker; this can also apply to the engineering or system schematics of the satellite.
5. Extraneous service damage: an attacker can use a controlled satellite as a springboard to degrade the service of another satellite
6. Capability hijacking: the attacker uses the instrumentation and capabilities of the satellite without permission
7. Information forgery

We finish our cursory look at ASAT cyberweapons with our now familiar framework, starting with our EDOM metric. Cyberattacks -ASAT or otherwise- and cyber capabilities in general are fairly inexpensive compared to modern weapon systems. Very little hardware and dedicated facilities are needed compared to both DEWs and kinetic weapons and most of the costs are concentrated in the human capital doing the cyberattacking and hacking. While this isn’t to say that cyberweapons are cheap in an absolute sense, they are far less expensive than their material alternatives, which justifies their placement in the high EDOM category.

When it comes to a cyberattack’s capability to interfere with the functioning of a spacecraft, the astounding granularity and scalability of cyberwarfare immediately comes to the fore: as we’ve seen above, with sufficient time and effort any internal system and component of a satellite can be taken over, manipulated or turned against the intended user. In addition, the logical architecture of most satellites is designed to be simple, straightforward and parsimonious, due to the obvious constraints of the space environment (Fortescue, Stark &

Swinerd, 2003), and is usually built with rad-hard[23] components that are outdated by several years if not decades compared to their surface counterparts, making them more resistant against the might of cosmic radiation but vulnerable to malicious hackers. Most of the threats outlined above fall below the threshold of what many countries would consider hostile actions, due to their inability (for the most part) in causing first order effects (Van Puyvelde & Brantly, 2019); yet one should not underestimate the possibility of an ASAT cyberattack causing physical damage to the target. The power system can be compromised, causing damaging overvoltages to sensitive equipment; fuel valves can be tampered, causing an explosion; the satellite itself can be commandeered and forcefully de-orbited or made to collide with debris or another satellite. An even more troubling suggestion is put forth by Pavur and Martinovic (2019), whereas an attack on the SSA systems[24] commonly in use by satellite companies and agencies is simulated: the SSA web server is infiltrated, and counterfeit data pertaining to the position of fictitious debris is inserted into the SSA database. This will cause the satellite to engage in manoeuvres to avoid the fictitious debris, putting it into a collision trajectory with actual debris. The simulation resulted in a 93% collision success rate, at a very low projected cost and a high degree of deniability due to the policy employed by Pavur and Martinovic of modifying the smallest possible amount of data to reduce the possibility of detection. An important point to keep in mind is that - unlike DEWs or kinetic weapons - defences against cyber intrusions can be continuously upgraded, even when the satellite is already in orbit. Patches can be uploaded, protocols amended, bug fixed and backdoors



Graph 3 - Characteristics of destructive cyberattacks as radar plot

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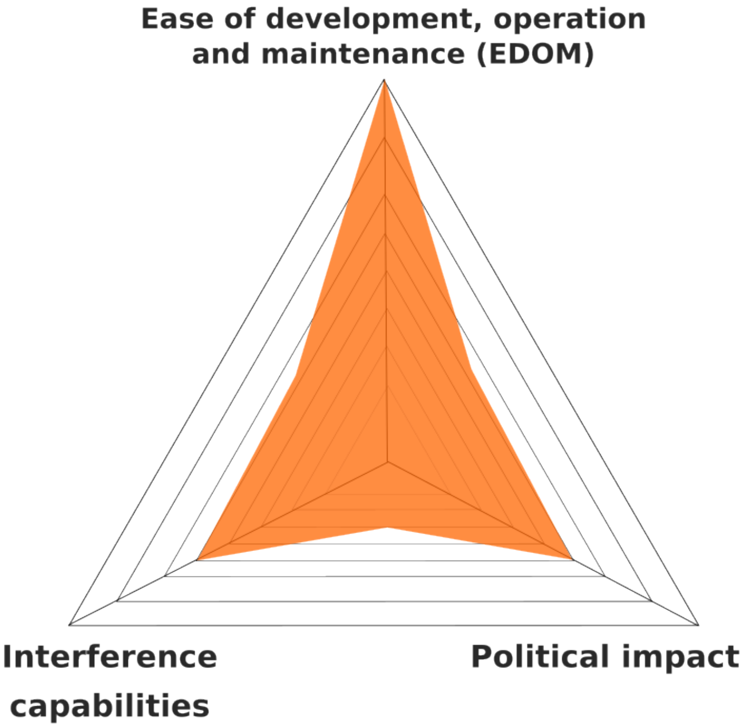
[23] Electronics and components used in satellites are hardened (resistant) against radiation (i.e. rad-hard). Incoming charged particles (from the Earth's own Van Allen Belts, solar wind as well as cosmic rays) can and do impact the satellite and the electronics, interfere with their functions and can even physically damage them, hence the need to make them resistant to radiation.

[24] SSA stands for Situational Space Awareness, and comprises a variety of systems, both earthbound and spacebound, used by national space agencies as well as private companies to monitor objects in orbit, as well as debris, asteroids and space junk that could threaten the physical integrity of space assets.

closed, although this requires time and effort. These factors make the assessment on the possible destructivity vis a vis interference of a cyberattack difficult. The scalability of cyberattacks makes them similar to DEWs in that regard, but the breadth of possible threats is significantly enlarged, ranging from mere annoyance to complete destruction of the asset. It's for this reason that I decide to divide cyberattacks in destructive and non-destructive when it comes to both interference capabilities as well as political impact (the severity of the attack would have no bearing on its costs, so EDOM remains the same for both), as the gulf between the two is simply too wide to be put in the same category as DEWs were. Obviously, destructive attacks score the highest on our interference capability metric, as one can scarcely imagine anything more impactful than making a satellite detonate or forcing it to collide with another. As for non-destructive, while the path of entry can change (either the satellite itself, the ground control station, or the user segment), we only consider cyberattacks as relevant for our analysis if the objective is the operation of the satellite itself. In other words, events such as the Viasat attack of February 24th 2022 would not be relevant to our analysis[25]. In any case, non-destructive attacks by definition do not physically



Graph 4 - Characteristics of non-destructive cyberattacks as radar plot

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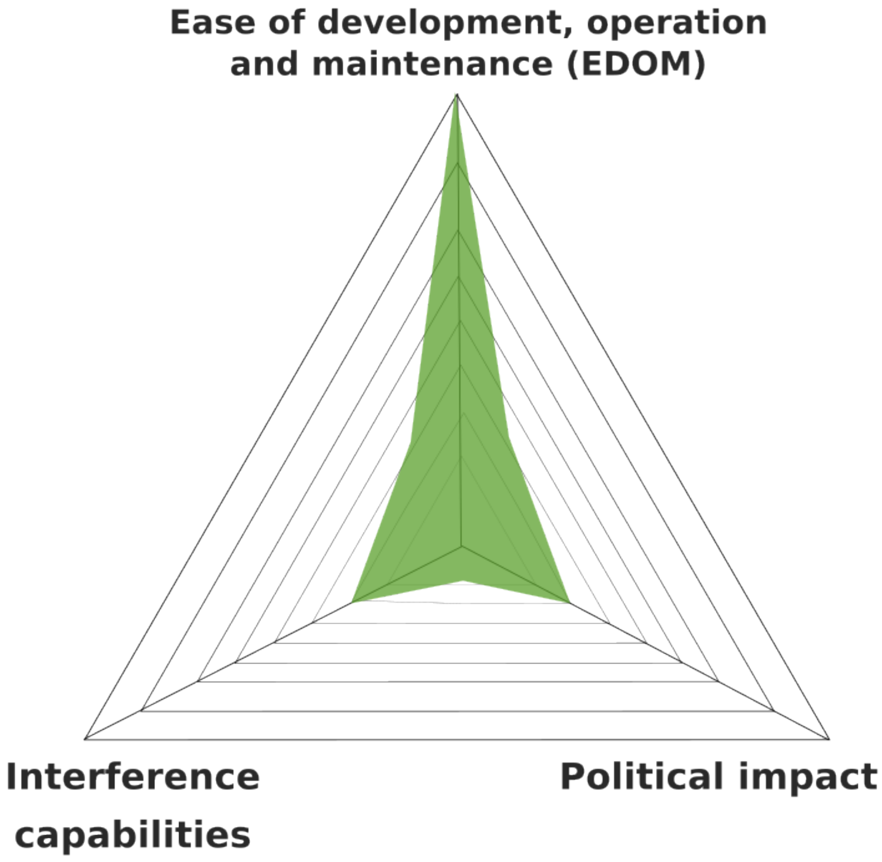
[25] This clarification is necessary, I believe, to avoid having to create an additional (and in my opinion not analytically useful) distinction between cyberattacks that target the satellite and cyberattacks that target the ground segment or the user segment, which would naturally have different interference capabilities much like destructive and non-destructive cyberattacks do. The Viasat attack (Cyber Peace Institute, 2022), where a group of hackers infiltrated the commercial segment of a broadband internet satellite company, causing widespread internet shortages around Europe, is a fitting example to highlight this. In this case, the satellite segment was completely ignored by the hackers, which instead elected to infect Viasat modems connected to the network with a malware called AcidRain, which wiped them and rendered them unusable. In the Viasat attack the presence of satellites was immaterial, and would have achieved the same effects if the provider of internet services were using regular optic fibre cables instead. What is relevant for our analysis is the tampering of a satellite, and while we are not predisposed to any particular point of entry, the satellite must be the objective, and not a mere part of a system that is being hacked

damage any component of the satellite; as such they are classified as having medium class interference capabilities.

Cyberweapons present various challenges when modelling the political impact of their use, and it is beyond the remit of this thesis to go through them. Suffice to say that most cyberattacks do not register as hostile actions on par with physical attacks, and are tendentially difficult to attribute to specific countries or organisations, making retaliation -or the taking of merit- difficult for parties involved. And yet attribution is a different beast of sorts when it comes to the space domain: specifically because so much is possible (at least for now) due to the vulnerability of space infrastructure, malicious actors will have a tendency to select the type of attack that best suits their level of technical expertise as well as their political or economic objectives, since there are less constraints and security measures compared to ground infrastructure. In other words, the freedom allocated to malicious cyber-agents by the lax cybersecurity standards of the space industry will make them “tell on themselves”, making attribution a less complex and uncertain endeavour. This undermines a key advantage of cyberattacks, *plausible deniability* (Valeriano & Maness, 2012). For example, when it comes to entry points, network insertion is considered the most approachable and less technically demanding option, on-board and ground segment software as middle of the road in terms of complexity, and hacking of the hardware components of the satellite as the almost exclusive purview of state-sponsored hackers (ENISA, 2024). Instead, if we consider the type of attack being employed, state-sponsored hackers will be more likely to use sniffing and eavesdropping on targeted space assets (NSR, 2022) since one of the main values of satellites lies in the informational advantage they provide to their governments; on the other hand, criminal elements may prefer to take control of a satellite - e.g. by replacing its SDLS (Satellite Data Link System) authentication keys - to ransom its control back to its owners. This means that a lot more information can be gleaned from an attack on space infrastructure compared to ground infrastructure, if we assume that countries aren’t able to “resist” and content themselves with more basic, less impactful attacks. If so, non-destructive attacks could be more effectively traced back to the source, giving them additional political weight (and costs attached). As for destructive attacks, we know that the more complex and destructive an attack is, the weaker is the role played by plausible deniability (Van Puyvelde & Brantly, 2019), as the group of possible perpetrators shrinks for both technical reasons as well as motives. In addition, the consequences being permanent and potentially far reaching (creation of debris, interference with third party satellites) add an extra element of political gravity. Non-destructive attacks will therefore be put into the medium level category of political impact, while destructive attacks will be put in the high level category.

Completing our analysis of ASAT systems requires us to go over one last category of ASAT capabilities: electronic weapons. Electronic weapons take advantage of the fact that satellites communicate with each other and with the surface wirelessly, specifically using highly focused radio waves, and target them to various effects. If the signal is blocked or scrambled by interfering with the signal with an overlapping, stronger one, it prevents the user from accessing the service provided by the satellite, which is too degraded to be of any use: the attacker is jamming the satellite. On the other hand, if the user is transmitted a manufactured, fictitious signal - overriding the original - the attacker is spoofing the signal from the satellite. Jamming and spoofing can be employed on the *downlink* (the signal travelling from the satellite to the ground station or the user) or on the *uplink* (the signal travelling from the surface to the satellite), but both practices are subjected to a series of technical constraints. A common restriction is the physical proximity to the target that both methods need to maintain in order to be effective: the jammer or spoofing equipment must be in the general area of the receiver - i.e. the targeted user - and must be able to point its attack towards the latter. These restrictions are comparatively less cogent when jamming or spoofing is done on the ground and on the *downlink*: since the



Graph 5. Characteristics of electronic weapons as radar plot

jammer/spoofer is much closer to the user than the user is to the satellite, it needs much less power, and doesn't have to as precise in pointing towards the receiver. As for uplink interference, ground based jamming/spoofing is technically feasible, but practically doable for just a specific subset of satellites: communication and broadcast satellite placed in geosynchronous orbit, which are fixed in the sky and cover a large area, making them easier to interfere with. If the targeted satellite is not in a geosynchronous orbit - and most satellites aren't - its broadcast area will move with it and will be smaller, making it harder to jam or spoof. This isn't the case when the disruptive equipment is taken to orbit: a jammer could be placed on a satellite and pointed towards another spacecraft, preventing it transmitting to the surface. However, this approach has a fundamental drawback: both receiving and broadcasting antennas are placed on the bottom of the satellite (as it has to transmit and receive signals from the Earth's surface which, from the perspective of the spacecraft, sits directly below it). As the body of the satellite would shield the antenna if the jamming/spoofing was coming from above its orbit or further along it, the orbital jammer/spoofer must be placed below its intended target. This would give the jammer a smaller, tighter orbit, which would be faster, such that it would pass below its target too quickly to maintain the interference signal.

Spoofing and jamming, which are usually used to target GNSS signals, are the only ASAT systems that have seen actual use in military engagements: the American GPS has been jammed by the Iraqi during the 2nd Gulf War, and in certain conflict theatres such as Syria (Westbrook, 2019) and Ukraine (Clonts, 2023) jamming and spoofing are a daily occurrence. The reason why most spoofing and jamming attempts are concentrated on GNSSs is twofold: firstly, they represent a fundamental component of contemporary warfare and warmaking, as well as of civilian infrastructure; secondly because the signal coming from GNSSs constellations is fairly weak and therefore relatively easy to interfere with (Westbrook, 2019). The reasons spoofing and jamming are employed are manifold: they can be used to block out broadcasts, civilian and military, with relative ease; they can cut off a military force from a reliable guide for navigation in hostile or an unknown territory, or they can shepherd that very same force towards an ambush or encirclement by feeding it false data. Jammers can also put pressure on governments through sustained signal degradation, which has important economic fallouts, as well as to goad and provoke other countries through a low intensity hostile action. (Westbrook, 2019).

Ending our analysis with electronic weapons, we start as usual with assessing the ease with which countries can develop, use and maintain jamming and spoofing capabilities. Similarly to cyberweapons, electronic weapons are fairly cheap and easy both to make and use: commercially available jammers can interfere with signals in a 100 kilometres radius; in fact, someone with cursory knowledge in electronics and circuitry can build a simple jammer with instructions readily available on the internet (Wright, Grego & Gronlund, 2005). Spoofing is more technically demanding, but not relative to other systems we've examined prior. While more sophisticated systems may exist theoretically and would be fairly expensive, actual devices employed today are, as outlined above, fairly cheap and easy to use. As such, electronic weapons score as high in the EDOM score.

When it comes to effectiveness, it's hard to argue against the efficacy of jammers and spoofers, considering they see regular use in battlefields across the globe. Regardless, our interference capability metric does not score on effectiveness of an ASAT system's stated purpose, but on its effects on the operation of the satellite. Since electronic weapons are only able to interfere with the signals emitted or received by the satellite and not the spacecraft itself, they are consigned to the lowest level of interference capability.

Political impact of electronic weapons is comparatively easier to analyse, as these systems have seen widespread use for almost two decades, and so the political effects of spoofing and jamming can be observed empirically. We see that both are used frequently in battlefields, eliciting no response that would be considered out of place during an armed conflict, and jamming has seen use in peacetime, to understated responses and no aggressive retaliation as of yet. It is therefore appropriate to consider electronic weapons as having a low political impact.

1.4 CONCLUSIONS

In this first chapter, we have examined the most widely recognised and debated ASAT capabilities available to state actors today, and outlined their principles of operations, their limitations as well as the advantages they provide to countries which may decide to use them. As we did so, a scheme has started to emerge, such that we can start to draw some simple inferences: we've seen that certain capabilities are destructive in nature and run the risk of creating debris, or escalating tensions to the point of open conflict, while other can be modulated more effectively according to the situation, allowing for flexibility and the possibility to defuse a potentially tense confrontation. Kinetic weapons are ruggedly effective, relatively affordable and carry a heavy political price, while energy weapons are expensive, sophisticated, but less risky politically speaking. On the side of “immaterial” warfare, cyberweapons are eminently cheap, but potentially dangerous and lose out on part of their elusiveness when translated in the space domain. Lastly, electronic weapons present as a low-cost tool to even out a battlefield and have a rather limited overall impact. It’s clear then that these weapons and systems are not born equal and each may serve a specific use, or come to occupy one or more niches. Yet, the inner workings of these ASAT weapon systems, as useful as an analytical springboard as they may be, do not allow us to see the full picture. While tools inform the way the artisan uses them, there’s more to the craft of international politics than a series of technical specifications: countries consider more than what their weapons can and cannot do when deciding to use them or not. We’ve spent the last chapter analysing the weapons currently being pointed at outer space, but to gain additional understanding, we must come to know what exactly is being targeted. In the next chapter we’ll go through the various types of satellites and constellations currently employed by countries and private companies around the world, as well as the strategic and physical characteristics of the medium they are situated in: outer space. We’ll see that not all satellites are born equal, that different space assets have wildly different strategic value depending on their function and that space itself, with its supremely hostile environment, has a way of discouraging open, violent conflict due to the risks generated by debris generation.

CHAPTER 2 – THE PHYSICAL AND HUMAN GEOGRAPHY OF SPACE POLITICS

Space is vast and empty, on a level incomparable to even the most desolate places on the surface. The sheer scale of it runs contrary to our lived experience on such a level that it is no wonder that still to this day there is still no compelling and accepted framework with which to analyse the way states and military forces should act in it (Klein, 2006). Space is also hostile, inhospitable and hides its complex geographical features beyond what is visible to the eye. And yet these features -as real and tangible as mountains, rivers and oceans are on Earth- can have profound effects on human conflict. In the preceding chapter, we have looked at the features of ASAT systems deployed or being currently developed; in this chapter, we shall examine closely the environment in which these weapons operate, its features and the effects it may have on their usage, as well as the way these features shape the way governments and organisations perceive space politically and strategically, following a geopolitical[26] perspective. For the purposes of our analysis, we will consider the natural geography of space, and how it influences its human components, i.e. satellites. Much like mountain ranges or deserts on the surface, natural space features act as barriers or multipliers to human action (military and otherwise) and so inform the way governments, space agencies and private firms operate in space in deep and meaningful ways. We shall see that while space appears boundless and featureless, movement is not free and without limits, and that orbits and gravity wells provide clear and exacting limitations - as well as opportunities. We will observe that satellites are not made equal in terms of strategic, economic or political value; that the way space infrastructure is set up makes it less vulnerable to singular attacks due to a distinct lack of bottlenecks, as well as distinctly interconnected and codependent, even when considering space assets of hostile nations. As we will be using technical terms from astronomy and

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[26] While often used in common parlance as synonym or stand-in for international politics, geopolitics as discipline consists of the study of the effect of geographical features (both human and natural) on politics, and this is the definition I will employ in this chapter. The idea that geography has an effect on politics has long roots, harkening back all the way to Thucydides, but the term itself has its origin in post-WWI Germany, where the systematic study of the interplay between geography and political outcomes found a fertile ground, as well as a most unfortunate patron of sorts in the Nazi ideology. Its association with Nazism and totalitarianism marred the reputation of the discipline for decades (Sloan, 2017), until a somewhat recent resurgence in the 80s, replete with a rediscovery of the great non-fascist geopolitical thinkers of the first half of the 20th century like Mahan (who had remained popular in the American cultural sphere), Spykman and Mackinder. There have been some attempts at creating a comprehensive geopolitical analysis of the space domain akin to the one done by Clausewitz for land, by Mahan and Corbett for the sea and by Douhet for the air (e.g. Klein, 2006 and Dolman, 2005), but as I've touched upon in the introduction to this chapter, no clear winner has emerged yet from the (admittedly limited) academic debate.

celestial dynamics, a short appendix explaining the basic principles of orbital mechanics is available at the end of the chapter. It is advised for the reader not versed in these subjects to read it before continuing with this chapter.

2.1 THE GEOGRAPHY OF OUTER SPACE

As I've briefly touched upon in the introduction to this chapter, space presents itself as a featureless, uniform void dotted by some variety in the forms of planets, asteroids and stars. However, it is anything but: unseen but always present, gravity and radiation are fundamental geographical features of space, which dictate the limits of what we can and cannot do outside our atmosphere. While radiation[27] is a massive concern for practical operation of satellites, our analysis is chiefly concerned with the constraints and the opportunities created by gravity, i.e. orbits.

As Dolman (2002) points out, an effective way of understanding orbits from a practical and strategic point of view is to think of them as akin sea routes. While a ship is technically able to -once it leaves port- go off in any direction it so wishes, there are still issues to take into consideration by the captain and the crew when deciding the route: the amount of fuel that is available, as well as food, the conditions of weather, the ability of the ship to endure the conditions of the open sea. And so it is that mariners tend to stick to specific paths, or sea routes, that provide a good mixture of fuel economy, safety from the elements and the possibility of restocking the ship's pantry amongst many such considerations. These routes do not take ships from point A to point B in a linear fashion, and are not influenced by the presence of obstacles or lack thereof. Orbits function strategically (but not physically) in a similar manner: they are "routes" per se, characterised by a relative convenience for a specific mission, but are not defined by geographical barriers. There is no obstacle to surmount to move from one orbit to another except for the speed necessary to move up (or down), much

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[27] Outer space is a high radiation environment, due to both the abundance of sources of radiation as well as the lack of protection afforded on the surface by our atmosphere and magnetosphere. Important sources of radiation in space near the Earth are solar winds (flows of charged particles emitted by the outer layers of the Sun's atmosphere), cosmic rays (highly charged particles emitted by various celestial phenomena, like blackholes, supernovas and magnetars) and the Van Allen belts (regions of the Earth's atmosphere full of energised particles; special care is needed for satellites and crewed missions passing through this region of space due to the high risk of damage or injury)

like a ship doesn't have to wade through a forest or traverse a swamp to go off an established route, but has to keep into consideration how much fuel and food it has to complete the journey. Therefore, like sea routes, orbits are precious, and have different values - economic and strategic - attached to them depending on what they can be used for: from observation to navigation, to signal broadcasting to weather forecasting, each use of the space environment is best served by one - or more - orbital configurations. In the next section we will examine a small typology of these orbits, accounting for their most common uses, the tradeoffs in terms of economic and operational capabilities they all offer and how this may influence whether governments may consider viable or desiderable the use of ASAT systems.

2.1(A) LOW EARTH ORBITS (LEO)

The vast majority of artificial satellites existing today[28] orbit quite close (relatively speaking) to the surface, occupying what are commonly referred to as LEO, or Low Earth Orbit. LEO is usually defined as any orbit with an altitude between 200 km and 1000 km above the surface, and with an orbital period between 90 and 120 minutes (Hintz, 2022). Orbits at these altitudes are the only ones that have to contend with atmospheric drag, the friction generated by the atmosphere slowing down the satellite, which means that any spacecraft placed in these orbits will eventually fall down back to the surface if not periodically readjusted. This naturally put important limitations to the design of LEO satellites, as they require fuel for the readjustment, taking up precious weight and space on the payload. On the other hand, these orbits require less energy to be reached, making them cheaper and more accessible to a wider range of countries and firms. As LEOs sit close to the surface, they have a short orbital period[29] and a small footprint[30], making them unsuited for long-term monitoring of a specific area of the Earth, or for continuous broadcast. What LEOs lack in width, they gain in depth: the closeness to the surface allows for a much better resolution and for a much stronger received signal. That is the reason why, with the advent of more affordable launchers[31], LEO is rapidly

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[28] More than 80% of all satellites sit in LEO; for more information consult the following link: https://nanoavionics.com/blog/how-many-satellites-are-in-space/

[29] 90 minutes on average.

[30] The area directly reachable by the satellite's signal at a given moment: the closer the satellite is to the surface, the smaller it will be and vice versa.

[31] The average cost per kilogramme to reach LEO was around $1700 in 2021. If it seems like a lot, one must remember that first commercial LEO launches had a cost of around $65000 per kg; see Daehnick, Gang & Rozenkopf (2023)

becoming the realm of big commercial constellations: the small viewing windows and limited time spent above a given area of the Earth is offset by the sheer number of satellites present, allowing for continuous coverage even when close to the surface. An example of this is the internet provider Starlink: before the cost of sending satellites in LEO plummeted due to innovation in launcher technology pioneered at SpaceX, satellite internet was confined to geosynchronous medium earth orbits and to voluminous, heavy satellites like the Anik series. Starlink employed a different approach, using the cost effectiveness of LEO to put in orbit dozens of small satellites per launch, reaching a total of more than 7000 satellites providing internet broadband with almost global coverage.

LEOs are also where most military observation satellites are located (Dolman, 2002)[32], and highly eccentric orbits (HEO) like *Molniya* orbits[33] do their passover at this altitude. HEOs function differently from regular LEOs, as they spend the majority of their periods far above normal altitudes. Unlike geosynchronous orbits, which we will examine next, there's much less international regulations surrounding the use of LEOs (ITU, 2022), which certainly helped with the proliferation of satellites placed at these altitudes[34]. This is due to the physical characteristics of geosynchronous orbits more than anything: LEO satellites require coordination to avoid reciprocal interference with their respective signals and to avoid collisions in particularly crowded orbital segments, but not much more than that.

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[32] Many intelligence observation satellites are put in a sun-synchronous retrograde orbit to make sure that the satellite passes on the same spot of the surface always at the same time of day (with respect to a surface observer). Intelligence observation satellites are usually outfitted with large quantities to fuel to manoeuvre around different orbital levels more expediently (Moltz, 2024)

[33] *Molniya* orbits are a type of orbit used by arctic countries to maximise observation capabilities around the poles. They are highly eccentric retrograde orbits, which slow down significantly when reaching their perigee, allowing for long observation of polar and subpolar areas. These types of orbits are mostly used by countries like Russia and Canada, which have a pressing need to have almost constant surveillance over the North Pole and the surrounding areas.

[34] In fact, in many circumstances notifying the ITU of the launch and adhering to the regulations on radio frequencies assignment is enough.

ADVANTAGES	**DISADVANTAGES**
Clear, powerful signal with low latency	*Fuel is necessary to maintain orbit due to atmospheric drag*
Great resolution for imaging and surveillance	*Small observation windows and short orbital period: constellations are necessary to unlock full potential*
Cheap and accessible to many countries and firms	*Crowded, risks of debris generation*
Less international regulation	*Reachable by DEW ASAT systems*
WHAT IS IT USED FOR?	*Imaging, broadband Internet, military surveillance, intelligence gathering*
HOW MANY SATELLITES IN LEO?	*7700 as of November 2024*[35]

Chart 1. LEO in summary

2.1(B): MEDIUM EARTH ORBITS (MEO)

Medium Earth Orbits are defined as having an altitude above the upper bound of LEO and high Earth orbit, between 1000 and 35000 km (Hintz, 2022). At these heights, the energy required to put a satellite in orbit is far larger, such that the launch cost balloons significantly to around $30000 per kg (Koelle, 2003), twenty times that of LEO. The high barrier to entry in terms of cost, the latency due to the distance from the surface and the tight regulations on the most lucrative and strategically relevant orbit at these altitudes - geosynchronous orbit - has for now stopped the proliferation of microsatellites and constellations currently underway in low Earth orbit. One shouldn't take this to mean that MEO is less valuable or relevant compared to LEO. On the contrary, medium Earth orbits are host to the most valuable pieces of space infrastructure existing today, as well as the most well known by the general public:

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[35] See https://orbit.ing-now.com/low-earth-orbit/

global navigation systems like GPS and GLONASS have their space segments at these comparatively high altitudes[36], but MEO is also host to fundamental communications satellites for maritime and military use as well as television broadcast satellites, broadband internet, early warning systems and nuclear test detection (Moltz, 2024).

There are two main orbital types commonly used in MEO: the first is the **semi-synchronous orbit,** which has a 12 hour period, meaning it passes over the same spot on the surface twice in 24 hours. Semi-synchronous orbits are stable and predictable, making them ideal for constellations of navigation satellites like GPS or GALILEO. The second type is the **geosynchronous orbit**, which merits a closer look, due to its unique features and importance. Simply put, a geosynchronous orbit (or GEO) has an orbital period equal to that of Earth's rotation (that is, approximately 24 hours). The most important characteristic of GEO is that since its period matches the Earth's rotation it will occupy the same portion of sky relative to the surface; the consequence of this fact is that the satellite can continuously monitor and communicate with one specific part of the surface (e.g. one or more countries), and that the need for tracking is vastly reduced, since for an observer on the planet the satellite in question will remain in the same quadrant of sky.

If the satellite sits at an altitude of at least 35.000 km and has inclination equal to zero, it will appear as a fixed point in the sky, completely stationary. This subtype of geosynchronous orbit is called **geostationary orbit (GSO)**, and is the most economically valuable planetary orbit in use today (Dolman, 2005), as it provides unparalleled, constant coverage of a portion of the Earth and requires no tracking whatsoever on the ground; moreover, since the satellite is stationary, it can provide a point-to-point communication between any two -or more- locations on the ground as long as they are both in the observation window of the satellite itself[37] (Stark & Swinerd, 2011)). However, the fly in ointment comes from the nature of the orbit itself: since geostationary orbit needs to lie on the equatorial plane of Earth and the satellite must remain at 35.000 km of altitude, all geostationary spacecraft effectively occupy the same orbital track, and must remain spaced at specific intervals to avoid interference with each other. This means that only a limited amount of space assets can be placed into geostationary orbit; to be more specific, 2200 total orbital slots (Finch, 1986), of which

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[36] For example, GPS satellites orbit the Earth at 19.000 km above sea level; in comparison, the International Space Station, the largest man-made object ever put into space, orbits the Earth at a far more "modest" 400 km of altitude.

[37] Three satellites in geostationary orbits are enough to provide an almost global coverage to any kind of communication system.

around 1800 are still available. To launch a satellite in geostationary orbit, a company or country must acquire the right to use a specific slot by the ITU, which has been tasked by the UN with administering orbital slots as well as transmission frequency allocations. FIrms and governments can also reserve the right to use a specific slot and then “sit on it”, since they are not obliged to use it and just need to renew their reservation every 20 years to maintain ownership of it (Ogden, 2022). The current status-quo on geostationary orbits is accepted, but it is not well liked by both firms (specifically newcomers to the satcom market, which can’t acquire orbital slots since the process is on a *first-come-first-serve* basis) and countries of the equatorial regions. Governments of some of these nations[38] adopted what became known as the Bogotà Declaration in 1976, in which they laid claim to the portions of GSO above their national territory. This claim had, for most experts on space law, a tenuous basis (Gangale 2006) and has been put aside by its own proponents to concentrate on the efforts to reform the current system as administered by the ITU (*ibid.)*. GEO and GSO’s combination of high reliability, steep cost to launch, wide coverage and latency makes it suitable for various types of mission: navigation systems, high volume data transfers, weather observation and constellation interlinking are all examples of activities uniquely suited for medium Earth orbits. Perhaps the most important representatives of MEO infrastructure are global navigation systems (GNSS), the most famous of which is the American GPS (Global Positioning System)[39]. As long as the user is visible to at least four satellites of a given constellation they will know their position anywhere on the planet. While the United States of America were the first to build a sat nav system, the GPS isn’t the only game in town. Three alternative constellations exist: GLONASS, which is owned by the Russian Federation, BeiDou, which is owned by the People’s Republic of China and GALILEO, which is owned by the European Union. They share the same operating principles, and receivers on the surface are able to receive signals from any of them, as they are all available to civilian applications free of charge. All four constellations employ more than 20 satellites each in semi-synchronous orbits at varying altitudes (usually between 10.000 and 20.000 km). While

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[38] Indonesia, Ecuador, Brazil, Colombia, Kenya, Congo, DR Congo (then Zaire) and Uganda

[39] The basic operating principle of GNSS is quite simple, as they are all based on a method of navigation called “trilateration”. In layman’s terms, navigation satellites are constantly broadcasting a passive signal which contains the satellite’s relative position in the sky (i.e. the *ephemeris*) and a timestamp of when the signal was emitted by the satellite. This very faint signal is picked up by a receiver on the ground, which reads the timestamp and calculates the distance between itself and the broadcasting satellite by multiplying the time with the speed of light (the speed at which radio signals propagate). This tells the receiver that their user is lying on the surface of a sphere that has the radius of the calculated distance and that is centred on the satellite. When the receiver acquires and calculates the distances with other three satellites (two to resolve the positional unknowns and one to resolve time), the intersection between the four spheres is the accurate position of the user on the planet.

the advantages of being able to know one’s position anywhere on the planet within centimetres of accuracy at any given time are clear, it’s not simple to put into words just how integral GNSS are to the global economy and how important of a military asset they are. The GPS saw its baptism as a military tool during the 1st Gulf War, and even without being fully operational the tactical advantage it provided to the allied troops was self-evident. A key factor when considering GNSS from a strategic is how they embody a design concept commonly used in space system engineering[40], that of **graceful degradation**. Once a satellite is in orbit, physical repairs are impossible; for that reason, spacecraft are usually built with multiple redundancies in place to ensure proper operations even in case of damage. When the mission requirements call for a constellation, redundancy is inserted into the structure of the constellation itself, and they are designed in such a way as to ensure continued operation even when a component is out of commission. Any singular part of the constellation is not integral to the functioning of the whole, and the system is designed to operate horizontally; in other words, every satellite has the same function, and there’s no central node or structural bottleneck (like a master satellite that controls all the others) that can be targeted to bring down the entire system. This guarantees that even if one or more satellites of a constellation malfunction or are destroyed, the whole will continue to function, albeit with a gradual - i.e. *graceful* - degradation proportional to the amount of satellites out of commission. In the case of GNSS, there are two thresholds to consider. The first, which we have already mentioned, is that any user needs to have at least vision of four satellites for the system to work. The second threshold is what guarantees that coverage is truly global[41], and consists of 24 satellites: all the GNSS mentioned above have “spare” satellites ready to be slotted in should one or more become inoperable. Below this threshold, the signal provided is not available 100% of the time on a 100% of the surface. The resilience of constellations (Stark & Swinerd, 2011) is one of the leading causes for their rapidly increasing use both in civilian and military applications For this reason, limited, surgical strikes aren’t really possible when it comes to a critical constellation: either most or all of it is destroyed or it will continue to function in a more limited capacity.

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[40] System engineering is the discipline of turning the requirements of a space mission (e.g. analysing weather patterns, observing the Solar atmosphere, hunting for secret military installations) into an actual and engineeringly sound design for a spacecraft.

[41] This threshold is called the *absentee ratio* (the minimum number of satellites to guarantee that the right amount of them will be available at any given time), and it’s a function of both the mission type as well as the orbital altitude chosen.

ADVANTAGES	**DISADVANTAGES**
Highly predictable in case of semi-synchronous	*Steep cost barrier for launches: difficult to afford for many countries*
No need for tracking in case of GSO, reduced in case of geosynchronous orbits	*Signal latency due to distance*
Wide coverage with few satellites	*Regulation in place favours incumbent firms and spacefaring nations, creates international friction*
Commercially lucrative	*Limited slots available in case of GSO*
	Debris retention risk
WHAT IS IT USED FOR?	*Weather observation, technical (maritime, militar, industrial) telecommunications, navigation, backhauling, television broadcast*
HOW MANY SATELLITES IN MEO?	*743 as of November 2024*[42]

Chart 2 - MEOs in summary

2.2: DEBRIS, SPACE JUNK AND KESSLER SYNDROME

The first law of Newtonian motion states that an object in motion remains in motion unless an external force acts upon it. This apparently basic principle of classical physics has profound consequences when it comes to space and any kind of man-made object cruising through it. A cannonball shot on the surface of the Earth will follow a parabolic trajectory and eventually hit the ground, brought down by friction and the gravitational pull of the planet. A cannonball shot in space, on the other hand, will continue to fly through the universe at the same speed forever, unless it impacts something (which is absurdly unlikely) or is captured in the gravity well of a celestial body. The same principle applies to a significant portion of the objects humanity has put into orbit for the past decades: unless the orbit is low enough that atmospheric drag becomes a concern, a satellite will continue to zoom around our planet for a

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[42] https://orbit.ing-now.com/medium-earth-orbit/

long time, if not forever (at least in terms of time on a human scale). This is why satellites at the end of their life cycles are either deorbited and destroyed by atmospheric reentry or put in a high-altitude “graveyard orbit” away from other spacecraft. However, satellites aren’t the only man-made objects revolving around our planet: much like any other activity on Earth, space missions produce refuse, commonly referred to as “space junk”. This interstellar trash moves at very high speeds, such that even a small fragment can cause significant damage. Figure 2.3 shows us the hole caused by a small fleck (under 1 mm) of paint impacting a window of the Space Shuttle *Challenger* during a mission in 1983. To put into perspective the forces at play, the window panes used in Space Shuttle missions are around 6.6 cm thick (Miska, 1993).

Spent boosters, specks of hardened paint, loose bolts, old satellites spun out of control, metal, plastic and glass fragments and much more crowd the outer reaches of our planetary neighbourhood in a thick blanket of expensive and dangerous space trash. As space becomes more and more accessible and economically attractive, the proliferation of satellites and constellations correlates heavily with the proliferation of space junk, which has become not just an important practical concern for space operators and national agencies, but a political and economic issue as well, which has been proving difficult to resolve (Lambach & Wesel, 2021). Depending on the altitude, the type of impact, accident or procedure involved, the ensuing debris can remain aloft for periods ranging from months to millennia (Kelvey, 2024), constituting a physical danger to most space assets with varying degrees of severity. A potential worst case scenario is epitomised by the so-called **Kessler syndrome**, an hypothetical situation in which the amount of objects in orbit -be they debris or spacecraft- reaches a critical threshold after which a catastrophic cascade of impacts is all but inevitable: as satellites are struck by debris they fragment into even more shards, which impact more satellites, which break up even more, creating a negative feedback loop which would cover the immediate vicinity of the Earth with a cloud of orbital debris so thick that it would make

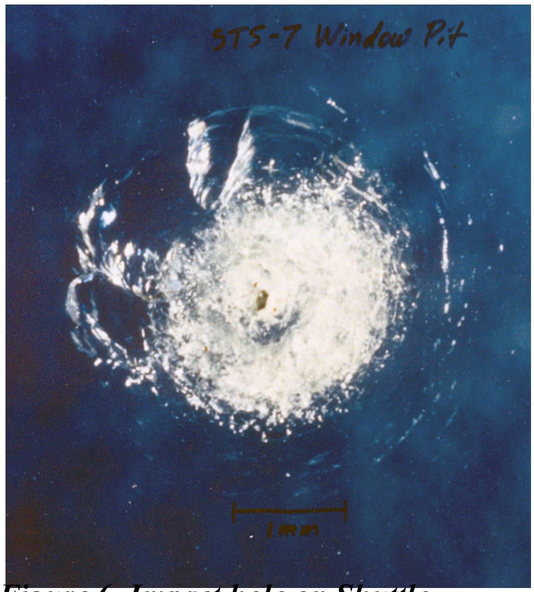

Figure 6. Impact hole on Shuttle window, courtesy of NASA

space travel extremely difficult for years, if not for decades (or longer)[43]. Far from being a remote, far-off eventuality, Kessler syndrome is taken extremely seriously by space agencies and governments and is all but guaranteed to manifest into being if measures are not taken in the immediate future to actively remove debris as well as design spacecraft with less of an impact on the space environment.

Testing of kinetic ASAT capabilities have contributed their fair share of debris to the burgeoning pile[44], and they give us an interesting -if concerning- glimpse at what could happen as destructive forms of warfare are brought into space. As of now, only four countries (the US, China, India and USSR/Russia) have tested kinetic ASAT systems, and they have all generated a varying, but always worryingly large, amount of fragments and debris. These tests have been all been kept well below higher altitudes orbits like MEO and GSO, and some hypotheses can be taken into consideration as to why:

1. We can safely discard reasons pertaining to **technological difficulties in reaching higher orbits**. Why? For starters, satellites are already present at higher altitudes than low earth, and the technology to reach such orbits (MEO and potentially FEO) have existed for decades. Secondly, tracking is much easier at higher altitudes due to the lower speed of the targeted satellites.
2. Another potential reason is the **debris retention potential**. We know that both orbital levels - LEO and MEO/FEO - carry the risk of runaway debris creation events (i.e. Kessler syndrome), but we know that tendentially, the lower the collision, the less it will take for dangerous fragments to de-orbit and burn up in the atmosphere. If the collision happens at a high enough altitude, the ensuing debris cloud could remain aloft for periods of time far exceeding human timescales, if not effectively forever. This could cause certain orbital paths to be interdicted permanently (or at least until the debris are removed), and we have already established that certain high altitude

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[43] It's important to note that unlike what is shown in the popular feature movie "Gravity" by Alfonso Cuaròn, most experts agree that a Kessler syndrome scenario would not be an abrupt series of events that takes place in mere hours, but a steady increase in collisions that would probably require years. It's hard not to draw parallels between Kessler syndrome and global warming: both are gradual, epoch-defining processes that could severely cripple the collective progress and well being of our species; both are "wicked problems" - as public policy scientists are wont to define them - of difficult resolution.

[44] For example, the 2006 Chinese ASAT test created at least 35.000 pieces of debris of at least 1 cm in diameter. The fragments started to spread beyond the original orbit of the downed satellites within minutes of impact and eventually distributed around the planet. The uptick in fragments created was significant enough to be clearly visible in NORAD's catalogue of orbital objects, which follows a time series spanning all the way to 1957, as a 9.4% increase in just a year. For a more detailed report, the reader can consul Kelso (2007)

orbits (like geosynchronous orbits) are extremely economically - and strategically - valuable, as well as potential points of diplomatic contention. It stands to reason that the political fallout of causing such precious and limited orbital slots to become unusable could compound the already high risk of undergoing an ASAT test and dissuade countries from testing their system in high orbit, although not necessarily prevent them from developing such weapons in the first place

3. The third reason, which will be examined more closely in the following chapter, pertains to the **undermining of the regulations and norms surrounding the use of space**. The regulation of high orbits is a contentious issue managed by the ITU on behalf of the entire international community: it is, in a sense, a realisation of the image of outer space as a peaceful realm shared by all countries as a common good in open collaboration. To introduce conflict in a context where diplomacy, negotiation and the rule of law have allowed nations to participate in peaceful scientific and economic endeavours could be construed by the targeted country as well as other members of the international community as a rupture of a sort of "unspoken" compact, and open the floodgates to an open weaponisation of space.

2.3 THE PUZZLE OF SPACE WARFARE: A PARTIAL SOLUTION

Putting together what we now know of the natural geography of space, a clearer picture starts to take form. We know that due to the physical characteristics of space, there are a series of sidereal sea routes, **orbits**, which have distinct properties and differing strategic and economic value. **Low Earth orbits**, due to their short orbital periods and vicinity with the surface, are ideal for observation, surveillance and personal communications, but only if serviced by constellations, which are increasingly more common due to the advancements of launching capabilities and the growth of the space economy: we are, in fact, observing a spectacular rise in terms of spacecraft launched at these altitudes. As such, the value of a singular LEO satellite is low, as a lone asset can do little at these altitudes. On the other hand, we have seen that **high-altitude orbits**, with their longer periods and distances from the Earth, are unsuited for imaging and personal communications, but are able to cover significant portions of the surface, and can even become fixed points in the sky: this makes spacecraft at these altitudes great for high volume communications, backhauling and navigation. It is for these reasons that satellites in MEO and GSO are far fewer and far bigger than their LEO relatives: the cost of getting a satellite in orbit so far away from the planet is significant, leading to firms and governments trying to get as much “bang for their buck” with a single launch as possible; this is compounded by the fact that GSO and MEO satellites require bigger antennas to communicate with the surface. As such, the value of a singular MEO or GSO satellite is fairly high.. We've also seen that space, much like the surface of our planet, is in a way “polluted”. Vast quantities of debris and trash orbit the Earth like satellites, and present a significant danger to the integrity of any satellite. However, depending on the altitude at which these fragments are created, there is a significant variance in their projected lifespan: debris clouds at lower altitude burn up fairly quickly, in a matter of days or months, and this number goes up the further we move away from the Earth. At geostationary altitudes it would take entire geological eras -millions of years- for the debris to re-enter the atmosphere. Lastly, we know that kinetic ASAT systems -the only that have seen thorough testing and relatively easy to access - produce significant amounts of debris.

When these elements are assembled together we can see that the natural geography of space puts an important constraint on the use of destructive ASAT systems, at least at first glance. How so? Let us assume that country A is at war with country B, and has decided that the two key pieces of space infrastructure that its adversary has, a LEO imaging system that allows for constant surveillance of the battlefield in multiple spectra and a MEO navigation system for its troops, are providing too much of an advantage, and they need to be destroyed. Country A has only destructive kinetic ASAT systems at its disposal, well known to country B as well as the rest of the world, and it’s about to decide which system it should strike first. The imaging LEO constellations make for an enticing target, but country A’s high command soon realise that things are not as straightforward as they’d like. The value of country B’s space imaging capabilities lies in the constellations, not in a single asset: to disable it, country A would have to destroy most of the constellations, dozens if not hundreds of satellites, as we’ve established when we have introduced the concept of graceful degradation. This would naturally create an enormous amount of debris, which would quickly (in a matter of months) de-orbit and burn up in the atmosphere. However, LEO is fairly crowded, and country B is not the only one operating satellites at those altitudes: country A and a lot of third countries, uninvolved in the conflict, have constellations in LEO that could be damaged by the clouds of space junk

(Thiele & Boley, 2023). Country A's high command somberly realises that due to the crowdedness of LEO, the fact that dangerous debris would re-enter relatively quickly is counterbalanced by the fact they'd put their own constellations and that of third countries at risk. And so we see that the physical characteristics of LEO encourage proliferation of satellite constellations, and that very proliferation creates an enmeshment of vulnerability between all actors who have space assets at that altitude, an **interdependence** between agents that discourages the use of any anti-satellite weapon that could generate debris. Country A's high command is dispirited but not deterred from taking action. Surely, if the LEO constellations are off-limits, the MEO navigation constellation is a valid target? After all, due to the distance from the Earth, country B's navigation satellites only amount to a "paltry" twenty, instead of hundreds. And to top it off, unlike LEO, there's no crowding in MEO, and the risk of impacting unintended spacecraft is minimal, if nonexistent. There would seem no reason not to strike; however, the physicist advisor to country A's top general raises a valid point: due to the distance from the Earth, the clouds of debris created by destroying B's navigation satellites would persist indefinitely, at least on a human time-scale. This would make the entire orbital path unusable to anyone: country A, country B and all other governments on the planet. Would the international community be accepting of an attack causing the permanent interdiction of a valuable common resource? While we do know that countries and space agencies aren't fond of the fallouts of ASAT testing (Mosila & Burch, 2024), the destructive magnitude of such an attack and the permanence of its consequences makes it all the more likely that the political fallout would be severe and long-lasting, not discounting the fact that a far more valuable infrastructure, much more expensive and freely available to third parties. Depending on the nature of the conflict between the two countries, A may simply decide that the international opprobrium caused by its actions would not be worth the trouble, especially if country B could count on the use of navigation systems of potential allies. Much like LEO we see that the physical characteristics of MEO incentivize a specific type of satellite: relatively small constellations of highly valuable satellites, which tend to provide services to the general public of many countries and not just the owners of the constellations themselves, Moreover, any debris generated at these altitudes becomes a permanent fixture unless removed, preventing future use of an important common good. While the **interdependence** of MEO is of a different nature -economical and political rather than structural[45]- the end result is not dissimilar: checks are placed on the use of kinetic anti-

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[45] A similar (but not identical) point is raised by Harrison, Jackson and Shackelford (2009) with the concept of *deterrence by entanglement*. The key difference is that Harrison *et al.* do not distinguish between different types of "entanglement" as pertaining to different altitudes and different typologies of satellites, do not mention the

satellite weapons and these political and technical constraints are a direct consequence of the natural properties of MEO: the geographic informs the political.

What about the other types of ASAT systems we've examined in the preceding chapters? Are DEWs, cyberweapons of the destructive and non-destructive varieties as well as electronic weapons subjected to the same limitations as kinetic weapons? Constraints are still present, even if they're not quite the same. When it comes to DEWs, atmospheric attenuation, scattering and other optical phenomena reduce the power of ground-based optical lasers, but this is less of a consideration for dazzling, as it is only applicable to imaging satellites, which are mostly located at low altitudes. However, dazzling or even blinding these satellites, now that we know about constellations and graceful degradation, seems less of a productive endeavour: unless most of the satellites of the constellation are blinded at the same time, others will pick up the slack. This would limit the utility of blinding and dazzling to lone observation satellites of the military variety, or to interdict an area of the surface preemptively (if your satellite flies above my base it will get blinded). As for higher altitudes, most assets located in MEO and above would not be considered a valid target for DEWs due to the lack of the optics, as well as the distance from the surface causing loss of power through divergence and atmospheric absorption. Cyberweapons are obviously unimpeded by distance and surface conditions, so there's functionally no difference targeting wise between a LEO and MEO/GSO satellite. If constellations aren't properly designed in terms of network architecture and are able to insulate infected nodes quickly and effectively, then their horizontal organisation offers no protection against non-destructive cyberattacks, and this goes for both LEO and MEO. This shouldn't come as a surprise, as cyberweapons function in a parallel "geographic" environment -cyberspace- compared to the rest of our ASAT systems, which interact with their targets in physical reality.

Destructive cyberattacks call for a specific analysis: first we must assess whether our cyberweapon creates debris (e.g. the malicious agent takes control of a satellite and slams it into another) or not, and then whether an entire constellation is targeted or just a singular asset. A debris-creating cyberattack, be it in LEO or MEO, has the same consequences of a kinetic attack, regardless if the target is singular or collective, so we should be considering both as being subjected to the same constraints. A destructive "clean" attack requires us to go

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possibility of debris backfiring on the attacker and put a stronger emphasis on the economic aspects of "entanglement" *vis a vis* the physical risk of damage for third parties.

even more in depth: since repair is not possible in orbit, any cyberattack that renders a satellite permanently inoperable would not be considered with levity by the offended country, since the end result is the same as it had been shot down when it comes to its usability. If the satellite is a singular entity and not part of the constellation, the attack would probably be framed as a grave aggression by the aggrieved government, doubly so if the target was in GSO, due to the extremely valuable nature of these satellites, both strategically and economically. If the attack was launched on a part of a constellation, the victim would probably temper their response, as spares would be available and it's unlikely it would impede the operation of the whole system. For this reason we can expect such an eventuality to be fairly remote: the attacking country would not gain much, if anything, by such an attack, except causing a nuisance to the attacked and being subjected to some form of international diplomatic fallout. Lastly, if the clean attack was launched on the entirety of the constellation, the difficulty in gauging an appropriate response on part of the affected parties is increased: the attack generates no debris, and so it has not put at risk any third parties' satellites, or other satellites of either the attacker or the attacked. However, an entire constellation is inoperable permanently: depending on the purpose of the aforementioned, this can constitute an important economic damage or a crippling attack on critical infrastructure. The reaction of the victim will chiefly depend upon this distinction, but it will not be brushed aside as a mere annoyance regardless of the circumstances. In any case, it is reasonable to think that the answer will not be equal to the worst case scenario, i.e. the physical destruction of the entire constellation, simply because collateral damage to other assets is taken out of the equation.

As for electronic weapons, jamming and spoofing (Salkield *et alia*, 2023) have been widely employed (especially the former) in many scenarios, ranging from battlefields to criminal enterprises. When used in armed conflicts, electronic weapons become a target of military action, but they have the potential to escalate relatively peaceful situations if used as a means of persistent area denial. For example Russia has been engaging in persistent jamming of the Baltic Sea area ever since the start of the 2022 Ukrainian War, creating economic and logistical disturbances for Finland and the Baltic states. Since the attacks have not resulted in any loss of life, it is difficult for the countries involved to come up with an effective response and deterrence strategy (Eggert, 2024). In any case, electronic weapons aren't beholden to the features of space as much as they are to those on the surface: for example, spoofing requires the "overshadowing" of the downlink signal of the satellite in question, and that calls for precisely modulating the signal strength as not to overpower the receiver, and doing so from a relatively close position, stealthily (Salkield *et alia*, 2023) and with line of sight of the victim . The orbital position of the satellite is relevant only insofar as most attempts at jamming and spoofing are done on GNSS signals, which are easy to block or spoof as they are exceedingly weak, with such a weakness determined by the great distance of the transmitters. Unlike other ASAT systems, which are in more than a way influenced by space geography, electronic weapons are anomalous as they are far more connected to the ground than to the satellites themselves; gaining insights as to their continued and widespread use will require us to employ a different paradigm compared to the one we've been using in this chapter.

Many of the hypothetical scenarios considered in the preceding paragraphs sit below what could be considered open warfare, and fall into the so-called "grey area", a liminal zone between conventional war and peace. More than competition but less than armed conflict, in the grey area countries try to upend the international status quo by engaging in hostile actions that fall below the threshold that would guarantee an armed military response (Morris, Mazarr, Hornung, Pezard, Binnendijk & Kepe, 2019). In our analysis, these actions would correspond to dazzling or partially blinding a satellite, non-destructive cyber-attacks, jamming and spoofing. Over time the academic literature has organically defined a set of common elements (ibid*.)* that define grey area hostilities:

1. Not severe enough to warrant a military response
2. Gradual and cautious rather than sudden and temerarious
3. Difficult to attribute
4. Often justified by political and legal arguments based on historicity
5. Not posing an existential threat to the victim
6. The use of the threat of escalation as leverage
7. Rare employment of military tools and assets
8. Targeting of specific vulnerabilities (e.g. social and political cleavages)

The more the aforementioned ASAT "attacks" would adhere to this set, the more difficult it would be to parse an adequate response (*ibid*.). This would naturally muddy the waters in terms of deterrence in the space domain, to the detriment of our analysis[46]. However I argue

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[46] Briefly expanding on this point, ASAT warfare is, as of the time this thesis was conceived and written, still an hypothetical. Ways to disable satellites exist and have been publicly tested, but no country has ever attacked a rival's satellite. While I'm not the first to draw parallels between space deterrence and nuclear deterrence, I want

that a lot of the uncertainty inherent to hostile interaction in the space domain (Flanagan, Martin, Blanc & Beauchamp-Mustafaga, 2023) can be effectively removed if the factors we've outlined in the first and second chapter are taken into consideration. What ASAT system is used, on what type of satellite, to which extent and in which orbit: these factors alone allows us to glean information from what would otherwise be a potentially obscuring "grey area" operation, even if they may not be enough to define with relative certainty how countries would react in the hypothetical. The mechanisms of action and reaction to an ASAT attack outlined in section 2.3 of this chapter aren't meant to be exhaustive, but to provide an example as to how to employ some of the key elements of our framework, as well as to set the analytical groundowork for chapter 4.

2.4 CONCLUSIONS

Summarising what we've learned and established so far, we've seen that space, far from being a featureless void, has geographical features that can affect a powerful impact on human activity: chief of these features is the orbit, which provides a series of paths or routes, with differing but desirable qualities for satellites. These qualities inform the type of spacecraft we can likely observe at given altitudes, such that the current space infrastructure isn't uniformly distributed geographically or invariable in its functions; rather, it is clustered around particularly relevant orbital avenues, which provide unique advantages to specific missions. The ASAT weapons we've analysed in chapter 1 are similarly influenced by the geographical characteristics of space, be they natural or human. In some cases, as is the case for physical weapons, physics itself plays a role in setting boundaries for their use: lower altitudes can easily be reached by both kinetic systems and DEWs, but the risk of runaway debris generation (i.e. Kessler syndrome) and the possibility of damaging one's own infrastructure or other countries' in the crossfire discourages their use. DEWs are not beholden to such issues, but they are limited as to what they can achieve, considering that lower altitude orbits are

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to underscore what I believe to be a particular point of interest: mercifully, nuclear weapons have been used offensively only once in history, and have since proliferated to numbers more than capable to sterilise our planet of most life multiple times over. This has meant that nuclear warfare has evolved, in academic and military circles, towards both caution and a marked attention to hypothetical scenarios, psychological elements, the perception of risk and reward and the concept of deterrence. While space warfare thankfully does not have the same life-ending potential, it shares a similar analytical situation, wherein the weapons are all there, so are hostilities and conflicts, and yet no round has been shot. If and when such a round (or missile) will fly, there's a good chance this work will have been made obsolete by reality: until then, I believe we are better served by taking inspiration from nuclear analysts and game theorists' attention to the problem of deterrence.

steadily turning to constellations, against which directed energy weapons are much less effective. Further away from the Earth, the far smaller numbers of satellites involved would imply a freer use of kinetic weapons, and yet the limited amount of spacecraft in MEO and above is offset by the sheer strategic and economic value of the targets, which are more often than not the backbone of globally shared infrastructure (like navigation, weather monitoring and remote communication) as well as the risk of permanently "polluting" valuable orbital real estate with debris. Cyber weapons of the destructive variety, which are unaffected by physical distance and geographical features, are however similarly beholden by the consequences of their use, which is the generation of harmful debris. Taking into account the material, physics-based parameters which inform both space infrastructure and space weapons, the puzzling situation which we can observe today (a plethora of weapons available, especially of the destructive variety, a general re-entrenchment of international society along conflict lines and yet a strong recalcitrance to even test such weapons in the first place, much less use them) makes way for a clearer picture: the space environment itself is placing important constraints on the use of ASAT systems, hence their conspicuous lack of utilisation. However, if the factors outlined in this chapter were the only ones at play, we would still be witnessing a different scenario compared to what we see today. Keeping in mind that there are no physical constraints to the use of non-destructive cyberattacks, and no risk of debris generation for dazzling and blinding observation satellites, why don't we see these types of ASAT capabilities used more freely? Why aren't our news feeds full of stories about cyber attacks on constellations and of satellites being blinded or dazzled when approaching sensitive military installations?

In this chapter I touched briefly on what reactions may be expected by the international community in case of various kinds of ASAT attacks as a possible constraining factor for aggressor countries; in the next chapter I expand on this point and I argue that, far from being a secondary concern compared to the geopolitical aspects of space warfare, international society as well as international law, *mores* and even the very perception of space in the mind of the public provides important boundaries to the introduction of hostilities in space. I will endeavour to prove that something akin to a taboo on space conflict exists today, similar to what Nina Tannenwald argued for in her landmark paper on nuclear warfare, and that this normative and cognitive prohibition, born from the history of space exploration, international treaties and the necessity of coordination between countries to avoid physical interference, is the key to explain the lack of use of less damaging forms of anti-satellite weapons.

CHAPTER 3 – INTERNATIONAL NORMS AND SPACE POLITICS: THE STIGMA AGAINST SPACE WARFARE

While the data available is scarce[47], attacks on space infrastructure do happen with a certain regularity, but to date always of the reversible, non-damaging variety. Even in conflictual contexts of heightened hostility and great historical significance, space powers involved have showed remarkable restraint (Gurantz, 2024) in interfering with satellite operations, which can be puzzling at first glance, if one considers the stakes involved, as well as the strategic significance that space assets have played in recent conflicts. As we've seen in the preceding two chapters, looking at space warfare through the lens of the physical capabilities of weapons, as well as the geopolitical features inherent to our orbital neighbourhood, we see that significant constraints are placed upon the use of destructive ASAT systems. However, when engaging in a war of significant import for the actors involved, such as the Russian-Ukrainian War, one would imagine that such concerns could at least partially fall to the wayside. And yet, so far they haven't: while jamming proliferates on the Pannonian Plain and beyond, satellites and constellations continue to operate freely, especially for the Ukrainian side, which enjoys a significant advantage in terms of access to recognisance and imaging compared to its adversary. The purported cybernetic might of Russia is not as widely expended as was expected before the war (Mueller *et al.* 2023), and when it is its effects are strategically lackluster (Kostyuk & Gartzke, 2022). While this can be explained by a general "overhype" surrounding the possibilities of cyberwarfare (*ibid.*), one can not easily discount that in the first conflict of our times where space assets are relatively plentiful, the cannons - be they physical or digital - lie silent and unused. Understanding this predicament requires additional elements that our previous analysis - based on geography, physics and technical qualities - cannot provide; to complete our framework we need to examine how space is conceived and thought about on a conceptual level; space not as a physical location with rules and boundaries, but space as an idea and as an *ideal*. In this chapter we will propose that,

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[47] No space power has been forthcoming when discussing the amount of attacks they have been subjected to. An interesting comment by General David Thompson of the US Space Force could imply that reversible, low power attacks on government satellites are actually quite common (Rogin, 2021), but no data is publicly available.

similarly to what Nina Tannenwald theorised in her seminal paper on nuclear warfare, a taboo of sorts exists surrounding hostility in space, although not as extensive in its normative power as the one surrounding the use of nuclear weapons. It is this taboo that -together with the physical and geographical factors analysed before in this thesis- stays the hand of space powers, creating a sort of bubble, or veneer of pacifism over space as a place for human endeavours which countries are afraid to pop. I posit that three deeply interrelated processes chiefly contributed to the mythopoesis of outer space as a realm of peace: the international legal framework surrounding space endeavours, the natural tendency of said endeavours to gravitate towards what is commonly referred to as *scientific internationalism*, as well as the public perception of space, which tends to be fairly positive and laden with significant undercurrents of pacifism and humanism; together, they coalesce into a nebulous and ill-defined but persuasive image of a peaceful realm of open collaboration among nations, which is able to exert a degree of influence on both the strategic thinking as well as the general framing of ASAT warfare of space faring nations. We will then define our hypothetical norm more rigorously, outlining its objective and intersubjective components, as well as the process through which norms may be generated, and see that the framework proposed by Tannenwald applies effectively to our hypothesized stigma.

3.1 INTERNATIONAL LAW AND THE PEACEFUL USE OF SPACE

For the longest time, the skies and the celestial spheres were unreachable, and so were taken to be symbolic of a superior realm -ontologically and morally- detached from earthly concerns and exclusive purview of the divine; it is no wonder then that in almost every human culture, physical ascension is associated with spiritual elevation (Deudney, 2020). Air was minimally regulated under Roman law, and throughout the Middle Ages and the early modernity the issue was debated on a theoretical level. The invention of hot air balloons gave way to the first aeronautical regulation in history in 1784, which prohibited the wanton use of balloons over Paris without proper authorization, but it wasn’t until the invention of powered flight that the need for an international legal framework became comprehensive (Engvers, 2001). The sky ceased to be separate from Man with the invention of powered flight by the Wright brothers, and naturally necessitated to be portioned, defined and ultimately made orderly, which meant that it had to be regulated through law. It probably doesn't come as a surprise to the reader that space law existed first as an appendix (or more precisely, as an extension) of aeronautical law: what may come as a surprise is that decades before the flight of Sputnik I in 1957 the idea that the area beyond the reach of regular aircraft would eventually be reached and that it required regulation was already being discussed in academic circles (Lyall & Larsen, 2025). The foremost obstacle faced in legal terms was the principle first set down in the 1919 Paris Convention, which established total sovereignty of a country over its own airspace: as technological advancements made the prospect of one day breaching beyond the immediate atmosphere more and more likely, the question of whether the sovereignty of a country could -and should- extend *ad astra* needed to be answered. The issues on the table were numerous: should satellites ask for permission when they fly above another country's territories? Would a country be within their legal rights if they decided to shoot down a ballistic missile momentarily transiting hundreds of kilometres above its lands? After 1957 these questions ceased to be purely academic and became eminently practical; hence the need, as we've already touched upon in chapter 1, to create a legal framework to at least partially regulate space activities and deal with the most pressing matters on the table. As of 2024, this framework incorporates several elements, including international treaties, technical regulations, memoranda of understanding, soft law and provisions of customary law. The core of international space law is made up of five UN treaties and five UNGA resolutions[48] (von der Dunk, 2001): the former are cogent law instruments, while the latter exist in a nebulous, difficult to define space between soft law and customary law (Lyall & Larsen, 2025). The five pertinent UN treaties are the 1967 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space* (commonly referred to as the Outer Space Treaty or OST), the 1968 *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space* (Rescue Agreement), the 1972 *Convention on International Liability for Damage Caused by Space Objects* (Liability Convention), the 1976 *Convention on Registration of Objects Launched into Outer Space* (Registration Convention) and the 1984 *Agreement Governing the Activities of States on the Moon and Other Celestial*

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[48] General Assembly Resolutions 1962, *Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space*; 37/92, *Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting*; 41/65, *Principles Relating to Remote Sensing of the Earth from Outer Space*; 47/68 *Principles Relevant to the Use of Nuclear Power Sources in Outer Space*; 51/122, *Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of all States, Taking into Particular Account the Needs of Developing Countries*; see von Der Dunk (2001).

Bodies (Moon Agreement). An additional treaty, the 1963 *Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water* (Partial Ban Treaty) is also relevant when considering key components of space law (Nakamura, 2024). An in-depth analysis of these legal instruments would be beyond the scope of this chapter and of this thesis. Nonetheless, even a brief look at the aforementioned treaties is enough to showcase just how pervasive pacifism and humanism is in the legal framework regulating outer space (Blount, 2021), at very least at a rhetorical level. Let's take for example the Outer Space Treaty, commonly considered to be the "lynchpin" of international space law (Lyall & Larsen, 2025), with its preamble already concisely foretelling the principles outlined in the main body of the treaty:

> *"Recognizing the common interest of all mankind in the progress of the exploration and use of outer space for* ***peaceful*** *purposes, [...] Desiring to contribute to* ***broad international co-operation*** *in the scientific as well as the legal aspects of the exploration and use of outer space for* ***peaceful*** *purposes, [...] Recalling resolution 1884 (XVIII),* ***calling 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****, which was adopted unanimously by the United Nations General Assembly on 17 October 1963, Taking account of United Nations General Assembly resolution 110 (II) of 3 November 1947,* ***which condemned propaganda designed or likely to provoke or encourage any threat to the peace, breach of the peace or act of aggression, and considering that the aforementioned resolution is applicable to outer space*** *[...]"*

Specifically, the OST sets out the following key provisions for all parties to the treaty:

4. Space is the "*province of all mankind*[49]*",* available with no discrimination to all countries.
5. Space and all celestial bodies are unclaimable and cannot be considered to be under the sovereignty of any one country[50].
6. Military installations and weapons cannot be placed on any celestial body, and any non-peaceful use of the aforementioned bodies is forbidden[51]

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[49] Art. 1, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies,* RES 2222

[50] This provision, amongst others present in the OST, is directly inspired by the Antarctica Treaty of 1959

7. Nuclear weapons or other weapon systems of mass destruction cannot be put into orbit or on a celestial body.

The other four treaties make explicit reference to the peaceful uses of outer space, and the four provisions outlined above are considered the four legal pillars of international space law (Rathore & Gupta, 2020). The accession rate of the five treaties is also relatively widespread, with over 95% of UN member states ratifying or signing at least one of the treaties mentioned above (Lyall & Larsen, 2025). Adoptions only paint a partial picture: even if states outwardly present themselves as committed to the ideal of a peaceful and amicable cosmic neighborhood, what is of interest to us, as is commonly the crux of the matter when discussing confluences between international law and politics, is whether states feel beholden to these provisions or not. In other words, we want to assess if these provisions may be respected because there is, as legal scholars would say, an *opinio iuris* on key principles of space law, or because they provide a convenient screen for military activities in orbit, or can be used as a form of international regulatory capture by governments against their international opponents. The most commonly employed method to attest the existence of *opinio iuris* of a certain norm is to look at state practice: what do governments do and say as pertaining to a theoretically unlawful conduct can be the simplest and most direct clue to assess the presence of a binding legal provision. However, when it comes to the peaceful uses of outer space, state practice is -at least at first glance- fairly mercurial: on the one hand, as we've already pointed out numerous times, no country has attacked another in space. Importantly, all space-faring nations also participate in a series of international forums centered specifically around peaceful collaboration in space affairs, such as the UN's COPUOS (Committee On the Peaceful Uses of Outer Space) and OOSA (Office of Outer Space Affairs), the IOAG (Interagency Operations Advisory Group, which is a coordination group for national space agencies), the CCSDS (Consultative Committee for Space Data Systems, which is an international organization dedicated to the sharing of data handling technologies, best practices and standardization efforts between countries) and more. National space administrations and governments routinely collaborate on scientific projects, some of which of gargantuan proportions like the International Space Station, rightly considered a significant milestone for international cooperation (Stuart & Dittmer, 2022). At different points in time in the past twenty years, the US, China, the EU and Russia have all proposed alternative legal frameworks to guarantee that space remains conflict-free. The ban

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[51] It's important to note that militarisation is forbidden on celestial bodies (the Moon, asteroids, other planets), but not in space *per se*; i.e. it is possible to place military assets in orbit.

on nuclear emplacement in space has held for the better part of sixty years[52], and even tests against one's own decommissioned assets can cause significant international backlash. There are even supranational space agencies like ESA (European Space Agency) or the recently founded AfSA (African Space Agency), that pool together funds and expertise from different countries to collaborate on space activities. On the other hand, military assets do exist in space, providing surveillance, navigation, secure communication lines and more to armed forces, and an international trend towards securitisation and increased competitiveness in space can be observed (Moltz, 2019). Most damningly ASAT weapons -dormant as they are- do exist, and have been under development ever since the earliest days of the Space Age. Taken in its entity, state praxis seems double-faced if not cynic, hiding behind lofty ideals of pacifism and international collaboration to covertly militarise space. However, two objections can be levied against this argument: the first is that, as we shall see more in depth in section 3.3, militarisation is not equal to weaponisation: nothing in the OST explicitly prohibits countries from placing military assets in orbit, and their presence does not automatically raises the risk of conflicts breaking out, either on the surface or in outer space, and so doesn't necessarily tarnish the image or the concept of space as peaceful. Secondly, to say that the international legal framework pertaining to space is a dead letter, as tensions mount internationally and more and more countries place military assets in orbit, would be premature and a misconstruction of the mechanisms with which international law is able to influence foreign policy. A more traditional IR approach, such as classical realism, would tell us that space law can reduce uncertainty in difficult interactions, but is ultimately a crude device for a primitive (international) society with no ruler, judge or parliament to speak of (Chas, 2024): as long as the interests of the two space-faring superpowers were aligned in avoiding an orbital weapons race, space law could be a genuinely useful tool to mend fractures and avoid unnecessary conflicts. With the interests of the two countries shifting in different directions and the emergence of competing powers, space law would lose its utility and fall to the wayside. A constructivist approach, which I believe to be more appropriate for the space domain, would instead highlight the fact that after decades of social interaction between space powers in public fora informed by the four main precepts of space law would have created what is called a "background" (Brunée & Toope, 2012), a commonality of understanding on certain principles and concepts which would inform and influence - not cause - policy decisions. Whatever explanation one may subscribe to, it is doubtless that while space law is

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[52] US officials have been reported warning about Russian plans for basing a nuclear ASAT weapon in orbit, but no evidence to support this claim has been given by the DoD: https://www.vox.com/world-politics/350663/russia-space-nuke-satellite-weapon-putin

founded on the principle of peaceful utilisation, the inherent vagueness of the concept (West, 2024) and the lack of progress towards a more structured and cogent legal framework (Hitchens, 2021) create difficulties when parsing whether there's a genuine adherence to a perceived binding norm *vis a vis* a cynical use of lofty legal declarations to shroud military efforts under a cloak of pacifism. It could very well be that such a dichotomy is in and of itself an analytical trap: after all, cynicism and idealism in political organisations can coexist at both the individual level (Christian, 2023) as well as at the aggregate (Tannenwald, 1999). Perhaps the most indicative clue of this enmeshment between *realpolitik* and adherence to legal norms lies in the fact that the US, the EU, Russia and China have proposed different legal "solutions" to the problem of space warfare through disarmament or the creation of a comprehensive code of conduct (Hitchens, 2021): while the proposals (such as the PPWT by China and Russia, or the Space Code of Conduct by the EU) were systematically sabotaged by one another due to the increasingly fractured international arena, parallel efforts of a more technical nature (such as collaboration on SSAs) keep moving forward, seemingly indicating that states are both moving towards a more pragmatic, sectoral based approach to space governance (*ibid.*), but are also unwilling to abandon the original, discussion-based approach that laid the foundation of space law as it is today.

3.2 SPACE AND THE ROLE OF SCIENTIFIC DIPLOMACY AND INTERNATIONALISM

On the grand scale of human history, science is a young newcomer, a disruptive and willful upstart who suddenly erupted onto the scene of human endeavours and changed the way we see ourselves, our surroundings and the very Universe so profoundly that dreamt possibilities of visionaries and madmen, thought to reside in the exclusive realm of the divine and fantastical, have become everyday occurrences. On the other hand, diplomacy is an old friend, if not the oldest. Historians and anthropologists aren't sure when exactly the diplomat as a specific figure (Wiseman, 2020) and diplomacy as a professional expertise came to be, but it's plausible that the act of settling conflicts through dialogue and compromise rather than violence has always been part of our natural, innate repertoire of social tools (*ibid.).* However one should not think that the large age gap between the two prevented a long-standing, effective relationship from forming: while technological exchanges have often been used in diplomatic talks, and throughout history men of learning we could liken to modern scientists have often acted as diplomats (Fähnrich, 2017), the two disciplines truly started to meaningfully interact with one another after the end of World War II (Colglazier, 2018). With rocketry and the invention of the atomic bomb physical science at its highest levels of abstraction became the new political elephant in the room: science promised unlimited prosperity and untold destruction within the breadth of a single sentence, and diplomacy was one of the tools needed to reign in the unprecedented uncertainty brought to the fore by nuclear and space technology. Diplomatic talks over nuclear weapons lasted decades (*ibid.*) and produced a series of treaties and best practices to manage proliferation and deterrence, and as we have touched upon in the previous section, similar results were achieved in international space law, with a family of treaties that have partly entered into customary law (Macchi, 2024) as well as a bevy of resolutions from the General Assembly which have had a certain influence and moral suasion effects over space discussion in various fora even without being cogent law.

These developments, historically and politically important as they may be, are not the subject of this section. Events such as those mentioned above exemplify a very specific type of relationship between the disciplines of science and diplomacy, specifically, that of *science in diplomacy*[53], i.e. when scientific expertise is used in service of foreign policy. In the case of nuclear talks, the goal was to prevent mutually assured destruction, and expertise in nuclear sciences (and other scientific disciplines as well) was needed if negotiation was to be productive. However, when dealing with *science in diplomacy*-type of situations, political goals predate any form of interaction between the parties, and science is used instrumentally to achieve those goals. In our nuclear talks example, the fear of ending life on Earth predated the talks between nuclear powers US and USSR, and it didn't form originally and organically through repeated scientifically themed "socialisation" between the two: science was a tool to avoid extinction, and was brought into the talks as such. What we are interested in is *science for diplomacy*, in which scientific collaboration between countries or institutions affect changes in international relations. Scientific collaboration in space matters historically ran in parallel with forum discussions on space regulation, and was not only used as a potent diplomatic tool in times of heightened tensions during the Cold War, but - as I propose - was

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[53] I'm using the typology outlined in Gluckman *et al.* (2017), who in turn is quoting AAAS & Royal Society (2010)

also able to tightly weave together the notions of "space" and "collaboration" into a conceptual monad that persists to this day.

We start with engaging with a question of deceptive simplicity: why do countries collaborate in space matters? A simple answer would be "because it is expensive", and it would certainly be correct, if a bit reductive. It is no secret that the vast majority of countries in the world do not have the capacity to conduct meaningful scientific or economic activities in orbit on their own: the amount of expertise, technical know-how, resources and liquidity needed to even put a small satellite in orbit using entirely domestic technology is astounding: the most expensive singular project in human history is the International Space Station (ISS) itself, clocking at over $100 billion (Davey, 2016), well over the yearly GDP of most countries on the planet. Even "less" ambitious projects, like the Space Shuttle, required the tune of $49 billion[54] for R&D, plus hundreds of millions of dollars for every single launch. Even developing launching capabilities can be a significant endeavour in terms of money and resources, as exemplified by the failure of ELDO in the late 60*s* (Krige, 1993)*,* and the time and public funds it took for SpaceX to create a functioning reusable rocket. However, the question becomes more difficult to answer if we consider that up until the 90s, the US and the USSR enjoyed an unparalleled technological advantage over other countries, as well as the economic means to go at it alone. And yet both countries, and Russia thereafter, frequently collaborated with allies and even amongst themselves in the space sector which, as Krige (2006) points out, would not have been a trivial decision to make: most (if not all) space technologies are double-use and can be adapted to military deployment (and in some cases no adaptation is needed). While technical collaboration between the US and the USSR was highly controlled, European and Japanese allies had access to potentially disruptive technologies and know-how, the reverse engineering of which could jeopardise the US' position as the leading scientific and technological power (Krige, 2006). The apparent contradiction to basic tenets of political realism can be easily amended by considering a more sophisticated cost/benefit analysis, one that incorporates the advantage that stable, grateful, technologically advanced and ideologically aligned allies provided the United States. And yet, reducing these diplomatic efforts and scientific collaboration to a straightforward calculus of power politics would be misleading us into forgetting the ideological and conceptual landscape underpinning international diplomacy at the time. Let's take for example the US itself: far from being a wholly cynical actor weighing its diplomatic options with surgical accuracy, the United

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[54] Adjusted for inflation to 2020, see https://www.planetary.org/space-policy/sts-program-development-cost

States were instead riven between the officials and scientists dealing with nuclear energy and weapons and those in other departments (such as meteorology or aviation) (Miller, 2006). The latter were strong proponents of the merits of scientific internationalism[55] and confident in the ability of scientific cooperation to bring about peace, while the former were not as optimistic as to the political outcomes of widespread scientific collaboration and knowledge sharing. The work of the Interdepartmental Committee on Scientific and Cultural Cooperation, founded during FDR's first presidency, proved instrumental in pushing the sharing and creation of scientific knowledge with international partners to the forefront of American foreign policy for the better part of ten years (*ibid.*). The USSR placed even more value than the US' intelligentsia on the transformative and liberative power of scientific research (Kojevnikov, 2008), and yet it took more time for Soviet leadership to see the worth of scientific internationalism on a diplomatic level. Only after the death of Stalin and the advent of Nikita Kruschev did the USSR start to open itself up to the world in the realms of culture and science, with many Soviet scientists sharing the enthusiasm of their Western counterparts for international cooperation. It was in no small part thanks to the continued pressure of top Soviet physicists lobbying for sharing knowledge with West (Da Silva Neto & Kojevnikov, boh) that the USSR started to declassify their nuclear secrets related to power generation and particle acceleration and paved the way for its participation in the 1955 Geneva Conference on the Peaceful Uses of Atomic Energy, from which the International Atomic Energy Agency (IAEA) was born. If these seems minor happenstances compared to the relentless ideological battles and proxy wars sustained during the Cold War, one should keep in mind that although academic interest on the subject is still somewhat limited, research seems to show a far more profound influence than previously assumed of scientists and experts on the foreign policy of Cold War powers (Manzione, 2000). Due to the inherent difficulty of the subject matters (space, nuclear physics, propulsion technology, agricultural techniques and more) politicians and diplomats were dependent on the expertise of their advisory cadres to interact with each other on the international level, a mechanism reminiscent of the asymmetric dynamic between career politician and bureaucrat famously described by Weber (Page, 2010); as such, on some level decision-makers had to acquiesce to the demands of the experts nominally under their authority, who were part of an international community of scientists sharing similar values - such as openness in sharing scientific knowledge - and that science as a discipline knew no political barriers and was a common good to be used by mankind as a whole (Manzione,

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[55] Scientific internationalism is the belief that the inherent "openness" of science as a discipline facilitates international cooperation and therefore peace. For a more in depth treatment of the subject, the interested reader can consult Manzione (2000).

2000). As a solitary force, scientific internationalism isn't obviously enough to guarantee lasting peace; but it is telling to observe just how many important diplomatic breakthroughs and achievements throughout the decades since WW2 carry within themselves the *fil rouge* of science: the JCPOA (Joint Comprehensive Plan of Action) between the P5+1 and Iran, CERN and ITER (Colglazier, 2018), the Antarctic Treaty Regime, the SESAME laboratory in Jordan, the creation of ESA and the 2016 Paris Agreement are all examples amongst many other[56] of partial or total successes buttressed by scientific diplomacy. How much of what we've outlined above is related to space diplomacy specifically? Certainly, there's evidence that scientific internationalism is alive and well at least in certain sectors of the space industry: the leading UN space agency, COPUOS, is explicitly meant to encourage peaceful cooperation among countries and space agencies. Studies have shown that both ESA (Zabusky, 1995) and NASA (Miyamoto, 2010) harbor internal cultures that highly prize cooperation and internationalism as key goals, standing side by side with scientific progress. Additionally, the status of space as a global commons naturally affects the extent to which international cooperation is resorted to when solving issues of a technical or political nature (Gallagher, 2010). Like Antarctica or the high seas (to both of which space law owes much of its inspiration (Lyall & Larsen, 2024)), space belongs to one; unlike either of them, not only no country can legally claim a piece of outer space for itself, but it's unlikely it would be even physically possible to do so. The complete lack of geographical barriers and the impossibility of fortifications or static defenses makes everyone equally vulnerable, and presumably equally willing to resort to negotiation rather than conflict. As Finnemore argues (1993), sectorial and international organizations composed of cadres of experts can be important producers of international norms, and while there isn't -to my knowledge- academic research done specifically on the normative impact of international organizations in the space sector, it stands to reason that the combination of shared vulnerability and interdependence coupled with the constant need for technical coordination amongst countries in space would prove to be fertile ground for norm-building of the pacifist variety. A particularly important success story for space multilateralism is the International Space Station (ISS), the largest and most expensive space object ever built. Slightly longer than a football field and weighing over 450 tons, the ISS is massive both in physical as well as ideational terms. Frequently hailed as not just as a stunning technical achievement, but a seminal example of successful diplomacy (Mauduit, 2017) and a lesson in how to begin a process of rapprochement, the ISS is a poignant example of the enmeshment between space diplomacy and peace on multiple levels:

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[56] For a brief but comprehensive treatment on the subject, the reader can consult Turekian *et. al.* (2015)

for starters, the International Space Station is a singularly powerful metaphor steeped in symbolism: much like it was concretely built piece by piece by the various contributor countries, the idea of the ISS was slowly made to coalesce by successive and insistent diplomatic efforts, making it a conceptual assemblage of successful cooperation (Stewart & Dittmer, 2022) as much as a physical one; with a public image unblemished by a specific political or partisan affiliation, the Station itself stands above the concerns of earthly governments figuratively and literally. Secondly, the ISS showcases just how much the technical intricacies of space travel can be turned into a useful tool for diplomacy and trust-building: Russia was given the task of building was going to be known as the ROS (Russian Orbital Segment), containing the Guidance and Control system for the whole ISS - a key piece of hardware - and support to Roscosmos was maintained through various delays and cost overruns, a stark contrast to the behaviour of the US for the "prototype" of the ISS, the space station *Freedom*, in which all participating countries were supposed to be relegated to supporting (in space jargon "enhancing") roles, leaving the main body of technological research and development to the States.

3.3 PERCEPTION OF SPACE IN THE PUBLIC

The idea that public opinion may exert an influence on foreign policy is a longstanding, hotly debated issue in IR academic circles, with many great realist thinkers both past and present discussing on the apparently volatile and mercurial outlook of the public on foreign affairs, and the necessity for great statesmen and women to "stay" the course and weather through the vagaries of the electorate (Nincic, 1992). While properly describing this ongoing academic debate would be beyond the scope of this work, it is of interest to mention its existence for the reader, as its determinants (material factors *vis a vis* internal, ideational factors) closely mirror the dynamics explored in the previous and current chapter; in this work however, the ideational and material factors work in concert, buttressing one another, rather than work in opposition. Scarcely anything makes this more apparent in the context of ASAT warfare as the widely held (Deudney, 2020) public perception of space as a realm of peaceful collaboration between countries rather than a theatre of conflict. Far from simply being born through a bottom-up process in the civilian populace, this mythology of space as peacable and cooperative was historically pushed by both the US and the USSR at the dawn of the Space Age (West, 2024) for eminently material reasons related to the necessity of providing a coverage of sorts for their initial activities, which were overwhelmingly military oriented. Both Blount (2024) as well as West (2024) present this myth as ineffective at preventing militarisation of space, but efficacious as providing a cover for it to the wider international audience. This is a relevant argument to consider when the scope of analysis is -understandably so- limited to the realm of power politics and international relations between the highest levels of government; however, it fails to address the possibility that this myth, while cynically manufactured to shield states from scrutiny, may take roots into the perception of the public and what consequences it may have on the policies of space powers.

A series of issues, such as the legal feasibility of satellites transitioning over foreign territory, or the need for the US to recoup its first burning defeat with the launch of Sputnik created strong incentives on both superpowers to reframe space in the collective consciousness as a location of peace and friendly competition, which allowed the increasing militarisation of space to continue relatively unimpeded. This led to an international legal framework that specifically avowed the pacific nature of outer space, as we've already outlined in section 3.1, but also served as a frame for the Space Race that the USSR and the US engaged in until the lunar landing in 1969; a competition of technologies, ideologies and ambition, but not of arms. It cannot be discounted that at the height of the global interest for space, when the Cold War was in full swing and the world was still reeling from a nuclear disaster averted in Cuba, the US and USSR put their full technological might behind and staked so much of their reputation in a peaceful competition of science and discovery, instead of might and aggression. One could make an argument that then and there outer space was fully and effectively framed by the leading powers of the day as a place outside of the conflictual lines existing on Earth, not just through the opportunistic and circumstantial declaring it as such, but through their mutual engagement in what could essentially be described as a highly charged but bloodless and amicable competition between ideologies. The symbolic worth of space was clearly showcased in what is considered the closing act of the Space Age, the 1975 Apollo/Soyuz docking (Burwell, 2018), in which the two orbital vehicles docked each other in a show of *detente*. The technical difficulty of the mission would have been minimal, if not for the adamant desire of both superpowers not to appear as having been "penetrated" by the other through the docking process (in other words, either ship being described as being docked into the other) leading to the creation of a custom build “androgynous” docking system through which both ships could interface on equal grounds (Blount, 2024). Still, it is telling that it was decided that space would be an appropriate staging ground for showcasing the rapprochement of American and Soviet relations: often mentioned in passing compared to the concurrent Helsinki Conference on Security and Cooperation in Europe, the Apollo/Soyuz docking, broadcasted live all over the world, was taken with extreme seriousness by both sides, and was considered a key step towards ensuring a successful *detente* (Battaglia, 2012). Again, in the public eye, much like the earlier phases of the Space Race, outer space was figuratively mending what the surface was tearing apart. A key step of the ideological clash between communism and democratic liberalism had been settled by the Moon landing, with cannons silent and missiles cold for all the world to see, and six years later space was chosen as the most fitting location to signal to the whole planet the strong commitment both superpowers had towards a thawing of tense relationships, to the benefit of humanity as a whole. The undisputed fact that all the way up to the ‘80s, the US and the USSR grew increasingly reliant on space for security purposes, basing weapons guidance systems, navigation satellites and early warning apparatuses in orbit does not diminish the symbolic value of space as a whole: as Neufeld (2021) rightly points out, this constitutes a militarisation, but not a weaponisation of space[57]. The increasing reliance that both superpowers put on outer space was to buttress the defensive mechanisms of nuclear deterrence, rather than to make orbits a parking spot for weapon systems to strike the surface with, such that one could say that, beyond the symbolic significance of the sidereal void, it pragmatically helped preserve peace on Earth (*ibid*). It is telling that this strategic process was done in complete secrecy, away from the public eye (i*bid.*): however cynically one may regard the constructed mythology of space, the US and the USSR never willfully broke the “illusion”, if they ever believed such an illusion even existed.

Empirical research, though limited in scope, can also provides us with an additional view of what space means to the ordinary citizen: a Pew Research study (2023) on Americans’ views of space recorded that the amount of respondents positive that the US will engage in open warfare in orbit in the next 50 years is about the same as those who believe that intelligent life will be discovered on another planet (44% to 48%). The American public in the 90s also

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[57] It is, practically speaking, impossible to demilitarise space: essentially all space technology (imaging, navigation, telecommunication, rocketry etc. etc.) is dual-use, in the sense that it can be employed almost seamlessly for both civilian and military purposes, such that any civilian space asset can be potentially considered a military asset.

widely supported the creation of the International Space Station, as well as collaboration in outer space with the USSR first, and Russia thereafter (Launius, 2003). The vast majority of European citizens seem to have positive attitudes pertaining to space activities, and place great importance on the collaboration between European countries with regards to outer space (ESA, 2019). Famous space photographs like *Earthrise* or *Pale Blue Dot* have exerted a profound effect on societal perceptions of not just space, but of our own species and our planet (Yaden *et al.,* 2016), having been credited for inspiring a nascent environmental consciousness worldwide (Smith, 2009)**.**

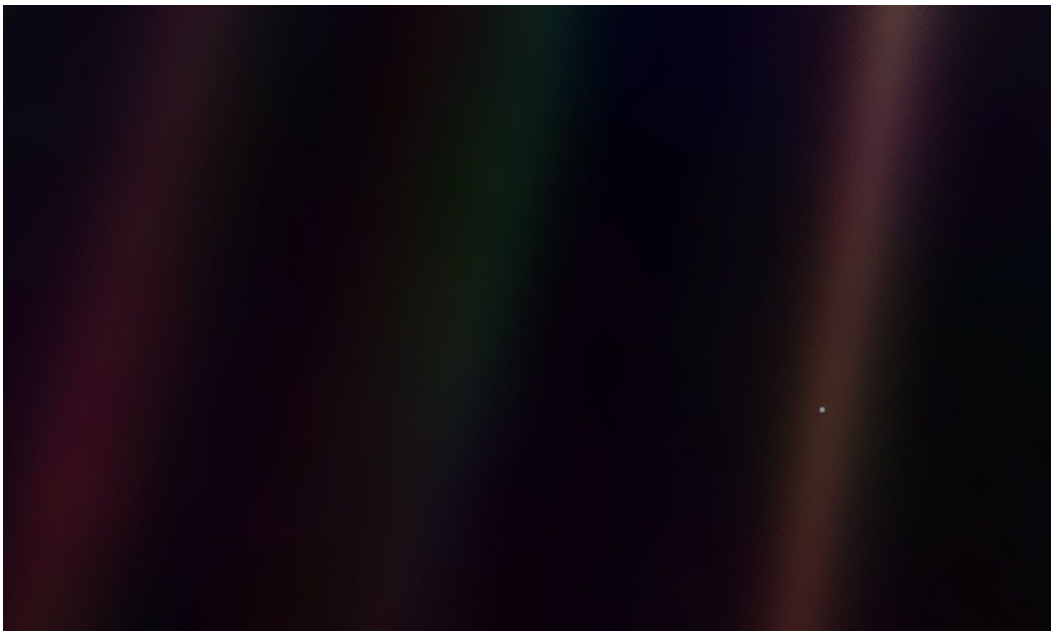

Figure 3.1 Pale Blue Dot, courtesy of NASA
This photo was taken by Voyager 1 in 1990, at an approximate distance of 6 billion kilometres from our planet, well beyond Pluto. The small bluish point barely visible in the center right portion of the photo is planet Earth.

With the setting of the era of superpower competition and the birth of "New Space", new frames and narratives that have engaged with the imagination of the public have emerged. As Burwell points out (2018), space mythology in the Western world has turned away from grand, epoch-defining endeavours incorporating both cosmopolitan ideals and nationalistic undertones, and has moved towards a "democratisation" of space in the form of its individualisation: space as no longer the exclusive realm of the *élite*, but as an open frontier which should -and is being made- available to the average person. Outer space as a discriminate, singular experience is a key component of space expansionism, an ideology[58] commonly espoused by members of the space industry, leading scientists and science popularisers as well as eminent economic figures with business interests in space, such as Jeff Bezos and Elon Musk. Expansionism pushes a vision of endless -and necessary- extension of humanity’s domain into our cosmic neighbourhood, untethered by old, fractious divisions of Earth. The spreading of mankind among the stars is for ostensibly pragmatic reasons (to guarantee the survival of our species), but is characterised by a truly religious fervor, which links expansion to a fulfillment of mankind’s inherent destiny. To deny this destiny is to deny the “true” nature of our species and to remain in a debased state, our potential squandered and unrealised. While space expansionism is obviously not without its demerits[59], it has appealing qualities that can account for its significant transversal popularity amongst industry insiders and regular people alike (Deudney, 2020).

3.4 NUCLEAR TABOOS AND SPACE CONFLICT STIGMA

I propose that three historical and ideational processes we’ve outlined above -**pacifism inherent in space law, in scientific and space diplomacy and in the symbolic perception of space at large**- came together over time to give rise to a prohibition over space conflict, not on legal or strategic grounds, but on normative ones. A similar argument, expressed in far more detail than this thesis could allow, has been put forth by Tannenwald in a series of landmark papers arguing for the existence of a taboo over the use of nuclear weapons. The existence of this supposed cogent international norm has been a contested issue in academia, following the well known theoretical cleavage between realism and constructivism, with one side asserting that the lack of use is due to the strategic mechanisms of deterrence, and the other proposing an alternative explanation in the presence of a widespread normative prohibition on nuclear warfare (Potter, 2010). Both explanations have, of course, theoretical flanks open and vulnerable to attack: material factors purported by realists are unable to explain the lack of nuclear attacks against minor non-nuclear powers, and constructivists have

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[58] I use the term “ideology” descriptively, meaning a relatively organised set of beliefs and norms about society, the human condition, the political system and more which informs the way its adherents conceptually frame the world as a whole, or social, economic or political relationship between individuals or groups.

[59] For an in depth treatment of the subject, the reader can turn to *Dark Skies* by Deudney (2020). In any case, our research question means we do not need to engage with the question of whether space expansionism can be a net positive for humanity, but how it conceptually present space to its adherents: it does so by painting space as a refuge from existential threats quintessential to humanity as an aggressive species as well as threats of an exogenous nature, such as meteoric destruction of the biosphere or a climatic catastrophe.

a hard time with quantifying the relative strength of their proposed norm vis à vis pragmatic concerns of strategic nature (*ibid.)*. I believe the impasse can be traced back to the unwillingness by both sides to incorporate fully -not simply as a lip service to theoretical eclecticism- the points raised by the other. As we shall see in the next chapter, I believe that the two perspectives can be neatly incorporated with the concept of "intensity thresholds": as the level of aggressive behaviour in space changes, different interlocking constraints, working with each other rather than in opposition, combine to dissuade further escalation. Material and normative factors work in concert in the space realm, varying their relative weight to each other according to the threat expressed. However, to give a proper theoretical treatment to our hypothesis we must first properly define our space prohibition norm, henceforth referred to as **space conflict stigma**. Taking stock from Tannenwald's illuminating example, we will see that the theoretical framework used to argue the existence of a nuclear taboo can be applied to space as well. Starting with the characteristics of the nuclear taboo as defined in Tannenwald (2005):

1. The nuclear taboo, like all taboos, has **objective components**. The objective components refer to the strength of the prohibition, the possibility of grave consequences if the prohibition is not respected, and the belief that by breaking the taboo, we enter into a new, different world. If we were to assess the presence of our proposed space conflict stigma simply by the observed adherence to its theoretical norms, the case for its existence would be even stronger than for its nuclear counterpart. Unlike nuclear warheads, destructive ASAT weapons, physical or otherwise, have never been used against another country and the number of live tests on actual satellites can be counted on one hand; in comparison the number of nuclear tests done in space, underground, in the sea and in the air is far greater. As for the the possibility of grave consequences and the entering into a new world after the prohibition is not respected, I believe it to be more effective to consider them in conjunction, since in both cases (nuclear and space warfare) they are tightly interwoven with one another. The consequences of using destructive ASAT weapons are potentially far more insidious than what we briefly outlined in chapter 2. It's not guaranteed that the potential destruction of one or more satellites would be enough to trigger a Kessler syndrome-type event, but even forgoing our worst case scenario we would be faced with a world fraught with dangers, a world in which space is not off limits anymore, and in which every satellite is a potential target. In such a world, as

Deudney points out (2020), nuclear war is more likely to happen, as many early warning systems are space-based. While the future that awaits us if satellites start to drop isn’t as bleak as the outcome of a nuclear exchange, it would certainly usher in a new era of deep insecurity and heightened risk of potentially catastrophic conflicts.

2. Taboos also have **intersubjective components**, the set of beliefs and values associated with the taboo itself by social actors. While difficult to measure, whether these components exist or not can be assessed from various sources, such as the declarations and documents produced by international and national organizations, speeches given by leaders and decision-makers as well legal norms defining the taboo as cogent. We’ve already touched upon the fact that many international organizations present in the space sector are outspokenly pacifist[60], or have internal working cultures placing importance on international collaboration and pacifism, as well as international advocacy groups that fight for space disarmament, such as the Union for Concerned Scientists and the Secure World Foundation; their role in the formation of our stigma against space warfare can be likened to that of the international antinuclear movements, albeit on a much smaller scale. Interestingly, unlike the nuclear taboo (Tannenwald, 2005), our proposed space stigma does have a legal basis in the Outer Space Treaty, although restricted to the use of astral bodies. Lastly, while it would be beyond the scope of this thesis to minutely catalogue the space relevant declarations of most political leaders, we’ve already touched upon how the two leading space powers of their day crafted the appearance of their efforts in space as wholly pacific endeavour. In fact, the Space Race is often characterised as far more hostile and laden with competitiveness than it actually was, as an extension of the highly volatile relationships that the USSR and the US were establishing on Earth. This is, in fact, historically incorrect (Davis Cross, 2019), with both the highest levels of government pursuing peaceful cooperation from day one, especially in the sector of orbital nuclear basing, as well as a varied melange of scientists, interest groups, space enthusiasts and aerospace entrepreneurs lobbying for the exact same thing; the norm-building relevance of these organizations has been growing in recent years (*ibid.*), with the proliferation of new private and institutional actors staking their claims in orbit.

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[60] One particular organization I haven’t cited yet is the Conference on Disarmament (UNODA), which has provided statements and reports on the issue of the proliferation of weapons in space numerous times. Another organization which is bound to become more relevant with the increase of orbital debris is the IADC, the Inter-Agency Space Debris Coordination Committee, composed of the globally leading national space agencies.

Having established that, with due differences, there are significant parallelisms between Tannenwald's nuclear taboo and our proposed space conflict stigma, we turn to the sources of our normative prohibition, where the interplay between the three processes we've delineated in the previous sections is most evident.

9. The first source of international norms is "**societal pressure**". In our case, the actors involved in the creation of the norm (advocacy groups, organizations of concerned citizens or experts, NGOs, international organizations) are of a similar nature to those responsible for the nuclear taboo and in some cases are shared between the two domains[61]. These actors, as Tannenwald puts it, "shape the discourse" through a "bottom-up process" (Tannenwald, 2005), framing it in terms that eventually come to influence the highest levels of government, through the practices we've touched upon when discussing **science and space diplomacy**. While it would be difficult to argue that the moral opprobrium surrounding space warfare is equivalent to that of nuclear weapons, I believe that **the perception of space as pacific being held** not just by experts and enthusiasts but **by the public at large** is additionally of significance interest when assessing the relative strength of societal pressure in contributing to the creation of the stigma on space warfare. Outer space is the only place accessible to human beings where there are no claims as to its ownership, existing beyond and above the Earth-bound divisions of mankind. Having been characterised as an open frontier, "without history, without victims, and without rules" (Van Eijk, 2021), it should not come as a surprise that space is laden with humanist, cosmopolitan symbolism; to underestimate the effects that this widely held view would have on the decision-making process of political leaders would be an analytical misstep.
10. The second source consists of "**strategic social construction**", a process through which countries try to create or influence international norms of conduct to gain an advantage over their opponents, for example by delegitimising some of their policies or capabilities at the international level. In other words, strategic social construction weaponises rhetoric and moral suasion to affect. Numerous instances of this type of behaviour can be observed in the history of space exploration: from the willful framing of US space efforts as wholly pacific and scientifically minded (and the painting of Soviet space achievements as being informed by cynical power politics) by

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[61] An example is the Union of Concerned Scientists, which campaigns for nuclear disarmament and space disarmament both.

the Eisenhower administration (Buono & Bateman, 2024), to the repeated efforts by Russia and China to present an alternate, united front on the question of space disarmament during a period of particularly hawkish (Harper, 2008) American attitudes on the subject, space powers have often used grandstanding and rhetorically charged policy announcements to present themselves as the virtuous party in the space domain. The shared construction of a **pacifist apparatus of international space law** by the US and the USSR, as well as the various attempts by both the Western allies (with the the most recent being the joint EU/US Moratorium on Asat Testing) and the Russian-Chinese axis (which we have already mentioned) of proposing new and disarmament oriented legal frameworks betrays the relevance that space powers assign to space law when it comes to its ability to influence the playing field to a more favourable configuration. At this point we've come full circle on the point raised at the beginning of the chapter by West and Blount on the "sincerity" of the peaceful space myth during the Cold War. It is clear by now that whether it was sincerely meant or not is hardly relevant: as strategic social construction is just one of a possible sources of normative provisions, even conventions and mores created out of *realpolitik* concerns can evolve beyond the control of the countries that pushed them in the first place.

11. The third source is the **personal convictions** of decision-makers. This is obviously far more complex to assess than strategic social construction, but there is a distinct possibility that leaders may personally believe, be it a sincerely held conviction or as a result of a strategic outlook on the subject, that space is off-limits when it comes to warfare. One such example is the declaration by the President of the Russian Federation Vladimir Putin on the 20th of February 2024: when asked about addressing American claims that Russia was developing a space-based nuclear platform, Putin vehemently denied it, saying that "*we have always been categorically against and are now against the deployment of nuclear weapons in space*" (Faulconbridge, 2024). A peculiar -and telling- statement for a reader familiar with Putin's frequent and worrying proclivity to threaten the use of nuclear weapons ever since the start of Russian-Ukrainian War of 2022 (Yüksel, 2023).
12. The last, and perhaps most important source of normativity for space warfare stigma comes from **iteration**, i.e. the continued repetition of behaviours for prolonged periods of time; in our case, iterative behaviour would be consisting of (1) not destructively attacking space assets, (2) not basing nuclear weapons in orbit and (3) not interfering

> with the functioning of key pieces of space infrastructure (such as GNSS constellations) unless in grave circumstances. None of these possibilities have materialised yet, giving our proposed space warfare stigma a potent justification through the existence of at least an informal convention against certain aggressive actions in orbit.

3.5 CONCLUSIONS

Summarising salient points, our argument that a normative -not legal- prohibition exists of introducing armed conflict into space. We've applied Tannenwald's nuclear taboo framework to the space domain and to our supposed three key determinants of space conflict stigma; that is, pacifism inherent in space law, scientific internationalism present in advocacy groups and scientific diplomacy in general (which is abundant in the space sector) and lastly the symbolic associations drawn by the general public - and encouraged over the course of decades by governments - of space and peace, and saw that each of our determinants contributed to the creation of the space conflict stigma through the four norm-creating mechanisms outlined above. However, one shouldn't be too deterministic in determining the interplay between these three factors: each element can reinforce the other organically to strengthen the normative prohibition. For example, public support for peaceful space activities can embolden space agencies to petition for increased fundings, which will finance even more international scientific collaboration amongst them. The pervasive internationalism of the space sector could encourage more countries to try out the ESA model, which has happened with the recent (2023) founding of the AfSA, the African Space Agency under the aegis of the African union; the entry of additional countries, especially those belonging to the Global South, traditionally rhetorically and materially excluded from space (van Eijk, 2022), into the club of space faring countries could put additional pressure onto the leading space powers to sit down and hammer down a new legal regime on disarmament. The possibilities of mutual interaction between our three factors is what gives stability and adaptability to our space conflict stigma: since all three processes are tightly interwoven with one another, a gain in a sector spills over in the other two.

Concluding this chapter, we've argued for the existence of a prescriptive convention on keeping armed conflict away from orbit, as an explanation for the lack of attacks or interference with satellites that couldn’t be explained by the geopolitical constraints of our near Earth space or the technical characteristics of weapons. In the next chapter, we will put the three pieces of our (very) small puzzle together, finally revealing the image that has been hinted at throughout this thesis. We shall see that all three factors work together in combination to discourage conflicts in space, with their relative weight of each one shifting according to the thresholds of intensity of the possible attack, the resilience of the attacker and the defender as well as the location of its target. Our model will be able to explain why the ease of access to destructive weaponry and cyberattacks, coupled with the relative helplessness of most space assets hasn’t resulted in a single attack so far, and that the actors that could be most likely to attack space infrastructure aren’t the highly advanced and affluent space powers, but politically isolated states with few to no satellites to speak of.

CHAPTER 4 – A MODEL FOR SPACE POWER POLITICS

Our model, as we've touched upon in the introduction to this thesis, is heuristic in nature, and is meant to capture broad tendencies at the international level, rather than being able to predict if the outcome of a singular set of interactions between specific countries would result in space warfare with granular precision. However, it is my hope that its fuzziness would be conducive to make it adaptable to rapidly changing circumstances, such as important technological advancements, dynamic social and economic environments as well as possible upheavals in the international sphere. Beyond being informed by analytical eclecticism and a heuristic-minded approach to international relations, this model follows the well known methodological tradition of bounded rationality, which we've already introduced in our introductory chapter: as an answer to the unbounded or olympic rationality employed in economic decision-making, Herbert Simon introduced the concept of bounded rationality, i.e. the proposition that individuals and organisations can't be modelled as having perfect information about a situation and its outcomes, as well as being able to order their preferences instantaneously and with flawless cost-maximisation (Simon, 1999), and, more generally, positing that individuals have various cognitive limitations and employ heuristical reasoning that affect their decision-making. This pertains to our work insofar as we consider political actors in our model do not start from a neutral, dispassionate point of view when assessing space power politics, but rather from a specific, socially and historically constructed point of reference that presents space as pacific and heavily constrained in physical and economic terms.

This conceptualisation constitutes a reference frame - an analytical tool first theorised in prospect theory[62] and the first component of our model - that defines the cognitive starting

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[62] The strong assumptions on the degree of rationality exhibited by individuals as theorised by neoclassical economists have often been criticised (Vieider & Vis, 201), and Kahneman & Tversky were the first to present a series of empirical experiments which seemed to contradict some basic tenets of expected utility theory, and constructed an alternative framework for decision-making, applicable to both individuals and firms. This

point of all political actors involved in space politics, and which is determined through the continuous actor-to-actor interactions that have taken place over the last seventy years as defined by the constraints we've described in the past three chapters: the technical limitations of ASAT systems, the physical and economic interdependence of space and the pervasive image of space as a pacific, cooperative environment. The reason we've dedicated so much space to a singular element of our framework is simple: we assume that our actors will look at the frame we propose as a default political state of sorts, a baseline they may be satisfied or unsatisfied with and against which they will judge their actions and those of other countries as either losses or gains. As the baseline is defined by our constraints, they permeate every facet of space politics and every component of our model.

Regardless, a reference frame is irrelevant if there are no decision-makers swayed by it; as such space political actors - our relevant decision-makers - constitute the second element of our model, as defined by their relative space capabilities; we will see that different actors have different needs in terms of infrastructure, security and economic stability, as well as different -and often limited- options to protect their space interests; as such, our reference frame will not affect our agents uniformly and with the same intensity. This point brings us to our third analytical element: decisional variables. Our reference frame informs decisions on ASAT warfare, but doesn't define or produce them[63]; as such, we have to account for the factors that would push a government into interfering or destroying a satellite, and how they would be influenced by the reference frame. Lastly, actors do not - can not - operate and make decisions in an ill defined, nebulous environment, with no boundaries and no limitations. It has been said that International Relations as a whole is in a territorial trap (Agnew, 1994), wholly dependent on territoriality and spatiality as a framing device but unwilling to look at it critically. While that is certainly correct, what should we make of space as a space? Unlike

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alternative framework is prospect theory, and it has found fertile grounds for applications in International Relations studies, although often not appropriately from an analytical point of view (ibid.). Specifically, of great interest to us is the concept of reference dependence, the tendency of individuals to consider to judge the worth of an action by as comparing to a specific reference point instead of the final outcome (Vis & Kuijpers, 2018); the consequences of this is that depending on how a certain situation is framed, people will respond differently.

[63] The literature on frames is enormous and essentially intersects the entirety of social sciences, and to give even a simple synopsis would be an endeavour worthy of a work of its own. For our purposes, we can simply refer to the most widely accepted definition of cognitive frame: a collection of interrelated ideas and concepts that are used to make sense of an environment, a situation or an activity. As such, they define the knowledge background needed for the making of a decision, but they aren't able to provide a decision on their own. As an example, the cognitive frame for murder entails a series of elements (death, prison, moral judgement, violence, blood, etc etc) that obviously discourage the act itself, much like our reference frame does for space warfare, and yet people still kill each other. The reasons for doing so (e.g. passion, hatred, political or ethnic grievances) may be tempered or nullified by the murder reference frame, but they aren't produced by the frame itself. For a fascinating and well written work on the subject of frames, the reader can consult Sullivan (2023)

the surface, with its clear and visible features, space is essentially empty, uniform and without a specific boundary: how can humans function in such an alien environment, without imposing some semblance of demarcation and territoriality? We posit then that political actors can’t help but “ground” their space policies and decisions in a series of areas, the ones we already touched upon in chapter 2: LEO, MEO and GEO. As actors move across these boundaries both physically and conceptually, they cross geographical thresholds that hold different characteristics in geographical as well as in ideational terms. These four components are the building blocks of our model, but before we examine them in detail, we need to provide the reader with both a quick synopsis of the conclusions we’ve reached in the preceding chapters. Next, we tackle a question raised in the second chapter, that of deterrence strategies. While not a specific element of our model, space deterrence emerges organically from the constraints we’ve already discussed, and its prevalence in the security considerations of political actors makes it so it merits its own treatment. Afterwards, we will assemble our model and discuss our findings to close out the chapter

4.1 THE CONTEXT SO FAR

We’ve already established in chapter 1 a relatively simple taxonomy for ASAT weapon systems and their capabilities: we’ve divided ASAT weapons in four categories: kinetic and directed energy weapons (DEWs), which directly attack the physical structure of the satellite to varying degrees of destructiveness; cyberattacks, which are able to effect a spectrum of interferences on the operation of the space assets, ranging from mere annoyance to the logical systems of the spacecraft to complete destruction; electronic weapons, consisting of spoofing and jamming, which aren’t able to directly affect satellites but are the only ASAT weapons which see frequent usage. We’ve also ranked these weapon systems on their ease of development, operation and maintenance (EDOM), interference capability and political impact: kinetic weapons are relatively easy to manufacture, fairly destructive and impactful from a political point of view, while DEWS are complex, expensive machinery capable of granular (but rarely permanent) damage and moderately impactful from a political point of view. Cyberattacks are so wide-ranging in their possibilities that they are required to be split in two different subcategories, destructive and non-destructive. Destructive cyberattacks are cheap and relatively easy to implement, highly damaging and impactful, while non-destructive ones are similarly cheap, but do not effect permanent damage onto the spacecraft and have low political impact. We've hypothesised that - taken together - these findings paint an overall unclear picture of what we can expect from orbital warfare and are not able to explain the seventy years of peace we've witnessed in the space domain. Of the various typologies of ASAT systems we've examined, only destructive cyberattacks and kinetic weapons ranked highly in destructiveness and cost effectiveness (with other systems relegated to far less impactful interference), and yet they have never been used. If we were to base the answer to our research question exclusively on the effectiveness and cost of ASAT weapons, we would come up short. As such, simply looking at what weapons can and cannot do simply isn't enough to explain why they may or may not be used.

In chapter 2 we moved from analysing the properties of ASAT weapons to discussing the environment they would be employed in, outer space (or, more specifically, near Earth space). We proposed that the unique environmental conditions of space have profoundly influenced its human geography in ways that set it apart from its terrestrial counterpart. If on Earth rivers, plains, seas, mountains and other disparate geographical features define polities and their actions, in contrast space presents itself as a flat expanse with no reliefs or barriers to speak of. Far from being the case, chapter 2 showcased that the physics of space travel belie a rich and diverse set of environmental factors that - though not immediately apparent - affect important boundaries on spacecrafts and people alike. We've outlined two key features of our sidereal neighborhood. The first is that orbits are not equal, and each type serves distinct purposes and encourages the use of specific types of satellites and of architectures. More specifically we've seen that LEO circular orbits are poised to become the future of space infrastructure thanks to the advancements in micro-satellite manufacturing and launching capabilities, MEO is ideal for medium to small constellations for navigation purposes, and GEO contains highly valuable and hefty satellites, and is the only orbital area that is strictly regulated internationally. Secondly, we've established that lack of the atmospheric medium makes the existence of orbital debris a central concern for all space faring countries and firms (Clormann & Klimburg-Witjes, 2022), although this concern can ebb and flow depending on the altitude and the type of space architecture more prevalent in a given orbital area. Although the addition of a geopolitical outlook to our analysis has enhanced our findings, it is clear that it is still not enough to explain the almost complete lack of space aggression in the past two thirds of a century. While debris generation is certainly a concern, DEWs do not generate any, and neither do non-destructive cyberattacks. Why do we not see constant dazzling and blinding, as well as frequent cyber-attack-related outages and issues like we see on the surface? And what of MEO, where the debris generation concerns are far less pressing? It's clear that there are still some gaps, some wiggle room that should have allowed the door to aggression to swing open in these past decades, if we would have stopped our analytical treatment here.

Completing our series of constraints, we've proposed the existence of a stigma against space aggression. Like any other norms, it provides the international community and its actors with a series of expected behaviours and social expectations: in our case a prohibition on destructive warfare in orbit. This interdiction does not extend to the concept that space can't be oriented toward military uses, neither legally nor empirically, but it is my hypothesis that, while stigma hasn't reached a point of full internalisation (Finnemore & Sikkink, 1998) in international society, it is has sufficient moral suasion to raise the most basic level of mutual hostility at which destructive or highly disruptive attacks are an acceptable proposition. In other words, stigma against space warfare would not be able to prevent attacks in orbit in the case of, for example, an existential conflict between space powers, but it would be able to prevent less intense conflicts from spilling over to the space domain. Now the picture becomes clearer, if still incomplete: there are constraints - technical, physical, economic and normative - on orbital warfare, but is it wholly and exclusively thanks to these constraints that aggression has not emerged in the space domain for the past seventy years? One fact is evident: even if space-capable countries seems reluctant to engage in space-borne attacks (be they strong forms of interference or straightforward destruction), they nonetheless consider the possibility of such attacks very real and are preparing themselves accordingly, shoring up their defenses, bolstering their arsenals and working on creating stronger normative forces against space aggression, and a similar apprehension is shared by the UN and its agencies. It is clear then that even the restrictions we've just examined are not enough to completely dispel the spectre of space conflict from the mind of international actors: a more sophisticated analytical treatment is necessary to tackle our research question. We start such a treatment by introducing a more formalised treatment of the concept of space deterrence we've introduced in chapter 1, with the following section providing a useful reference point for the reader to come back to whenever we discuss issues of security and retaliation unearthed by our model.

4.2 DETERRENCE IN SPACE

Whether we are on Earth or in orbit, attacks can be retaliated against. The logic of deterrence, which can change significantly between different domains and types of warfare, nonetheless tells us that to properly defend against a threat, answers to aggression must be credible, swift and override any possible gain the aggressor may accrue (Quackenbush, 2010). Therefore, when considering an attack on space assets, the attacker must contend with the possibility - and in some cases the certainty - that there will be a retaliatory response. Debates on whether this response should be specular or immensurate have been abundant in the literature pertaining nuclear deterrence, and similarly the debate could be translated to the literature on space.

Let us imagine that State Alpha, with a dozen military satellites to its name, is deciding on whether to strike at State Beta's telecommunication satellite in geostationary orbit, one of Beta's 30 plus militarily significant space assets. State Alpha has access to kinetic weapons (missiles) that can reach Beta's satellite with ease and destroy it. If Alpha believes in the fecklessness of Beta, it will surely attack and destroy the asset. However, the two countries are locked in a brutal war, and it would be surprising to say the least if Beta didn't respond to such an aggression: and so the question moves to whether Alpha would respond or not, to how strong the response would be. Beta has 30+ satellites, and the one targeted in geostationary orbit is only one amongst others that provide telecommunications services to its troops on the ground. Alpha on the other hand has only twelve satellites, and only one is able to guarantee safe communications for military purposes. Even if Beta would limit itself to a proportionate response (tit-for-tat), Alpha would come out the loser, since it would result in the destruction of its only telecom satellite. This tells us that as long as retaliation responses will be at the very least proportionate, the side with the highest reliance on their space infrastructure will be discouraged from aggression.

However, judging the reliance of a country on its space infrastructure is a complex endeavor: do we consider it with respect to a single asset, or to the entire sector? The question is complex to answer because it cannot be considered univocally. At a given point in time, a country may be reliant on one specific asset among many, because it is the only one able to provide what is needed at that moment, but this reliance may be confined to a single operation or circumstance. Conversely, the country may be heavily reliant on its space infrastructure, but with said infrastructure being composed of constellations, a singular component of which may have little to no value as a target (Erwin, 2022). So, it is not just the reliance that matters, but the resilience of both the attacker and the attacked.

We’ve already established in chapter 1 that passive defences like installing armour on satellites is simply not feasible today, technically or economically (Wright, Grego & Gronlund, 2005). Then, the only methods available to increase the resiliency of one’s space infrastructure would be to increase the number of satellites in orbit, and to share orbital services and platforms between allies and third parties to guarantee coverage and uptime. Some countries, like the US, embrace proliferation as a fundamental component of their space strategy (Lopez, 2024), employing deterrence-by-denial to discourage attacks due to the impossibility of shooting down hundreds, if not thousands of satellites. Proliferation is part of two of the three space deterrence archetypes presented in Flanagan et al. (2023): denial-dominant deterrence, which hopes to discourage the attacker by making the possibility of any meaningful gain from aggression very low, and mixed deterrence, which nomen omen employs both resilient space infrastructure as well as some weapon systems capable of degrading the aggressor’s space assets.

Perhaps ironically, the effective, straightforward destructiveness of kinetic weapons, and the relative ease with which they can be manufactured or repurposed from preexisting missile systems, makes them amongst the most limited weapons when it comes to scopes of usage: since they are effective, able to reach any orbital altitude, and can be potentially deployed by a relative large group of countries, their very existence invites the familiar iron logic of deterrence into the space domain. Space powers, unable to physically defend their space assets, will either turn to proliferation, building constellations upon constellations of satellites that are too numerous to be brought down in big enough numbers to degrade operations, or will fashion an offense-dominant deterrence policy that guarantees widespread destruction to any attacker, which in turn will push competing countries to turn to resilient architecture to cope, reducing the efficacy of the aggressive approach to deterrence. Space-faring countries of smaller caliber, with a far more compact satellite fleet, not able to engage effectively in proliferation on their own to reduce their reliance, will decide to band together and shoulder the costs of proliferation collectively (as is the case of ESA and the EU) or will partly make use of the infrastructure of greater powers, which will make them dependent on them, and more easily coerced. Lastly, countries with trivial to non-existent fleets are in the unique position of not being reliant, at first glance, on space infrastructure. However, one must keep in mind that even countries with no space assets will still be reliant on space assets[64], just not their own. Much like the lesser space-faring countries, they could still be deterred from attacking space infrastructure -by threat of being cut off from its most critical components- and perhaps even more so: the lack of satellites on which to retaliate could push certain states to answer on the surface, turning a bloodless aggression into a planet-side conflict with potential loss of life.

Putting it in different terms, it is my opinion that the inherent efficacy, straightforward implementation and reach of kinetic ASAT weapon "warp" the deterrence discourse around them, such that they can't be ignored; the two paths (denial, resilience-based deterrence, or offensive-dominant deterrence) to mitigate their effects become focal points[65] of sorts for space policy. In the game of destructive space warfare, the players can have different stakes and payoffs, with the ones standing most to lose being the countries most heavily reliant on space assets, and the ones least affected being those with scarce or null reliance.

With space being a domain that in its current configuration heavily favours sudden first strikes (Evans et al., 2024)[66], the apparent conclusion would be that those with the most assets in space would also be the most vulnerable. However, when proliferation is used as the main deterrent strategy against kinetic attack, the entire space environment is pushed towards it as a natural consequence. Let us explain this in a more orderly fashion: we have said that since fortifications or active defences are not yet possible in space from a technological point of view, the two main venues for deterring physically destructive attacks are proliferation and threat of overwhelming punishment. Of the two, which one is the most effective? Flanagan et al. (2024) posits that each has its own place, but the latter introduces important complications

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[64] Just as an example, the GPS provides not "just" free navigation signals, but is also used worldwide to manage power grids, telecommunication networks, digital banking transactions and financial trading, due to the highly precise atomic clocks present on board the satellites

[65] A focal point is an important concept in game theory, describing an organically reached solution among players in a game where direct coordination is not possible. Focal points are usually associated with coordination games, in which participants play simultaneously and only win if they choose the same strategy (Schelling, 1990). This doesn't neatly apply to space deterrence because countries can, and will communicate, about their space policies with allies and opponents, and space deterrence is a multi-stage game; nonetheless, the concept of different countries arriving at similar conclusions when having a small amount of information to go on shares some similarities with the concept of focal points.

[66] The reasons being that satellites cannot be armoured effectively, and will be moving through predictable orbits (Evans et al., 2024).

to the process of managing deterrence, specifically in the process of de-escalation. I'm instead of the opinion that once proliferation is introduced by at least one important space power, overwhelming punishment and preemptive first strikes of the shock-and-awe variety present in Chinese and Russian military space strategies (*ibid.*) cease to be effective. Proliferation uses "flocks" of low value, low cost satellites in LEO to distribute operational effectiveness of space infrastructure, making it diffuse, without bottlenecks worthy of being singled out. If the main vector of attack is in fact kinetic attacks, the only way to disable the constellations is to degrade a significant portion of them, if not their entirety. However, as we've already explained in chapter 1, LEO space is especially vulnerable to debris cascades (Viasat, 2022); the deflagration of even just one constellation would probably be enough to start an uncontrollable reaction that could blanket the lower orbital paths surrounding Earth with an enormous mass of highly dangerous debris, creating two negative consequences for the attacker: the first is that space access would be severely limited, if not precluded entirely, for periods of time that are difficult to estimate, but could range from months to decades (ibid.); the second is that its own infrastructure will probably be impacted in the following period[67]. With the increase of not just governmental (Zisk, 2022) but also commercial constellations in LEO, the time window in which a kinetic attack at low altitude would still be feasible and strategically sound is rapidly closing, or may have already closed. The two leading space adversaries of the US, China and Russia, seem to concur[68], as the recent pivot both appeared to have taken towards weaponising the natural high radiation areas surrounding the Earth (the Van Allen belts) seems to signal (Chen & Singer, 2024). While similar considerations cannot be made for satellite constellations at higher altitudes (such as GNSS constellations), different constraints (interdependence and stigma) step in to reign in potential kinetic attacks.

One additional point to consider as pertaining is the fact that many constellations and satellites provide services to a wide global audience, both institutional and private: companies like Starlink and Viasat have firms, private individuals and entire governments as clients, and

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[67] Quantitative studies (for example the already cited Thiele & Boley, 2022) highlight that the risk of a satellite being impacted at least once during its operational lifetime increases nonlinearly with respect to time, and eventually reaches a point of certainty after a few years even in current environmental conditions. In general, sudden debris injection (as the result of a kinetic impact) carries a significant risk of increased collisions (Liang, Fanto & Signoracci, 2024)

[68] This development carries fascinating parallelisms with the concept (already mentioned in chapter 1) of the inversion of defense and offence in nuclear deterrence. The deterrence strategy undertaken by the US, eminently defensive in nature, is perceived as offensive by China and Russia because it could allow the United States to theoretically weather through either rapid first strikes or retaliatory strikes and answer in kind. This would make Chinese and Russian space infrastructure far more insecure, as they are smaller and more easily targetable, and both countries would not have at their disposal any deterring answer to American aggression.

many of these institutional customers may not necessarily be space capable countries, making them not just dependent on these services, but unable to supplant them internally in the short term. This is even more relevant when considering GNSS constellations, which usually provide civilians access to the signal free of charge, and are used for many critical applications and not just navigation. Therefore, the fallout of these attacks would not be restricted to the defendant, but to all users of the service. That economic enmeshment and trade between countries might help stimy the tides of war is not a novel concept (Feldman, 2009): from Norman Angell to economically-minded liberalism, the fortunes of this argument have ebbed and flowed throughout the decades and have recently hit a low point in the failure of the wandel durch handel approach employed by many European countries with the Russian Federation. Nonetheless, the logic of the argument is sound, and there is research pointing out that trade -and cooperation in general- do play a part in conflict management and avoidance (Mansfeld & Pollins, 2001). Applying the *doux commerce* line of thought to the space environment does require an important caveat: a common argument in economic peace theory is that it's the trade bonds between two countries that discourage hostilities between them (*ibid.*); I argue that in space it's the bonds between the defender and all other countries making use of their space services that discourage hostilities, rather than the bonds between the attacker and the defender. *Exempli gratia,* in an hypothetical war between the US and China, each would be wary of attacking GPS or BeiDou satellites, since they are both widely used by many countries which would not be a part of the conflict. It isn't necessary for specific ties to exist between the two, as long as ties running through space assets exist between each of them and third parties to the conflict[69]. For this reason, it is unlikely (but not impossible,) that space infrastructure with a global user base would be impacted in a conflict; lending credence that economic bonds constitutes a viable deterrence strategy is the fact that the US' (US Department of Defense, 2023) space policy explicitly set increased collaboration with both firms and allies as a key step for "mission assurance" (pag. 6, *ibid.*): in other words, the enmeshment between the US and its allies and firms can be a powerful tool to increase resilience.

To summarise, kinetic attacks are the elephant in the room: too destructive to ignore, too easy to manufacture for most determined countries, but impossible to defend against in a conventional manner. The most vulnerable (space powers with important satellite fleets) can

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[69] Which isn't to imply that this space interdependence is able to prevent conflicts from forming at all. My point is that it stops conflicts from spilling over to the space domain, which is the objective of space deterrence in the first place.

decide to either deter would-be aggressors through threat of retaliation, or by making themselves too vast in numbers and diffuse to effectively bring down. This strategy is dominant and once introduced makes the offense-oriented alternate strategy useless, as its employment would cripple the attacker as well; the initial state of insecurity borne by space powers' growing reliance on their space assets has to contend with the existence of kinetic weapons, and the latter shapes the former into mutually exclusive strategies of deterrence, with one -proliferation- emerging as the clear winner, due to its ability to both "neuter" kinetic weapons as well as inure space infrastructure from direct damage by sharing the burden of its loss with partners and firms. The efficacy and relative accessibility of kinetic weapons is starting to mold the human space environment in such a way that they can no longer be used effectively, and they do so by encouraging deterrence strategies that increase resilience: in other words, kinetic weapons are so efficient that they are making themselves obsolete.

But of what other ASAT systems we described, such as DEWs, cyberattacks and electronic weapons? We've established that directed energy weapons, cyber and electronic weapons, unlike kinetic weapons, can modulate their destructive capabilities, and this is particularly relevant when considering laser-based DEWs. The output of these systems can be adjusted on a continuum, such that the same weapon could dazzle sensors or blind them, damaging them permanently. As pointed out by both Evans et al. (2024) and Cannin (2021), the reversible nature of DEWs (and of other ASAT systems) could be effective to manage conflict escalation[70]: the use of capabilities that do not permanently disable space assets could be a potent tool to signal to the opponent that there is no intent of increasing the severity of hostilities. Another argument in favour of reversible weapons is that they allow breathing room for conflicts between space powers to remain localised: a small-scale military operation (for example the retrieval of a downed spy pilot in hostile territory) benefiting from the temporary disabling of imaging or surveillance satellites could do achieve that without any damage to the targeted assets (through a cyberattack, or through dazzling); this would not be possible if the only interference tools at the disposal of the rescue party were kinetic weapons. Of course, one could make the argument that by making such small scale operations more likely to happen, countries would engage in them more, and thus create more reasons for

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[70] Specifically, Cannin considers terrestrial uses of DEWs against enemy combatants, but his reasoning can be easily translated to ASAT DEWs as well.

escalation. It is a persuasive point, but I would argue that reversible ASAT weapons would not necessarily make these engagements more likely, but rather more likely to succeed.
Lastly, the fact that electronic weapons enjoy widespread use on the battlefield seem to lend credit to the hypothesis that these systems can work as a pressure valve, allowing for the temporary denial of military space services without having to resort to more aggressive forms of interference, which would complicate crisis management for both attacker and defender. These points do not apply to cyberattacks of the destructive variety, as they present the perfect crisis-destabilising confluence of inexpensiveness, ease of implementation and efficacy. However, the fact that the few available military taxonomies of ASAT systems place cyberattacks (without distinguishing between the two) in the middle of pack as pertaining to reversibility (Defense Intelligence Agency, 2022 & UK Ministry of Defence, 2022), could imply that our initial assessment of destructive cyberattacks as easy to develop and implement was incorrect. It could be that the physical destruction of a space asset via digital means is considered to be technically unfeasible by leading space powers; this could be due to a variety of reasons, such as the risk of the cyberweapon being turned against its owners, the fact that patching and closing vulnerabilities is par of the course in the digital domain (Van Puyvelde & Brantly, 2019), and the possibility to shore up the resilience of constellations through e.g. increased encryption, network segmentation or real-time continuous intrusion detection (Kareem, 2024). Regardless, the same constraints we've outlined in the first part of this section for kinetic weapons would similarly apply to destructive cyberattacks (if not even more so, as a cyberweapon could be reverse engineered and turned back on the attacker) due to similar effects on the space environment.

4.3 PUTTING IT ALL TOGETHER: OUR MODEL AND ITS FINDINGS

It is now time to put together the four concepts we've outlined in the introduction to this chapter - reference frame, decisional variables, political actors and geographical thresholds - in a coherent framework for the analysis of space warfare. Our argument is that, when taken together, these four analytical elements coalesce into a flexible model for the prediction of broad trends in the space domain and general policies of space powers. Our objective for this section is to approach this poietic process in a structured manner and to provide the reader with a clear sense of the conceptual "flow" of the model, as to better employ it independently.

This section will be structured thusly: we will first describe each of the four components of our model in detail, then we will then move on to describe how to apply it to a specific situation between specific actors or for a general outlook on international developments. We will conclude the section and the chapter with our final findings.

4.3(A) THE REFERENCE FRAME

We start by tackling the most defining element of our model, the reference frame. This specific concept found particular fortune in International Relations studies, but is not without its methodological difficulties, the chief of which is how to define the reference point (Mercer, 2005). Political psychologists and economists have gradually defined five possible types of reference points, each with its own strengths and weaknesses (ibid). If an actor considers themselves as successful or unsuccessful (or, in technical terms, in a domain of gain or loss) in its endeavours by judging the outcome of its actions against what they perceive to be a state of normalcy, their reference point is a status quo; if judging against a different and desired status quo, their reference point is an aspiration; if the evaluation is done using cognitive shortcuts we say that the reference point is heuristic; instead, if the evaluation of the gains and losses comes from the comparison with a situation perceived to be similar, the reference point is analogic; lastly, if the actor heavily incorporate emotions in their evaluation process, our reference point is emotion-based. While I believe that all of these variants have the potential to provide useful insight on space power politics, I've chosen the status quo typology for two reasons: the first is that the alternatives require the study of each space power, or possibly every country and international organization separately, as to glean their aspiration, their most commonly used heuristics or the emotional states of leaders and decision-makers, defeating the purpose of creating a simple, agile and straightforward model applicable to all actors. The second is if we take our proposed reference frame to be real and effective, the status quo frame is the one that in my opinion follows empirical reality more closely. As we've already said numerous times in this thesis, countries seem loath to the idea of space aggression, and this behaviour has been repeated, upheld and even rhetorically encouraged by space powers since 1957; it follows that the current international space environment has been held to be at least partly desirable by most parties involved since its inception, and has perhaps been reinforced in its suasive power by the persistent lack of significant political threats to its upheaval; routine and habituation are after all key processes underlying bounded rationality in political organisations (Jones, 1999). This is why we've chosen a pacifist status quo as our reference frame, constructed from the constraints we've outlined in the past three chapters. It's important to clarify that our three constraints are not subsumed into a singular pastiche, and each contributes to a specific facet of our frame. In turn, as we shall see in the next sections, each facet is not uniformly influential, with their relative weight varying following a geographically-minded distribution i.e. our geographical thresholds. We propose the following constitutive elements to our reference frame:

1. ASAT weapons are divided in two broad categories: reversible and irreversible (or destructive). Destructive weapons are believed to be effective and the "default" option when it comes to developing dedicated space-capable systems, due to their relative ease of development and doubtless efficacy, but are also perceived to come with significant political baggage due to their deleterious consequences for the near-Earth space environment. DEWs have limited destructive capability and can modulate their output power, but they simply do not have the reach to target many key satellites, and are considered ancillary assets. The limited information available on cyberattacks seems to indicate that states consider them a legitimate weapon, but there's a lack of data available due to the secrecy maintained in these matters. Lastly, jamming and spoofing are clearly legitimate and have seen widespread use.

2. The space environment is perceived as interconnected both physically as well as economically. Debris formation as a consequence of ASAT usage is seen as a legitimate concern on both normative and strategic grounds, and some space powers consider the enmeshment and entanglement of firms, space agencies and governments as providers of space-based services as an effective tactic to enhance resilience and bolster deterrence.

3. Space has been constructed repeatedly throughout the decades as peaceful domain of open cooperation, first by the US and the USSR during the Cold War, and afterwards by *big science* endeavours like the ISS as well as the repeated attempts by China, the US, Russia, the EU and international organizations like UNOOSA in creating a legal regime for space disarmament. Whether this construction is sincerely internalised by governments is beyond the scope of this thesis, but the absence of physical aggression

in space as well as the placement of weapon systems in orbit even in times of heightened international tension indicates that states are deterred by engaging in space warfare by more than just material and strategic factors.

These three points, each determined by the constraints we've outlined in chapter 1, 2 and 3, form the cognitive starting point for any decision in space power politics. When picturing space in political terms, I propose that this what coalesces in the mind of decision-makers and experts worldwide: a deeply interconnected, interdependent and mostly pacific environment, under constant threat by dangerous and impactful kinetic weapons and with limited alternatives available to defend oneself or to discourage aggression, due to the technical limitations of competing systems.

4.3(B) POLITICAL ACTORS

The actors involved in the space environment are numerous: governments, firms and international organizations, as well as advocacy groups coexist and reciprocally influence each other in deep and meaningful ways. We've described some of these interactions in the preceding chapters, but incorporating each of these potential stakeholders and decision-makers as standalone actors would defeat the purpose of creating a simple, heuristically minded model efficient in its determinants. Furthermore, while many of these groups and organizations hold significant sway in national and global space politics, it is only states that have the legal right and the material capabilities of actually attacking space assets. Therefore, for the purpose of our model and following a well-established analytical tradition in realist IR writing, only sovereign states will be considered as relevant actors insofar as space warfare is concerned. However, the aforementioned groups aren't excluded wholesale, but contribute to the shaping of norms, preferences and are key participants in the creation of a reference frame for political action in space.

We define four different types of actors, in decreasing order of space power available: space superpowers own significant parts of the global space infrastructure, have their own launching capabilities, finance space programs with weighty budgets and define the sum trajectory of space exploration and exploitation directly and indirectly through the decisions they take and the programs they fund. The leading space superpower is the US, with China in a rapidly advancing second position. Space powers are the second tier of space capable countries: they have space assets numbering in the dozens, a domestic industry covering at least part of their technological need for the space sector, a national space policy that incorporates both civilian and military uses for satellites and may have domestic launch capabilities. Canada, Japan, Italy, France, Germany, Israel and the United Kingdom are the leading space powers, together with Russia and India: the former has lost their past status after the fall of the USSR and the subsequent ill fortunes of its economy and the mismanagement of its space sector (Vidal & Privalov, 2022), although it retains a significant cost advantage vis a vis the West, while the latter could reasonably become a space superpower in the near future, owing to a successful and cost-effective space program and the development of affordable launchers with which to implement its aspirations. Rogue states[71] have space capabilities comparable to a middling space power, but are defined in terms of their place in the international community as isolated both economically and politically, as well as their open hostility to the status quo. The vast majority of countries are actually grounded states: some of these nations may very well have a handful of space assets to their name, but all of them don't have any launching capabilities or the capacity to develop and launch a satellite independently.

Any country with even a relatively minor stake in both the space sector and the stability of international society faces strong disincentives to initiate physical hostility in space. However, we can hypothesize that if a political not as beholden to the constraints and processes outlined above existed, it would be more predisposed towards aggression. Such an actor would have to harbour a deep dissatisfaction with the international status quo, such that they would not consider themselves constrained by international code of conducts such as the emerging norms of space pacifism; a minimal if nonexistent space infrastructure, making domain to domain retaliation an ineffective deterrent; diminished economic and political ties with the rest of the world and to the space sector, which would render moot considerations on eventual retaliatory sanctions or exclusion from space-based services. Only one type of actor satisfies these three requisites: rogue states. Rogue states can put to use one of their defining features, isolation from the international order, as a sort of armour to shield themselves from the most common forms of space retaliation. However, one should not fail to take into consideration that retaliation for an orbital attack isn't necessarily confined to orbit (Flanagan et al., 2023) and that rogue states risk miscalculating the seriousness of the response: if the attack is sufficiently damaging and on strategically or economically relevant assets, countries may

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[71] The very definition of rogue state is politically and academically contentious (Rose, 2011 and Hoyt, 2000), and they are most often defined by what they are not rather than what they are. We do not however put in doubt the very existence of such a typology, subscribing to the general definition proposed by Rose (pag. 12, ibid.), that "rogue states are states that possess the power and credibility to, and engage in behavior that sharply conflicts with the net interests of international society as defined by major powers."

retaliate on the surface with violence even though the original offense may have been an orbital, sans blood, attack.

4.3(C) DECISIONAL VARIABLES

While our reference frame gives the starting point from which all considerations regarding space policies are made, it isn’t able to elucidate the reasoning behind the decision to attack, in what capacity and against which target. To properly understand the final outcome of such a decision, we need to take into consideration not just why countries may be discouraged in pursuing space aggression, but why they would entertain it in the first place. It is for this reason that we introduce the second element of our model, the three decisional factors that countries employ to assess the benefits - and the risks - of aggression against space assets.

The first of these factors is the reliance of both the attacked and the target on space infrastructure. It is intuitive that when deciding whether to strike at certain space assets or not, a key piece of information is how much the target depends on it (in terms of warmaking, intelligence gathering, communication, navigation, economy, and so on). A country wholly dependent on a few choice assets will be an appetising target, since it takes a comparatively small effort to disable it. Conversely, the attacking power will also be wise to take into consideration their own dependency on space infrastructure when deciding to attack or not: aggressive actions could be retaliated against, and so the attacked country could answer in kind and disable the aggressor’s spacecrafts.

Secondly, we have to consider the strategic (or tactical) value of the target considered[72]. Destroying a key geostationary communications satellite is an enticing proposition, while disabling a small spy satellite among dozens considerably less so; this follows the point we’ve raised in chapter 2 that not all satellites are made equal when it comes to their strategic significance.

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[72] A point that could be raised against this taxonomy of factors is that the dependence of the attacked country on the target is a significant strategic consideration, and so one could incorporate it into the calculations of strategic value to simplify matters. I address this critique by a twofold argument. To start, dependence on the target and strategic value of the target are two independent calculations: one considers the loss as it impacts the attacked, and the other as it impacts the attacker. Secondly, the two may not be coincident: an attacker may destroy a target of great strategic value to their current operations, but on which the victim does not depend much and vice versa.

Finally, one has to consider the historical and political context present when the decision is taken. One key empirical finding frequently presented in bounded rationality literature is that the risk aversion of individuals changes with respect to the gains and losses they're poised to get. A similar point could be made for international relations when it comes to the "temperature" of the situation in which a decision has to be taken; for example, it is not sure that the constraints we've examined in the first three chapters would be able to stay the hand in case of an existential war between superpowers. The perceived gravity of a situation can change the priorities of decision makers and turn what was once viewed as unthinkable into a plausible course of action.

Taken together, these three factors give us a simple framework to understand the train of thought that the decision makers of a particular country may go through when deciding whether or not to attack a space asset: what do they stand to lose, what do we stand to gain and does the situation call for it? However, they aren't enough to fully resolve the decision-making process of political actors. To achieve that, we need to spatialise their reasoning with the concept of geographical thresholds.

4.3 (D) GEOGRAPHICAL THRESHOLDS

While we posited that political actors think of space in general in terms of our frame of reference, they also have a need to conceptualise space in grounded, physical terms, hence the need to introduce an actual geographical element to our analysis. As we've mentioned, space itself is too apparently featureless and uniform to be understandable without resorting to some form of territorialisation or demarcation of boundaries. A significant body of social science research has consistently shown how pervasive spatial considerations and concepts are in politics in general, and in contentious politics specifically (Martin & Miller, 2003). I believe it would be a grave mistake to discount the human need to think of the world in spatial terms, doubly so when it comes to a particularly ephemeral environment like outer space. That is why I propose the concept of geographical thresholds, consisting of the three orbital altitudes we've described in chapter 2: LEO, MEO and GEO. We hypothesize that when said thresholds are crossed, certain constraints and processes gain potency while others lose in relevance; to be more specific, we refer to the singular facets we've outlined in the frame subsection. In the chart below we can see clearly how our proposed geographical thresholds are able to influence the decision-making progress by establishing clear boundaries when it comes to actionable and non-actionable acts of aggression or interference. We will now proceed to describe in more detail how such boundaries unfold by considering each orbital area at a time.

	LEO	**MEO**	**GEO**
Weapon specifications	*High relevance*	*Low relevance*	*Low relevance*
Economic interdependence	*Medium-to-low relevance*	*High relevance*	*High relevance*
Physical interdependence	*High relevance*	*Low relevance*	*High relevance*
Stigma against space warfare	*Medium relevance*	*Low relevance*	*High relevance*

Chart 3. Relative weight of frame facets at different geographical thresholds

4.3(E) LEO

LEO is a highly congested and profitable orbital area, projected to be the stage for the explosive growth of the New Space economy in the near future. At these altitudes the proliferation of assets due to the increased use of constellation architectures reduces the strategic and economic value of any singular satellite and increases the risk of runaway collisions and debris creation, and it isn't an exaggeration to say that LEO is already severely crowded and at high risk of a Kessler syndrome scenario (Viasat, 2022), even without any actual attack having taken place. Moreover, many of these constellations and satellites provide services to a wide global audience, both institutional and private: companies like Starlink and Viasat have firms, private individuals and entire governments as clients, and many of these institutional customers may not necessarily be space capable countries, making them not just dependent on these services, but unable to supplant them internally in the short term, and while these constellations aren't as pivotal to the functioning of the world's economy or to maintain high level of nuclear security like MEO and GEO satellites, they are still widely used and so are partly shielded by the economic interdependence of space infrastructure. It is here that the full spectra of ASAT systems can be used: kinetic, DEWs, and cyberattacks are all effective and usable at these altitudes, and the constellation architectures popular in LEO are specifically vulnerable to horizontal attacks. This makes LEO the only area in which both the limitations and the advantages of each anti-satellite system can be utilised, and the geographical threshold in which the specifications of ASAT weapons as a whole, and not just those of the kinetic variety are the most relevant. The fact that only cyberattacks and sophisticated and expensive weapons like DEWs can be used without incurring the risk of a catastrophic debris-generating cascade of impacts naturally limits the range of possible aggressive actors. It is unlikely that most grounded states would be able to field effective directed energy weapons, leaving them with only kinetic weapons and cyberattacks as methods of attack and deterrence; yet, their dependence on foreign space infrastructure and the risk of reputational harm would discourage hostility. Space powers are even more dependent on a debris-free LEO than grounded states are, discouraging the use of kinetic weapons. However, developing and fielding DEWs is not beyond the means of most space powers, giving them an effective way of deterring possible aggression at these altitudes. Space superpowers are similarly beholden to consideration of debris generation and own-reliance, such that they organically gravitate towards less aggressive forms of deterrence or attack, like dazzling or non-destructive cyberattacks. Still, their rapidly engorging fleets of satellites and constellations give space superpowers strategic depth and reduce the self-reliance on any given asset, such that we can probably expect both China and the US to possibly engage in more pro-active forms of interference in LEO, compared to middling space powers[73] who would develop such capabilities on a defensive basis. Regardless, the risk to one's own infrastructure, or that of third parties, is simply too high to justify the use of kinetic weaponry or of destructive cyberattacks. Lastly the only inhabited structures present in space are in LEO as well, creating unique complications, not found at higher altitudes, in terms of possible collateral damage and international opprobrium: it is only here that our stigma against space warfare intersects with the possibility of ending human lives. However, the creation of permanent human outposts on the Moon, which is on the agenda of both the Chinese-Russian space axis as well as the US and ESA could change the extent to which the space stigma facet affects space aggression in LEO. If a permanent human presence will be established on the Moon in the near future, coupled with the future decommissioning of the ISS and the eventual decommissioning of the Chinese space station Tiangong, LEO could get depopulated of human beings entirely, removing at least one barrier against orbital attacks.

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[73] One such example is France, which has limited counter space capabilities specifically for defensive purposes (Flanagan et al. 2023).

4.3(F) MEO

MEO satellites are out of reach of any currently available DEW, leaving us with only kinetic weapons, cyberattacks and (perhaps most importantly), jamming and spoofing. The lack of human presence, the vastness of the area considered and the sparseness of satellites present at these altitudes compared to LEO make physical interdependence a relatively unimportant concern. The space between satellites or constellations in MEO is simply too vast for errant debris to constitute as much of a threat as they are in LEO. On the other hand, economic interdependence is king at these heights. All GNSS constellations (GPS, Galileo, Beidou and GLONASS) are found in MEO, and their importance to the global economy as a critical infrastructure cannot be understated. Moreover, the navigation services provided to their respective militaries, not just for troops on the ground, but for seacraft, aircraft and missiles makes them an invaluable tool for any country using them in such a manner. An attack on a GNSS constellation could not be construed as anything else but a declaration of war, and it would trigger a commensurate response if available, cancelling out any advantage such an aggression might bring the attacker. Moreover, a Pearl Harbour-style surprise attack would only be worth it in case of a major conflict, and only if the aggressor could hide its preparations on the surface for said conflict, which is unlikely. While assets here are relatively few in numbers, they are too important both militarily and economically to risk retaliation and international backlash; furthermore, alternative ground based navigation systems are available and can be used in a crisis situation. The same argument could be made for cyberattack of the destructive variety, regardless of how much debris they'd produce. One avenue is left to address the strategic issue of satellite navigation, and that is the use of electronic weapons on the battlefield: considering that non-escalating and battlefield-proven alternatives present in jamming and spoofing, the incentive to actually attack the constellation becomes even smaller, and discouraging the use of such systems could push an hostile country to actually attack the constellation itself. Lastly, the lack of any specific symbolism associated with satellites present at this altitude and the relatively low risk of environmental concerns and damage to the global commons that are space orbits makes it so space stigma is relatively less influential in MEO, with the chief considerations being security and economic fallout of an attack.

4.3(G) GEO

GEO hosts some of the most important singular pieces of space infrastructure, both military and civilian. Since geosynchronous orbit is a relatively tight band of altitudes, the risk of debris is present, although not to the same extent as to LEO; this is partly due to the fact satellites in GEO are appropriately spaced to avoid reciprocal radio interference. Most importantly, geosynchronous orbit is tightly regulated by the ITU, following a legal regimen that's not regarded as equitable, but is still accepted due to the enormous value GEO brings and the need for coordination to properly extract that value. As I've mentioned in chapter 1, geosynchronous orbit is the one place in orbit where countries have truly come together to create a functional (if skewed and imperfect) framework for accessing the boundless resources of outer space in a somewhat cooperative manner; a flawed but accepted conversion of the idealistic principles of the Outer Space Treaty and its lofty ideals of equal sharing of the bounty of space between all countries. Bringing physical destruction to such a place could be a grave misstep in terms of international reputation, and could blow back on the aggressor far more severely than anticipated. In the terms of brinkmanship, such an action would be a miscalculation of the opponent's intent, when the threat "that leaves something to chance" (Schelling, 1960) results in a slip and a fall: delegitimising the stigma on space warfare could cause a sort of "open season" period of anarchic opportunism in terms of space aggression, which would hardly be a favourable outcome for the attacker. Doubly so considering just how many vital strategic assets are present in GEO, like nuclear early warning systems and telecom satellites for high-level military communication. Attacking these kinds of satellites would be a reasonable proposal only in the case of nuclear first-strike, at which point all regular strategic calculations would evaporate under the spectre of nuclear holocaust. GEO is simply too valuable as of now, both in symbolic as well as in strategic terms, for any kind of attack, except maybe for the mildest forms of reversible interference.

4.3(H) APPLICATIONS AND FINAL FINDINGS

We've described all the elements of our framework, and what remains is to assemble into a useful predicting and modeling tool. To do that, we must first consider what is the intended use of the model, and what question we intend to ask. While it can be used to try and predict more granular outcomes (for example, the solution to a space diplomatic crisis between two countries), our model was always meant to elucidate overall trends in the domain of space power politics first and foremost. As such, the procedure involved in the two cases is different. In both, the process is sequential, meaning we consider each element in order to obtain our findings; what changes is the starting point, which is the reference frame. When considering a single event or a specific situation between two or more countries, the reference frame remains as given, as we do not consider any singular actor as capable of upsetting the status quo independently and within a singular political juncture; conversely, when trying to predict general trends in the international arena we need to reassess the reference frame to account for any possible key technological, material, or normative development[74] before engaging in the analysis proper.

For the sake of clarity I will provide an example of how the model works when used to analyse discrete political events in the space domain: let us consider two fictional countries, A and B, currently engaged in a prolonged and intense political spat over a disputed territory both lay claim over. Neither is apparently willing to back down, and both have signaled they are willing to use violence to obtain the contested territory. Tensions are high, with armies from A and B amassing on their respective borders in a show of force. Most countries in the area seem to think a war between A and B is imminent, and are preoccupied with the rhetoric from both countries threatening each other’s vital infrastructure with destruction. What is the chance that space infrastructure could be targeted in a hypothetical exchange? Our model can provide an answer to this question by considering each component we’ve outlined in a sequential and additive manner, meaning that the insight provided by each element is compounded by what it came before.

1. We start with considering our reference frame: as we said, when addressing singular instances, we consider it as given and we do not reassess it. Therefore, both country A and B conceptualise space as peaceful, economically and physically enmeshed and with limited options available in terms of interference and aggression

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[74] For example, the introduction of an ASAT capable space bplane, the emergence of a new important private player in the space economy or a successful international conference on space disarmament producing a binding treaty; each of these events could upset the delicate balance of pacifism, economic and physical interdependence which constitute our reference frame.

2. We now have to consider what kind of political actors A and B are with respect to our simple taxonomy: both are space powers with private and governmental fleets numbering in the hundreds of satellites, but are not comparable in terms of technological expertise and material capabilities to this world's space superpowers. A has its own regional navigation constellation, while B has to rely on the GNSS of its closest ally, and both have imaging and spy satellites, as well as access to kinetic ASAT weapons, but not DEWs. With both being fully integrated members of the international community, we know that - unlike rogue states - A and B will be hesitant to threaten the status quo in the space domain.
3. Having defined A's and B's material capabilities and assets, we need to ground them in the physical reality of space by considering which geographical thresholds each country occupies. Country A has its own small navigation constellation in MEO, and a series of spy and imaging satellites in LEO. B also has a similarly sized sigint and surveillance constellation in LEO, but does not possess assets at any other altitude. If we take a look at chart 3 we can see that both countries are limited in the use of kinetic weaponry against each other, as the majority of their strategic space infrastructure sits in low Earth orbit, where the risk of runaway collisions and blowback is most severe. At these altitudes stigma against space warfare is less prevalent and mostly tied to the risk of kickstarting Kessler syndrome and the (fairly remote) risk of actually endangering the lives of ISS and TianGong astronauts; as such DEWs could prove to be effective and would probably not harm the reputation of A and B, but due to the costs and know-how needed to develop them, neither country has them. In MEO we know that debris considerations are minimal, and so is space stigma, but economic interdependence is pivotal. A has its own regional GNSS constellation, but it is limited in both geographical scope and features, making it useful exclusively to A and its immediate neighbours. B does not have its own navigation satellites and uses the globally available navigation constellation provided by its closest ally.
4. Our last step is to consider our decisional variables, implementing all the information we've obtained from points one to three. Starting with the historical and political context: A and B are fighting over a long disputed territory, but most external observers and neighbouring countries seem to think that neither is willing to turn this into an existential war of total conquest; it is therefore unlikely that either one would risk severe reputational, economic or infrastructural damage. Moving to reliance on space infrastructure, both countries clearly depend on space infrastructure to the same

extent and employ space in the same strategic capacity, but considerations have to be made with respect to the navigation segment. A has its own RNSS, but it is far smaller in terms of components compared to B's foreign-based GNSS[75] and so more easily targetable by B's attacks; one could say that A is more vulnerable than B on a physical level, and it would be a correct, but incomplete assessment of the situation. A's RNSS can be easily brought down, and isn't widely used by other countries or firms, and so economic interdependence becomes a secondary concern. However, such an act would constitute a breach, no matter the location, of a normative rule of international behaviour, and it could be seen as a dangerous slope towards normalising attacks on navigation constellations. As such, it is likely that B's ally would communicate both to B and to the international community the need to not threaten GNSS satellites in any capacity, fearing it would create a precedent that could endanger its own infrastructure. B, at the mercy of a foreign power which can remove access or degrade the signal, would be inclined to comply. Conversely, A has no incentive to attack, both to avoid retaliation and because it would consist of an act of aggression against an uninvolved third party. LEO constellations are even more protected against physical aggression, through the mechanism of physical interdependence, with the political and environmental consequences of destroying an entire constellation. Their reliance is symmetrical, and although different in its determinants, it brings about similar security considerations. With assessing the strategic value of possible targets, LEO is where the bulk of each country's fleet is concentrated, but the entirety of it consists of surveillance and sigint constellations: the value of a singular satellite is minimal, and the target is shifted to the entire constellation, which is significantly harder to bring down, especially for countries with limited resources like A and B; one also has to take into consideration that while useful, imaging and surveillance technology aren't. MEO contains the most strategically valuable objectives, but we've already described how issues of deterrence, normativity and political precedents create insurmountable barriers to physical aggression. As DEWs are not available, what is left is non-destructive cyberattacks on the LEO segments and jamming and spoofing on the MEO segments, which have the added bonus of reducing the efficacy of the opponent's navigation assets without damaging them and risking a dangerous escalation.

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[75] For example, India's NavIC RNSS has 7 functional satellites, while the GPS has more than 30.

The outcome becomes clear and the question is answered: it is unlikely that either country will entertain the possibility of attacking the opponent's space infrastructure with kinetic weaponry, as the nature of the dispute in question, the acceptance of the actors involved with the space status quo (in the form of our reference frame), the specific geographical distribution of assets with all that it entails and the limited counter space capabilities available heavily reduce the strategic options available to A and B. What of applying our model to international society in more general terms? Keeping in mind our sequential approach, this is what we've been doing for the entirety of this thesis, as we've assessed our reference frames in the first three chapters before considering each analytical component of our model in turn in the current chapter. We can finally and definitively answer the research question we've posed in the introduction: why is it that we don't observe any form of destructive orbital warfare, or constant cyberattacks and interference attempts on space infrastructure, pivotal as it is to the global economy and the military efforts of most countries? Why does the apparent proliferation of space armaments (UN General Assembly, 2023) not seem to translate into increased hostility in orbit? The answer is, as our model has hopefully shown, that the conditions which seem to be so conducive, at least on a surface level, to the explosion of space warfare, are actually far more restricting than commonly described. The inherent limitations of space weapons, coupled with the peculiar physical characteristics of space vis a vis the surface and an evolving international normative discourse discouraging physical aggression create a uniquely structured reference frame for countries: far from being seen as a lawless, limitless frontier where everything goes, space is thought up to be a crowded and delicate oasis of international cooperation and of fundamental strategic importance, constantly on the verge of being destroyed by errant hostilities. This image acts on the most basic of cost-benefit analysis calculations of sovereign countries, making them cognisant of their own vulnerability to retaliation or to runaway debris collisions, removing the strategic gains from destroying any singular satellite, and turning space warfare into a weapon of last resort to be used only in the direst of circumstances instead of a tool like any other.

CHAPTER 5. THE EUROPEAN UNION AS A *SUI GENERIS* SPACE POWER

The European Union is a fascinating case study for a multitude of reasons: for starters, while the EU is not a country, in certain sectors it has capabilities far exceeding most. The unique place that the Union occupies in most political taxonomies is a well known point of contention in political science (Phelan, 2012): more than an international organization but not quite a federation, the EU stands out from the political actors we've described in the previous section as a non-country that nonetheless owns significant examples of highly advanced and critical space infrastructure. Secondly, the Union does not currently possess any internal capabilities to produce space assets or launchers: its space crown jewels, Galileo and Copernicus, were developed and built by another international organization, ESA, which is not part of the EU and with which the Union maintains a somewhat mercurial relationship. Lastly, the Union is a complex subject of analysis in terms of space policy due to the difficulty in disentangling its own capabilities from those of its member states. This section hopes to engage with these analytical difficulties borne by the sui generis political status of the EU by putting our framework to the test. We shall see that the Union enjoys unique advantages and disadvantages vis a vis its main competitors - or allies - in the space domain, China and the US, and if it can leverage its peculiar strengths and shore up its internal weaknesses it could easily become the third or fourth space superpower of the 21st millennium. The next section is organised as following: first, we shall provide the reader with a short synopsis of the Union's achievements in space and the agencies and internal organizations that engage with the space sector; we will then apply our framework to the EU, highlight how the EU is uniquely positioned as a normative space power with the potential material capabilities of a superpower; lastly, we will put forth some policy proposals to reinforce the Union's position in the space sector in the medium term.

5.1 THE MAKEUP OF EUROPEAN SPACE

When it comes to the space domain, the European Space Agency (ESA) has been an enduring reference point for European space cooperation ever since its inception in 1975 all the way to the emergence of the European Commission as a pivotal partner for the agency and the development of the three pillars of European space infrastructure: Galileo, Copernicus and IRIS2. Following the failure in producing a functional launcher rocket, the two coexisting european organizations dedicated to the exploration of space, ESRO and ELDO, were conjoined into a singular organisation, the European Space Agency. Until the early 90s, it was ESA that spearheaded European efforts in the space domain (Reillon, 2017), and the Communities and the subsequent European Union did not involve themselves deeply in the inner workings of the sector. This changed with the outbreak of the Yugoslav Wars, and the intervention of American and NATO forces in the area: the US degraded the signal available to combatants on the grounds to protect its aircrafts, and in doing so disrupted it for nearby European countries as well: this event was a major catalyst for the subsequent push by the Commission to develop a proprietary GNSS constellation (Sigalas, 2012). As of 2024, the EU has financed and owns two key pieces of space infrastructure, Galileo and Copernicus. The former is a GNSS constellation like the GPS or GLONASS, and the latter is an Earth imaging constellation which can be used for observation, public crisis management, climate monitoring and more. The Commission is also in the process of financing IRIS2, a secure satellite-based surveillance and communication network for governmental use. The day-to-day management of Union space infrastructure and the implementation of its space programme is left to EUSPA, the European Union Space Programme Agency, the successor to the European GNSS Agency founded in 2021. Without delving too deeply into the history of the European Union space policies - a fully fledged research topic in its own right - we can trace two important historical processes underscoring the EU’s forays into the space domain:

1. An increased interest in the strategic and economic potential of space activities. This stands in stark contrast with the most scientifically and pacifist minded inclinations of ESA, both internally and amongst member states, which are reluctant to part with their traditional purview of security in favour of the EU in orbit just as much as they are on the surface. The official starting point was the Commission’s 2007 document on the European Space Policy, explicitly defining security and defence as one of the pillars

on which to build more concerted European efforts. With the inclusion of space among the shared competences between Union and member states in the Treaty of Lisbon (art. 189), the stage was set for the Commission to take an increasingly proactive role not just in the creation of a common European space infrastructure in the form of Galileo and Copernicus, but in the increasing presence of the Union in the securitisation of the European space sector. The 2022 European Union Space Strategy for Security and Defense, specifically aimed at addressing -amongst other threats- the risk of ASAT systems being used against European assets, is an example of this recent development.

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3. The fragmentation and duplication of efforts (Küsters, Nolen & Stockebrandt, 2024) which has characterised European space cooperation ever since its inception, with the dual agencies ESRO and ELDO, tasked respectively with scientific research and with the development of a European launcher. This fragmentation was only apparently recomposed with their fusion, but the can was merely kicked down the road. As the Communities became the European Union and the Commission acquired political prominence and budgetary strength, European space became fragmented along an ideological cleavage, between the pacifist ESA and its member states backers, and the strategically minded Commission (Davis Cross, 2021), which eyes civilian and commercial space infrastructure as an avenue of economic and social betterment for the European citizenry (Reillon, 2017), as well as a key strategic domain. This divide was partly bridged by the 2004 EU-ESA Framework Agreement, which assigned to the former the downstream segment of European space, while the latter would deal with the upstream[76]. However, the relationship between the two hasn't been the rosiest for some time, with an attempt at incorporating ESA as a Union agency (ESA 2007) failing by its deadline of 2014, and a thawing process has only started in recent years (Foust, 2021).

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[76] By downstream we mean the commercialisation, tendering, legal framework necessary to run space activities; upstream is the day-to-day operation of satellites and space infrastructure, as well as R&D, assembly, transportation and launch.

5.2 DETERRENCE AND COUNTER SPACE CAPABILITIES IN THE EU

Keeping these two ongoing historical and institutional processes well in mind is fundamental to apply our model to the peculiar and utterly unique European space environment. Let us begin by addressing the elephant in the room: as the EU is not a country, and the question of European defence efforts is open and far from being resolved (Molnar, 2024), the possibility of a Union-backed counter-space defence system is not currently feasible. The legal, political and technical limitations for EU-owned and operated kinetic or otherwise offensively minded ASAT systems are beyond resolution in the short to medium term; as such, some constraint-borne processes we've described in the previous sections of this chapter would not apply to the Union; for example, the threat of physical retaliation against hypothetical opponents of the EU is impossible due to lack of capabilities, and its current institutional framework would not allow for the quick decision-making necessary to effect punishment-dominant deterrence anyway.

However, that doesn't mean that the Union is defenseless in the face of aggression: as we've seen, the leading space superpower, the United States, consider both proliferation and norm entrepreneurship as effective tools of deterrence and resilience for its space infrastructure (US Department of Defense, 2023). What this means for our model is that the explanatory variables we've used to explain when, how and why a country might attack in space cease to be such when we examine the EU, since it cannot attack or interfere with foreign space assets in any meaningful capacity; therefore, what is relevant for this case study is not the outcome of the decision-making process behind orbital aggression, which is given, but rather how our proposed frame interacts specifically with the EU and its purely defensive posture and which insights it can give us into possible trajectories of European space policy.

Due to the interconnected nature of space, a purely defensive, denial-based approach can potentially work, and it can be undoubtedly effective for the EU, which frames itself and is thought of as a pacifist, normative power (Holland & Chaban, 2011). As deterrence is a psychological phenomenon first and foremost (Flanagan et al., 2023), the image of the Union as a power-to-be loathe to - and incapable of - direct attack lends a legitimacy to its deterrence policy that other powers lack. For example, a key feature of Chinese space policy is its uncertainty over whether the US would be willing to strike its space infrastructure in case of conflict (ibid.), and no amount of American posturing on the importance of a peaceful orbital neighborhood or its emphasis on resilience and proliferation can change the fact that US policy documents have always declared the intention to maintain space supremacy. China is in a state of uncertainty when it comes to American policy, and uncertainty is a traditional realist fuel for international conflict, but this state ceases to be when it comes to the EU: it's not that the Union doesn't want to attack, it's that it can't. By its very nature, the European Union is a transparent power that can't disguise itself, its policies and its behaviour in an effective manner, doubly so for an extremely contentious internal issue for member states like shared defence. However, this transparency can work to its advantage in the space domain: removing the uncertainty from the interactions between the EU and other space powers removes a possible cause of conflict as well. In other words, the Union does not have to worry that another power will attack because it fears it might get attacked first. More generally, the first constraint on state action we've examined, the technical specifications of ASAT weapons, is much less relevant for the European Union simply because it can't directly field any of them; rather, we are interested in whether the EU is equipped or capable to "weather the storm" against each type of system, and to what extent; this point will be examined more closely in a following section, when we will once again employ our concept of geographical thresholds

5.3 PHYSICAL AND ECONOMIC INTERDEPENDENCE: A VIABLE STRATEGY FOR EUROPE?

If the most viable strategy for European deterrence is proliferation, then the question becomes whether the Union - or rather its industrial base - is capable of matching its defensive needs. Development and procurement will become a fundamental concern for the safety of European space infrastructure, and it isn't clear if the European Union is up to the challenge, with the 2024 Eurospace report on the European space sector paints a somewhat bleak picture: the share of the Union space budget against the wider European industry total budget is a mere 19%, and the trend is not improving significantly in the short term, with the budgetary allocations hovering around the €2 billion mark for the past three years. The European space industry is also highly concentrated , with the top five national budgets accounting for 81% of the sum total of the sector, and is losing steam in terms of sales and market share (Greenacre, 2024); this is most concerning, considering that by far the main drive of the new space economy in recent years has been the private commercial actor (OECD, 2023). In fact, the total Europe-wide budget allocated to space in 2023 amounted to around €11 billion (ESA, 2024), less than half that of NASA (Planetary Society, 2022), which does not include military expenses related to space. This is further compounded by a general malaise of European productivity and growth rates, which has been ongoing and well documented, with a marked move towards service-centered economies to the detriment of the manufacturing sector (Erixon, Guinea & du Roy, 2023). It does not help that, as we already mentioned, there is not a singular European space effort but several, fragmented between the three levels of national civil and military programs, ESA and the EU itself; this fragmentation has dire consequences for the lack of long-term planning (Küsters, Nolen & Stockebrandt, 2024) pivotal in a sector like space, which has long development times and a need for both significant capital and a substrate of highly educated professionals (Leloglu & Cocaoglan, 2008).

While this simple snapshot paints a fairly disheartening picture, there are some positives to consider:

1. The EU has already chosen a proliferated, diffuse architecture for its next pillar of space infrastructure, IRIS2. IRIS2 is a planned satellite constellation, multi-function and multi-orbital (as in, present in LEO, MEO and possibly GEO), with the stated objective to enhance secure communications between member states and European institutions and to provide new digital tools for crisis management and the commercial sector[77]. Unlike its predecessors, which had dual-use capabilities centred more prominently around civilian applications, IRIS2 is the first pan-European space project based on security and strategic objectives, a fact reiterated by its very acronym (Infrastructure for Resilience, Interconnectivity and Security by Satellite). With a proliferated architecture of around 170 satellites at different orbital levels (Shankar, 2024), IRIS2 is an important step in the right direction.
2. Instead of fragmented, we can perhaps elect to see Europe's space sector as decentralised. As Weinzierl (2018) points out, an important factor in the downturn of

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[77] A full list of functions can be found at: https://defence-industry-space.ec.europa.eu/eu-space/iris2-secure-connectivity_en

US governmental space efforts in the late 80s and 90s was its very top-down approach to space exploration, which discouraged commercial involvement in the industry. As the government retreated, reeling from the failures of the Space Shuttle program, there was room for private enterprises to fill the gap. Weinzierl posits that the decision of shifting NASA from its traditional role of overseer of the entire sector to partner was instrumental in the development of the new domestic launching capabilities leading to the massive fall in launching costs we observe in LEO today. The EU can take advantage of its numerous institutional and industrial actors to replicate the massive success of the US' Commercial Orbital Transportation Services program and reach a similar degree of technological innovation by creating an economic environment which fosters innovation and doesn't punish or discourage risk-taking.

3. Physical interdependence is a question of shared vulnerability towards collision cascades amongst all satellites: own (as in, specific to a country or a constellation) proliferation may discourage direct attacks to a specific target, but general proliferation in LEO discourages attacks on the entire orbital area, such that EU assets will be passively more secure as more and more satellites are introduced to LEO.
4. Economic interdependence is a viable and low-cost (if not profitable) strategy to bolster security. The Union does not need to directly increase its physical presence in space if it can increase the dependence on its assets by foreign governments and firms. It helps that each of the three pillars[78] of Union space infrastructure can provide a myriad of commercial services.
5. The EU has taken significant steps in addressing its cybersecurity needs, and although most of its policies are not specifically tailored to space cybersecurity, its assets will nonetheless benefit from it (Jacobs, 2023). The Union has been following a three-pronged approach, addressing resilience of digital systems from attack with its NIS (Network and Information Systems) and CER (Critical Entities Resilience) Directives of 2023. The former provides operators and firms with strict and exacting guidelines for maintaining the security of the Union's digital backbone, with heavy fines for non-compliance, while the latter provides a list of best practices for relevant industry; procurement of critical components with the 2023 Chips Act and its deterrence policy with the Cyber Diplomacy Toolbox, which permits sanctions against malicious state or private actors. However, as Jacobs (ibid.) correctly points out, the legal framework of the Union, which doesn't call for exclusive competences in the realm of

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[78] Galileo, Copernicus and the proposed IRIS2

cybersecurity, as well as the diaphanous attribution issues when it comes to cyberattacks do not allow the EU to fully express its potential in the realm of digital security. Coupled with the limited amount of information available on the cyberspace capabilities of governments with respect to the space sector, I find it difficult to make accurate predictions pertaining to the efficacy of these policies.

5.4 THE THIRD CONSTRAINT: STIGMA, NORM ENTREPRENEURS AND THE BRUSSELS EFFECT

The concept of the European Union as a new kind of political actor which bases its power on normativity, moral suasion and by leading example is a well known and oft explored subject in political science, and has spawned an important body of research analysing this conceptual framing (Moran, 2024). With respect to space, this normative, soft-ish power can potentially be employed with efficacy, as some space powers[79] seem to recognise the possible stabilising - and therefore securitising - role that international norms play in the space domain; the EU may be uniquely positioned to take advantage of such a development, due to the fact that its lack of offensive capabilities may portray its calls for a more ordered and peace oriented space domain as genuine, rather than a screen to cover increasing militarisation. While the Union has tried and failed to put forward a legal and normative framework for good conduct in space[80], it does not mean that the original attempts did not bear some fruits, or that subsequent attempts should be ruled out as ineffective. As we've mentioned in chapter 3, a key source for international norms is iteration, continued repetition of consistent behaviour in the international arena; in the realm of norms, persistence can pay off. It is in the best interests of the EU to present itself as a responsible space power and to engage in norm entrepreneurship as much as possible, with a wide variety of actors beyond the governmental level.

The capability of the EU to exert a profound influence on foreign regulatory efforts through its own, a phenomenon referred to as the Brussels effect, is often presented as one of the

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[79] The US and France openly state the role strategic social construction as we've defined it in chapter 3 play a relevant role in their space security policy (Flanagan et al., 2023). While a similar commitment is not outwardly present in what we know of Russian and Chinese space policy, it is telling that they jointly presented international proposals for a legal disarmament of space at different points in time in the past 20 years.

[80] Specifically, the failed International Code of Conduct for Outer Space activities of 2014 (for a brief treatment, consult Johnson, 2024)

Union’s greatest strengths (Bradford, 2012). I’m unsure as to whether such an advantage could be translated effectively in the space domain, for two key reasons: the EU through the Commission has limited experience and know-how pertaining to the space domain (Küsters, Nolen & Stockebrandt, 2024), and regulatory capacity is a key determinant for the Brussels effect according to Bradford (2012); a significant portion of space regulatory efforts, due to the inherent need for coordination to avoid collisions and mutual transmission interference, is done at the intergovernmental or international level. In other words, the niche is already filled and there’s little room for the EU to elbow its way in through its regulatory prowess[81]. What the Union can do is use its significant soft power to empower these fora for regulation as much as possible, enhancing rapports between scientists, engineers, physicists and other space related professionals along the way; as we’ve mentioned in chapter 3, scientific internationalism can provide a powerful aid to the cause of space pacifism.

5.5 A PRAGMATIC EUROPEAN SPACE DEFENSE: GEOGRAPHIC THRESHOLDS AND POLICY PROPOSALS

Having defined how our constraints interact with a pacifist-by-design European Union, we analyse the insights we’ve gained in the preceding sections can be grounded in the physical reality of European space infrastructure by turning once again to our concept of geographical thresholds. Considering the limited amount of space assets available to the Union, we can be more granular with our analysis by engaging directly with the three pillars of EU space infrastructure - Galileo, Copernicus and IRIS2- when considering the EU’s defensive needs and possible policy recommendations.

Starting with LEO, we’ve established in this chapter that considerations of physical (and to a lesser degree economic) interdependence dominate security considerations. After the implementation of IRIS2, the EU will have two of its pillars -with the second being

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[81] One additional argument that could be put forward is that the EU is most successful in its regulatory spillovers when regulating highly elastic consumer markets (Bradford, 2012). While the launcher market in itself seems to be fairly elastic with respect to price, I’m not sure we could consider it akin to a regular consumer market, and the confusion is only compounded by considering other economic segments of the space sector; research on the pricing dynamics and other related economic factors would be a welcome help in assessing the EU’s possible regulatory reach.

Copernicus- at these altitudes. It is therefore critical to secure both and to do so in a way that is tailored to the specific set of security challenges that satellites face in LEO. There isn't much to say for IRIS2, as a single satellite has yet to launch and its chosen architecture follows what we've established as the best method to shore up resilience in low Earth orbit: a highly dispersed constellation numbering in the hundreds. Copernicus, however, doesn't share in IRIS2' secure position, as it is organised in discrete Sentinel missions composed each of a singular set of twin satellites, with each mission providing a different and non-interchangeable service. The lack of redundant capabilities and straightforward, concentrated architecture is par of the course for imaging satellites, which tendentially operate alone and not in constellations (Li et al., 2022). As the schedule for all Sentinel missions has already been drawn, adjustments to the architecture are not possible (or technically feasible) leaving the Copernicus imaging segment vulnerable to interference.

A possible risk mitigation strategy could take advantage of the capabilities of the Sentinel satellites themselves, which are able to provide accurate imaging, as well as significant amounts of environmental and climatic data to users, which can be used for climate mitigation policies to great effect. As the effects of climate change become more and more severe, environmental and imaging data will become a valuable commodity in high demand. Exploiting this demand by enmeshing the security needs of the Union with those of climate affected countries dependent on satellite data could prove to be an effective strategy to reduce the chances of attack.

As for MEO, Galileo, the crown jewel of the Union's space infrastructure can be found at these altitudes, and it is here that the inability of the EU to field any form of serious physical deterrence shows itself as the glaring weakness that it is. Since orbits at these altitudes are spread over a large area and the number of satellites is limited the risk of a collision or a Kessler syndrome scenario are fairly low, such that physical interdependence is not a concern. Similarly, the lack of possible retaliation removes the concern that an attack on an enemy's GNSS constellation will inevitably lead to the destruction of one's own. What avenues are left to the apparently toothless European Union? The first solution would be for at least a member state to credibly commit to the defense of Galileo, with France as the most likely candidate due to its relatively advanced (if limited) counter space capabilities. Another answer could be found in pursuing an international normative policy, based on scientific internationalism, pacifism and the strengthening of international fora, but such an effort can’t wholly substitute for the deterring power of arms.

CHAPTER 6 – CONCLUSIONS AND PROPOSALS

> *“[..] If you look at it, you see a dot. That's here. That's home. That's us. On it, everyone you ever heard of, every human being who ever lived, lived out their lives. The aggregate of all our joys and sufferings, thousands of confident religions, ideologies and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilizations, every king and peasant, every young couple in love, every hopeful child, every mother and father, every inventor and explorer, every teacher of morals, every corrupt politician, every superstar, every supreme leader, every saint and sinner in the history of our species, lived there on a mote of dust, suspended in a sunbeam.”*
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> ***Sagan, C., Pale Blue Dot: A Vision of the Human Future in Space, Ballantine, 1997, p. 12***

It is no secret that after the fall of the Soviet Union, the world was swept up in a phase of utopian, pacifist euphoria. Gone - or so it seemed - was the spectre of nuclear annihilation, of ideological wars between capitalism and socialism turned to the battlefield. Liberalism had won the great battle of our times, and for all times to come (Fukuyama, 1992), and what awaited mankind was the inexorable and systematic destruction of barriers, physical, economic and ideological against peace and prosperity. It is now clear that these hopes have been hopelessly dashed, with international society finding itself increasingly fragmented and vulnerable to the new epoch-setting threat of climate change, the resurgence of far-right ideologies and the increasingly tense relationship between the world’s major powers. International society is becoming more and more fragmented, and moving towards a multipolar configuration of powers (Peters, 2023). With the emergence of new conflictual rifts between the global North and the global South, between a rising East and an increasingly flustered West, and with the re-surfacing of old political cleavages of religious and ethnic origins that threaten the stability of political communities worldwide, conflict and aggression are once again returning to the fore as tools for international political change and influence.

Concurrently with the unfolding of these troubling developments, space has become a constant presence in the everyday life of billions of people, with the tendrils of its infrastructure spanning economies and societies across borders, connecting the world as well as offering unprecedented amounts of strategic and tactical advantages to any country with the inclination and sufficient means access to widespread surveillance, navigation, munitions guidance and more. The increasing securitisation of space, as well documented as it is, brings with it the possibility of conflict and aggression, with countries all over the world increasingly concerned that the final sanctuary for peaceful cooperation and advancement might be embroiled in conflict. It is with this very possibility that our thesis has tried to engage, as we posed ourselves a deceptively complex research question: if space is so pivotal to the economic well being and the strategic needs of so many countries, and if satellites are so vulnerable, why haven't we witnessed a significant rise in space hostilities?

To answer this question, we endeavoured to create a qualitative model that could capture the underlying trends present in space power politics and order them in such a way that tentative predictions could be made. We first engaged with the question of what constraints were placed upon space warfare, and we settled on three defining elements: the technical specifications of ASAT systems, which allowed for both widespread and relatively cheap destruction at the cost of severe environmental damage, and finely tuned interference which could be tailored to avoid any lasting damage; the physical characteristics of space, which create heterogeneous areas of interest in the form of orbital levels, and that of spacecraft, which has seen the rise of the constellation as the leading architecture for space assets; lastly, we proposed the existence of a normative prohibition on the more destructive forms of space warfare which stays the hand of countries when strategic and environmental concerns aren't enough. These constraints were used to construct a reference frame for space warfare, and we posited that such a frame was the baseline against which all actions and developments in the space domain are judged by the relevant actors. This frame became one of four analytical elements underlying our qualitative model, together with the decisional variables that countries use when deciding whether to interfere with space assets or not (and to what extent), the geographical thresholds that decision-makers use to conceptualise space on a physical level and the political actors themselves, which we've categorised based on their level of available space power.

Assembling our model provided both an answer to our question as well as the capacity to predict in broad strokes the future trends of space power politics. We posit that the reason why aggression is still a hypothetical in space is due to the deeply interconnected nature of space assets, both in orbit and on the ground, such that a strike against a satellite entails risks beyond “simple” retaliation. The creation of orbital debris can blow back on the attacker both in physical terms as well as in reputational terms, and the state of play for ASAT systems is such that the most destructive weapons of the bunch are too effective and easily manufactured to be ignored, warping the human space environment by making it more resilient, more interconnected and therefore more vulnerable to the logic of debris creation and to the risk of a Kessler syndrome scenario. This process, coupled with the tendency of political actors to think of space as a pacific realm by “default” and with the limited options available for interference beyond low Earth orbit tells us that space warfare, judged by many to be more likely than ever, actually faces severe technological, strategic, geographical and ideational constraints that discourage aggression by most countries. The one exception we’ve found is the rogue state, which - due to its economic and normative isolation from international society - is less beholden to these constraints and can therefore entertain the idea of attacking or interfering with a space asset in a destructive manner more seriously. Lastly, we’ve considered the European Union as the subject of a brief case study, outlining how its sui generis nature can work both against it and to its advantage, and that leveraging the EU’s credibility as a wholly pacific actor is the best way to ensure the resilience of its space assets.

We are then left with the question of what are some possible future developments we can extract from our analysis? Our model suggest three key developments:

1. The increasing rate of yearly launches, the commercial success - and resilience - of constellations, the growth of the space economy and the new lunar Space Race between the US, EU, China and Russia, will strengthen the constraints on physical aggression, further reducing the chances of sudden aggression.
2. The need to address in some capacity the capabilities and advantages offered by space assets will lead to a massive increase in both the use of jamming and spoofing, even beyond the battlefield[82], as well as cyber attacks on commercial satellites. This trend will probably not follow a linear trajectory, and it may plateau at some point if China

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[82] A worrying trend can be currently observed in the Baltic Sea, where Russian jamming against its neighbours is creating tensions in the area (Shevchenko, 2024)

reaches fleet parity with the US, to discourage an all-out cyber war between the two superpowers.

3. States like North Korea and Iran will probably start to threaten the use of destructive weapons against Western-aligned space assets. It is unlikely that these attacks could involve more than a handful of satellites of secondary relevance; it is more plausible that the threat of such an aggression will be used to avoid foreign intervention in regional crises or on domestic soil. In any case, unless a major conflict breaks out between the two space superpowers, the most likely perpetrator of physical aggression in orbit in the near future will be a rogue state.
4. It is unlikely that we will see space power on space power physical aggression in LEO in our lifetimes, barring radical technological developments to prevent debris formation after impact. However, as laser weaponisation improves with time and the technology becomes more accessible, we may observe an uptick of dazzling or even blinding. A new norm allowing for the legal dazzling of satellites transiting above off-limits areas of the surface may be pushed by major powers like China, the US or Russia, but I would think it unlikely for it to grain traction due to its lack of practicality and the gradual entry of more countries to the club of space-faring nations. Destructive, but non-debris generating cyberweapons specifically for constellations could be developed (or already be in development), tailored to “brick” the entire constellation without the shedding of the debris. The deployment of such a cyberweapon would probably be reserved for open conflict among major space powers. Regular cyberweapons of the non-destructive variety will be widespread as constellations are particularly vulnerable to them: this could cause a shift in the long term towards a similarly diffuse architecture, but designed with more resilience in mind.

Some points still need to be raised in regards to what can be done to improve our model, and for suggestions for future research on the subject. Regarding our model, I believe additional work should be done on the subject of our proposed space warfare stigma. A more ordered research approach, with in-depth historical and archival research, coupled with a rigorous analysis of past and present declarations and policies of key space powers, as well as fictional media, could provide additional insight into the nature of space norms beyond the legal variety.

As for future research, an interesting avenue could be the weaponisation/militarisation dichotomy we've touched upon in chapter three, and whether technological advancements or political developments could upset this delicate balance. After all, the dichotomy is held aloft by both the dual use capabilities of most space assets as well as the underlying technical difficulty of holding weapons in orbit we've mentioned in chapter 1: if such difficulties were removed by new scientific developments, or with the establishment of self-sufficient permanent outposts beyond Earth's atmosphere, this delicate balance that favours the use of space for ancillary military applications rather than basing weapons in space could be undone. A possible economic and political shift of space power politics from Earth orbit to the Moon, brought about by the new lunar Space Race between the US and the EU vis a vis China and Russia could similarly prove detrimental to maintaining space weapon-free, with the relative (at least in space terms) vicinity of US and Chinese/Russian personnel on our natural satellite constituting a possible source of future armed conflict.

In these uncertain times the powerful words of Carl Sagan resonate more clearly than ever: this planet, our single abode in a vast cosmos, is all that we have, and few endeavours have showcased this fragility and dependence more than space exploration, and as hostilities rise and widespread disorder and conflict loom ever closer, the one place left untouched by conflict and violence is poised to be thrown into the violent grinder of human history. While the objective of this thesis wasn't to reassure but rather to elucidate, it is my hope that our qualitative treatment of space warfare has convinced the reader of the powerful political and technological constraints present in space politics, which acts as a powerful deterrent against destructive aggression. However, this isn't to imply that the conditions that are now discouraging countries from engaging in orbital warfare will exist forever, or will be as potent as they are now. Politics, like all human institutions, is the province of change, and no status quo can be maintained forever, especially in a dynamic and endlessly evolving domain like space. One can only hope that the future that awaits us all among the stars is one of peace and cooperation, rather than conflict.

Appendix 1. Basic terminology of orbital mechanics

This appendix will clarify the most important physical characteristics of orbits insofar as they are relevant to our analysis, and allow readers to have a constant place to reference the more technical terminology I'll be using in the rest of the thesis; of course, no prior knowledge of physics or astrodynamics is required to understand the following paragraphs.

Orbits are, simply put, the curved trajectory undertaken by an object around another object or a point in space. While orbits don't necessarily have to be a closed, stable loop, man-made satellites are always placed in such orbits and so we will limit our explanation to repeating orbits, like those of a communication satellite around the Earth or of our very own planet around the Sun. Orbits can be effectively approximated by the Newtonian laws of motion, but in extreme situations (such as orbits close to massive bodies like the Sun), only Einstein's general relativity is able to calculate precise orbital motions. However, for the purposes of this appendix, a comprehensive explanation is wholly unnecessary. What we are interested in is the basic principles of orbital motion as described originally by Kepler and Copernicus. These principles are still applicable today and have a profound influence on the strategic value of space assets and the orbits they occupy. In order:

3. **Orbits are measured by speed**. Orbits are indifferent to mass: a grain of sand and an asteroid will need to achieve the same speed if they want to orbit at the same distance from the Earth; or, put differently, all objects moving at the same speed will occupy the same orbit. A consequence of this is that **the closer a satellite is to its orbited body, the faster it will have to go to maintain that orbit and vice versa**. This fact may seem irrelevant for our analysis, but as we shall see in chapter 2, it is anything but. The average speed required to maintain a low-Earth orbit is around 7,8 km/s, or 28000 km/h. This required speed will go down as we move further and further away from the planet.
4. **Orbits require energy to start but not to maintain (kind of)**. A plane needs constant thrust to remain afloat, due to the friction created by the air and gravity. No such thing happens in space: once the speed needed to maintain an orbit is reached, the

satellite will remain in orbit with no additional thrust needed[83]. However, most satellites are placed in low-Earth orbits (LEO), where the Earth’s atmosphere is still present, albeit at much lower concentration compared to the surface; this results in a very slow but constant slowing down effect on the satellite due to friction (a phenomenon known as **atmospheric drag**), requiring minor adjustments every so often. This point is the main reason why it is inadvisable to think of the space domain as an extension of the air domain. The need for constant thrust to remain afloat puts important design and strategic constraints on aircraft, since it needs to refuel to remain operational. Many satellites, on the other hand, will continue to orbit as long as nothing physically intercepts them.

5. **Orbits must pass through the same plane as the centre of the orbited body[84]**. Orbits can’t have a circumference that is smaller than the circumference of the body they are orbiting. This creates problems for polar countries such as Russia, which may be interested in maintaining surveillance over polar regions, which are ill-served by regular orbits. The solution is to use highly eccentric polar orbits, commonly referred to as *Molniya* orbits.

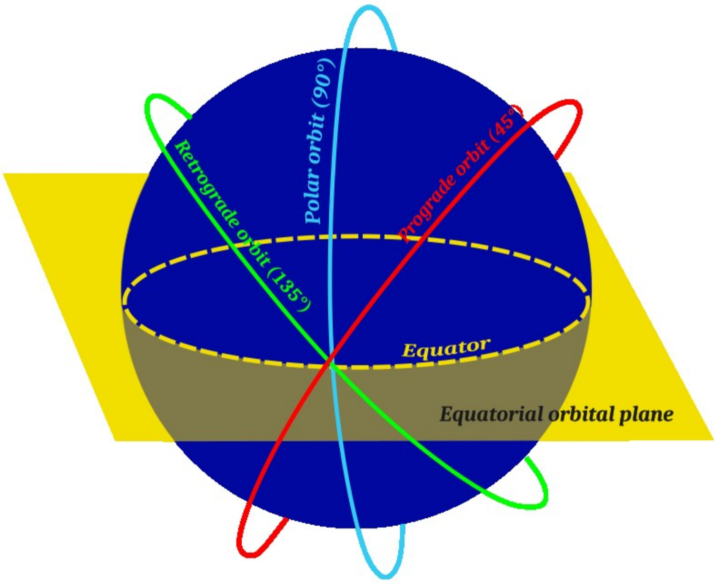

Figure 7. Basic orbital dynamics terminology visualised

Let’s finish our appendix with a simple glossary of terms the reader will be faced with in the main body of the chapter.

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[83] The reasons for this are twofold: for starters, there is no air, so friction can’t slow down the satellite. The second is that the satellite is technically in free-fall towards our planet. Contrary to common parlance surrounding space, orbits aren’t a zero-gravity environment: the gravitational pull of Earth is still present and it is actively pulling the satellite towards the surface. However, the Earth is not flat, but spherical, so its surface curves away from the satellite, like a rug that is being constantly pulled away. The satellite is going so fast that the speed at which the surface of Earth slips away from it is bigger than the speed at which it’s falling towards the surface. In simpler terms, satellites are eternally falling towards the surface but never quite reach it.

[84] Picture a satellite orbiting Earth in a circular motion; then imagine the orbit as laying on a uniform plane that contains it entirely. That uniform plane is called the “orbital plane”, and it’s the imaginary geometric surface upon which our orbit is superimposed. As per our third rule, the orbital plane must always pass through the centre of the orbited object.

1. The **altitude** of an orbit is the distance between it and the surface of the Earth. Excluding specific cases, orbits are modelled as ellipses, not perfect circles, so the altitude varies at different points of the orbit. The highest point in altitude of an orbit is called the **apogee**, while the lowest is called the **perigee**.
2. The **eccentricity** of an orbit is a number ranging from 1 to 0 which tells us how closely the orbit in question matches a perfect circle. An eccentricity of 0 means that our orbit is perfectly circular, while an eccentricity above 0 indicates that our orbit is more elliptical, with 1 being an open, parabolic orbit.
3. The **orbital period** is the amount of times it takes for a satellite to do a full revolution around the Earth. Shorter (i.e. lower) orbits have shorter periods and vice versa.
4. The **inclination** is the angle that the orbit has with the equatorial plane of Earth. An angle of 0° means that the satellite orbits our planet around the equator; an angle of 90° means that the satellite is perpendicular to the equator and passes above both poles. An orbit with an inclination between 0° and 90° is called **prograde**, and an orbit with an inclination between 90° and 180° is called **retrograde**. Retrograde satellites are rare due to the additional fuel requirement required to reach orbit (as the launcher is moving **against** Earth's rotation rather than with it), but they have seen use: an example is the Ofek series of observation satellites used by Israel. The fact that they move in the opposite direction to our planetary surface means that the relative velocity of the satellites is higher, allowing for more passes per day above Israel and the surrounding countries.

APPENDIX 2. AN AGENT-BASED MODEL FOR SPACE WARFARE[85]

The following appendix contains a short report detailing a computerised agent-based game theoretical model based on the analytical framework developed in this thesis. The purpose of this model is to introduce the concepts of agent-based modeling and game theory to space power politics, with the hope to glean some insights into the realm of orbital warfare by observing the emerging strategies of virtual countries over thousands of simulations with different parameters, including tendency to cooperate, the relative cost of ASAT capabilities vis a vis

. As the toy model is still being refined at the time of writing and does not yet include every analytical element we've presented in this thesis, this synopsis represents more of an example of a hopefully successful attempt at a confluence between qualitative and quantitative research efforts rather than mature academic output, hence its placement in an appendix to this thesis for the interested reader.

The model is structured into the following discrete steps:

1. The **initialisation phase**, in which a number *N* of agents is generated, given a random endowment of material resources and placed in either a circular network structure, in which every agent has an identical number of neighbours, or a random network structure with a stochastic distribution of agents and connections. The agents will then decide how to divide their endowment between into two different accounts: **civilian**, which will increase the number of satellites available to the agent, and **military**, with which the agent shores up its defensive and offensive capabilities but does not produce additional satellites. Moreover, civilian accounts are further split between two specific strategies: producing satellites on their own or doing so in collaboration with their neighbours. The amount of endowment spent as a sum total is always equal to 1 in fractional terms, such that a decrease in the military account will cause a proportional

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[85] This model has been developed jointly by the author of this thesis and doctoral candidate Ren Manfredi of the IMT School for Advanced Studies in Lucca (ren.manfredi@imtlucca.it), whom I thank profusely for his patience and willingness to embark on this novel research venture, and without whom this appendix would not have been possible.

increase in the civilian account. Endowments are assigned using a skew-normal distribution, the skewness of which can be controlled through a specific parameter a. If $a = 0$, then the distribution of wealth among actors will follow a regular gaussian distribution.

2. In the **production stage** agents will produce either satellites or counter space capabilities according to their allocations to their military or civilian accounts. To account for the positive effects of international cooperation on space efforts, an enhancement factor r amplifies the resources pooled together for cooperation with neighbours. Modifying the enhancement factor allows us to model more open -or closed- international societies.
3. After production is completed, agents enter the **strategy update stage**. As the name implies at this step agents re-evaluate their endowment distribution by computing two factors: the agent's **military risk**, which is based on a comparison between the agent's total military strength and that of its neighbours' average and the agent's own dependence on domestic space infrastructure, and its **cooperative success**, which is how much the agent is profiting from its cooperation efforts. Specifically, the agent will first assess its security needs by computing its military risk, which will then determine the new military and civilian accounts: e.g. if agent A computes a decreasing military risk, it will shift resources to the civilian account. After the overall balance between the military and civilian accounts is decided, the agent will settle on how much of its civilian account will be allocated to international cooperation.
4. Lastly, in the **ASAT attack stage** two agents are chosen at random and designated as the attacker and the defender. The probability of attack is then computed based on three factors: own and defender dependence, own and defender military power, own vulnerability to debris blowback and the political cost of a destructive attack i.e. the translation of our space warfare stigma to the ABM. Political cost is based on the fraction of actors that have not yet attacked, meaning that the first attack will be extremely costly, and each subsequent infraction will find its political cost lowered. Each attack will also have attached to it a chance to generate a catastrophic amount of debris: if debris is indeed generated by the attack, the political cost is reset back to default. Retaliation is also possible and similarly computed on the relative military strength of the defender. While the model is still in the refining stages, two key processes of interest have already begun to emerge during testing:

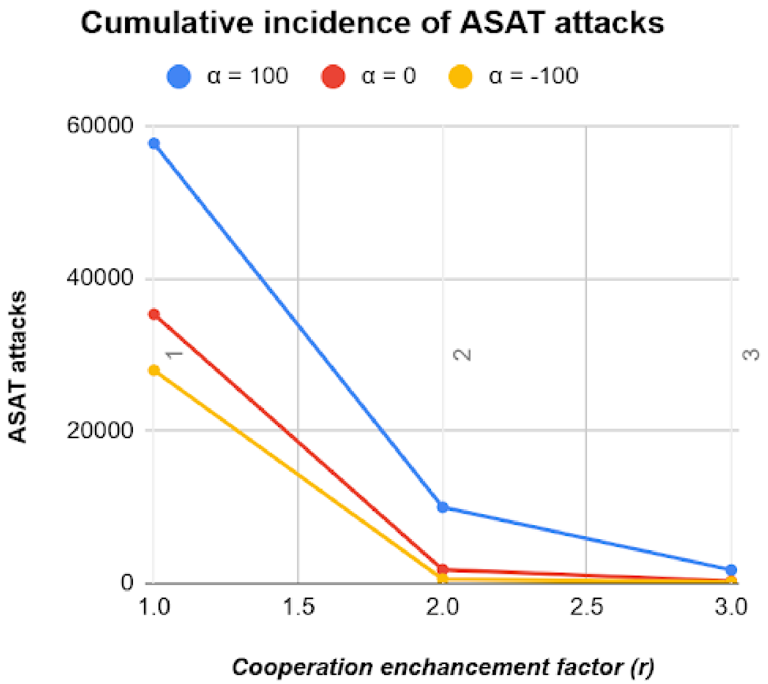

Chart 4: Incidence of ASAT attacks with three difference skew parameters and enhancement factors

The distribution of wealth among countries and the strength of the gains borne from cooperation seem to have an effect on the incidence of ASAT attacks. Specifically, when endowments are either following a normal distribution, or a right-skewed distribution (meaning very few countries have small endowments) the level of attacks decreases with the enhancement factor held constant; conversely, increasing the enhancement factor reduces attacks at every skewness level. The influence of wealth distribution on conflict -specifically internal conflict- has long been an important and fruitful subject of research (Blattman & Miguel, 2010), although the question of what exactly is the causal link between poverty, inequality and conflict hasn't been answered yet (Humphreys, 2003). Analytical work is needed in order to translate the insights of poverty or inequality induced violence research onto the space domain (especially considering that most works on the matter deal with internecine conflicts), but at first glance it seems that our argument that economic interdependence and international cooperation stimy aggression may merit additional consideration.

Militarisation may not correlate directly with aggression. We've already introduced the two processes of militarisation and weaponisation of space in chapter 3, and put forth an argument that while the two processes may appear similar, they are not causally connected as tightly as one might think. Our agent-based model goes one step further by implying that an increase in production of military counter-space capabilities does not correlate with aggression. As can be seen from Chart 2, production of ASAT systems is not affected by the degree to which cooperation is favourable (the enhancement factor *r*), but responds powerfully to the skewness of the endowment distribution. Most importantly, higher levels of ASAT weapons production are associated with left skewness, which is conversely associated with lower attacks and more cooperation. In other words, in our ABM an increase in weaponisation is associated with a decrease in aggression. This shouldn't come as a surprise, as aggressors factor in the military strength when assessing whether to attack or not. If we consider this result in the wider scope of our qualitative model, we can liken it to an increase in the relative weight of the deterrence logic borne from the technical characteristics of ASAT weapons in the decision matrix of the countries; such an increase could imply that the parallels between nuclear and space deterrence may run deep (Mueller, 2003).

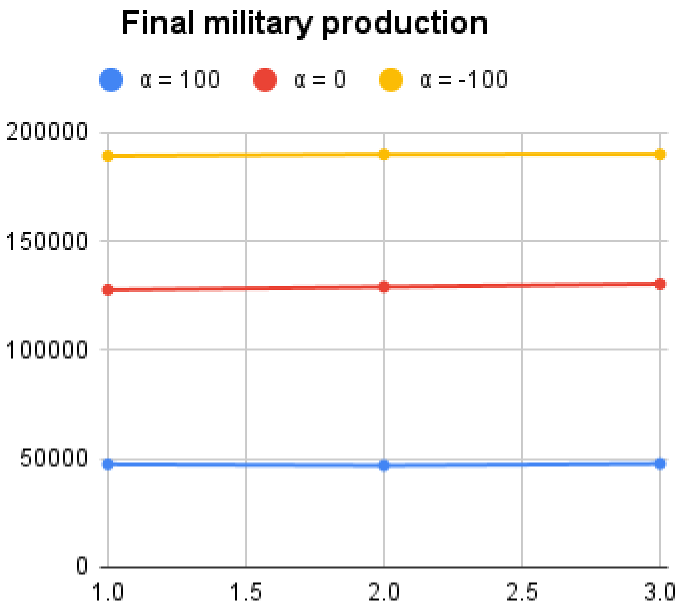

Chart 5: Production levels of kinetic weapons with three difference skew parameters and enhancement factors

To conclude this brief appendix, our still unrefined agent-based model has already allowed us to gain some possible insights into the nature of ASAT warfare, but the work is far from complete, with some parts of the qualitative model presented in this thesis still absent from the ABM, and several scenarios (such as hostile political dyads, highly fragmented cooperative clusters or uniformly endowed agents) still waiting to be tested. Regardless, we hope that this research effort will spark interest in the academic debate on space politics, and we hope to share our structured findings in the near future.

GLOSSARY OF ABBREVIATIONS

- ESA – European Space Agency
- GNSS -Global Navigation Satellite System
- RNSS – Regional Navigation Satellite System
- SSA – Situational System Awareness
- UNOOSA – United Nations Office for Outer Space Affairs
- LEO – Low Earth Orbit
- MEO – Medium Earth Orbit
- GEO – Geosynchronous Orbit
- DEW – Directed Energy Weapon
- EDOM – Ease of Development, Operation and Maintenance
- OST – Outer Space Treaty
- ASAT – Anti-Satellite
- COPUOS – Committe On the Peaceful Uses of Outer Space
- AfSA – African Space Agency
- IRIS - Infrastructure for Resilience, Interconnectivity and Security by Satellite

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