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Space and Crisis Stability

Abstract
Space activities pose a particular risk of sparking or exacerbating terrestrial crises in ways that may be difficult to predict or manage. This is due both to the physical nature of space operations and to space's deep and historic connection to military posture. This paper explores looking at space security through the lens of crisis stability to see if it can help to identify which space activities and strategies are particularly dangerous and to prioritize unilateral and collective approaches to mitigating these problems.

Why crisis stability?

For the foreseeable future, military tensions between the United States, China, and Russia are likely to remain high, as are those between China and India. Even absent intentional confrontation, regional problems, such as those in the Baltics and East and South Asia, have the potential to draw these actors into conflict. Thus, it is imperative to pay attention to any pathways that could lead an actor considering crossing the nuclear threshold, or approaching it very closely.

The United States and Russia continue to retain large nuclear arsenals on high alert[1]. Each are developing new strategic weapons, including hypersonic conventional prompt global strike systems with a suggestion mission of holding ground-based anti-satellite weapons at risk.[2] Russia has declared the existence of novel nuclear delivery systems as a response to US missile defense systems,[3] weapons which complicate the management of crises. China is reportedly considering increasing the size, capacity and alert status of its nuclear weapons delivery systems[4] and is also developing new kinds of strategic weapons. China is also developing hypersonic weapons,[5] and the ingredients for an arms race around these technologies is in place. India continues to increase the sophistication of its strategic posture. And India, China, Russia and the United States have or are pursuing missile defense technologies that are important both in the

[1] According the Status of World Nuclear Forces, by Hans M. Kristensen and Robert S. Norris, nearly 1,800 US, Russian, British, and French weapons are on high alert. https://fas.org/issues/nuclear-weapons/status-world-nuclear-forces/

[2] See, for example, James Acton's 2015 Congressional testimony http://carnegieendowment.org/2015/12/08/prompt-global-strike-american-and-foreign-developments-pub-62212 (get better ref)

[3] Anton Troianovsky, "Putin Claims Russia Has Nuclear Arsenal Capable of Avoiding Missile Defenses." Washington Post. March 1 2018. https://www.washingtonpost.com/world/europe/putin-claims-russia-has-nuclear-arsenal-capable-of-avoiding-missile-defenses/2018/03/01/d2dcf522-1d3b-11e8-b2d9-08e748f892c0_story.html?utm_term=.495dc8f3c5cc

[4] Gregory Kulacki, China's Military Calls for Putting Its Nuclear Forces on Alert. Union of Concerned Scientists. January 2016. http://www.ucsusa.org/sites/default/files/attach/2016/02/China-Hair-Trigger-full-report.pdf

[5] Ankit Panda, "China's Hypersonic Weapon Ambitions March Ahead." The Diplomat. January 8, 2018.https://thediplomat.com/2018/01/chinas-hypersonic-weapon-ambitions-march-ahead/

nuclear realm but in space issues, since missile defenses present demonstrated or inherent anti-satellite capabilities.

Thus it is critical to ensure that in times of tension, no actor escalates the crisis inadvertently or against their better judgment, and that misperception does not play an important role in the initiation or progress of the crisis. And that hostilities, if initiated, resolve as quickly as possible.

Thomas Schelling's encapsulated an aspect of this idea in his landmark work this way:

> This is the problem of surprise attack. If surprise carries an advantage, it is worth while [sic] to avert it by striking first. Fear that the other may be about to strike in the mistaken belief that we are about to strike gives us a motive for striking, and so justifies the other's motive. But if the gains from even successful surprise are less desired than no war at all, there is no "fundamental" basis for an attack by each side. Nevertheless, it look as though a modest temptation on each side to sneak in the first place — a temptation too small by itself to motivate an attack — might become compounded through a process of interacting expectations, with additional motive for attack being produced by successive cycles of "He thinks we think he thinks we think … he think we think he'll attack; so he thinks we will; so he will; so we must.[6]

This suggests that it is important to make the advantage of surprise attack negligible and the disadvantages as great as possible, to make sure that all actors understand this, and to make sure that actors have as clear an understanding of each other's motivations as possible to avoid miscalculation.

In the last twenty years, space assets have become important not only for strategic missions but also increasingly underpin conventional military force for modern militaries, and especially those with expeditionary forces, such as the United States. They are essential not only for militaries, but are a critical provider of essential civilian, commercial, and scientific services. Not only do satellites perform many more missions than they have in the past, there are many more space-faring nations. While most satellites belong to the United States, Russia, and China, more than sixty countries own satellites or a large stake in one.[7]

At the same time, the technologies that are useful for holding satellites at risk have grown significantly in sophistication and capacity even in the last decade, and have become more widely available. This is particularly problematic because attacks on satellites can create or escalate terrestrial crises in potentially difficult to predict ways. The world is drifting towards a

[6] T.C. Schelling, "The Reciprocal Fear of Surprise Attack," RAND paper P-1342, April 16, 1958, revised May 28, 1958, p. 1.

[7] Around 20% of satellites are military owned, and about half are commercial satellites. The US, Russia, and China claim around 2/3 of satellites collectively. Union of Concerned Scientists Satellite Database http://ucsusa.org/satellites.

space regime that faces an ever more prevalent and more sophisticated anti-satellite technology and greater numbers and types of targets in space, with very little mutual understanding about how actions in space are perceived.

While space's foundational legal document, the 1967 Outer Space Treaty, sets out the principles by which space is used and provides a number of useful, most recognize that more is needed to secure lasting peace on earth and the long-term health of the space environment. Different stakeholders are tackling space security issues from different angles. Under the aegis of the United Nations Conference on Disarmament's (UNCD) Prevention of an Arms Race in Space (PAROS) agenda item, Russia and China have invested in the Treaty for the Prevention of the Placement of Weapons in Outer Space, a comprehensive ban on the deployment of space-based weapons and on threats of any kind against satellites.[8] The United States has stated that it sees little value in this treaty, but has not proposed revisions that would make it more acceptable nor suggested its own preferred legally-binding treaty. And the UNCD has struggled to extricate itself from a deadlock that has kept it from moving forward on discussions on this (and all other) topics. Others have suggested a ban on destructive anti-satellite weapons development and testing,[9] and limits on exoatmospheric missile defense tests.[10] These efforts have not yet produced any appreciable progress.

Others prefer the approach of starting with confidence building and transparency measures that are politically binding rather than legally binding. The European Union moved forward a Code of Conduct for Outer Space Activities,[11] which would set out rules of the road for space, creating transparency and building confidence. It did not address directly core security issues, and the gestures it made in this direction (the requirement by the United States that it include a specific reference to the right of self-defense) created disagreements serious enough to not be easily addressed in this format. The process hit a wall in 2015. A United Nations Group of Governmental Experts, convened to consider TCBMs for space, produced a consensus document,[12] though for a number of reasons, little progress has been made on implementing them.[13]

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[8] Foundational documents and drafts of the draft treaty texts and US responses are available at the United Nations Conference on Disarmament archive of documents. https://www.unog.ch/80256EE600585943/(httpPages)/D4C4FE00A7302FB2C12575E4002DED85?OpenDocument

[9] Laura Grego "A Ban on Destructive Antisatellite Weapons: Useful and Feasible." Celebrating the Space Age: 50 Years of Space Technology, 40 Years of the Outer Space Treaty— Conference Report 2–3 April 2007, Geneva, UNIDIR, 2007 https://www.peacepalacelibrary.nl/ebooks/files/UNIDIR_pdf-art2679.pdf

[10] Mark A. Gubrud (2011) Chinese and US Kinetic Energy Space Weapons and Arms Control. Asian Perspective: October-December 2011, Vol. 35, No. 4, pp. 617-641.

[11] https://eeas.europa.eu/headquarters/headquarters-homepage/8466/security-and-sustainability-outer-space_en

[12] https://www.stimson.org/sites/default/files/file-attachments/GGE_July_2013_1.pdf

[13] "Implementing the GGE: Challenges for Space Security Diplomacy" Remarks by Paul Meyer to UNIDIR Conference Sustaining the Momentum: the Current Status of Space Security, April 28-29, 2016, Geneva, Switzerlandhttp://www.unidir.ch/files/conferences/pdfs/implementing-the-gge-challenges-for-space-security-diplomacy-en-1-1130.pdf

Perhaps the greatest progress in creating new guidelines has come under the aegis of protecting the long-term sustainability of space. (While the long-term sustainability of space does imply that core security questions are solved enough to not threaten the space environment, work on this topic does not take the issue head-on.) The United Nations Committee on the Peaceful Uses of Outer Space has drafted a set of such guidelines which will be referred to the General Assembly in 2018.[14]

For its part, the United States, currently the most heavily invested in space in sheer capacity and in posture, is investing significant intellectual energy in creating a deterrence strategy to protect its military interests in space. While this is closely related to crisis stability, this work is distinctly from a US point of view.

Each of these approaches have something distinct to offer. The aim of this paper, however, is to look at the issue differently and to use crisis stability (rather than, e.g., preventing an arms race, preserving the space environment) as an organizing principle or lens to help identify which facets of space activities are particularly dangerous, and to prioritize the existing initiatives, as well as to offer other unilateral and collaborative actions that can help reduce the pathways to confrontation between nuclear powers.

Why space is a particular problem for crisis stability

For a number of reasons, space poses particular challenges in preventing a crisis from starting or from being managed well. Some of these are to do with the physical nature of space, such as the short timelines and difficulty of attribution inherent in space operations. Some are due to the way space is used, such as the entanglement of strategic and tactical missions and the prevalence of dual-use technologies. Some are due to the history of space, such the absence of a shared understanding of appropriate behaviors and consequences, and a dearth of stabilizing personal and institutional relationships. While some of these have terrestrial equivalents, taken together, they present a special challenge.

The vulnerability of satellites and first strike incentives

Satellites are inherently fragile and difficult to protect; in the language of strategic planners, space is an “offense-dominant” regime. This can lead to a number of pressures to strike first that don’t exist for other, better-protected domains. Satellites travel on predictable orbits, and many pass repeatedly over all of the earth’s nations. Low-earth orbiting satellites are reachable by missiles much less capable than those needed to launch satellites into orbit, as well as by directed energy which can interfere with sensors or with communications channels. Because launch mass

[14] http://www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities.html

is at a premium, satellite armor is impractical. Maneuvers on orbit need costly amounts of fuel, which has to be brought along on launch, limiting satellites' ability to move away from threats. And so, these very valuable satellites are also inherently vulnerable and may present as attractive targets.

Thus, an actor with substantial dependence on space has an incentive to strike first if hostilities look probable, to ensure these valuable assets are not lost. Even if both (or all) sides in a conflict prefer not to engage in war, this weakness may provide an incentive to approach it closely anyway.

A RAND Corporation monograph commissioned by the Air Force[15] described the issue this way:

> First-strike stability is a concept that Glenn Kent and David Thaler developed in 1989 to examine the structural dynamics of mutual deterrence between two or more nuclear states.[16] It is similar to crisis stability, which Charles Glaser described as "a measure of the countries' incentives not to preempt in a crisis, that is, not to attack first in order to beat the attack of the enemy,"[17] except that it does not delve into the psychological factors present in specific crises. Rather, first strike stability focuses on each side's force posture and the balance of capabilities and vulnerabilities that could make a crisis unstable should a confrontation occur.

For example, in the case of the United States, the fact that conventional weapons are so heavily dependent on vulnerable satellites may create incentives for the US to strike first terrestrially in the lead up to a confrontation, before its space-derived advantages are eroded by anti-satellite attacks.[18] Indeed, any actor for which satellites or space-based weapons are an important part of its military posture, whether for support missions or on-orbit weapons, will feel "use it or lose it" pressure because of the inherent vulnerability of satellites.

Short timelines and difficulty of attribution

The compressed timelines characteristic of crises combine with these "use it or lose it" pressures to shrink timelines. This dynamic couples dangerously with the inherent difficulty of determining the causes of satellite degradation, whether malicious or from natural causes, in a timely way.

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[15] Forrest E. Morgan, "Deterrence and First Strike Stability in Space," RAND, 2010.
[16] Glenn A. Kent and David E. Thaler, First-Strike Stability: A Method for Evaluating Strategic Forces, Santa Monica, Calif.: RAND Corporation, R-3765-AF, 1989.
[17] Charles L. Glaser, Analyzing Strategic Nuclear Policy, Princeton, N.J.: Princeton University Press, 1990, p. 45.
[18] James Finch, "Bringing Space Crisis Stability Down to Earth." Joint Forces Quarterly. Issue 76, Q1 2015. http://ndupress.ndu.edu/JFQ/Joint-Force-Quarterly-76/Article/577582/bringing-space-crisis-stability-down-to-earth/

Space is a difficult environment in which to operate. Satellites orbit amidst increasing amounts of debris. A collision with a debris object the size of a marble could be catastrophic for a satellite, but objects of that size cannot be reliably tracked. So a failure due to a collision with a small piece of untracked debris may be left open to other interpretations. Satellite electronics are also subject to high levels of damaging radiation. Because of their remoteness, satellites as a rule cannot be repaired or maintained. While on-board diagnostics and space surveillance can help the user understand what went wrong, it is difficult to have a complete picture on short timescales. Satellite failure on-orbit is a regular occurrence[19] (indeed, many satellites are kept in service long past their intended lifetimes).

In the past, when fewer actors had access to satellite-disrupting technologies, satellite failures were usually ascribed to "natural" causes. But increasingly, even during times of peace operators may assume malicious intent. More to the point, in a crisis when the costs of inaction may be perceived to be costly, there is an incentive to choose the worst-case interpretation of events even if the information is incomplete or inconclusive.

Entanglement of strategic and tactical missions

During the Cold War, nuclear and conventional arms were well separated, and escalation pathways were relatively clear. While space-based assets performed critical strategic missions, including early warning of ballistic missile launch and secure communications in a crisis, there was a relatively clear sense that these targets were off limits, as attacks could undermine nuclear deterrence. In the Strategic Arms Limitation Treaty, the US and Soviet Union pledged not to interfere with each other's "national technical means" of verifying compliance with the agreement, yet another recognition that attacking strategically important satellites could be destabilizing.[20] There was also restraint in building the hardware that could hold these assets at risk.

However, where the lines between strategic satellite missions and other missions are blurred, these norms can be weakened. For example, the satellites that provide early warning of ballistic missile launch are associated with nuclear deterrent posture, but also are critical sensors for missile defenses. Strategic surveillance and missile warning satellites also support efforts to locate and destroy mobile conventional missile launchers. Interfering with an early warning sensor satellite might be intended to dissuade an adversary from using nuclear weapons first by degrading their missile defenses and thus hindering their first-strike posture. However, for a state that uses early warning satellites to enable a "hair trigger" or launch-on-attack posture, the interference with such a satellite might instead be interpreted as a precursor to a nuclear attack. It may accelerate the use of nuclear weapons rather than inhibit it.

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[19] cite
[20] The text of the SALT treaty: http://www.nti.org/media/pdfs/aptsaltI.pdf?_=1316712383

Misperception and dual-use technologies

Some space technologies and activities can be used both for relatively benign purposes but also for hostile ones. It may be difficult for an actor to understand the intent behind the development, testing, use, and stockpiling of these technologies, and see threats where there are none. (Or miss a threat until it is too late.) This may start a cycle of action and reaction based on misperception.

For example, relatively low-mass satellites can now maneuver autonomously and closely approach other satellites without their cooperation; this may be for peaceful purposes such as satellite maintenance or the building of complex space structures, or for more controversial reasons such as intelligence-gathering or anti-satellite attacks.

Ground-based lasers can be used to dazzle the sensors of an adversary's remote sensing satellites, and with sufficient power, they may damage those sensors. The power needed to dazzle a satellite is low, achievable with commercially available lasers coupled to a mirror which can track the satellite. Laser ranging networks use low-powered lasers to track satellites and to monitor precisely the Earth's shape and gravitational field, and use similar technologies.[21] Higher-powered lasers coupled with satellite-tracking optics have fewer legitimate uses.

Because midcourse missile defense systems are intended to destroy long-range ballistic missile warheads, which travel at speeds and altitudes comparable to those of satellites, such defense systems also have inherent ASAT capabilities. In fact, while the technologies being developed for long-range missile defenses might not prove very effective against ballistic missiles—for example, because of the countermeasure problems associated with midcourse missile defense—they could be far more effective against satellites. This capacity is not just theoretical. In 2007, China demonstrated a direct-ascent anti-satellite capability which could be used both in an ASAT and missile defense role, and in 2009, the United States used a ship-based missile defense interceptor to destroy a satellite, as well. US plans indicated a projected inventory of missile defense interceptors with capability to reach all low earth orbiting satellites in the dozens in the 2020s, and in the hundreds by 2030.[22]

Discrimination

The consequences of interfering with a satellite may be vastly different depending on who is affected and how, and whether the satellite represents a legitimate military objective.

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[21] See, for example, the International Laser Ranging Service: https://ilrs.cddis.eosdis.nasa.gov/network/index.html
[22] https://mostlymissiledefense.com/2016/01/25/how-many-sm-3-block-iia-missiles-january-25-2016/

However, it will not always be clear who the owners and operators of a satellite are, and users of a satellite's services may be numerous and not public. Registration of satellites is incomplete[23] and current ownership is not necessarily updated in a readily available repository. The identification of a satellite as military or civilian may be deliberately obscured. Or its value as a military asset may change over time; for example, the share of capacity of a commercial satellite used by military customers may wax and wane. A potential adversary's satellite may have different or additional missions that are more vital to that adversary than an outsider may perceive. An ASAT attack that creates persistent debris could result in significant collateral damage to a wide range of other actors; unlike terrestrial attacks, these consequences are not limited geographically, and could harm other users unpredictably.

In 2015, the Pentagon's annual wargame, or simulated conflict, involving space assets focused on a future regional conflict. The official report out[24] warned that it was hard to keep the conflict contained geographically when using anti-satellite weapons:

> As the wargame unfolded, a regional crisis quickly escalated, partly because of the interconnectedness of a multi-domain fight involving a capable adversary. The wargame participants emphasized the challenges in containing horizontal escalation once space control capabilities are employed to achieve limited national objectives.

Lack of shared understanding of consequences/proportionality

States have fairly similar understandings of the implications of military actions on the ground, in the air, and at sea, built over decades of experience. The United States and the Soviet Union/Russia have built some shared understanding of each other's strategic thinking on nuclear weapons, though this is less true for other states with nuclear weapons. But in the context of nuclear weapons, there is an arguable understanding about the crisis escalation based on the type of weapon (strategic or tactical) and the target (counterforce—against other nuclear targets, or countervalue—against civilian targets).

Because of a lack of experience in hostilities that target space-based capabilities, it is not entirely clear what the proper response to a space activity is and where the escalation thresholds or "red lines" lie. Exacerbating this is the asymmetry in space investments; not all actors will assign the same value to a given target or same escalatory nature to different weapons.

For example, the United States is the country most heavily dependent on military space assets. Its proportionally higher commitment to expeditionary forces make this likely to be true well into

[23] Ram Jakhu, Bhupendra Jasani, and Jonathan McDowell. "Critical Issues related to registration of space objects and transparency of space activities," Acta Astronautica. Vol. 143 February 2018 p 406-420. https://www.sciencedirect.com/science/article/pii/S0094576517315138
[24] Air Force Space Command Public Affairs, "Schriever Wargame Concludes," February 18, 2015. http://www.schriever.af.mil/News/Article-Display/Article/735507/schriever-wargame-concludes/

the future. So while the United States seeks to create a deterrence framework, punishment-based deterrence would not likely target its adversary's space assets. But then there is difficulty finding target on the ground that would be credible but also not unpredictably escalate a crisis. If an American military satellite were attacked but without attendant human casualties ('satellites have no mothers'), retaliation on an adversary's ground-based target is likely to escalate the conflict, perhaps justifying the adversary's subsequent claim to self-defense, even if the initial satellite attack didn't support such a claim.

Little experience in engaging substantively in these issues

Related to this issue is that there is relatively little experience among the major space actors in handling a crisis with the others. The United States and the Soviet Union, then Russia, have had a long history of strategic discussions and negotiations. This built up a shared understanding of each other's point of view, developed relationships between those conducting those discussions, and created bureaucracies and expertise to support those discussions. This experience and these relationships are important to interpreting events and to resolving disputes before they turn into a crisis, and to managing one once it begins. There is nothing like this level of engagement around space issues between these two states, and much less between the US and China.

One of the participants in a 2010 US space war game, a diplomatic veteran, imagined[25] how things would play out if one or more militarily important US satellites failed amidst a crisis with an adversary known to have sophisticated offensive cyber and space capabilities:

> The good news is that there has never been a destructive conflict waged in either the space or cyber domains. The bad news is that no one around the situation room table can cite any history from previous wars, or common bilateral understandings with the adversary, relating to space and cyber conflict as a guide to what the incoming reports mean, and what may or may not happen next.
>
> This is the big difference between the space-cyber domains, and the nuclear domain. There is, in this future scenario, no credible basis for anyone around the president to attribute restraint to the adversary, no track record from which to interpret the actions by the adversary. There is no crisis management history: the president has no bilateral understandings or guidelines from past diplomatic discussions, and no operational protocols from previous incidents where space and cyber moves and counter-moves created precedents. Perhaps the adversary intended to make a point with one series of limited attacks, and hoped for talks with Washington and a compromise; but for all

[25] Ambassador Lincoln P. Bloomfield, Jr. "National Security Fundamentals in the Space and Cyber Domains," High Frontier, Volume 7, Number 1. November 2010.

> the president knows, sitting in the situation room, the hostile actions taken against America's space assets and information systems are nothing less than early stages of an all-out assault on US interests.

Where to start? How to prioritize efforts

Using this lens, what does this say about where efforts around space security should be focused?

Start a substantive, high-level arms control discussion

Starting a credible high-level discussion will require countries to identify key domestic stakeholders, assemble teams of experts on relevant issues, and develop detailed policy positions. The resulting informed dialogue will increase understanding between countries, identify important areas of agreement and disagreement, clarify intentions, and establish better channels of communication.

The easiest path seems to be a resumption of the discussion of the European Union's Code of Conduct. This also would serve to establish important norms of acceptable behavior in space and supports predictability, very useful in avoiding misperceptions.

However, it does have some drawbacks. Because the Code is not a binding treaty, the stakes are lower. This may make it easier to get started, but that may also serve to not get states to engage at the deepest levels. There's a significant difference in the level of preparation and buy-in that states require when participating in a UNCD negotiation than in a voluntary Code.

While the PPWT has little support from the US, through the lens of crisis stability, it may be quite a good place to start. While one of the US objections to the Russian-Chinese PPWT is that it does nothing to prevent the development of ground-based ASAT weapons, space-based weapons are especially dangerous from a stability point of view, more so than ground-based equivalents. Additionally, because the PPWT does not explicitly limit ground-based ASAT weapons, this may allow leaving for later the issue of limiting ground-based missile defenses, which have significant ASAT capability and which the US fields the greatest number of. And which is a particularly politically sensitive topic.

Reduce the incentives to "use it or lose it" or to strike first

Unilateral and cooperative measures can be implemented to reduce the attractiveness of a surprise or first strike attack.

One unilateral approach is to improve the resiliency of one's space assets. The vulnerability of satellites can be reduced by hardening them to attack; this is analogous to moving nuclear armed missiles into hardened silos or onto mobile platforms that are hard to locate. Or one can reduce the value of each target by distributing the mission over a constellation of satellites, roughly analogous to distributing nuclear assets over different platforms or de-MIRVing nuclear missiles. (This analogy has weaknesses. While each additional nuclear weapon delivery system may increase the risk of catastrophic use, breaking a large satellite into a constellation of smaller ones does not similarly increase risk.) These are just a few aspects of a resiliency approach.

While a resilient posture can reduce one's own incentives to "use it or lose it," the effective communication of this resiliency can reduce one's potential adversary from attempting to strike them first because they will not reap the benefits they seek, i.e., "deterrence by denial."

Additionally, states should resist locating weapons in space, particularly if objectives could be met with terrestrial alternatives. While space is well-suited to many missions that involve observing the earth or universe, or relaying or broadcasting information, it is poorly suited to missions that require rapid transfer of mass, such as ground-attack weapons or ballistic missile defenses,[26] and little would be lost by foregoing them.

Reducing first strike incentives can also be pursued via cooperative agreements. In the nuclear realm, the powers took steps that improved stability such as limiting the numbers and types of weapons and defenses, ensuring robust crisis communications channels, and exchanging information about forces and policies. Again, the processes of negotiating these cooperative agreements provided each side with institutional experience and working relationships with each other.

More capable situational awareness

While the strategy is helpful in that it helps satellites become less likely targets, services are more robust and resilient, it does present the problem that failures may be more likely. If space postures do indeed move toward more distributed capabilities and hence larger constellations of lower quality assets, satellites may fail more. Satellites may also be built to be less robust as launch becomes cheaper. Even if a relatively unimportant satellite's failure does not present a crippling of capability, it might send a signal that must be interpreted—is this the onset of a bigger attack? Additionally, current trends indicate there will be many more small satellites on orbit, scores or hundreds. Many are not designed to be controlled from the ground. Some will lose control because of failure. If they are not trackable, they may present collision hazards, and more problematic, the collisions may not be predictable or attributable.

Additionally, the credibility of retaliation can be undermined if the attacker has a reasonable expectation of being anonymous or that the attribution will be unclear. This incentive works against stability.

[26] See discussion in Section 9 of The Physics of Space Security, by David Wright, Laura Grego, and Lisbeth Gronlund. American Academy of Arts and Sciences. https://www.amacad.org/content/publications/publication.aspx?d=352

Thus, it is critical to build systems that provide accurate information about the health of satellites to their operators, as well as where the satellites are and will be. This could be enhanced if all satellites meet a minimum trackability standard and ability to transmit telemetry.

While improved space situational awareness is critical for each space actor, some of this information would necessarily be kept secret. So there is a real role for a civil society or civil/government partnership entity that could provide robust, trustable, impartial data about the on-orbit behavior of satellites. Such an entity could identify potentially aberrant or abnormal on-orbit behavior, and verify compliance with norms and agreements. The ASTRIA project at University of Texas is building an experimental version of such a system.

Example of a cooperative agreement that could alleviate misperception: keep out zones

Closely approaching a satellite that is unable (or unwilling) to cooperate is a broadly useful technology. It may facilitate the repair or refueling of a satellite in orbit, or to begin to build large or complex structures in orbit. It also may be used for less benign purposes; for example, if a satellite can closely approach an adversary's satellite without the cooperation of the adversary, then an attack may be mounted using relatively unsophisticated technologies that can disrupt or destroy the target satellite. This may be an especially attractive technology, because it may permit disabling an adversary's satellite without creating a large amount of debris.

The United States has developed this technology both through its civilian space agency NASA (DART)[27] and its military research arms (XSS-11,[28] MiTeX[29]) and presently fields two Geosynchronous Space Situational Awareness Program (GSSAP)[30] satellites in GEO orbit which plan to closely approach and survey 600 satellites. China has tested rendezvous technologies with its BX-1 satellite[31] and Russia has, as well.[32]

A satellite owner who detects a satellite closely approaching without having asked permission or given notice may legitimately feel threatened and take actions on that basis. For example, in an environment without norms of behavior, valuable satellites could host defensive weapons on board or have a defensive escort. Without clarity around intentions and expected behaviors, the followed satellite may use defensive weapons to pre-empt an attack by the follower, whether or not the follower had ill intent.

[27] NASA's Demonstration of Autonomous Rendezvous Technology (DART) satellite program ended early when it bumped into the target satellite. https://www.nasa.gov/mission_pages/dart/main/
[28] XSS-11 was a project of the Air Force Research Laboratory to build a semi-autonomous, proximity operations satellite. https://directory.eoportal.org/web/eoportal/satellite-missions/v-w-x-y-z/xss
[29] The two small MiTeX satellites were reportedly used to approach and investigate satellites in geosynchronous orbit. http://gizmodo.com/5138954/pentagon-mitex-satellites-are-the-first-to-actively-spy-on-other-satellites
[30] http://www.afspc.af.mil/About-Us/Fact-Sheets/Article/730802/geosynchronous-space-situational-awareness-program-gssap
[31] http://www.thespacereview.com/article/1235/1
[32] http://allthingsnuclear.org/lgrego/russias-small-maneuvering-satellites-inspectors-or-asats

As an arms control measure, the idea of keep out zones, which would establish protected areas around satellites, was generally held to perhaps be modestly useful but unworthy of significant amounts of high-level time to negotiate.[33] But it may look different if the organizing principle is stability.

A common argument against keep out zones is that the protection they provide is limited and won't stop a determined adversary. The hostile satellite could loiter outside the keep out zone indefinitely and then be poised to interfere with the satellite when the timing was right. Although the keep out zones could be devised based on contemporary threat assessments, the adversary satellite could be equipped with an ASAT technology that was developed specifically to hold satellites at risk from the distance indicated by the keep out zone. It could use lasers, high-powered microwaves, or projectiles, for example.

The other way to look at it though, would be to view a keep out zone as providing not protection, but accountability and transparency. While a country may have legitimate reasons to occasionally come near a keep out zone, it would have no reason to loiter at its periphery. The restraint or the absence of it could deliberately signal the intentions of the potential adversary.

How might such an arrangement be verified and how would responsibility be set? Some of the responsibility can be assigned to operators of highly maneuverable satellites. Such satellites could be required to amplify their trackability with technological aids that are already in use, such as highly radar reflective coatings, optical retroreflectors, or signaling beacons. Because the economics of satellite repair, on-orbit structure building, and active debris removal are becoming more realistic (or at least being perceived as such, so that investments are being made), norms are being established already for the close approach of satellites for peaceful purposes.

The technical requirements to monitor declared maneuverable satellites are relatively low, since the satellites are trying to be tracked. However, to ensure that no undeclared maneuvering satellites enter protected zones, those zones must be monitored. While it would not be possible today to monitor keep out zones for every object, it would be feasible to do so for a subset of more important satellites. Satellite capability scales with mass, and generally, the more massive a satellite, the more capable and valuable it is. Large satellites are clearly visible from the ground and all of them can be tracked. Additionally, particularly critical satellites may carry their own sensors that monitor the space around them.

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[33] See, for example, US Congress Office of Technology Assessment, "Anti-Satellite Weapons, Countermeasures, and Arms Control." September 1985, and Michael A. Levi and Michael E. O'Hanlon, "The Future of Arms Control." Brookings Institution Press, 2005.

Should a regime for protective zones be established, states could negotiate the number of protected satellites allowed, as well as terms for inspection satellites to be allowed into the zone, should there be a need to confirm that the satellite complies with other agreements.

Clarify permissible and impermissible behaviors

Unlike other major arms control treaties such as the Nuclear Nonproliferation Treaty or the Chemical Weapons Convention, the Outer Space Treaty does not have a review conference or a Conference of States Parties which serves to ensure compliance or review relevant new technical developments. The Outer Space Treaty, in Article IX, does provide states a consultation mechanism to engage other states around its own planned activities that may interfere with others' "peaceful exploration and use" of space, or to consult with other states that it has reason to believe are planning such activities. It appears that no state has invoked this, and may have carefully avoided doing so even when it looked potentially to apply. (The 2007 Chinese ASAT test, for example, or 2009's US Burnt Frost satellite interception.) This lack of state practice may undercut the perception of its usefulness, but alternatively it may reflect the past era in which space was less crowded and provided benefits to fewer actors. Article IX also states that space activities be conducted with "due regard to the corresponding interests of all other States Parties to the Treaty."

In the absence of these consultations, civil society efforts can play a role. Projects such as the Manual on International Law Applicable to the Military Uses of Outer Space (MILAMOS)[34] and the Woomera Manual seek to lay out how existing laws apply to military uses of space, in the tradition of the Tallinn Manual on the International Law Applicable to Cyber Operations[35] and the San Remo Manual on International Law Applicable to Armed Conflicts at Sea36. These seek to clarify the fundamental rules applicable to the military use of outer space, in times of peace, in periods of rising tension, and during armed conflict.

Looking forward

It will take sustained and substantial effort to keep the space and nuclear powers working toward peaceful resolutions of their differences and toward the eventual elimination of nuclear weapons. But as that process proceeds, it is critical to minimize the risks that conflicts will escalate catastrophically. This includes careful consideration of the ways space activities provide additional pathways to escalation and finding ways to mitigate this problem. Those offered in this paper are just a start.

[34] https://www.mcgill.ca/milamos/
[35] https://www.cambridge.org/core/books/tallinn-manual-20-on-the-international-law-applicable-to-cyber-operations/E4FFD83EA790D7C4C3C28FC9CA2FB6C9
[36] http://assets.cambridge.org/97805215/58648/excerpt/9780521558648_excerpt.pdf