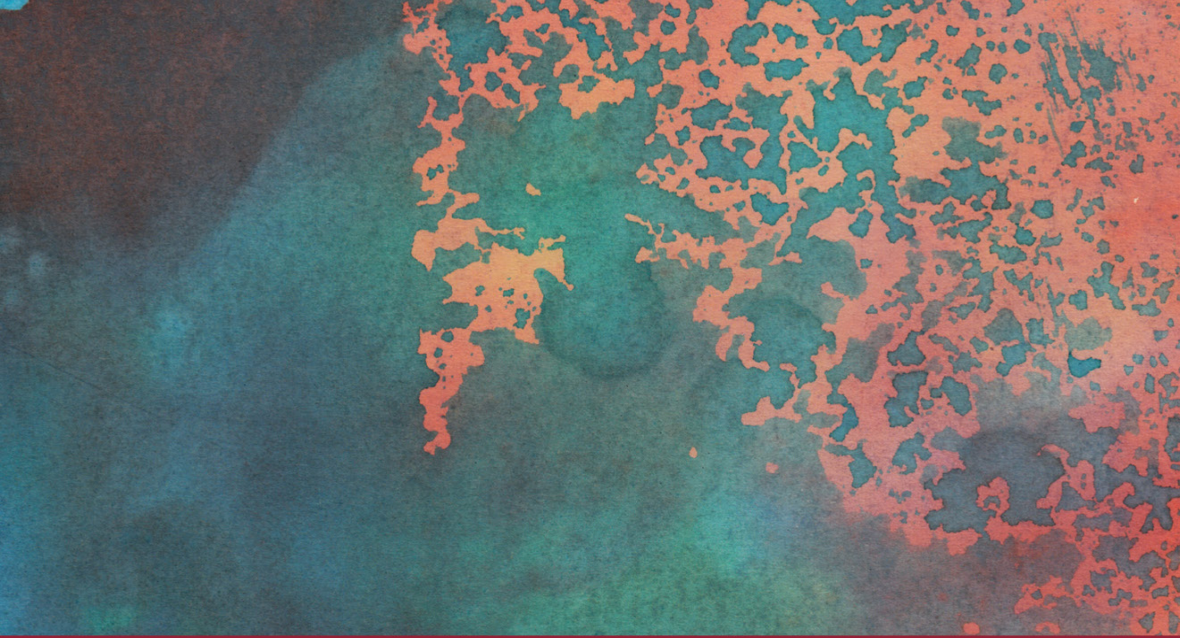

New International Relations

UNCERTAINTY IN GLOBAL POLITICS

Edited by
Miriam Matejova and Anastasia Shesterinina

Uncertainty in Global Politics

This book engages in a constructive, practical debate on the nature and effects of uncertainty in global politics. International contributors explore the processes associated with different forms of uncertainty in the context of environmental issues, diplomacy and international negotiations, and conflict and security. From the collapse of the Soviet Union to the 1997 and 2008 financial crises to the Arab Uprisings and the European migrant crisis and the COVID-19 pandemic, assessments of many events with lasting consequences on the global order have begun with: “why didn’t we see this coming?” There is much to learn from how phenomena that affect the global order generate uncertainty and what effects such uncertainty has on actors and issues. Presenting perspectives from all corners of the discipline and emerging and established scholars the book provides an up-to-date overview of the state of the literature; a concise yet conceptually rich theoretical framework; a mix of regional and global contemporary issues; process-oriented empirical evidence and methodological tools to assess different forms of uncertainty and propose practical solutions to addressing uncertainty in diverse contexts. The book will be of interest to scholars of global politics, international security, global environmental politics, international organizations and institutions, social movements, and conflict studies.

Miriam Matejova is Assistant Professor in Political Science at Masaryk University and Fellow at Norman Paterson School of International Affairs, Carleton University. Her coauthored book *Disaster Security: Using Intelligence and Military Planning for Energy and Environmental Security Risks* was published by Cambridge University Press.

Anastasia Shesterinina is Professor and Chair in Comparative Politics, UKRI Future Leaders Fellow, and Director of the Centre for the Comparative Study of Civil War at the University of York. Her book *Mobilizing in Uncertainty: Collective Identities and War in Abkhazia* was published by Cornell University Press.

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and Anastasia Shesterinina

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Contributors

Sofie Bedford is an affiliated researcher at the Institute for Russian and Eurasian Studies (IRES) at Uppsala University, Sweden. She has been working on a research project problematizing the concept of "opposition" in post-Soviet authoritarian states with Azerbaijan and Belarus as the case studies. Her publications on this topic appeared in academic journals such as *Government and Opposition*, *East European Politics and Societies and Cultures*, and *Democratizatsiya: The Journal of Post-Soviet Democratization*.

Adam Bower is Senior Lecturer in the School of International Relations and Director of the Centre for Global Law and Governance at the University of St Andrews, UK. His research explores the interaction of international law and political power in shaping outcomes in global politics. His book *Norms Without the Great Powers: International Law and Changing Social Standards in World Politics* was published by Oxford University Press.

Jesse Driscoll is Associate Professor of Political Science and Chair of the Global Leadership Institute at the University of California San Diego, USA. He is an area specialist in Central Asia, the Caucasus, and the Russian-speaking world. His work has appeared in the *Journal of Conflict Resolution*, *Security Studies*, *Journal of Experimental Political Science*, and *Post-Soviet Affairs*. His book *Warlords and Coalition Politics in Post-Soviet States* was published by Cambridge University Press.

Christian Elliott is a PhD candidate in the Department of Political Science at the University of Toronto, a Joseph-Armand Bombardier Canada Graduate Scholar, and an associate with the Environmental Governance Lab at the Munk School for Global Affairs and Public Policy, Canada. He researches the political economy of climate change and sustainable finance, in particular. He has published in the *Journal of Environmental Politics and Planning*.

Miao-ling Lin Hasenkamp is Senior Research Associate at the University of Rostock, Germany. Her research interests include comparative political systems, international human rights, comparative public policy analysis in the fields of human rights, sustainability, global health, and migration issues, democratic governance, and global justice. She has published in the *Journal of International and Global Studies* and edited *China and Autocracy: Political Influence and the Limits of Global Democracy* (I.B. Tauris).

Katharina Hunfeld is Associate Lecturer in the School of International Relations at the University of St Andrews, UK. Primarily interested in epistemic injustice, de/coloniality, and International Political Theory, her research explores the ways in which African thought can offer an alternative, decolonial perspective on some main issues of the global justice debate. She has published in the *Journal of Global Ethics*.

Ilan Kelman is Professor of Disasters and Health at University College London, UK and Professor II at the University of Agder, Norway. His research interest is linking disasters and health, including the integration of climate change into disaster research and health research. His book *Disaster by Choice: How Our Actions Turn Natural Hazards into Catastrophes* was published by Oxford University Press. He coedited the *Routledge Handbook of Hazards and Disaster Risk Reduction*.

Roxani Krystalli is Lecturer in the School of International Relations at the University of St Andrews, UK. Her research explores various dimensions of feminist peace and conflict studies, particularly the ethics of storytelling about violence and peace. Her work has appeared in the *European Journal of International Relations*, the *International Feminist Journal of Politics*, the *Journal of Refugee Studies*, the *Oxford Handbook on Gender and Conflict*, and the *Companion to Peace and Conflict Fieldwork* (Palgrave Macmillan).

Leah Matchett is a U.S. federal government contractor and a former Knight Hennessy scholar at Stanford University, USA, from which she also holds a PhD in Political Science. Her work focuses on the domestic politics of foreign policy.

Miriam Matejova is Assistant Professor in Political Science at Masaryk University, Czechia and a fellow at Norman Paterson School of International Affairs, Carleton University, Canada. Her research centers on environmental disasters, risk assessment and uncertainty, and environmental movements. She has published in *Global Environmental Politics*, *Environmental Communication*, and the *Australian Journal of International Affairs*. She coauthored *Disaster Security: Using Intelligence and Military Planning for Energy and Environmental Security Risks* (Cambridge University Press).

Liam Moore is a PhD candidate at the University of Wollongong, Australia. His current research interests include the intersection of issues of forced migration, protection, and climate change and debates around constructivist International Relations theory. His PhD thesis strives to understand how and why Pacific states are developing, implementing, and promoting domestic-level policies on climate-related displacement and mobilities.

Stephen Noakes is Senior Lecturer in Politics and International Relations and Director of the China Studies Centre at the University of Auckland, Australia. His research focuses on the connections between global and domestic civil society organizations, human rights protection, and processes of institutional dynamism in nondemocracies. His book *The Advocacy Trap: Transnational Activism and State Power in China* was published by Manchester University Press.

Phil Orchard is Associate Professor of International Relations at the University of Wollongong and Senior Research Fellow at the Asia-Pacific Centre for the Responsibility to Protect, Australia. He is the author of *Protecting the Internally Displaced: Rhetoric and Reality* (Routledge) and *A Right to Flee: Refugees, States, and the Construction of International Cooperation* (Cambridge University Press), which won the 2016 International Studies Association Ethnicity, Nationalism, and Migration Studies Section Distinguished Book Award.

Berenike Prem is a postdoctoral researcher at the Institute of Intercultural and International Studies (InIIS), the University of Bremen, Germany. Her research concentrates on the evolving practices of warfare, with a focus on the activities of Private Military and Security Companies (PMSCs) and the role of new military and security technologies. She is the author of *Private Military and Security Companies as Legitimate Governors: From Barricades to Boardrooms* published by Routledge.

Natalia Savelyeva is Lecturer at the University of Wisconsin-Madison, USA and a researcher with the Public Sociology Laboratory of the Centre for Independent Social Research in St. Petersburg, Russia. Her research focuses on the perspectives of participants in the fighting and its aftermath, with an emphasis on the pro-Russian side in the violent conflict that began in Ukraine in 2014. She has published in the *International Journal of Politics, Culture, and Society*.

Anastasia Shesterinina is Professor and Chair in Comparative Politics, UKRI Future Leaders Fellow, and Director of the Centre for the Comparative Study of Civil War at the University of York, UK. Her research examines the internal dynamics of international intervention in armed conflict. Her book *Mobilizing in Uncertainty: Collective Identities and War in Abkhazia* published by Cornell University Press received the 2022 Charles Taylor Book Award and Davis Center Book Prize.

Haley J. Swedlund is Assistant Professor in the Department of Political Science, Centre for International Conflict Analysis and Management (CICAM) at Radboud University, Netherlands. Her research focuses on foreign aid and development, ethnic conflict and violence, Sino-Africa relations, and diplomacy and engagement after the sudden regime change. Her book *The Development Dance: How Donors and Recipients Negotiate Foreign Aid* was published by Cornell University Press.

Shambhawi Tripathi is a PhD candidate in the School of International Relations at the University of St Andrews, UK. Her research explores the absence of a conceptual human in International Relations and the alternative worlds that can be apprehended through an emotional retelling of the human and the discipline. Her work has appeared in the *Sociological Review Magazine* and *Contemporary Voices: St Andrews Journal of International Relations*.

Umut Yüksel is a Marie Skłodowska-Curie Postdoctoral Fellow at Universitat Pompeu Fabra, Spain. His research explores how international legal rules are produced and modified through multilateral and judicial lawmaking, how international law becomes more uncertain in the process, and the consequences this uncertainty has on state behavior and interstate outcomes. He has published in the *German Law Journal* and the *Global Encyclopedia of Territorial Rights*.

11 Orbital uncertainty and the governance of outer space activities

Adam Bower

Space technologies are an increasingly vital backbone of modern information-centric societies, providing unprecedented information about the natural environment and human activities on Earth. Since the 1960s, the leading space powers (initially the Soviet Union and the USA, but now also others like China and European states) have used satellite-based sensors to detect military maneuvers, assess compliance with arms control agreements, and provide early warning of intercontinental ballistic missile launches. Ultraprecise position, navigation, and timing (PNT) systems enable everything from geolocation and just-in-time logistics to banking transactions. The US LANDSAT, EU Copernicus, and China High-resolution Earth Observation System monitor environmental conditions in the atmosphere, on land, and the oceans, and support security and emergency management services. Commercial satellite operators including Capella, Maxar, and Planet now collect vast amounts of data daily and are increasingly employing machine learning to provide tailored geospatial analysis to clients.

As a result, states, private companies, intergovernmental and nongovernmental organizations, academics, and citizens can access information of a previously unparalleled scale and depth. For example, optical and synthetic aperture radar imagery can help uncover clandestine military activities and human rights violations; infrared and hyperspectral imagery is employed to track agricultural practices, and measure greenhouse gas emissions energy use; and radio frequency analysis can be used to assess global transportation networks and detect activities (like illegal fishing) in hard-to-access areas. The rapid growth in data sources, quality, and processing power has led some analysts to suggest that we are approaching an information "singularity" where even private citizens will have access to pervasive real-time Earth observation data and analytics (Koller 2019).

But while satellites have radically expanded our knowledge of terrestrial phenomena, information regarding the nature and operation of these space-based systems is comparatively limited because near-Earth (orbital) space poses unique challenges for the effective monitoring and management of space assets. This chapter contributes to the volume's theme by examining the sources, implications, and means of ameliorating uncertainty regarding orbital space activities. The first section conceptualizes "orbital uncertainty" as the product of limitations on the quantity and quality of measurable data and its utilization – what Matejova and

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Shesterinina characterize as *ontological uncertainty* in the introduction to this volume. I argue that space operations experience both external (environmental and technological) and human (interpretive and political) constraints on the accuracy, precision, and timeliness of information concerning artificial space objects.

The present case study reflects elements of three generic theoretical accounts identified by Matejova and Shesterinina (in the introduction to this volume). The convergence between the physical properties of outer space, diversity of actors and activities, and technical and human constraints generates *information deficits* that are central to rationalist approaches. In this context, there is enduring uncertainty concerning the position and trajectory of discrete satellites as well as the intentions of their operators, especially in instances of political or commercial competition between spacefaring actors. The development of technologies to detect, identify, track, and predict the future locations of objects in orbit around Earth – known as space situational awareness (SSA) – is vital to improving the monitoring and management of the space environment, but also has the perverse effect of multiplying the sources and quantity of information, which, in turn, risks overwhelming space operators. In this respect, the problem of *too much information* – as noted in institutionalist accounts – is an increasingly prevalent challenge in the space domain, requiring coordinated responses to standardize, curate, and disseminate data concerning spacecraft. Finally, while the chapter focuses primarily on these first two types, the picture is further complicated by the *absence of shared meanings* – associated with constructivist perspectives – that emerge from inherent cognitive biases in human or machine interpretation of data as well as differing views concerning the appropriate limits on space operations.

Space technologies serve human needs on Earth and are deeply embedded in the fabric of global politics. The inability to accurately identify all space objects, determine their precise location, and predict their future behavior has led to growing concerns for the long-term sustainability of orbital space, especially in light of the proliferating scale and complexity of space activities and corresponding congestion in primary orbital zones. The second section, therefore, examines how orbital uncertainty impacts the conduct of contemporary international affairs. The absence of clarity concerning actor capabilities, operations, and intentions introduces sources of misperception and mistrust that can undermine effective coordination and exacerbate conflict. Gaps in timely and precise information also increase the risks to space assets from accidental or intentional interference and collisions, or deliberate attacks. In turn, accumulating space debris could generate a negative feedback loop which renders key orbital zones unusable, with catastrophic consequences for societies on Earth.

Orbital uncertainty thus represents an important global governance challenge since improving information concerning outer space activities is increasingly vital to managing interactions between spacefaring actors and preserving the outer space environment.[1] The third and final section traces current and proposed pathways to mitigating uncertainty in orbit, highlighting technical, diplomatic, legal, and economic mechanisms to improve transparency. However, while the governance of space activities can be enhanced, the physical, technological, and human sources of uncertainty can never be fully overcome. Attempts to reduce orbital uncertainty to a finite calculation of risk based on known quantities are, therefore, illusory; uncertainty must be managed, rather than eradicated.

Uncertainty in orbital space: Information and its limits

There are now over 5400 active satellites orbiting our planet, a figure that has tripled in the last five years and is predicted to grow 10- to 20-fold over the coming decade (Oltrogge and Christensen 2020: 432; Union of Concerned Scientists 2022). The growing ubiquity of satellite-based services has generated widespread recognition of the need for detailed knowledge of satellite characteristics and operations so that operators and regulators at national, regional, and international levels can identify and potentially mitigate hazardous or threatening activities. In this context, space traffic management has emerged as a multifaceted governance effort directed towards 'the planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment' (Oltrogge and Alfano 2019: 72; Sorge, Ailor, and Muelhaupt 2020). The international community has developed a range of initiatives to support this objective, involving contributions from states, intergovernmental bodies, commercial operators, and civil society.

The 1967 Outer Space Treaty (OST) provides a general obligation for spacefaring states to inform the international community 'to the greatest extent feasible and practicable, of the nature, conduction, locations and results' of their space operations (United Nations General Assembly 1966: Article XI). More concretely, the 1974 Registration Convention requires states to register space objects under their jurisdiction and provide the United Nations (UN) Secretary-General with basic information concerning the satellite's state of registry, registration number, launch time and location, orbital parameters, and general purpose (United Nations General Assembly 1974; Jakhu, Jasani, and McDowell 2018). The UN duly maintains an international Register of Objects Launched into Outer Space containing data voluntarily furnished by states (United Nations Office of Outer Space Affairs, no date). A myriad of multilateral institutions (e.g., UN Committee on the Peaceful Uses of Outer Space, International Telecommunications Union, and Inter-Agency Debris Coordination Committee), industry consortia (e.g., Space Safety Coalition), and scientific bodies (e.g., Committee of Space Research) provide fora for information-sharing, dialogue, and standard-setting. Official information sources are supplemented by nongovernmental organizations, academics, and space enthusiasts who provide open-source analysis of space activities (McDowell 2021; Weeden and Samson 2021). Finally, much of the tangible regulation is conducted at the domestic level by national agencies which are responsible for licensing space launches and satellite operations and reporting these activities to the UN.

These institutions are supported by rapidly expanding SSA capabilities 'to provide decision-making processes with a quantifiable and timely body of evidence of behavior(s) attributable to specific space threats and/or hazards' (Jah 2020: 964). Major spacefaring states and commercial providers maintain networks of ground-based and space-based sensors and associated analytical capabilities to collect, analyze, and disseminate data concerning space objects.[2] This wealth of information is further aggregated and presented by commercial member bodies (e.g., Space Data Association), scientific networks (e.g., International Scientific Optical Network), and private initiatives (e.g., AstriaGraph and Celestrak). Dedicated communities of hobbyists also identify and track space objects (often clandestine spy satellites) and share their findings via social media and the Internet.

Despite these advances, 'the population of Earth-orbiting space objects is still neither rigorously nor comprehensively quantified, and the behaviors of these objects … are inadequately characterized' (Jah 2020: 962). Fundamentally, therefore, the state and nonstate space operators experience systemic forms of ontological uncertainty that stem from the *absence* and *overabundance* of information as well as the *lack of shared meanings* concerning underlying behaviors. Data regarding the nature and operation of artificial satellites is incomplete, derived from multiple and often incompatible sources, and requires human and – increasingly – automated interpretation based on a partial understanding of the objects and their relationship to the natural environment as well as the intentions of their operators. These limitations, in turn, are attributable to three principal types of challenges: the physical properties of outer space, the growing complexity of space operations, and the technical and human constraints on information acquisition and processing.

While the universe is effectively infinite, the usable orbital zone around Earth begins at approximately 160 km above the Earth's surface – the minimum altitude where an object can sustain itself in orbit – and extends to nearly 36,000 km, encompassing a volume of roughly 312 *trillion* cubic kilometers. This immense scale poses distinct challenges for identifying and tracking space objects, which increase with distance from Earth. Low-Earth orbit (LEO) extends to 2000 km, though most satellites operate below 1000 km. Proximity means that LEO is easier to monitor but objects at these altitudes move very rapidly – 7.8 km a second, or 28,000 km per hour – and are only briefly in view of a static point on Earth in a given orbit. This requires a network of sensors distributed around the world to maintain regular monitoring. By contrast, satellites in geostationary orbit (GEO) are much further from Earth (at 35,786 km) and thus appear as smaller and dimmer objects for Earth-based surveillance systems (Jakhu, Jasani, and McDowell 2018: 414).[3] This is mitigated by the fact that GEO satellites orbit at the same rate as the Earth's rotation, meaning they always remain visible at the same point in the sky.

Despite this enormous scale, orbital space is becoming increasingly crowded. Roughly 84% of active satellites are located in LEO (Union of Concerned Scientists 2022). Existing proposals envision the deployment of nearly 100,000 satellites by the end of the decade, the vast majority of which will be operated by private companies (Messier 2021). This ambitious target will not be reached, but even a fraction would still represent many times the total payloads placed in orbit over the entire Space Age to date, with a corresponding growth in orbital debris absent substantial mitigation measures. These satellites will increasingly be concentrated at particular orbital altitudes as part of large constellations.[4] The shift to smaller and cheaper satellites presents additional difficulties since these systems are designed for shorter life spans and may experience higher failure rates than expensive bespoke satellites (Muelhaupt et al. 2019: 83–84). They are also harder to detect with existing SSA sensors.

This growing satellite density in LEO reduces the distances between objects and multiplies the frequency with which distinctive satellite orbits intersect, increasing the prospect of near-misses and actual collisions. Satellites owned by the single largest operator, SpaceX, were recently estimated to be responsible for at least half of all collision risks. The expansion of their Starlink constellation may lead this proportion to grow to as much as 90% (Pultarova 2021). The testing of anti-satellite weapons constitutes a further challenge. The Russian Federation's deliberate destruction of one of its own satellites in November 2021 generated over 1500 pieces of trackable debris that have subsequently generated punctuated surges in the number of potential collisions between debris and active spacecraft; one commercial SSA firm has predicted up to 40,000 close encounters in a single week (Foust 2022b).

While the GEO region is not experiencing the same rapid expansion in activities, here too there are concerns for spacecraft congestion and potential collisions (Oltrogge et al. 2018). Despite its distance from Earth, the actual operational GEO belt is highly constrained: satellites must be positioned very near to the 35,786 km altitude and along the plane of the Earth's equator in order to remain stationary relative to the ground. And since the demand for GEO satellite telecommunication services is concentrated in certain high-density areas of the globe, orbital slots are a limited resource. The challenges of spacecraft operating in relatively close proximity are further complicated by extensive orbital debris that crosses through the GEO belt.

These congestion and collision risks in LEO and GEO have, in turn, radically increased the need for satellites to perform regular evasive maneuvers (Oltrogge and Alfano 2019: 72–74). At present, however, most satellites have limited maneuverability, as propulsion is finite and costly and orbital adjustments are time consuming and require actionable information regarding the appropriate response. The adoption of more efficient electrical propulsion and automated collision avoidance technologies will greatly improve spacecraft responsiveness (De Selding 2021). But these capabilities further complicate the operational environment since more regular orbital maintenance and collision-avoidance maneuvers make it harder to anticipate the precise position of a satellite into the future.

This growing operational complexity has radically increased the volume of tracking and identification requirements for SSA systems. Yet, current sensor technologies can only detect a tiny fraction of all artificial space objects: as of March 2022, the United States Space Surveillance Network identifies approximately 44,000 objects larger than 10 cm in diameter in Earth orbit but only tracks 25,600 of those due to insufficient data on the remaining objects (United States Space Command, no date). There are estimated to be between 500,000 and one million unidentified items ranging from 1 cm to 10 cm in size and between 100 and 330 million objects smaller than 1 cm.[5] Improvements in sensor capabilities will greatly expand the number of trackable objects but will still only cover a modest subsection of the total – and growing – population. This is problematic because ‘an impact in LEO with an object 1 cm or larger will cause damage likely to be fatal to a satellite’s mission. Therefore, there is a large latent risk from unobserved debris’ (Muelhaupt et al. 2019: 81).

Incomplete adherence to international reporting requirements further restricts the known space object population (Jakhu, Jasani, and McDowell 2018). While compliance with the UN Registration Convention is generally high, more than 10% of all spacecraft launched into orbit are not currently listed in the UN catalogue (United Nations Office of Outer Space Affairs, no date). State authorities submit only basic orbital data (often long delayed) without supplemental descriptive information that can help assess a satellite’s functions. Notably, major space powers typically do not publish technical details and orbital parameters of clandestine military and intelligence satellites. This opacity is symptomatic of the prevailing secrecy that surrounds national security space programs – an issue that is explored in detail in the next section. Much of the orbital debris created during launches or subsequently is also not reported.

Among the population of catalogued objects, there are important constraints on the accuracy (the degree of fidelity between the calculated and actual position) and precision (the extent of correspondence between independent measurements) of available data. The most common format, known as two-line element, provides only basic information concerning orbital parameters and lacks a contextual indication of the uncertainty associated with measurements (Jah 2020: 967; Oltrogge and Alfano 2019: 76). More sophisticated Special Perturbations data are usually not shared in their complete form. In addition, space object catalogues do not record the size, shape, material properties, or functions of satellites; this information has to be inferred indirectly from data sources. Even the most advanced models derived from cutting-edge astrodynamics express an incomplete understanding of how space objects interact with their environment and thus how small changes affect movement into the future. Hence, while an object’s basic orbital route can be defined with some precision, its present and future positions can only be predicted within a margin of error which grows as a function of time (Jah 2020: 979–980).

There are also no universally accepted practices for calibrating SSA sensors and a lack of standardized protocols for reporting and distributing SSA data to end-users. Indeed, since SSA systems are used by states to manage their own space assets and identify, monitor, and attribute potential threats, the underlying technologies and the resulting data are a national security capability subject to restricted distribution (Borowitz 2019: 19–20; Weeden and Samson 2021: xxxi).[6] Equally, commercial SSA operators are keen to guard their proprietary analytical capabilities and business case by restricting the availability of high-quality data to paying customers. The bottom line is that spacecraft operators lack a complete picture of their operational environment and often cannot rely on the same basic data when designing and executing missions or evaluating the relative risks posed by their activities or those of others.

While the above discussion has focused on information gaps concerning space activities, an *overabundance of information* from expanding SSA capabilities generates its own forms of uncertainty. The lack of SSA standardization noted above means that different systems frequently report divergent measurements for the same space object (Jah 2020: 969). The multiplicity of SSA sources poses substantial challenges to the effective management, curation, and integration of often incompatible data streams that can be translated into actionable guidance. The increased capacity to identify and track objects, coupled with a relatively large margin of error in object detection systems, has led to a proliferation of notices – known as "conjunction warnings" – alerting spacecraft operators of potential collisions with another space object. This risks overwhelming operators' ability to assess relative operational risks and implement evasive maneuvers (Oltrogge and Alfano 2019: 75). Improvements in the accuracy of SSA data will allow analysts to isolate more dangerous close approaches and reduce the rate of false alarms (Sorge, Ailor and Muelhaupt 2020: 5). But this still only applies to the small fraction of dangerous space objects that have been identified and tracked.

Finally, orbital space operations are also subject to a *multiplicity of meanings* problem identified by Matejova and Shesterinina (in the introduction to this volume) (Jah 2020: 966–967). On the one hand, sensors and computers render useable information based on hypotheses derived from an inherently incomplete understanding of the outer space environment. On the other hand, human interpretation of raw data is influenced by forms of bias stemming from imperfect scientific models and SSA practices – as discussed above.

The broader challenge is that both state and commercial space operators currently lack detailed intersubjective agreement concerning proper conduct and the nature of risk in orbit. International space law provides aspirational values and an institutional framework for space exploration but imposes only modest restraints on the military and commercial uses of outer space (Jakhu and Dempsey 2016).[7] The OST and subsequent space treaties lack regular diplomatic meetings of State Parties as well as verification and enforcement mechanisms. Space diplomacy instead takes place in venues like the UN Conference on Disarmament, Committee on the Peaceful Uses of Outer Space, and General Assembly First and Fourth Committees with specialized mandates that prevent holistic consideration of the myriad intersections between military, commercial, and scientific space operations and which largely exclude nonstate actors. Most actors accept that terrestrial international law – including the UN Charter's prohibition on the use of force and the law of armed conflict – applies in space, but this has not been elaborated in detail. Different actors, therefore, operate with varying fundamental operational perceptions, which may not be well understood by others.

In sum, more and better data regarding the approximate position and trajectory of space objects can reduce but never eliminate uncertainty concerning conditions in Earth orbit, for three key reasons. First, there are technical and political limits to data quality and completeness. Second, more data presents its own challenges in terms of information management and dissemination and its integration in subsequent decision making. Third, bias can never be expunged since human perception is inevitably entangled with technical systems even as increasing proportions of the analysis are undertaken by automated processes. Indeed, SSA data does not reveal the *intentions* behind observed behaviors, which requires direct understanding of actor capabilities and objectives. Yet, such information is typically difficult to access, especially in sensitive high technology domains like space operations.

Orbital uncertainty and global politics

Orbital space is an extension of terrestrial political, economic, and social processes and, therefore, offers an important but thus far underexplored empirical context for assessing the role of uncertainty in contemporary global politics. While IR theoretical paradigms conceptualize and operationalize uncertainty differently, there is broad agreement that ambiguities regarding actor capabilities and intentions exacerbate competitive pressures and impede cooperation (Kaplow and Gartzke 2021: 307).[8] This section sketches some implications of the incomplete understanding of the nature and behavior of space objects for national security, commercial, and civilian space operators.

Scholars have long been interested in how asymmetries and deficits of information underpin dynamics including security dilemmas, crisis escalation, and deterrence. As Kaplow and Gartzke (2021: 308) point out, some systems are inherently harder to accurately detect due to their size or operational location. Jervis (1978) famously argued that opacity concerning military technologies and doctrines can generate arms race dynamics and mutual insecurity. The military space domain is emblematic of this phenomenon. China, India, Russia, and the USA are developing and, in some cases, have already deployed a range of ground-based and space-based anti-satellite capabilities – including missiles, lasers and microwave energy, electronic and cyber warfare, and close proximity operations – and a number of other states are actively pursuing similar systems (Weeden and Samson 2021). On this basis, analysts with the UN Institute for Disarmament research have found that core conditions for an arms race in space – namely, rivalry between major space powers, broadly equivalent capabilities, and an acceleration in the development and deployment of military space systems – already exist (Silverstein, Porras and Borrie 2020: 15–20). This is reflected in a view among the major space powers that their adversaries are turning space into a warfighting domain despite each of these actors professing a commitment to the continued peaceful uses of space (Weeden and Samson 2021: 1.28–1.30, 2.38–2.40, 3.29–3.34).

In this context, the absence of clear information concerning the capabilities and precise location of satellites, and/or the intentions of their operators, produce worrying sources of instability. In his classic formulation of security dilemmas, Jervis (1978) emphasized the relative efficacy of offensive versus defensive technologies and, crucially, whether the two can be distinguished, as key drivers of conflict. On the one hand, it is very difficult to protect satellites since an object's orbit is regular and its future trajectory can be predicted with considerable (but not perfect) precision, and countermeasures such as shielding and propulsion are limited by weight and cost considerations. This has led some to suggest that space is an offense-dominant domain (Kopeć 2019: 124–125).[9]

On the other hand, the entwinement of military, commercial, and civilian satellite operations makes it difficult to differentiate between threatening and benign systems (Grego 2021: 274–275). States increasingly rely on commercial systems to supplement their own bespoke capabilities in areas like space launch, satellite communications, high-resolution imagery, and SSA data. Commercial operators may, in turn, offer their products to a range of governmental and nongovernmental end-users. The Russian–Ukrainian war has prominently demonstrated how commercial satellite imagery informs media and humanitarian organization's monitoring of conflict; this imagery is also used by Ukrainian forces to identify, monitor, and target Russian military formations (The Economist 2022). The technologies themselves are, therefore, often inherently dual use. Emerging capabilities to service satellites or remove debris in orbit could also be used to disable or destroy an active asset. Even explicitly military systems may possess both offensive and defensive applications: ballistic missile defense interceptors can be repurposed for targeting satellites while recent proposals to deploy "bodyguard" satellites to protect sensitive national security space assets risk blurring the line between anticipatory and reactive actions.

Existing information sources cannot resolve these ambiguities. SSA data provides insights into a satellite's mission since distinctive types of orbits are particularly suitable for certain roles. But these inferences cannot determine a satellite's specific capabilities or the intent behind an observed action (Jakhu, Jasani, and McDowell 2018: 411). For example, evidence that a satellite maneuvered to rendezvous with another object does not provide an explanation as to why it did so. In recent years, US officials have raised concerns about Chinese satellites undertaking coordinated close approaches with unidentified objects in the GEO region and instances where Russian satellites appear to have ejected subsatellites at high velocity, which the US characterized as a 'space-based anti-satellite weapons test,' which Russia strenuously denied (U.S. Space Command Public Affairs Office 2020; Weeden and Samson 2021: 2.9–2.10). Similarly, experimental technologies like the US X-37B reusable spaceplane have generated concern from China and Russia that the system could be a test of an orbital weapons system – despite US insistence that it is a platform for scientific tests – precisely because of the lack of detailed insight into the nature and purpose of these operations (Weeden and Samson 2021: 3.5–3.6).

This is particularly problematic as major space powers increasingly operate in proximity. China, Russia, and the USA all regularly conduct close approaches of satellites – including sensitive military communications and reconnaissance assets – in LEO and GEO (Weeden and Samson 2021: 1.2–1.11, 2.5–2.14, 3.3–3.11). These operations are currently conducted to gain information on the local orbital domain, assess adversaries' capabilities, and eavesdrop, but could be configured to interfere with or damage the target satellite. An accidental collision could, therefore, be interpreted as a deliberate attack, particularly if it occurred during a period of heightened tensions.

As this suggests, the ambiguity surrounding sensitive military satellites is especially dangerous since space systems are embedded as part of critical national security infrastructures. During the Cold War, the Soviet Union and the USA established relatively clear expectations that satellites used to support military communications, nuclear command and control, and ballistic missile early warning were central to nuclear deterrence and, thus, would not be targeted due to the risk that such interference would be (mis)interpreted as the prelude to a larger attack (Acton, MacDonald, and Vaddi 2021: 61–69). In addition, bilateral arms control agreements like the Antiballistic Missile Treaty institutionalized understandings that prevented interference with space-based "national technical means" (a pseudonym for intelligence and reconnaissance) used to verify compliance.

However, this understanding may be breaking down for four related reasons. First, other space powers may not recognize this strategic agreement. For example, a 2013 Chinese ballistic missile test that reached an altitude of approximately 30,000 km caused great concern among US officials due to the relative proximity to GEO, where many sensitive military satellites are currently located (Weeden and Samson 2021: 1.14–1.15). Second, the integration of space-based sensors controlling conventional and nuclear forces within the same satellite systems risks blurring lines in crisis management. One recent report warned that the entanglement of nuclear and nonnuclear systems

> could lead to an inadvertent escalation of a US–China conventional conflict into the nuclear domain were China, as part of its conventional military response or deterrence, to attack this key part of the United States' nuclear infrastructure. The United States may interpret such action as a prelude to a nuclear attack, and respond with a nuclear strike of its own.
>
> (MacDonald, Freeman, and McFarland 2023: 15)

Third, the expanding range of counterspace capabilities complicates assessments of intentionality and the threshold for determining the use of force. There is no international consensus, for example, as to whether nondestructive and reversible actions – such as temporarily dazzling a satellite's optical sensors or jamming, hacking, or spoofing its data links – constitute an armed attack. These forms of interference are becoming commonplace presumably because they are perceived to be less threatening, but the targets of nondestructive and reversible actions may not be able to immediately determine the extent or reason for disruption to their satellites.

Fourth, the growing use of commercial satellites for conventional military roles can be further destabilizing as actors may hold different perceptions concerning whether a given satellite is actively contributing to military operations and whether that assumed activity is sufficient to justify an attack. For example, modern commercial communications satellites frequently handle signals for multiple customers that may include sensitive national security missions alongside (though typically separated from) civilian uses. Here again the ongoing war in Ukraine provides an illustrative example of how entwinement and resulting ambiguity can inform decisions regarding the use of force. Commercial operator SpaceX has reported regular – and apparently increasing – attempted cyberattacks against its Starlink constellation, which has been providing broadband internet links for civilian and military users in Ukrainian-controlled territory. While not acknowledging specific attacks, Russia has declared that commercial space systems are legitimate targets when they effectively contribute to military operations (Russian Federation 2022: 7).

These same considerations hold potentially contradictory implications for deterrence (Bahney, Pearl, and Markey 2019). On the one hand, strategic ambiguity can enhance deterrence by leaving adversaries guessing regarding one's specific capabilities. Restraint could be further enhanced by the widespread recognition that armed conflict in space would increase the population of dangerous debris and, thus, degrade the ability of *all* actors to access and utilize Earth orbit. Interestingly, the very inability to accurately monitor all space objects and predict future consequences reinforces the sense of risk underlying caution.

On the other hand, uncertainty concerning the orbital environment raises the prospects of misperception and miscalculation that can generate pressures towards escalation (Grego 2021). The incentive to conceal or misrepresent private information regarding capabilities and intentions is a key impediment to effective bargaining and de-escalation in Fearon's rationalist model of war (Fearon 1995: 395–397). In a crisis, short decision-making timescales would be exacerbated by the limits on available data to inform judgements. For instance, if during planned NATO military exercises a sensitive Russian military reconnaissance or communications satellite were to malfunction, existing SSA systems may not provide sufficiently nuanced information by which to quickly and definitively identify the source of the disruption (they could not provide a complete picture of all possible space objects in the vicinity, especially untracked debris) or attribute responsibility to a particular actor or capability.[10] In some cases, therefore, it would not be possible to distinguish between a deliberate attack and an accidental collision caused by debris or satellites operating in excessively close proximity.

Inversely, intentional but limited attacks – such as temporarily disabling a satellite with lasers, electromagnetic interference, or hacking – may have larger and more lasting effects than intended by the attacker and could be viewed by the target as part of wider military action including, potentially, the prelude to the use of nuclear weapons (Grego 2021: 273–274). In circumstances of actual or anticipated armed conflict, these factors may incentivize first-strike mentalities to degrade adversaries' known or suspected space capabilities (Bahney, Pearl, and Markey 2019: 135; Grego 2021: 272–273). In short, the forms of orbital uncertainty identified above pose substantial challenges for effective signaling in crisis management.

For these reasons, transparency can be used to convey capabilities, perceptions of threat, objectives (what behaviors one is seeking to deter), and resolve (Kaplow and Gartzke 2021: 307). According to one senior US military commander, excessive secrecy currently impedes US efforts to signal to adversaries: '[d]eterrence does not happen in the classified world. Deterrence does not happen in the black; deterrence happens in the white' (Hitchens 2021a). In 2014, the USA decided to publicly reveal the existence of its highly sensitive Geosynchronous Space Situational Awareness Program (GSSAP) GEO monitoring satellites in order to clarify their purpose and deter adversarial threats to US space assets (Klotz 2014).

But the information provided was extremely modest. Russian authorities have complained that GSSAP operations close to their sensitive military satellites have, in the words of Western analysts, ‘made it very difficult to estimate the current and future position of the GSSAP satellite and the other object, creating difficulty in determining safe approaches and ascertaining the intent of the approach, which could lead to misperceptions and mistakes’ (Weeden and Samson 2021: 3.8). At present, therefore, major space powers do not agree on fundamental features of an intersubjective deterrence architecture including what constitutes an attack against a space asset, the threshold that would generate a retaliation, and how the integration of space systems in nuclear and conventional domains contributes to these calculations (Bahney, Pearl and Markey 2019: 137–143). Indeed, in contrast to other security issues, states have comparatively little experience in dealing with space crisis management and thereby gaining appreciation for others’ perspectives (Grego 2021: 277).

While this discussion has mainly focused on state-based security dynamics, civilian and commercial satellite operators are also affected by uncertainty concerning their operational environment. Operators have only a partial basis upon which to assess risks to their space assets and the need – and proper amount and direction – for evasive maneuvers. They must also grapple with incomplete knowledge concerning the risk acceptance (how close is “too close”) and operational capabilities (especially conjunction analysis and collision avoidance) of other actors (Muelhaupt et al. 2019: 82; Oltrogge and Alfano 2019: 75). Commercial and civilian operators have different organizational cultures and decision-making structures and often disagree in their assessments of the probability of a conjunction and the attribution of responsibility. Intense competition for market share may incentivize nondisclosure of accidents and near-misses so as to preserve the company’s reputation and profitability (Oltrogge and Alfano 2019: 72). As a result, direct coordination between operators is impeded by the absence of clear communication channels and right-of-way rules regarding who should move their satellite in the event of a potential collision. Ontological uncertainty, thus, imposes economically inefficient material costs in the form of managing information flows, calculating orbital maneuvers, and expending propellant to move at-risk satellites.

In many cases, these are not merely commercial disputes but hold international political implications as well. In one recent example, the Chinese government complained that close passes by SpaceX Starlink satellites had endangered its crewed Tiangong space station and called on the USA to exercise its legal obligation to ensure safe conduct by commercial operators under US jurisdiction (Jones 2021). The USA disputed the claim and asserted that its own – implicitly superior – SSA system did not detect any unsafe close approaches between the identified spacecraft (Hitchens 2021b). A further response from the Chinese Ministry of Foreign Affairs highlights the challenges posed by uncertainty over data sources and operator standards: ‘China’s competent authorities tried multiple times to reach the USA side via e-mail, but received no reply …. [The USA] is not showing a responsible attitude as a space power. Moreover, it is in no position to unilaterally set a threshold of emergency collision criteria’ (People’s Republic of China 2022).

Mitigating orbital uncertainty

Effective space governance, therefore, depends on managing and, where possible, reducing uncertainty concerning space operators' behaviors and intentions. This final section briefly explores international efforts to enhance transparency across four broad thematic approaches.

First, as already indicated, there is a widely acknowledged need to improve the quantity, quality, and transmission of underlying data concerning space launch and satellite operations. Next-generation SSA systems like the US Space Fence and LeoLab's Costa Rica Space Radar are able to detect objects larger than 2 cm in LEO, greatly expanding the potentially trackable population of space objects (Shimkus 2020; LeoLabs 2021). State and commercial monitoring of the GEO belt is undergoing similar advancements. High-quality ultraprecise data regarding object positions and trajectories will be especially vital in reducing false alarm conjunction warnings and powering automated collision avoidance systems in satellite constellations.

Analysts have also suggested means of enhancing state compliance with the Registration Convention, including more detailed and timely reporting of satellite deployments (especially for short-duration small satellites), establishing clearer rules on the national responsibility for privately operated space systems, and developing verification mechanisms using ground-based and space-based platforms (Jakhu, Jasani, and McDowell 2018: 413–417). The discussion above also demonstrates the need for greater transparency from major space powers, especially in relation to their national security space assets. The USA has recently begun to include more SSA data in its public catalogue, but security sensitivities continue to impede more comprehensive information sharing (Verspieren 2021).

Yet, as argued above, more data alone is not a solution; instead, actors need to develop common standards for the collection, curation, aggregation, fusion, and dissemination of state, commercial, and nongovernmental data (Borowitz 2021; Jah 2020). In other words, effective SSA requires cooperation and coordination and is, therefore, inherently a global governance challenge. This reality has generated proposals, thus far unrealized, for new institutions including an international SSA sharing platform modelled on the air traffic control paradigm or even an international satellite monitoring agency (Quintana 2017: 95 and 98).

Second, since ambiguity concerning capabilities and intentions is a primary source of conflict, further international action is urgently required to develop shared understandings regarding acceptable and unacceptable activities in orbital space (United Nations Secretary General 2021: 7–8). This involves both clarifying military, civilian, and commercial actor perspectives on the legitimate uses of space as well as perceptions of risk and threat. This can take multiple forms. Cold War bilateral information and assurance mechanisms could provide a model for direct dialogue among the major military space powers of China, Russia, and the USA on issues relating to nonconsensual satellite close approaches and hostile interference with satellite systems. Despite intense competition and mutual mistrust, the Soviet Union and the USA developed a range of legal restraints on advanced weapons systems and confidence-building measures aimed at reducing miscalculation and escalation in a crisis. For example, the 1972 Incidents at Sea Agreement provided operational means to deconflict and stabilize interactions between Soviet and US naval assets.

A range of potential initiatives appear possible even in this period of heightened geopolitical tensions. Recently, a senior US military commander proposed the creation of hotlines with China and Russia – similar to those employed for nuclear weapons and during military operations in Syria – to enable direct communication on space operations, particularly in instances where sensitive national security satellites may operate in close proximity (Erwin 2021). In the wake of its apparent near-misses with Starlink satellites, China issued a similar call for a bilateral communication channel with the USA to address matters of mutual space safety (Foust 2022a). Specific discussions could subsequently focus on discrete areas for mutual reassurance, such as the creation of "keep-out zones" around sensitive military communication and nuclear monitoring satellites (Acton, MacDonald, and Vaddi 2021: 61–69). Military space powers should as well specify how the UN Charter and international law of armed conflict apply to space operations.

The international community is also pursuing more inclusive dialogues that aim to foster consultation and coordination regarding best practices, norms, and legal rules to improve the transparency and safety of space operations. In 2013, a UN-sponsored Group of Governmental Experts (GGE) produced a final report that outlined a series of voluntary transparency and confidence-building measures including information-exchange concerning national space policies and operations; prior notification of potentially threatening activities such as planned maneuvers in proximity to another operator's satellite, dangerous re-entries, or the intentional destruction of satellites; and limited access to national space launch and control facilities (United Nations General Assembly 2013: 13–18). The GGE process is a rare example of security cooperation among China, Russia, and the USA; yet, there is little evidence of national implementation of the GGE recommendations thus far. In 2019, the UN adopted a set of voluntary Guidelines for the Long-Term Sustainability of Outer Space Activities, representing another effort to 'promote international cooperation and understanding to address natural and [hu]man-made hazards that could compromise the operations of States and international intergovernmental organizations in outer space' (United Nations Committee on the Peaceful Uses of Outer Space 2019: para. 8).

The United Kingdom is currently leading an effort at the UN to foster multilateral discussions to characterize responsible and irresponsible behaviors in outer space (United Nations Secretary General 2021). Submissions from states, IGOs, and civil society have emphasized the importance of information exchange, consultation, and coordination as the basis for stabilizing interactions among spacefaring actors and preserving the operational environment. In December 2021, the UN General Assembly created an open-ended working group to meet in 2022 and 2023 and assess current and future threats to space operations, evaluate existing legal and normative structures, and draft consensus 'recommendations on possible norms, rules and principles of responsible behaviors relating to threats by States to space systems, including, as appropriate, how they would contribute to the negotiation of legally binding instruments' (United Nations General Assembly 2021: para. 5(c)). In turn, these diplomatic efforts will need to draw on SSA data as the basis for verifying any resulting commitments.

Third, despite some modest progress at the multilateral level, the majority of governance will continue to operate through domestic regulatory structures that hold the primary responsibility for ensuring compliance with international reporting and operational requirements. In contrast to most domains of international law, in space law states, and not commercial or civilian operators, remain legally liable for damage involving space assets (Larsen 2019; United Nations General Assembly 1971). This provides additional incentive to ensure there are adequate restraints on the rapidly expanding commercial space sector. However, many national institutions are either underresourced or excessively bureaucratized – or both. For example, in the USA, the responsibility for regulating commercial space is spread across multiple agencies, depending on the activity. This has led to calls for regulatory rationalization and streamlining to improve responsive decision-making and oversight.

Fourth and finally, commercial space operators are themselves both the subject and initiator of governance mechanisms aimed at improving transparency. Given the scale of investment in space launch and satellite systems, operators have a clear interest in advancing best practices for the safe and sustainable uses of orbital space. This involves a range of technical improvements to satellite deployment, operation, and disposal; for example, there are proposals to utilize physical reflectors, or better still, high-precision onboard transponders to make satellites more easily trackable (Muelhaupt et al. 2019: 86). For our purposes, a particularly significant development is the increasing willingness of companies like SpaceX to share detailed data on satellite positions and maneuvers with other operators – including direct market competitors (Muelhaupt et al. 2019: 84–85). Standard-setting bodies like the International Standards Organization and Space Safety Coalition, and nongovernmental organizations like the Secure World Foundation, work to consolidate and disseminate voluntary best practices, which emphasize information-sharing as a key objective (Secure World Foundation 2017).

Financial and reputational incentives may also be brought to bear to promote compliance. Despite the fact that international legal liability attaches to states, commercial operators may still be subjected to scrutiny in domestic courts, which can award punitive damages (where this is permitted) (Larsen 2019: 110–113). In this context, liability insurance for commercial space launches and satellite operations serves as a mechanism incentivizing transparency and good behavior, especially when the policies are contingent upon oversight from relevant domestic agencies. This, in turn, can empower a relatively small group of insurance providers with *de facto* regulatory authority in mandating practices associated with space safety and sustainability (Harrington 2020). In a related vein, the World Economic Forum is working with academic partners to develop a Space Sustainability Rating, which will utilize voluntary questionnaires, coupled with external data, to evaluate space operations in terms of their alignment with international guidelines concerning space debris mitigation (World Economic Forum 2021).

Conclusion

This chapter has argued that the utilization and governance of Earth orbit is beset by limitations on the quality, quantity, and timeliness of information concerning space objects and the intentions of their respective operators. Put simply, this is a challenge of both knowledge and perception. Given the sheer complexity of space operations and the impediments to transparency under even optimistic conditions, ontological uncertainty can be reduced but never eliminated. As such, a holistic calculation of risk based on complete information is fundamentally impossible and spacefaring actors must, therefore, grapple with uncertainty as an inherent feature of their operations. This is the essence of space governance.

However, rapid technological advances are expanding the prospects for robotic and human exploration beyond Earth orbit. Recent years have witnessed a proliferation of scientific missions to the Moon, Mars, and beyond (Johnson 2022). Once fantastical, proposals for natural resource extraction on (comparatively) nearby celestial objects will soon be feasible. Perhaps most dramatically, entrepreneurs like Elon Musk of SpaceX explicitly aim to make humans a "multiplanetary species" by developing permanent human settlements on Mars (Musk 2017). And serious scientific programs continue to seek evidence of potential life-bearing planets and signs of intelligent life beyond our solar system.

While outside the scope of this intervention, it is worth briefly noting that deep space endeavors extend conceptions of uncertainty further still. On the one hand, the same dynamics of ontological uncertainty discussed above multiply in the infinite vastness beyond Earth orbit. The exponentially larger volume of space between Earth and Moon (known as cislunar space) poses even greater challenges to effective monitoring and communication between spacecraft and Earth-based operators.[11] Yet, current SSA capabilities are extremely limited beyond Earth orbit. China and the USA are, therefore, developing communication relay systems to support lunar missions, and the USA intends to deploy satellites to monitor the primary transit routes between Earth and Moon (Holzinger, Chow, and Garretson 2021: 15–17; Johnson 2022: 24). In the other direction, asteroid impacts are known to pose an existential threat to life on Earth but the total number of potentially dangerous objects, their sizes, and the probability of impacts – and, thus, the relative scale of risk – are not well understood and global cooperation is limited (Schmidt 2019).

On the other hand, the prospective development of the human species off of Earth would unsettle established social, political, and economic assumptions and introduce forms of epistemic uncertainty that are deeply existential in their implications for how we understand ourselves and our place in the universe (Deudney 2020). For example, the exploitation of essentially limitless natural resources in celestial objects raises complex questions concerning how these vast benefits should be allocated and distributed within terrestrial communities. In the longer term, interplanetary exploration will challenge our existing notions of sovereignty and citizenship. The extreme distances mean that space settlers would eventually develop conceptions of community that no longer recognize Earth-bound governments and societies. Even more fundamentally, the effects of radiation and low gravity would alter our biological processes leading to physically different beings. In such a scenario, our off-Earth descendants may no longer regard themselves as “humans” at all. So, while uncertainty is an enduring feature of our terrestrial societies, these dynamics will also eventually follow us beyond our planet.

Notes

1. These challenges are further magnified when extending beyond Earth orbit to encompass the zone between Earth and Moon – an area of growing activity (Johnson 2022). However, in this chapter, I limit my analysis to Earth orbital space.
2. SSA networks are operated by China, the European Space Agency, France, Japan, Russian Federation, and the USA. The USA maintains the most advanced and extensive SSA capabilities through its Space Surveillance Network operated by the 18th Space Control Squadron of the US Space Command (Verspieren 2021). Major commercial SSA providers include LeoLabs, ExoAnalytic Solutions, and COMSPOC.
3. There is growing use of space-based assets (such as the US military’s Geosynchronous Space Situational Awareness satellites) to address this latter challenge, but most sensors remain on Earth.
4. For illustration, some of the largest currently approved constellations are SpaceX’s Starlink (11,943 satellites between 335-570 km and seeking approval for a further 30,000); Amazon’s Project Kuiper (3236 satellites at 590-630 km and an additional 4538 proposed); OneWeb (648 satellites at 1200 km and an additional 6372 proposed) and Chinese national GuoWang/SatNet (12,992 satellites in clustered sub-constellations between 500-1245 km) (Messier 2021).
5. The smaller and larger estimates are provided by NASA (https://orbitaldebris.jsc.nasa.gov/faq/) and the European Space Agency (https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers), respectively.
6. The US Space Surveillance Network, for example, maintains both an advanced internal satellite object catalogue and a public version with more limited data that excludes US and allied military and intelligence satellites (Borowitz 2019: 23).
7. Most importantly, the OST enshrines a principle of free access to and use of outer space (Article I) and prohibits national appropriation of celestial resources (Article II). Moreover, OST Article IV insists that outer space shall be used for “peaceful purposes” and bans the placement of nuclear and other weapons of mass destruction in space (but does not address so-called conventional weapons), and military installations and weapons on the Moon or other celestial objects (but not in the voids between these objects).
8. My discussion of ambiguity refers to *contexts that are open to more than one interpretation*. This aligns with one sense of the term as described in Matejova and Shesterinina’s introduction to this volume.
9. For critique of assumption that space is offence-dominant see Townsend (2020).
10. The type of counterspace weapon matters for subsequent assessments. Ground-based ballistic missiles and lasers (if used directly against a satellite) and in-orbit interdictions are relatively easy to detect. Electromagnetic interference and jamming can be identified and attributed with varying precision. Cyber-attacks pose much greater challenges. Such information would not necessarily resolve issues of *intentionality*, however.
11. The outer edge of the most common orbits around the Moon are roughly 12 times further from Earth than the GEO orbit. When rendered in three dimensions, the volume of cislunar space is 1728 times larger than the volume of space encompassed within GEO Earth orbit (Holzinger, Chow and Garretson 2021: 4–5).

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