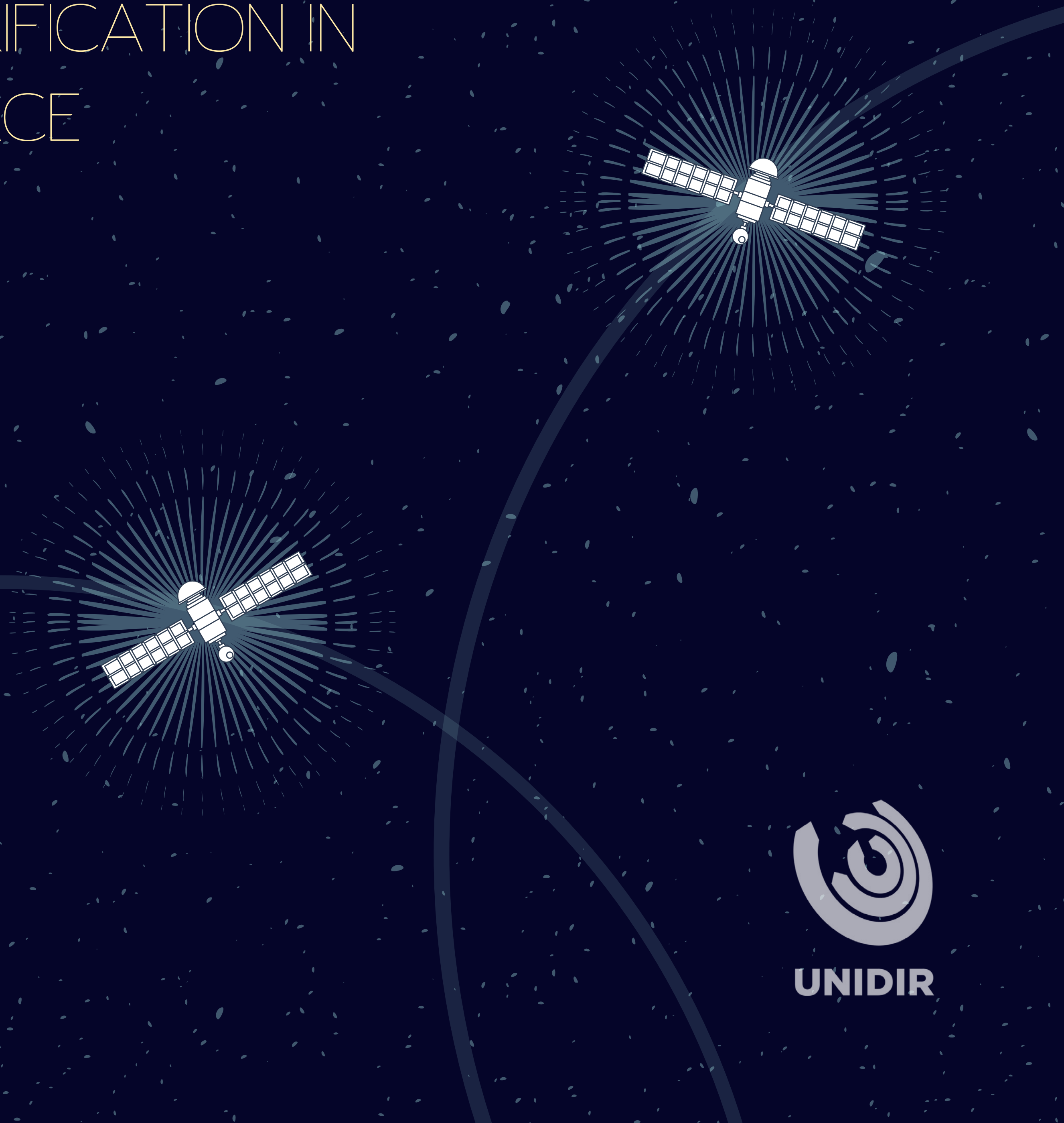
October 2019 — Space Dossier 4

EYES ON THE SKY

RETHINKING VERIFICATION IN SPACE



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NOTE

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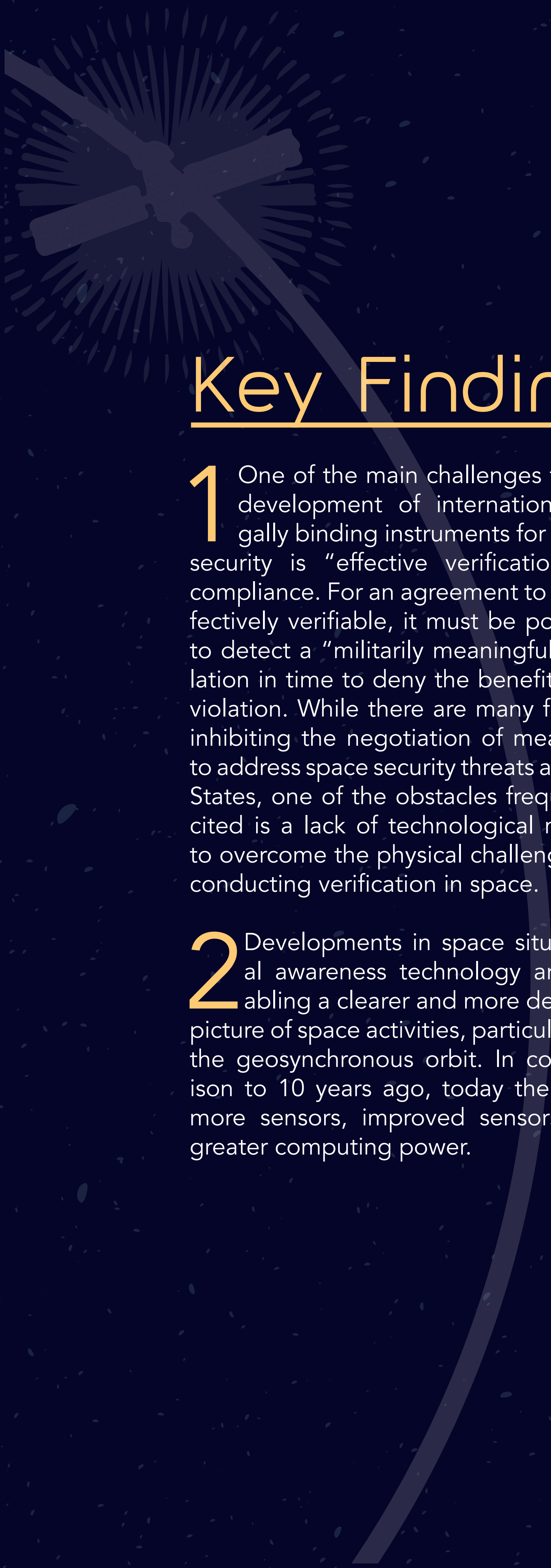
ACRONYMS & ABBREVIATIONS

AGI	Analytical Graphics Inc.
ASAT	anti-satellite
GEO	geosynchronous orbit
LEO	low Earth orbit
LIDAR	light detection and ranging
PAROS	Prevention of an Arms Race in Outer Space
SSA	space situational awareness
SSN	US Space Surveillance Network



Key Findings

1. One of the main challenges to the development of international legally binding instruments for space security is "effective verification" of compliance. For an agreement to be effectively verifiable, it must be possible to detect a "militarily meaningful" violation in time to deny the benefits of a violation. While there are many factors inhibiting the negotiation of measures to address space security threats among States, one of the obstacles frequently cited is a lack of technological means to overcome the physical challenges to conducting verification in space.

2. Developments in space situational awareness technology are enabling a clearer and more detailed picture of space activities, particularly in the geosynchronous orbit. In comparison to 10 years ago, today there are more sensors, improved sensors and greater computing power.

3. By combining new sensors and computing methodologies, it is possible today to effectively verify at least some types of activities related to space security. Measures such as prohibiting the testing of anti-satellite technology or rules of behaviour for on-orbit service vehicles, while limited in scope, can be effectively verified. These might be incorporated into a larger space traffic management framework, which could be effectively verified with existing space situational awareness technology.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1 Introduction

Recent developments in space security indicate that future conflicts will increasingly feature the targeting of satellites and their related networks for intentional disruption and destruction. The effects of such attacks could be considerable, impacting both military and civilian activities around the world. In view of this, United Nations Member States are exploring possible multilateral political and legal measures and arrangements intended to strengthen stability and security in space.

Within these discussions, the issue of verification of any arrangement is a divisive issue. While there is broad agreement among the international community on the need to strengthen the governance framework for space activities, there is little consensus as to what that agreement should be or whether compliance is even verifiable.[1]

In this context, advances in certain space technologies, particularly in space situational awareness (SSA), may provide a technical basis for verification that States can use to consider legal and policy options for future agreements on space security. By understanding the extent and limitations of SSA, States might be able to focus on those space security challenges that are verifiable, and which could be the subject of successful international negotiations.

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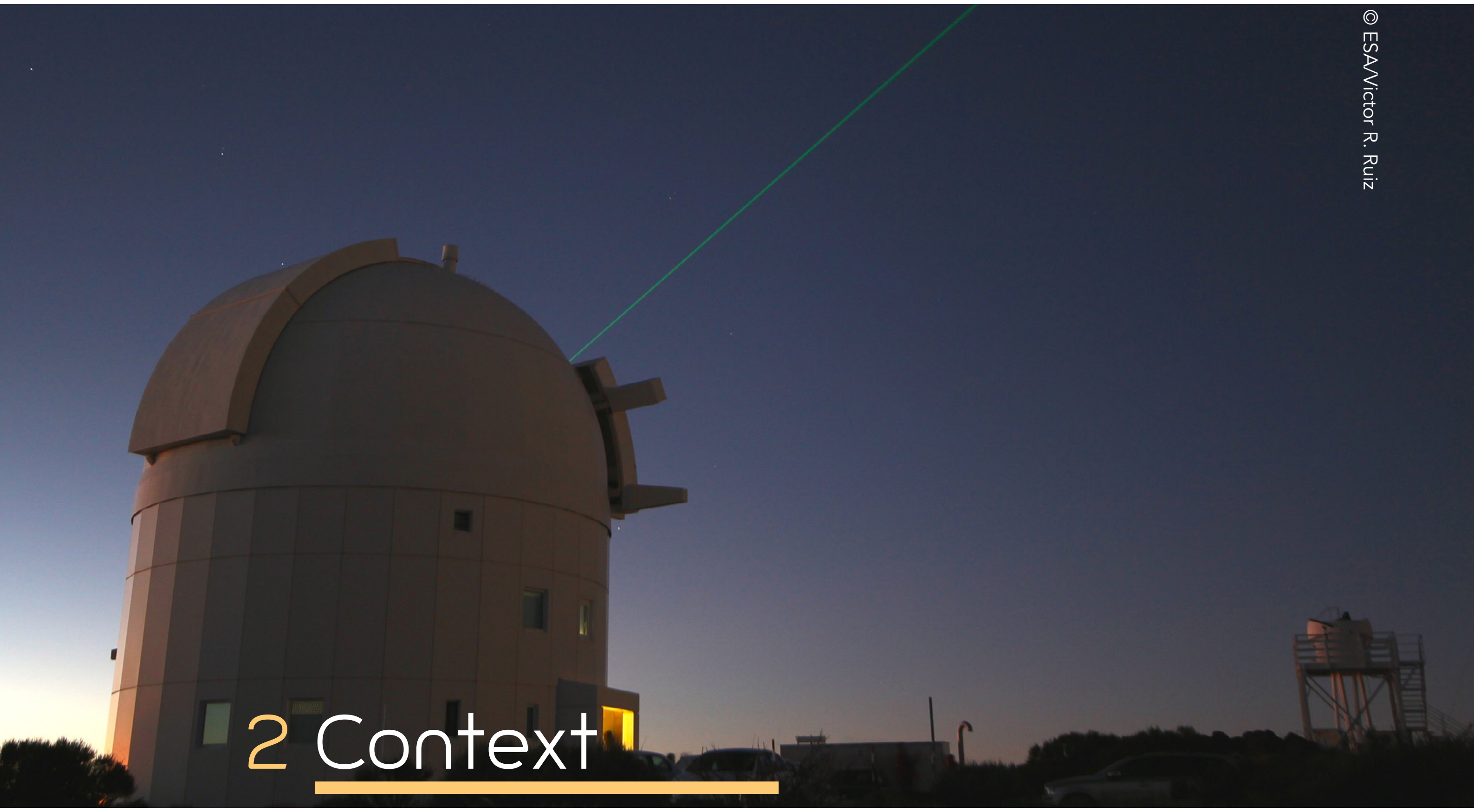
[1] See Report of the Conference on Disarmament Subsidiary Body 3: Prevention of an Arms Race in Outer Space, CD/WP.611, 3 September 2018, pp. 2–3, 5.



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2 Context

Parallel trends are driving an increase in threats to space security. First, space is increasingly important for nearly all aspects of modern human activities, especially military activities.[2] Conventional forces rely heavily on military and commercial satellites for telecommunications, data transmission and reconnaissance.[3] Satellites play a fundamental role in command, control, communication and intelligence systems.[4] Satellites are also key for early-warning, targeting and delivery systems for both nuclear and some advanced conventional weapons. States' reliance on military space systems will continue to increase in coming years.

Second, new technological developments are enabling 'counterspace capabilities', namely the ability to deny an adversary the use of their space systems through disruption or destruction. Some technologies

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[2] See "Competing in Space", National Air and Space Intelligence Center, December 2018, p. 1, https://media.defense.gov/2019/Jan/16/2002080386/-1/-1/1/190115-F-NV711-0002.PDF. See also "2016 White Paper on Chinese Space Activities", Information Office of the State Council of China, 27 December 2016, http://english.www.gov.cn/archive/white_paper/2016/12/28/content_281475527159496.htm. See also "Space Strategy for Europe", communication from the Commission to the European Parliament, the Council, the European Economic Social Committee and the Committee of the Regions, COM(2016) 705 final, 26 October 2016, file:///C:/Users/PORRAS/Downloads/COM_2016_705_F1_COMMUNICATION_FROM_COMMISSION_TO_INST_EN_V12_P1_864471.PDF.

[3] "Shared Risks: An Examination of Universal Space Security Challenges", UNIDIR, briefing paper for the Disarmament Commission, p. 7, http://www.unidir.org/files/publications/pdfs/shared-risks-an-examination-of-universal-space-security-challenges-en-775.pdf.

[4] James Acton, Tong Zhao and Li Bin, "Reducing the Risk of Nuclear Entanglement", Carnegie Endowment for International Peace, 12 September 2018, https://carnegieendowment.org/2018/09/12/reducing-risks-of-nuclear-entanglement-pub-77236.

can cause temporary disruptions to specific space objects, like jamming a telecommunication satellite or blinding a remote-sensing satellite.[5] Others, such as direct-ascent kinetic anti-satellite (ASAT) missiles, can physically destroy a space object, leaving behind space debris.[6] This debris can remain in orbit for many years and poses a threat of collision with other objects in the same orbit. Thus, counterspace capabilities—which several States are actively pursuing[7] —can have serious consequences for third parties, such as civil or commercial operators. With ever decreasing barriers to entry into space, even non-State actors may be able to interfere with national space objects soon.

When one considers these trends in combination with current geopolitical rivalries among states such as China, India, the Russian Federation and the United States, it suggests that space systems are at greater risk from intentional direct and collateral harm than ever before. For this reason, United Nations Member States undertook several efforts throughout 2018 and 2019 to clarify or reinforce the existing regime for space activities. However, due to the technical and political complexity of space security issues, including verification, these efforts have thus far had limited success.[8]

DEBRIS CAN REMAIN IN ORBIT FOR MANY YEARS AND POSES A THREAT OF COLLISION WITH OTHER OBJECTS IN THE SAME ORBIT.

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[5] Rajeswari Pilai Rajagopalan, "Electronic and Cyber Warfare in Outer Space", UNIDIR, Space Dossier 3, May 2019, p. 5, http://www.unidir.org/files/publications/pdfs/electronic-and-cyber-warfare-in-outer-space-en-784.pdf.

[6] Daniel Porras, "Towards ASAT Test Guidelines", UNIDIR, Space Dossier 2, May 2019, pp. 3–6, http://www.unidir.org/files/publications/pdfs/-en-703.pdf.

[7] See "Global Counterspace Capabilities: An Open Source Assessment", Secure World Foundation, April 2019, https://swfound.org/media/206408/swf_global_counterspace_april2019_web.pdf.

[8] Paul Meyer, "Diplomacy: The Missing Ingredient in Space Security", Simons Papers in Security and Development, no. 67/2018, November 2018, p. 13, http://www.sfu.ca/content/dam/sfu/internationalstudies/documents/swp/SWP%2067%20Meyer%20sp%20dip%20missing%20ingred%20nov%202018.pdf. Daniel Porras, "Anti-satellite Warfare and the Case for an Alternative Draft Treaty for Space Security", Bulletin of the Atomic Scientists, 75:4, p. 145.


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3 The verification challenge

In the field of arms control and disarmament, "'verification' is the process of gathering and analysing information to make a judgement about parties' compliance or non-compliance with an agreement".[9]

Verification is typically a major aspect of an internationally negotiated arms control, non-proliferation or disarmament arrangement. Yet it should be noted that verification is not an essential component of a legally binding agreement between states. For example, the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies (the Outer Space Treaty) contains the only explicit arms-control provision related to space in article II, which prohibits the placement of nuclear weapons or weapons of mass destruction in orbit. There is no further verification mechanism, yet the prohibition continues to be upheld, at least according to publicly available information.

Nevertheless, several States maintain the position that verification is critical for any form of agreement related to space security. [10] This position is evidence of the highly sensitive nature of certain space objects—such as early-warning missile defence satellites—and the low levels of confidence among rivals in space today. For these States,

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[9] "Coming to Terms with Security: A Handbook on Verification and Compliance", UNIDIR/VERTIC, June 2003, p. 1.

[10] Statement by Ambassador Robert A. Wood, US Permanent Representative to the Conference on Disarmament at the Conference on Disarmament Plenary Meeting on Agenda Item Three, "Prevention of an Arms Race in Outer Space", Geneva, 14 August 2019, https://geneva.usmission.gov/2019/08/14/statement-by-ambassador-wood-the-threats-posed-by-russia-and-china-to-security-of-the-outer-space-environment/. EU Statement to the Conference on Disarmament Subsidiary Body 3 on the "Prevention of an Arms Race in Outer Space", Geneva, 7 June 2018, https://eeas.europa.eu/topics/multilateral-relations/46129/conference-disarmament-subsidiary-body-3-prevention-arms-race-outer-space-paros-eu-statement_en.

any agreement must be independently verifiable to ensure that sensitive national space objects are not put at risk. Regardless of the basis or motivations for this position, verification presents a major challenge in discussions on possible legally-binding arrangements for space security for two main reasons.

The first reason that verification is challenging in space is due to the physical properties of the space environment and the objects in question. Objects at different altitudes vary greatly in size and speed. For example, the most economically valuable orbit today is the geosynchronous orbit (GEO), which is 36,000km in altitude.[11] Here, satellites move at the same relative velocity as the rotation of the Earth, so they can stay over the same spot on the Earth's surface. In this orbit, satellites are seen moving against the backdrop of other stars (see figure 1) and can be monitored with relative ease. However, objects in low Earth orbit (LEO), which are only 100 to 2,000 km in altitude, move at relative speeds of approximately 8 km per second. Despite being much closer to the Earth, the velocity of LEO objects makes them much harder to detect and monitor.

Space objects are also getting smaller and becoming more numerous. For example, the new SpaceX Starlink constellation will feature thousands of satellites roughly 1 m long, orbiting in LEO at an altitude of 550 km,[12] while other objects soon to be launched by both government and private actors will be little more than microchips with wires.[13] The challenge to accurately detect, identify and track space objects will, therefore, only grow in the coming years.

Figure 1: *an image of a satellite in GEO, with stars streaking in the background. (Courtesy of ExoAnalytic Solutions)*

The second reason verification in space is so challenging is that there is no consensus on what should be verified. Thus far, the international community has sought a comprehensive approach to addressing space security threats, as is the case with the "Prevention of an Arms Race in Outer Space" (PAROS) in the Conference on Disarmament and in the UN General Assembly. Discussions on this agenda item encompass all types of technologies, from ASAT missiles to jamming equipment.[14] Also relevant to

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[11] See Satellite Industry Association, "State of the Satellite Industry Report", May 2019, https://www.sia.org/wp-content/uploads/2019/05/2019-SSIR-2-Page-20190507.pdf, noting that satellite television, which broadcasts from GEO, continues to be the largest generator of revenue for global space services.

[12] MicroSat 2a, 2b (Tintin A, B)", Gunter's Space Page, last visited on 27 June 2019, https://space.skyrocket.de/doc_sdat/microsat-2.htm.

[13] Mike Wall, "Tiny Chipsats, Big Success: Cracker-Size Probes Phone Home From Orbit", Space.com, 4 June 2019, https://www.space.com/tiny-chipsats-ace-demonstration-mission.html.

[14] See Report of the Conference on Disarmament Subsidiary Body 3: Prevention of an Arms Race in Outer Space, CD/WP.611, 3 September 2018, p. 2.

this conversation are dual-use/multi-use technologies, such as co-orbital service vehicles, which are small manoeuvrable drones that can repair, refuel or even destroy a satellite.[15] These technologies and capabilities are vastly different. Partly as a consequence, no consensus has emerged on what the scope of a multilateral agreement might be or on what exactly needs to be verified.

IN THE CONTEXT OF SPACE ACTIVITIES, THERE ARE FEW STATES WITH THE REQUISITE TECHNOLOGY TO MONITOR ACTIVITIES IN SPACE.

There is also the question of who should conduct verification. For example, in the case of the Treaty between the United States of America and the Russian Federation on Measures to Further Reduction and Limitation of Strategic Offensive Arms (New START), there is an explicit provision that States Parties will conduct verification through "national technical means", and that States Parties will not interfere with these capabilities.[16] In the context of space activities, there are few States with the requisite technology to monitor activities in space. Moreover, those States that do have such capabilities do not always share their data.

Given the ongoing difficulties in multilateral discussions on verifiability in space, an alternative approach to pursuing multilateral arrangements to enhance stability and security in space could be to work backwards: determining the extent and limitations of current or emerging technology for gathering and analysing information related to space activities, and then extrapolating what types of threats might be effectively verified. In this way, international discussions could focus on those activities and capabilities for which compliance can be demonstrated, addressing those challenges that are solvable at this present moment in time and leaving more difficult challenges for the future. This approach has been successfully employed in past arms control negotiations.[17]

A 2010 UNIDIR study found that, based on the technology then in use, "Verifying the on-orbit actions of a space object

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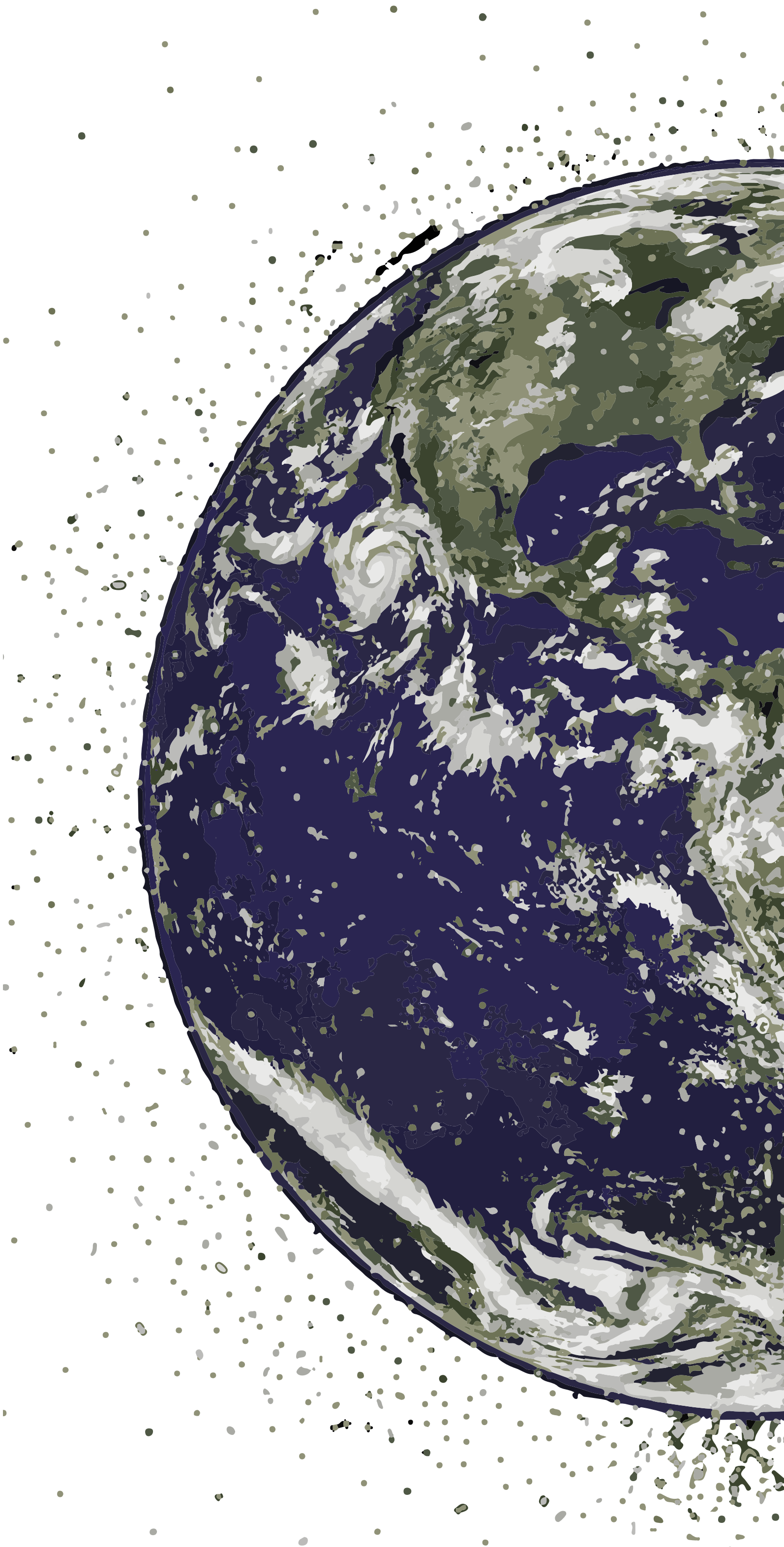
[15] See United States Remarks at the Conference on Disarmament, as delivered by Assistant Secretary of State for Arms Control, Verification and Compliance Yleem D.S. Poblete, Geneva, Switzerland, August 14, 2018, https://geneva.usmission.gov/2018/08/14/remarks-by-assistant-secretary-yleem-d-s-poblete-at-the-conference-on-disarmament/.

[16] Article X of the Treaty between the United States of America and the Russian Federation on Measures to Further Reduction and Limitation of Strategic Offensive Arms, signed in Prague on 8 April 2010, https://2009-2017.state.gov/documents/organization/140035.pdf.

[17] For example, during the negotiations of the Treaty Banning Nuclear Tests in the Atmosphere, in Outer Space and Under Water, States were unable to agree on an appropriate verification regime for underground explosions. In light of not possessing technology capable of permitting verification through national technical means, States agreed to drop underground explosions from the scope, clearing the way for agreement on explosions in the "atmosphere, outer space and under water". See Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Under Water—Narrative, US Department of State, last updated on 20 January 2017, https://2009-2017.state.gov/t/avc/trty/199116.htm.

is easier than verifying its functions".[18] The authors made several recommendations for implementing any verification system, two of which still stand out today: the establishment of limits for activities in space, and expanding efforts related to SSA.[19] In essence, the international community needs to agree on a scope for the space activities of interest, and to that end improve its abilities to know what is happening in Earth's orbits.

Since that study a decade ago, SSA technology has evolved, with improved sensors and greater computing power. In particular, machine-learning methodologies[20] can now be combined with better sensing capabilities to produce a network that can detect, identify and track objects with enough confidence for some verification purposes, even if not for all. By understanding the extent and limitations of current and near-future technical capabilities, the international community might be able to identify a workable scope for an international agreement. While this approach will not offer a comprehensive solution to space security concerns, it can help States focus intergovernmental discussions on specific objectives for which technical capacities exist and make progressive steps toward more comprehensive arrangements, as technological developments permit.



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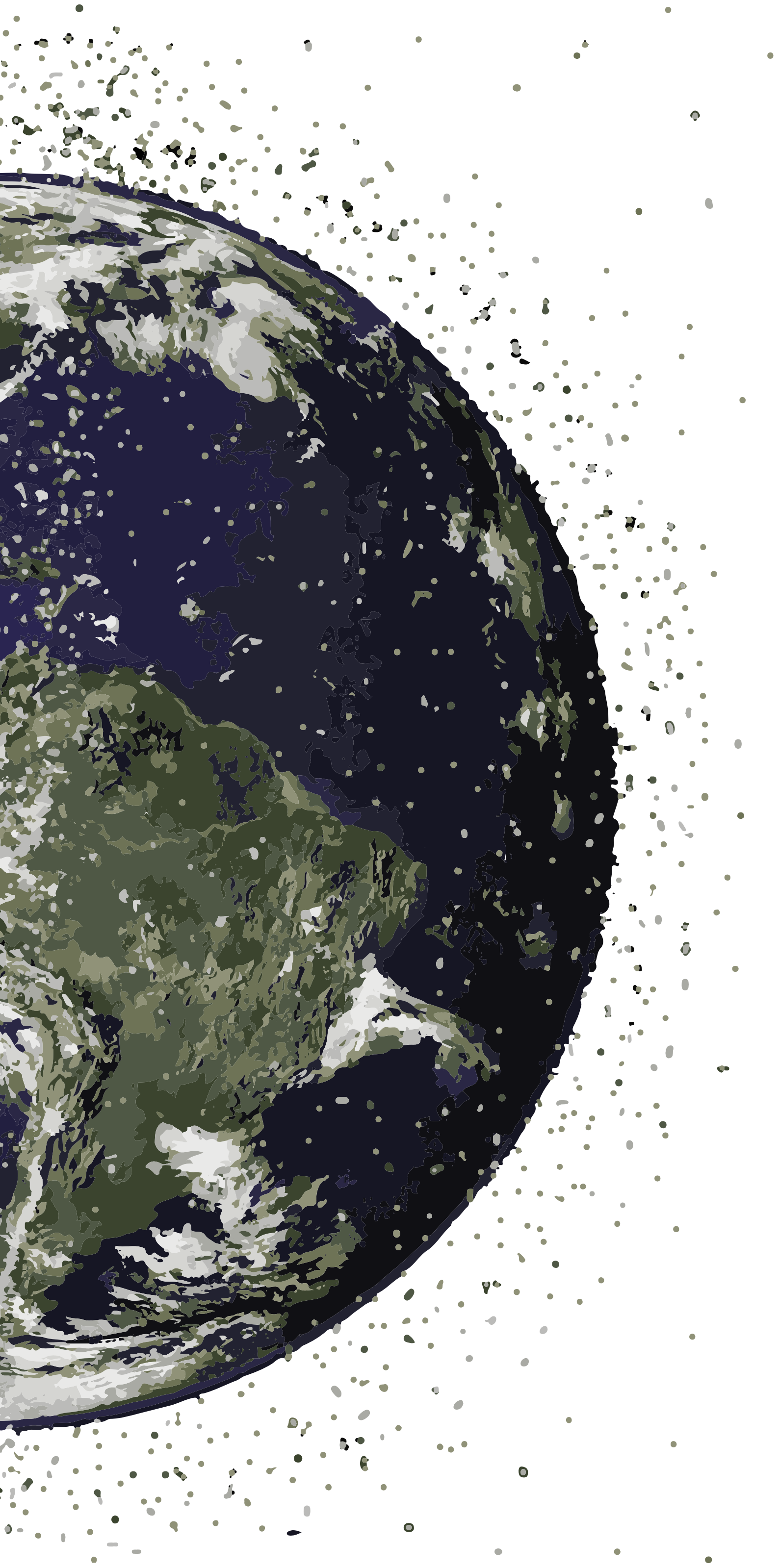
[18] Ben Basely-Walker and Brian Weeden, "Verification in Space: Theories, Realities and Possibilities", UNIDIR, Disarmament Forum, vol. 3, 2010, p. 43, http://www.unidir.org/files/publications/pdfs/arms-control-verification-en-320.pdf.

[19] Ibid., pp. 48–49.

[20] See generally Ben Buchanan and Taylor Miller, "Machine Learning for Policymakers", The Cyber Security Project - Belfer Center for Science and International Affairs, Harvard Kennedy School, June 2017.

4 Setting criteria for verification



Before reviewing new technologies and methodologies, it is important to set criteria for what a verification regime should achieve. Arms control experts often cite Ambassador Paul Nitze, one of the foremost architects of US foreign policy throughout the post-Second World War era. Ambassador Nitze stated that the goal of verification is to be able to detect a "militarily meaningful" violation of the obligations of a treaty in time to deny the benefits of the violation.[21] In this sense, a verification regime does not have to be perfect, but rather sufficient to detect a significant violation before a party gains an advantage from it.

Along these same lines, the 2003 UNIDIR/VERTIC Handbook of Verification and Compliance states that:

> the more effective a verification system, the more likely it is to deter parties from even contemplating a deliberate violation. Verification systems do not need to be one hundred per cent effective to provide a significant level of deterrence: just as parties to a treaty are unlikely to be absolutely certain that all other parties are complying fully, a non-compliant State can never be completely certain that its actions will go undetected.[22]

The Handbook adds that the more sources of data that exist—and the more layered a verification system can be—the more effective it will be in convincing possible offenders that they will be detected and caught before they

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[21] US Congress, Senate Foreign Relations, The INF Treaty, Hearing, 100th Congress, 2nd session, 1 February 1988, S. Hrg. 100-522 pt. 2, pp. 80–82, https://hdl.handle.net/2027/pst.000013399719.

[22] "Coming to Terms with Security: A Handbook on Verification and Compliance", UNIDIR/VERTIC, June 2003, p. 3.

can gain a meaningful advantage.

There is also a set of Principles of Verification, promulgated by the United Nations Disarmament Commission in 1988, which provide some useful criteria. These Principles are general in nature, but state, for example, that any regime should provide clear and convincing evidence of compliance or non-compliance in a timely fashion and the provision of evidence should be continuous. This is consistent with Ambassador Nitze's notion that, for a verification mechanism to be effective, detection should be possible in time to deny a militarily meaningful advantage, even if not every violation is caught.

When one considers how to apply this criterion to space security, some basic elements emerge as necessary for any system. For example, an effective verification mechanism will need to detect objects in orbit and monitor their activities with some regularity. This will entail taking readings of physical characteristics and patterns of behaviour, at least enough to be able to tell if the object in question would be in violation of any future agreement. These readings should also be of a diverse nature, providing multiple types of data in order to build a more complete picture of an object and its activities. The verification system should also be able to correctly attribute a space object to its owner, to be able to identify an offending party. Otherwise, it will not be possible to deny the benefits of a violation to the violator. Finally, the system should be able to continuously monitor objects and their activities in space such that it can detect when there is a militarily meaningful violation in time to prevent the benefits or advantages thereof. Of course, States Parties to any agreement would first have to decide on what exactly is a "militarily meaningful" violation.


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5 Detecting space activities

The first function of a space verification system must be to detect objects and activities in orbit. This includes launches and orbital re-entries, as well as actual on-orbit activities. In a previous study, UNIDIR laid out the technical feasibility for detecting object launches and re-entries, noting the various tools used to detect thermal energy released during a launch as well as those used to calculate the trajectories of objects for re-entry.[23] This study found that, already in 2010, it was not a problem to detect objects being launched or re-entering the atmosphere, but that objects in orbit presented a unique set of challenges, particularly in determining their function. Correspondingly, this paper will focus on the challenges and opportunities for a verification system in relation to on-orbit activities, namely SSA.

Space situational awareness is based on the detection and tracking of space objects. There is no internationally agreed definition of SSA but it generally refers to knowledge and characterization of space objects/activities and their environment, including space weather.[24] A diverse range of sensors—such as ground-based and space-based optical telescopes, radars, and laser-ranging sensors—collects data, while software and algorithms process the data to accurately depict space activities to the greatest extent possible. Governments and civil agencies have operated these systems for decades. Today, some of the most effective systems are commercial.

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[23] Ben Basely-Walker and Brian Weeden, "Verification in Space: Theories, Realities and Possibilities", UNIDIR, Disarmament Forum, vol. 3, 2010, pp. 40–42, http://www.unidir.org/files/publications/pdfs/arms-control-verification-en-320.pdf.

[24] US Space Policy Directive-3: National Space Traffic Management Policy, issued 18 June 2018, https://www.whitehouse.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/. See also Space Situational Awareness Fact Sheet, Secure World Foundation, last updated May 2017, https://swfound.org/media/205874/swf_ssa_fact_sheet.pdf.

Developments in three areas are facilitating a much clearer picture of what is going on in space today: more sensors, improved sensors and greater computing power.

5.1 MORE SENSORS

First, the sheer number of sensors available for SSA is steadily rising, particularly for monitoring GEO. The US Air Force operates the most relied-upon SSA system, known as the Space Surveillance Network (SSN). It consists of more than 30 ground-based radars and optical telescopes, as well as space-based sensors that can monitor objects directly from orbit.[25] The SSN tracks more than 23,000 objects (larger than 10 cm in diameter), making hundreds of thousands of measurements each day. Over the years, the US Air Force has partnered with governments, academia and the private sector in order to gain access to more sensors around the world, combining diverse sources of data to produce an increasingly better picture of space activities.[26]

Several other actors are developing their own comparable SSA networks as well. The Russian International Scientific Optical Network (ISON) expanded its number of instruments to more than 50 telescopes located in 17 countries, primarily for GEO observations.[27] Over the last 10 years, ISON multiplied the number of its daily detections by a factor of 200.[28] Other States, such as Australia, France, Germany, Spain and the United Kingdom are also looking for ways to leverage their own specialized capabilities to get a better picture of what is happening in orbit, including in LEO.[29] Since most States have few resources for SSA, current policies are to partner with other SSA actors to build a more comprehensive picture of the space environment.[30] The benefit of

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[25] Diane McKissock, "18th Space Control Squadron Brief", 14th Annual CubeSat Developers Workshop, 26–28 April 2017, http://mstl.atl.calpoly.edu/~bklofas/Presentations/DevelopersWorkshop2017/1a_18SPCS.pdf.

[26] See Lt. Col. Jeremy Raley, Ryan M. Weisman et al. "OrbitOutlook: Autonomous Verification and Validation of Non-Traditional Data for Improved Space Situational Awareness", conference paper, 2016 Advanced Maui Optical and Space Surveillance Technologies Conference.

[27] Igor Molotov et al., "ISON Search and Study the Near-Earth Space Objects", 1st NEO and Debris Detection Conference, Darmstadt, Germany, 22–24 January 2019, https://conference.sdo.esoc.esa.int/proceedings/neosst1/paper/406/NEOSST1-paper406.pdf.

[28] Bhavya Lal, Asha Balakrishnan et al., "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)", IDA Science and Technology Policy Institute, April 2018, p. 28, https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx.

[29] Lt. Col. Andrea Console, "Command and Control of a Multinational Space Surveillance and Tracking Network", Joint Air Power Competence Centre, June 2019, pp. 33–38, https://www.japcc.org/portfolio/command-and-control-of-a-multinational-space-surveillance-and-tracking-network/. See also GPCAPT Darren May, "Australian Defence Space Situational Awareness Activities", presentation at the International Symposium on Ensuring Stable Use of Outer Space, 2–3 March 2017, http://www.jsforum.or.jp/stable-use/2017/.

[30] Lt. Col. Andrea Console, "Command and Control of a Multinational Space Surveillance and Tracking Network", Joint Air Power Competence Centre, June 2019, pp. 30, 51, https://www.japcc.org/portfolio/command-and-control-of-a-multinational-space-surveillance-and-tracking-network/.

this approach is that it can spread costs among many actors. It also increases confidence in the system since there are diverse sources of expertise contributing and cross-checking data.

The most significant increase in sensors has been in the commercial sector. Already, companies are deploying hundreds of 'off-the-shelf' telescopes (i.e. not specially designed but available for mass production), as well as repurposing old sensors to establish their own global networks. US-based ExoAnalytics Solutions, for example, has 275 telescopes at more than 24 sites around the world to monitor GEO, particularly across the southern hemisphere where there were, until recently, relatively few SSA instruments.[31] Rather than deploying a few high-end telescopes to provide data, ExoAnalytics deploys many inexpensive telescopes to increase the rate at which they make detections. This strategy has enabled ExoAnalytics to surpass the US Air Force SSA capabilities in GEO, even though ExoAnalystics has only been in operation since 2008.[32]

Companies are also making strides in LEO, where there is much less information about space objects. Typically, objects in LEO are detected using ground-based radar, but this method has difficulty in characterizing passing objects. There are also few radars around the world, presenting a challenge in the frequency of detection (as LEO objects move relative to the surface of the Earth, unlike GEO objects). In addition to State-owned radars, the US company LeoLabs has built two radars, one in Alaska and one in Texas, that can detect objects as small as 10 cm in diameter.[33] A third radar is scheduled to be built in New Zealand. Moreover, LeoLabs (which has only been in operation since 2016) has recently teamed with the New Zealand Space Agency to launch the Space Regulatory and Sustainability Platform, a dedicated service that will enable New Zealand regulators to track and monitor relevant space objects and to receive alerts when a space object is not following prescribed rules.[34] While this platform will still face certain limitations, it demonstrates one possible model of a government-industry partnership in the SSA field.

Indeed, commercial actors are probably the most active in SSA developments today. To give an idea of the scope of this sector, today the value of the commercial SSA market is roughly USD

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[31] ExoAnalytic Solutions—Space Situational Awareness, last visited 12 July 2019, https://exoanalytic.com/space-situational-awareness/.

[32] See presentation by Ian Christensen and Brian Weeden, "Commercial Space Situational Awareness", Space Situational Awareness Workshop: Perspectives on the Future Directions for Korea, 24–25 January 2019, https://swfound.org/media/206343/icplusbw_commercial_ssa_for-kari-jan2019.pdf.

[33] See LeoLabs Platform for Operators and Developers: Our radar Network, website last visited on 20 September 2019, https://platform.leolabs.space/.

[34] "LeoLabs and New Zealand Space Agency Unveil Regulatory Platform for Low Earth Orbit", Cision PR Newswire, 25 June 2019, https://www.prnewswire.com/news-releases/leolabs-and-new-zealand-space-agency-unveil-regulatory-platform-for-low-earth-orbit-300874417.html.

1.15b and could reach around USD 1.4b by 2023.[35] This growth is driven by a need for governments and companies alike to know where their space objects are and what the environment around them looks like.

5.2 IMPROVED SENSORS

The second important development of the last 10 years is improvement in the quality of sensors and the type of data they offer. Optical telescopes and radars have advanced and allow actors to see smaller objects from further away. The US Air Force is preparing to launch a new Space Fence, a radar system located on the Kwajalein Atoll and on the Western Coast of Australia that will enable the United States to track objects as small as 1 cm in diameter (down from 10 cm), expanding its catalogue of trackable objects from 23,000 to more than 200,000.[36] This system will provide persistent coverage but will also be able to track specific objects in orbit selectively.

SSA actors are also deploying improved sensors in orbit to provide measurements that are not constrained by daylight or weather. For example, at the time of writing, the US Air Force and Japan have plans to deploy US sensors on board four Japanese satellites, providing additional coverage across the Southern Hemisphere, a region where the United States currently has few sensors. Companies such as NorthStar Earth and Space are also planning to deploy a constellation of more than 20 LEO satellites equipped with optical telescopes, and the data will be made commercially available.[37] This could be especially useful for tracking objects in LEO as the NorthStar satellites will be moving at similar relative speeds.
Another interesting commercial development comes from Space Strategies Consulting, which is planning to deploy light detection and ranging (LIDAR) sensors in orbit that can make a surface map of a 10 cm object at a distance of about 1,000 km.[38] LIDAR's principal function in the field of SSA is to make determinations about whether a space object is in need of repair or refurbishment, but LIDAR can also provide details about the form, and possible function, of a space object.

Investments are also being made in radio-frequency sensors that can track objects based on the signals they emit. Companies such as Kratos and Hawkeye360, for example, have begun using their radio-frequency sensors to provide SSA data, providing an

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[35] "Global $1.44 Billion Space Situational Awareness (SSA) Market 2018-2023—Analysis by Offering, Object and End-User", Research and Markets, 28 June 2018, https://www.globenewswire.com/news-release/2018/06/28/1530766/0/en/Global-1-44-Billion-Space-Situational-Awareness-SSA-Market-2018-2023-Analysis-by-Offering-Object-and-End-User.html.

[36] Gregory P. Fonder, Peter J. Hack and Matthew R. Hughes, "AN/FSY-3 Space Fence System—Sensor Site One/Operations Center Integration Status and Sensor Site Two Planned Capability", 2017 Advanced Maui Optical and Space Surveillance Technologies Conference, https://amostech.com/TechnicalPapers/2017/SSA/Hughes.pdf.

[37] Caleb Henry, "ExoAnalytic, NorthStar E&S Team Up on Space Situational Awareness", SpaceNews, 1 April 2019, https://spacenews.com/exoanalytic-northstar-es-team-up-on-space-situational-awareness/.

[38] See presentation by Col. Andre Dupuis, President of Space Solutions Consulting, UNIDIR Space Security Conference, 28–29 May 2019, Geneva, https://www.youtube.com/watch?v=PK3ByBjNAjg&list=PLEQ2SvONl8gzgeiE7MdfWmaRbSmgVrFhm&index=8&t=4910s.

additional layer of information about objects broadcasting radio signals in orbit.[39] These sensors will be especially useful as satellite jamming becomes more frequent.[40]

It is worth noting that many SSA developments are commercial or academic in nature, meaning that such services and technologies will be more widely available than if they were militarily produced. While it is still expensive for a single actor to build and operate an SSA network, it is increasingly possible to make a limited investment either in hardware or software and then join a network of commercial and/or academic SSA operators that share data.

5.3 BETTER COMPUTING

The third significant advancement in SSA is in computing power and software. Today, while many SSA actors are willing to share data, they do not share their software or algorithms that process the data into actionable information. In this context, governments and companies alike purchase raw data (e.g. from the US Air Force) to generate their own products. This includes catalogues of space objects, re-entry estimates, conjunction/collision analyses, and so on. Some governmental actors—including in France, Germany, Japan and the United Kingdom—use their own computational capabilities to improve the accuracy of the raw data they receive.[41] Such steps result in improved conjunction analysis, more comprehensive catalogues and other customizable SSA products. Consequently, even smaller and medium-sized space actors are becoming SSA actors.

Other important developments in SSA computation are related to the amount of data being processed and how it is processed. SSA actors are becoming increasingly proficient at integrating data from various sources to generate a more complete picture of orbital

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[39] Bhavya Lal, Asha Balakrishnan et al., "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)", IDA Science and Technology Policy Institute, April 2018, pp. 34–35, https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx.

[40] For more details about satellite jamming activities, see Rajeswari Pilai Rajagopalan, "Electronic and Cyber Warfare in Outer Space", UNIDIR, Space Dossier 3, May 2019, p. 5, http://www.unidir.org/files/publications/pdfs/electronic-and-cyber-warfare-in-outer-space-en-784.pdf.

[41] Ibid., pp. 39–42.

activities. For example, Analytical Graphics Inc. (AGI) operates the Commercial Space Operations Center, which takes data from numerous sources and turns it into its own SSA products.[42] Many commercial actors rely on this information to know if a collision is imminent and whether they need to move their satellites. The company's techniques, through observation and deduction, can also suggest the functions of satellites.

Finally, the introduction of machine learning, artificial intelligence and cloud computing is also improving SSA capabilities.[43] As the number of space objects grows, tracking each one and analysing the resulting data requires large amounts of computing power. By using artificial intelligence techniques, as well as cloud computing, SSA actors can operate large networks of telescopes remotely, feeding their data into a central database. By using improved computing power, new SSA actors can analyse and predict the trajectory of space objects with better accuracy than before. For example, private SSA actors can now predict a possible conjunction between two space objects 14 days in advance, as opposed to the current standard of three days in advance.[44] There is every indication that both governmental and private actors will continue to invest in these capabilities.

5.4 THE VALUE OF COOPERATION

As indicated above, SSA detection capabilities have come a long way in ten years. People can see more objects, smaller objects, and they can observe objects more often. The result of these advances is that an increasing number of actors hold better, but still disparate, pieces of information about what is happening in space. Some of these pieces overlap, while some are restricted to a few key actors. Nascent efforts at combining this data already shows that collaboration increases capabilities from what was possible 10 years ago. Examples of this include the Space Data Association, a consortium of private actors that share situational data,[45] and AstriaGraph, an academic endeavour to combine data from diverse actors such as the United States, the Russian Federation and private companies (see figure 2).[46] Indeed, the more layered a system is, the more effective it is at detecting space objects. While technology has

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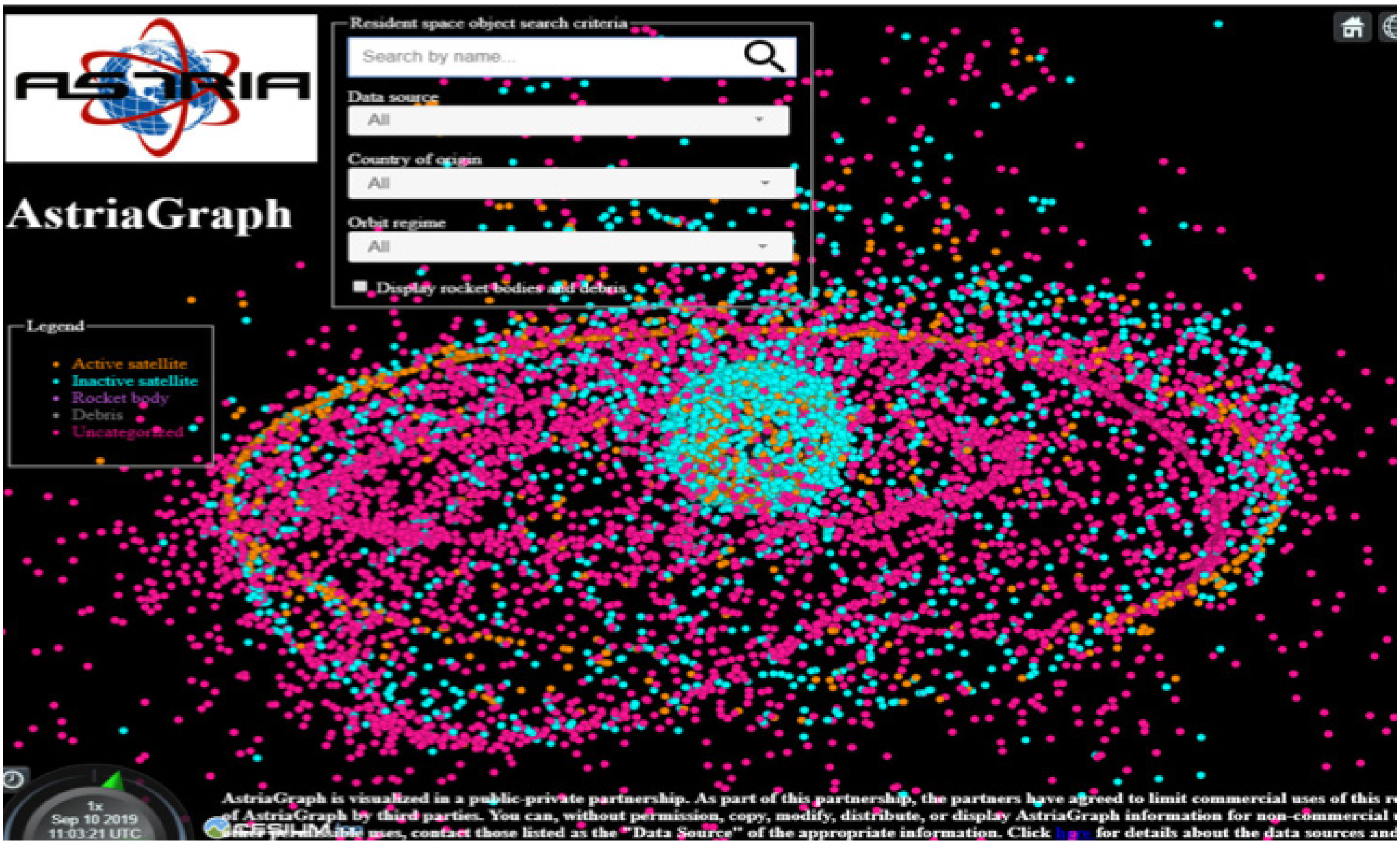
[42] OMSPOC factsheet, last visited on 19 July 2019, https://www.agi.com/comspoc.

[43] See Hao Peng and Xiaoli Bai, "Improving Orbit Prediction Accuracy through Supervised Machine Learning", Advances in Space Research, 16 January 2018, https://arxiv.org/pdf/1801.04856.pdf. Sandra Erwin, "Air Force Selects Slingshot Aerospace to Bring Artificial Intelligence into Space Surveillance", SpaceNews, 7 April 2019, https://spacenews.com/air-force-selects-slingshot-aerospace-to-bring-artificial-intelligence-into-space-surveillance/.

[44] Bhavya Lal, Asha Balakrishnan et al., "Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)", IDA Science and Technology Policy Institute, April 2018, p. 44, https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx.

[45] See Space Data Association website, last visited 10 September 2019, http://www.space-data.org/sda/.

[46] See AstriaGraph webpage, last visited 10 September 2019, http://astria.tacc.utexas.edu/AstriaGraph/



AstriaGraph is visualized in a public-private partnership. As part of this partnership, the partners have agreed to limit commercial uses of this r
of AstriaGraph by third parties. You can, without permission, copy, modify, distribute, or display AstriaGraph information for non-commercial
other permissible uses, contact those listed as the "Data Source" of the appropriate information. Click here for details about the data sources and

Figure 2: *Image of AstriaGraph web interface, displaying a compilation of objects from numerous SSA catalogues. (courtesy of AstriaGraph)*

progressed significantly over the last decade, it could move ahead much further as SSA actors increasingly share data and cooperate.

However, there is only so much that an SSA system can tell about an object in space without more information. To determine if an object is a threat, it must also be identified. This is the second element in developing an effective verification system, which is discussed in the next section of this paper.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6 Identification & threat assesments

Identification is the ability not only to detect that an object is present but also to recognize what it is and to whom it belongs. While civilian SSA applications typically focus on locating objects in space (detection), "military and security applications also include intelligence activities, such as the characterization of the objects in space, their capabilities and limitations, and whether they pose potential threats".[47] These characterization capabilities are especially important for dual-use/multi-use objects capable of both benign or hostile acts.

6.1 IDENTIFYING AN OBJECT

Identifying a satellite is not unlike identifying a person. Today, there are many studies in biometrics that use recognition technology to accurately identify a person, including persons who may be perceived to pose a threat to public safety and security. These systems consist of:

1. a system to extract features from a subject;
2. a database of subject profiles; and
3. a system that matches features to subjects from the database.

As noted in the previous section, there

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[47] Lt. Col. Andrea Console, "Command and Control of a Multinational Space Surveillance and Tracking Network", Joint Air Power Competence Centre, June 2019, p. 7, https://www.japcc.org/portfolio/command-and-control-of-a-multinational-space-surveillance-and-tracking-network/.

are already devices that can be used for feature extraction (namely, SSA sensors). The next challenge to overcome is to build a database of subjects and a system that matches features to profiles.

There are two ways to build a database in this regard.[48] The first is to solicit data directly from operators. This information can include physical properties (e.g. shape, mass, material composition, surface properties) or data about its mission (e.g. orbital trajectory, operational radio frequencies, anticipated lifespan). The information is stored in a repository as a unique profile. When an object is detected, measurements are taken and linked to the profile. Measurements taken over time provide evidence that an object is, in fact, what the data in the repository says it is. This process is relatively straightforward with traditional satellites because they follow predictable trajectories, allowing for consistent measurements to be taken at regular intervals. It could also be effective with civil and commercial actors that, at present, are willing to engage in practices that will provide greater awareness and predictability to protect their space objects, provided that the data solicited from operators is restricted to SSA uses only. The Space Data Association is an example of private actors, including some of the largest satellite operators, sharing SSA data and operational information to improve the situational picture for all.[49] However, there will be actors, particularly military actors, that do not wish to provide data voluntarily.

The second way to build a database of subjects is to build profiles directly from observations. Objects in space are exposed to everyone. When there is a launch, even amateur astronomers can see payloads being deployed.[50] Once detected, remote sensors can take measurements that populate a profile for a particular object. Different sensors, such as telescopes or radio-frequency detectors, can help populate the profile with greater detail by adding layers of data. The profile can be enriched as the object is monitored, using its behaviours and manoeuvres to provide additional information about the functions of the target object. If an object is of concern, specialized sensors, such as a LIDAR, can take more detailed readings. The object could even be inspected directly by an on-orbit service vehicle, should the owner be willing to consent to such an inspection. The profile can then serve as a template for similar objects. When unknown objects are detected, they can be associated with a pre-existing template until unique features are detected that necessitate a new profile. The more data that is compiled

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[48] See presentation by Dr. Moriba Jah, “Astrodynamics: Addressing the Underbelly of Space Situational Awareness, Space Traffic Management and Space Exploration”, University of Texas at Austin, 22 June 2018.

[49] See Space Data Association, last visited 22 July 2019, http://www.space-data.org/sda/.

[50] Amateurs demonstrated their capabilities recently when they detected four unauthorized cubesats (10 cm by 10 cm). These cubesats had originally been refused an operating license by the US Federal Communications Commission over concerns that the satellites were too small to be tracked by the US SSN. Tim Fernholz, “The US Government Said No. Swarm Technologies Launched Its Satellites Anyway”, Quartz, 20 March 2018, https://qz.com/1230354/swarm-technologies-how-the-silicon-valley-start-up-launched-satellites-without-government-permission/.

in the database, the more likely the system can accurately characterize and identify objects in space.

One example of how extensively a private actor can monitor an object in space and build a profile is the case of the US company AGI (mentioned above) tracking the Luch/Olymp satellite in GEO. Launched in 2013, AGI monitored and documented Luch/Olymp extensively as it moved between other objects in GEO.[51] The observations were specific enough to determine when the spacecraft was less than 100 km away from another object, including its orientation with respect to other craft. AGI suspects that the Luch/Olymp is a Russian military satellite eavesdropping on the communications of commercial satellites with military customers.[52] It should be noted that Russian SSA facilities similarly track and catalogue activities by US co-orbital vehicles, carrying out manoeuvres similar to those attributed to Luch/Olymp.[53] These examples illustrate that various State and commercial actors are sufficiently sophisticated to monitor objects intended for surveillance or other functions.

6.2 THREAT ASSESSMENT

While it is important to identify an object in orbit, one must also consider what constitutes a 'threat' in space. In risk management fields, a threat contains three elements: intent, opportunity and capability.[54] Intent refers to the desire of one actor to disrupt or even destroy a space object. Opportunity refers to vulnerabilities in a space object or its related systems that might be exploited, whether by physical, electronic or other means. Capability refers to the ability of an actor to achieve a desired outcome. Each poses challenges and opportunities for a verification system. For example, while the capability of an object that could pose a threat may not be known at first, over time, continued monitoring will give better indications of the object's range of capabilities. Thus, prolonged deployment prior to use will limit a counterspace weapon's utility for a surprise attack.

Discerning intent, however, will be difficult absent an official declaration from a space object's operator. However, by using new technologies and methodologies, it might be possible to

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[51] Analytical Graphics Inc. podcast, Episode 14: Luch Space Activities, 26 June 2019, https://www.youtube.com/watch?v=D67dg9P3eDY.

[52] Idem. The French Government expressed concern about the same Luch/Olymp co-orbital vehicle and subsequently announced that they will begin developing the means to defend their satellites in space, possibly with lasers that can blind other satellites. Christine Mackenzie, "France Plans to Boost its Self-defence Posture in Space", DefenseNews, 26 July 2019, https://www.defensenews.com/global/europe/2019/07/26/france-plans-to-boost-its-self-defense-posture-in-space/.

[53] Based on data provided to the author by Vladimir Agapov, derived from the ISON network.

[54] See generally Amanda Rynes and Trond Bjornard, "Intent, Capability, and Opportunity: A Holistic Approach to Addressing Proliferation as a Risk Management Issue", Idaho National Laboratory, July 2011, https://inldigitallibrary.inl.gov/sites/sti/sti/5223019.pdf. See also Adam Meyer, "Controlling What You Can Control: Using the Threat Triangle to Gain Focus", Surf Watch Labs—Cyber in Sight, 7 November 2016, https://blog.surfwatchlabs.com/2016/11/07/controlling-what-you-can-control-using-the-threat-triangle-to-gain-focus/.

gain a sufficiently clear picture of when space objects do represent a threat.

Referring back to the previous example of AGI, the company has developed an SSA product, called Space Object Threat Analysis, that focuses on objects that can potentially reach another space object quickly—"sifting through millions of possible trajectories" to identify opportunities for negative actions, based on suspected capabilities.[55] By using their experience in tracking other objects (using their own database of profiles), AGI developed a system that can provide timely warnings about possible threats from single or even multiple objects simultaneously. The downside of this approach is that the calculations are based on previous observations, so new objects with new capabilities will pose difficulties for the system. While still novel, the fundamental methodology for making such space threat assessments exists and will likely improve in coming years.

Despite new detection and identification capabilities, it is still difficult to comprehensively assess a threat without understanding intent. To address this issue, work is now being undertaken to strengthen knowledge surrounding certain space activities. Space Strategies Consulting, mentioned earlier, recently obtained a research grant from the Canadian Government to develop an algorithm to extract intelligence related to spacecraft from publicly available sources.[56] This would include not only public statements and notifications about a space object, but also policies and strategies related to it. The process will conduct traditional intelligence gathering at a much faster rate and more extensively than previously possible. This contextual information can then help to characterize the nature of a space object's mission. In other words, this tool may help to glean the intent behind an object, much the same way that a criminal investigator builds a case around motive. This technology is still in the prototype phase, but preliminary findings indicate that the tool will be able to provide some useful data. When combined with technical observations and measurements, such contextual information can further improve international awareness and, potentially, the predictability of orbital activities.

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[55] See presentation by Tom Johnson, "Space Threat Assessment", AGI, published 7 May 2019, https://www.agi.com/news/blog/april-2019/space-object-threat-assessment-tool.

[56] See presentation by Col. Andre Dupuis, President of Space Solutions Consulting, UNIDIR Space Security Conference, 28–29 May 2019, Geneva, https://www.youtube.com/watch?v=PK3ByBjNAjg&list=P-LEQ2SvONl8gzgeiE7MdfWmaRbSmgVrFhm&index=8&t=4910s.


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7 What to expect?

Considering the technology that is emerging and will soon emerge, what can one expect from SSA capabilities in the next few years? After all, international agreements can take years, even decades, to negotiate. Even if the international community agreed upon the scope of a treaty today, it would probably still take years bring into force.

What might SSA look like by then?

First, it is likely that there will soon be near-persistent eyes on the sky, and on GEO in particular. As more SSA actors expand their networks and combine their data, there will be more consistent and persistent monitoring of objects in orbit. Moreover, there is no indication that this trend will slow. While capabilities dedicated to LEO are still limited, there is every indication that these will follow the same developmental trajectory as capabilities focused on GEO. Cooperation and data-sharing will also play a key role in the effectiveness of SSA in the future. Even if every SSA network is unable or unwilling to share data through a single international system, at the very least it is likely that there will be several large SSA networks with many partners around the world. These different networks could act as checks on each other to confirm or refute evidence related to an actor or occurrence in orbit.

Second, the type of SSA measurements taken will continue to diversify. Different types of sensors will detect diverse aspects of space objects, continually improving the ability not only to track but to accurately characterize and identify them. Even if an object's capabilities are not known right away, over time an accurate profile can be built up through empirical measurements and,

importantly, link an objects' activities back to the operators. This process will not be perfect, but it will continue to improve, thereby reducing the number of unidentified human-made objects in space.

Finally, it is likely that new algorithms will make it possible to conduct meaningful intelligence-gathering from public sources that shed light on the intent behind a space activity. While it is difficult to gauge to what extent this method will reveal the specific purpose of a mission, it will help to build up context around space activities. By doing so, States may still not have 'smoking gun' evidence of intent but will have a better idea of whether an object presents a threat. However, as this technology comes into use, the behaviour of operators with malicious intentions will also likely change, leading to new types of subterfuge that seek to hide information regarding the true purpose of a space object (such as releasing false public information about the mission). As such, this method of gathering intelligence may not be enough to establish the true intent behind an activity. Nevertheless, better information built up around an activity in combination with empirical data will still be useful.

8 What to do with this technology?

Given the advances in SSA technology over the last 10 years, and what will likely develop in the next few years, what form might a new space security regime take?

8.1 PREVENTION OF THE PLACEMENT OF WEAPONS IN SPACE

At present, the only existing proposal for a treaty related to space security is the proposal on the prevention of the placement of weapons in space. The main objective is a prohibition of weapons in space. A 'weapon in space' is defined as:

> any outer space object or its component produced or converted to eliminate, damage or disrupt normal functioning of objects in outer space, on the Earth's surface or in the air, as well as to eliminate population, components of biosphere important to human existence, or to inflict damage to them by using any principles of physics.[57]

The scope of this proposal is considered problematic by several States and experts because of the dual-use/multi-

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[57] Article I of the Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects (Draft), 16 June 2014, https://www.fmprc.gov.cn/mfa_eng/wjb_663304/zzjg_663340/jks_665232/kjfywj_665252/t1165762.shtml.

use nature of certain space objects.[58] For example, a co-orbital vehicle capable of removing space debris might also be capable of removing a fully functional satellite in an aggressive or hostile manner. An SSA system could detect and correctly identify the full range of capabilities of a co-orbital vehicle in a timely manner but be under the false impression that the object's mission is for repair or refuelling only. In GEO, where objects are relatively close, a co-orbital vehicle might attack a nearby satellite before an operator could respond. One hypothetical scenario is that a State with considerable space resources might launch a constellation of co-orbital vehicles under the pretext that they will service satellites in GEO. However, this might also allow them to position their assets to carry out simultaneous attacks on many satellites, giving them a considerable military advantage.

When considering the criteria for verification set out above, it appears that current SSA technologies are not ideal for a wide-scope verification system yet. It would be easy to circumvent the system with any number of co-orbital vehicles, simply by claiming that the objects are for benign purposes. By the time an actor reveals its true intentions, it could be too late to prevent a benefit from the breach of obligations. And since this could be done with a constellation of co-orbital vehicles, the nature of the breach could reach the level of being strategically meaningful. This is not to say that a space security agreement with a wide scope is not desirable. Indeed, there are other reasons why adopting a treaty on the prevention of the placement of weapons in space could help to mitigate certain threats. However, if effective verification is a critical requirement for an agreement on space security, then current and near-term technology does not appear ready for that purpose.

8.2 RESTRICTIONS ON BEHAVIOURS

Another option for the possible scope of an agreement is to limit behaviours. As noted in UNIDIR's 2010 study, it is easier to detect and monitor activities than it is to determine the function of an object. This would make the technology underpinning a spacecraft irrelevant, so long as it is not used in a prohibited manner.

The first behaviour one might consider is the same as discussed above, namely a prohibition on the placement of weapons in space. However, considering the placement of weapons in space in this manner does not change the challenges for verification. An actor could still circumvent the system by claiming a dual-use object is for peaceful purposes until the last moment, at which time it is too late for an operator to respond. Modern SSA capabilities would still be insufficient for an effective verification system that prohibits placing weapons in space.

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[58] See footnote 10 of this document. See also, Michael Listner and Rajeswari Pillai Rajagopalan, "The 2014 PPWT: a new draft but with the same and different problems", The Space Review, 11 August 2014, http://www.thespacereview.com/article/2575/1. See also Jeff Foust, "U.S. Dismisses Space Weapons Treaty Proposal As "Fundamentally Flawed"", SpaceNews, 11 September 2014, https://spacenews.com/41842us-dismisses-space-weapons-treaty-proposal-as-fundamentally-flawed/.

Another, more limited, option is to regulate the intentional destruction of objects in orbit. Destroying space objects is a highly visible action that is detectable and attributable. Sensors can detect an ASAT missile upon launch and track the missile until it strikes an object. A high-powered laser would be more challenging to detect, although it is possible to estimate the source depending on the position of the target satellite. While these options for scope are relatively easy to detect, it would still be difficult to detect violations in time to deny an offending party the benefit of their actions. By the time sensors detect the destruction of an object, the damage is done. This will be especially problematic in a salvo situation where a party targets many satellites at once. In terms of performance, this is probably not an option for an effectively verifiable system based on the criteria set out above, although it may be useful for other challenges such as mitigating space debris.

A related approach could be the prohibition of destructive ASAT tests or demonstrations. Several experts have suggested that limiting the active testing of ASATs is one way to mitigate the creation of space debris, while still permitting States to develop counterspace capabilities.[59] The advantage of this approach is that current SSA technology can readily detect the intentional destruction of an object in orbit.[60] The testing itself will not necessarily give an actor a militarily meaningful advantage since the testing of ASATs can also be done with virtual targets, particularly direct ascent ASATs. However, testing with physical objects can lead to large clouds of debris that are an indiscriminate hazard to other objects. In terms of acceptability, this approach would likely be favourable to those actors with the most space objects, since they have the most to lose from debris. Leading space powers and other space actors may be willing to consider this limited approach to a space security agreement since they have interests at risk. It would also be difficult to cheat such a prohibition as today it is very hard to hide a major debris-generating event in orbit. From the perspective of verifiability, this approach could be a viable option for an agreement on space security.

Another way that a satellite might be destroyed intentionally is from an attack by a co-orbital vehicle, so a prohibition on co-orbital attacks might be possible. As noted above, there is concern today that one or many co-orbital vehicles will place themselves near strategically important satellites and strike either singly or simultaneously. Modern detection and tracking capabilities

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[59] "After Indian Anti-Satellite Test, Russia Proposes Complete Ban On 'Dangerous' Tests", Eurasian Times, 26 July 2019, https://eurasiantimes.com/after-indian-anti-satellite-test-russia-proposes-complete-ban-on-dangerous-tests/, quoting Roscosmos Chief Dmitry Rogozin: "Roscosmos plans to initiate international negotiations with the aim of banning full-scale anti-satellite weapon tests held by way of destroying spacecraft and littering low orbits". See also Daniel Porras, "Towards ASAT Test Guidelines", UNIDIR, Space Dossier 2, May 2019, http://www.unidir.org/files/publications/pdfs/-en-703.pdf. See also Doug Loverro, "Why the US Must Lead Again", The Space Review, 14 August 2017, http://www.thespacereview.com/article/3307/2.

[60] Sandra Erwin, "U.S. Military was Immediately Aware of India's Anti-satellite Missile Test", SpaceNews, 27 March 2019, https://spacenews.com/u-s-military-was-immediately-aware-of-indias-anti-satellite-missile-test/.

are certainly capable of detecting an explosion that results in the destruction of a satellite. However, this approach has the same flaw as some of those above, namely that detection will follow the violation, leaving no time for reaction. Once again, the performance level of this approach is not enough to be effectively verifiable.

A more feasible approach might be to set a safe standard of distance for space objects. One of the challenges with co-orbital vehicles is that it is difficult to know what their capabilities or mission might be. Even if a co-orbital vehicle's capabilities are fully known, it could still get close to another space object under a pretext that it is only conducting "peaceful" activities. In this case, setting a minimum separation distance for space objects is a verifiable option. If this distance is violated, a party wishing to protect their asset could take counter-measures, either in space or on the ground. Likewise, it could also be prohibited to place too many objects in the vicinity of any one space system's objects. For example, putting too many co-orbital vehicles near satellites belonging to another's constellation (such as the GPS constellation) could be prohibited. Restricting how close space objects can come to one another, and how many objects can approach at once, could allow enough time for a targeted party to respond accordingly. Of all the options, this approach could work best in terms of detecting a violation in a timely manner. It would be up to States, however, to determine what proximity, or how many approaching vehicles, would constitute a militarily meaningful violation.

8.3 COOPERATIVE SPACE SAFETY INITIATIVES

There are other benefits to setting a minimum distance between satellites. For one, such a provision would likely be acceptable if incorporated into a wider space traffic management framework. Indeed, today there is a widespread call for greater regulation of space activities as the rate of placing objects in orbit increases. Even commercial actors are calling for new regulations that define the 'rules of the road' for Earth's increasingly populated orbits.[61] Devising space traffic management rules, including minimum distances based on security concerns, could be more politically feasible than trying to prohibit the deployment of specific classes of weaponizable technology. There might also be greater appetite for a global SSA network if its objective is to service space traffic management generally, rather than to monitor and address security threats exclusively. In this context, new rules could be discussed not only in the Conference on Disarmament, but also in other forums. The international community could discuss and develop a global space traffic management regime in forums such as the Committee on the Peaceful Uses of Outer Space. This would have the additional benefit of bringing a diverse range of actors and

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[61] Greg Wyler, "Space Needs to be Regulated before Humans Ruin It", CNN Business, 22 July 2019, https://edition.cnn.com/2019/07/22/perspectives/space-low-earth-orbit-satellites/index.html.

resources to the negotiations, including civil space agencies, commercial actors and academia. Such support could be instrumental in generating the necessary political will to adopt formal rules for space activities.

Finally, the potential for circumvention of this type of verification mechanism would depend greatly on the number of actors willing to share SSA data. As discussed in this paper, a single actor such as the United States can develop an extensive and effective SSA system, but it will have limitations. By partnering with other SSA actors, including other States and commercial operators, all actors can greatly enhance their range of vision in orbit. In this context, the most effective verification system—one that is the least susceptible to cheating—is the one that has the most 'eyes on the sky', including numerous and diverse sensors and actors. A global SSA organization, one that can draw upon data from many international sources, would be the most effective option for an effective verification system for space security. An international body could serve as a clearing house for data, safeguarding confidentiality while ensuring that operators are kept aware of relevant on-orbit activities. Such a body could be structured much like a modern air traffic control system. Given the extensive level of investment in space assets and systems, such a body is warranted to ensure the highest level of safety and security for all space objects. However, if a global SSA body is not politically feasible, even regional consortiums of SSA actors could enable effective verification for a space traffic management system. While such a system would not be as effective as a global one, it could still be useful in monitoring most activities in orbit and could be used to cross-check any allegations of violations against a space actor.

In sum, current SSA capabilities and trends are best suited either for a prohibition on ASAT testing or for a space traffic management system as the scope of an agreement related to space security (see Table 1). By setting 'rules of the road' and forming a central repository for SSA data, the international community could help to ensure the integrity of space objects and their related systems. It could also limit the opportunities for undetected disruption or interference therewith. By establishing baseline norms of behaviour, States can also make it easier to spot outliers that might indicate threats to space objects. Such an approach could enhance both safety and security in space and tangibly contribute to the long-term sustainability of human space activities.

TABLE 1: Summary of scope options

Approach	Benefits	Verifiable	Possibility to Circumvent
Prohibition on the placement of weapons in space	Prohibits placememnt of objects clearly intended to cause harm to others	Sometimes	High with co-robital vehicles
Prohibition of intentional desctruction of objects in orbit	Prohibits destruction of obecjts in orbit, mitigates debris creation	Yes	Low, but only useful after the fact
Prohibition or guidelines on destructive ASAT tests	Mitigation of debris creation	Yes	Very low
Prohibition of co-orbital attacks	Mitigation of co-orbital vehicle threats	Yes	Low in GEO, higher in LEO
Safe distances for co-orbital vehicles, space traffic management framework	Mitigation of co-orbital vehicle threats, increased safety for space traffic, greater transparency in orbit	Yes for GEO, less for LEO	Low in GEO, higher in LEO

9 Conclusions

Considering the technology that is emerging and will soon emerge, what can one expect from SSA capabilities in the next few years? Even if the international community agreed upon the scope of an internationally-legally binding instrument today, it would still take years to negotiate a text and bring such an instrument into force.

As noted throughout this paper, one of the main challenges to the development of an international instrument on space security is ensuring that the instrument is effectively verifiable. This means that a monitoring system is put in place that will detect “militarily meaningful” violations before the offending party can gain advantage from the violation. In the past, this was a stumbling block for international discussions because SSA capabilities were not sufficiently sophisticated for an effective verification system. Over the last 10 years, however, a range of actors around the world have expanded and improved their SSA capabilities, especially in GEO. More sensors, improved sensors and greater computing power are enabling a clearer picture of what is happening in Earth orbit. Moreover, increased cooperation among diverse actors is bringing new layers of information, adding detail to the picture of the space environment.

Despite these advances, it is still difficult to negotiate the scope of a treaty that would be effectively verifiable. This paper indicates that there are currently two approaches that could be effectively verified in a timely manner. First, a prohibition on destructive ASAT tests is verifiable in the sense that violations are detectable, and violators can be held to account before gaining a militarily meaningful advantage. A second option could be setting minimum distances for satellites, stating that space objects shall not come within a certain distance, nor should too many objects hold station near one actor’s satellites. By setting these limits, there is a greater chance that space actors could detect and respond to threats in time. This approach has the added benefit of being compatible with, and perhaps even fundamental to, a broader space traffic management regime. By making space-security measures part of a larger framework, it might be possible to build a stronger space security regime and overcome one of the divisive issues blocking progress in multilateral discussions on space security today.

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EYES ON THE SKY

RETHINKING VERIFICATION IN SPACE

One of the main challenges to the development of new measures for space security is the effective verification of compliance. For an agreement to be effectively verifiable, it must be possible to detect a militarily meaningful violation in time to deny the benefits of a violation. Developments in space situational awareness technology are enabling a clearer and more detailed picture of space activities, particularly in geosynchronous orbit. By combining new sensors and computing methodologies, it would be possible to effectively verify certain types of agreements on space security challenges.

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