# 6

# Building a Sustainable Space Knowledge Commons

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## 6.1 INTRODUCTION

Knowledge of the space ecosystem – encompassing both objects and activities – has raised numerous concerns among state and nonstate actors, as the scope and significance of operations conducted in Earth orbit, and beyond, continue to expand. The question of knowledge is bound up in this discussion about identifying the nature of spacecraft and understanding the purpose of their operations and maneuvers. Knowledge is hardly monolithic, especially when considering the range of operators, military, governmental, or private, that can carry out space activities. Some spacecrafts are operated to support military operations. Different operations require different types of understanding. Just because a space operator is conducting a benign operation does not mean it is not testing other capabilities. A brief analysis of trendlines shows the need for knowledge and understanding by states, private operators, and observers to coordinate space activities better. Both information-sharing about and monitoring of the space domain continue to gain relevance owing to the multiplication of actors and spacecraft. Experts regularly share their concerns regarding unidentified space activities, disruptive maneuvers, and lack of transparency and cooperation.

From observation of astronomical phenomena and launches of a handful of objects to outer space, space activities now range from the provision of space applications enabled by single space systems or constellations of interconnected space objects to the conduct of scientific investigation on the Moon or other planets. For a variety of stakeholders, including public authorities, military forces, commercial operators, and civil society, contributing to and maintaining awareness of developments within outer space is essential (Borowitz 2022). This awareness facilitates informed decision-making, enables proactive responses to emerging trends, and supports alignment with practices in the field for better coordination and traffic management between operators. Consequently, stakeholders are actively developing various approaches to gather interpretable and actionable space-related data, either by utilizing proprietary tools or engaging in collaborative efforts. These initiatives



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reflect a strategic commitment to generating insights that inform decision-making and drive effective responses to emerging developments within outer space. Space-related data can concern both artificial objects (human-made spacecraft) and natural objects (resources on a celestial body, or a satellite body itself, such as a meteoroid, a planet or satellite, or an asteroid).

While there is currently no harmonized or standardized format for data collected and shared globally, whether by public or private entities, expanding access to space-related data to include more participants and possibly sharing more comprehensive data and services globally can foster continuous dialogue and trust-building. The work conducted by analysts and interpreters to process various resource forms and assess data quality is essential to ensure the information's reliability and usefulness. Sharing data underscores the potential for diverse contributions, not necessarily from those with direct data collection technology but from various fields that can enhance decision-making and algorithm development (Kostopoulos 2019, 9). Interoperability allows for the creation of a cohesive and usable picture of space activities. Using such space-related information does not bar other stakeholders from their capacity to use it. Rather, it contributes to general knowledge, and also helps verify the reliability of the data. The advantage of such platforms is that they provide reliable information, the dissemination of which does not prejudice the national interests of individual countries while protecting the interests of space operators.

However, information may not be shared, leading to the issue called the tragedy of the anticommons. Unlike the tragedy of the commons, where shared resources are overused to the point of depletion, the tragedy of the anticommons arises when multiple parties hold rights to exclude others from a resource, paradoxically leading to its underuse. This sheds light on how fragmented control and excessive exclusion rights can hinder efficient resource use, slow innovation, and limit access to valuable assets, ultimately resulting in missed opportunities. In the context of space knowledge, the tragedy of the anticommons may arise owing to concerns about security and national defense, intellectual property considerations, or international competitiveness – particularly when entities or nations aim to secure strategic or economic advantages.

If too many community members keep information secret or make it inaccessible, this not only causes cooperation between stakeholders to fail but also prevents the positive developments that making knowledge available enables. For instance, limited access to information restrains possibilities to anticipate risks and threats and better plan future space operations. In addition, it increases the costs of access to training and community participation, slowing down opportunities for progress and the willingness to participate and contribute to the community. Moreover, intellectual property limitations could hamper access to the general public, including civil society, the scientific community, and other governmental organizations. This is especially considering the growth of private actors in the space arena. Our goal is therefore to understand the interest of communities with the technology to collect

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data in sharing it, in order to advance cooperation between stakeholders, strengthen the sustainability of activities, and possibly benefit from the expertise of other members of the community (Ghosh 2007, 218).

In the rapidly evolving space sector, where the proliferation of private actors and technological advancements are redefining the dynamics of space governance, the development of a sustainable space knowledge commons is essential, by addressing the challenges of fragmented data sharing, such as the tragedy of the anticommons, and fostering strategic, economic, and scientific collaboration.

This research defines space knowledge commons, in this context, as the collection and sharing of space data for the safe and secure conduct of space activities, to foster long-term sustainability. We advocate for diverse space data-sharing proposals to establish various space knowledge commons that can be analyzed under the governing knowledge commons (GKC) framework. The goal is to ensure the mitigation of risks of disruptions and incidents, and the reduction of threats and misperceptions between space actors. It conceptualizes the notion of sustainable space knowledge commons for stakeholders to manage use and exploration of outer space. The GKC framework provides a useful research tool to ensure the safe, secure, and equitable use of outer space for current and future generations.

This chapter begins by examining the tragedy of the anticommons in space knowledge, offering an in-depth analysis of the factors that disincentivize information-sharing among actors. It then explores the concept of space knowledge by differentiating between space data and space knowledge, examines the context of space data, and presents a case study on space traffic management (STM). Lastly, it introduces the notion of sustainable space knowledge commons from three perspectives – strategic, economic, and scientific – and outlines the community involved. The goal is emphasizing the critical role of space-related data in promoting sustainable exploration and utilization of outer space, including safe and secure operations.

## 6.2 THE TRAGEDY OF ANTICOMMONS IN SPACE KNOWLEDGE

The governance of space data is particularly important given the increasing presence of private actors in the space arena, including companies such as SpaceX and Blue Origin, which lead in satellite launches and reusable rocket technology; Astroscale, which focuses on orbital debris removal and sustainability; Virgin Galactic and Blue Origin, which have ventured into space tourism; and Planet Labs and Maxar Technologies, which specialize in Earth observation and satellite analytics. Additionally, companies such as Axiom Space and Sierra Space are advancing space habitats and human exploration, while Eutelsat's OneWeb and SpaceX's Starlink are revolutionizing global connectivity with satellite constellations. These private actors significantly shape the governance, sustainability, and equitable use of space resources, gathering more knowledge about space.

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Currently, there are no formal rules applicable to the international community concerning how space-related knowledge should be collected, used, shared, or protected. Because copying and sharing digital information is relatively cheap and easy (Kellerer et al. 2019, 715), it would be much more difficult to totally block access to space data than to manage the supply of it to communities. Although the presence of space assets orbiting the Earth cannot be concealed from telescope owners, trajectory prediction is a complex endeavor and precise operations conducted by space operators are rarely publicly shared. Various interest groups have formed and dissolved over time, comprising operators, governmental entities, and experts, contingent not only on available technologies but also on the vested interests at play.

The increasing number of stakeholders involved in space activities and the multiplication of objects launched to outer space makes space data collection dynamic and complex. The multiplication of objects in space, the miniaturization of technology, and novel operational techniques all contribute to this complexity, making it difficult to interpret and verify certain activities (Ben-Itzhak 2022). Criteria for data quality, including timeliness, completeness, uniqueness, consistency, validity, and accuracy, are essential so they can be exploited with other sets of data to form relevant pools of information for a large number of players, so they do not rely on incomplete or outdated data.

However, the limitation of proprietary data collected by operators and the tendency to fiercely protect access and use of this information, motivated by intellectual property and economic and strategic stakes, lead to fragmentation of data availability. Manufacturers and operators may consider that protecting spacecraft designs and operational data can protect their competitive advantage on the market and prevent unauthorized replication or reverse engineering, and also ensure that their activities remain secure from unauthorized use. Each operator, seeking to increase the value of its own investments and avoid sharing its valuable analyses, limits access to this data, preventing maximum exploitation of its collective potential. So, although many players have access to fragmented data, the lack of cooperation and sharing mechanisms hampers synergy and innovation.

The theory of the tragedy of the anticommons proves to be useful here. As Garrett Hardin proposed in his 1968 essay, tragedy of the commons happens in a situation where individuals, acting in their own self-interest, deplete or overexploit a shared resource, leading to the resource's eventual degradation or collapse (Hardin 1968; Ostrom 1990; Ostrom 1999). In contrast, as Michael Heller explains, underuse in an anticommons is the "mirror image of overuse in a commons" (Heller 2013, 12). The tragedy of the anticommons arises when multiple owners are each endowed with the right to exclude others from a scarce resource, and no one has an effective privilege of use (Heller 2013, 18). When there are too many owners holding rights of exclusion, the resource is prone to underuse. Heller's theory was initially proposed to describe post-1990 developments in Moscow, where many buildings remained empty because potential users had to secure the agreement or permission

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of multiple agents, each with the power to exercise a right of exclusion (Heller 1998, 633–641). Heller and Rebecca Eisenberg further applied the tragedy of the anticommons theory to biomedical research (Heller and Eisenberg 1998). Patent holders, through exclusive licensing, exploit rental value, hindering follow-on developers from realizing potential gains. This stifles development and, ironically, undermines the very purpose of patents: to incentivize research investment.

In the context of space knowledge, we draw on the theory of the tragedy of the anticommons to describe the lack of data sharing, particularly in light of the growing involvement of private companies. We identify three key driving forces behind this phenomenon: national security and national interests, intellectual property concerns, and the pursuit of strategic or economic advantages.

First, regarding security and national interests, certain information concerning satellites placed in orbit to support military operations or test new space capabilities cannot be made public. These satellites, often equipped with advanced technologies, play a crucial role in intelligence gathering, secure communication, and support for strategic missions (Bataille et al. 2022, 9–13). Revealing details about their nature, position, or capabilities could compromise the security and effectiveness of ongoing military operations and expose space infrastructures to the risk of sabotage or espionage by threat agents (Garino and Gibson n.d., 274). Operators also ensure they retain exclusive rights to critical information, so they maintain a strategic advantage for future activities and exploration efforts. Moreover, as military and dual-use technologies are sensitive data, states can implement measures to prevent adversaries and competitors from acquiring critical technologies, promoting defense and security. Confidentiality around these programs is, therefore, essential to preserve technological superiority and national sovereignty. As such, some operators prefer to keep information about their space assets out of the public's eyes.

Second, various intellectual property measures can be put into place. These include patents for inventions implemented through software, particularly those involving novel algorithms aimed at solving real-world problems or offering technical advantages, such as predicting space assets trajectories or innovative computing technologies for data processing. Additionally, copyrights protect original works of authorship, such as software code (Malloy et al. 2003). Many of the problems, dilemmas, and limitations are to be found in the data-collecting and data-processing procedures. Moreover, access to pools of information is generally exclusive, given that space data often carries confidentiality or is protected under intellectual property law. There may be attempts to limit or restrict access and impose some rules and standards to data collection and utilization processes to increase the quality of pools of information generated for specific purposes, such as collision avoidance mechanisms (Buchs et al. 2023, 374–383).

Third, while data sharing is essential for the advancement of science and international cooperation, it needs to be balanced by appropriate safeguards. Indeed, once analyzed, data can be exploited for competitive purposes, particularly by

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entities or nations that might seek to gain a strategic or economic advantage when planning their activities. This preserves the interests of data collectors while ensuring that the information disseminated serves the common good without compromising the strategic or economic benefits associated with space exploration. Moreover, it provides a guarantee that the information shared is verified and contextualized, thus avoiding the propagation of incomplete or misinterpreted data that could harm further research or space security. This is particularly relevant in the context of the exploitation of space resources. Although access to extraction technology is minimal nowadays, as is humankind's ability to travel in outer space and fully exploit natural space resources, it would be appropriate to work on raising awareness of the risks of overexploitation of resources (Cheney 2024, 353–358). To a certain extent, limiting the dissemination of data about space resources, including their nature, location, quantity, and role for an operator's space activity, can help to avoid arousing the interest of competitors (Cilliers et al. 2023). Here, data dissemination, access to information, and pointers to areas of interest are considered through the lens of the collection and extraction of space resources to mitigate, in the long term, the degradation of certain celestial bodies.

Here is an example involving satellite operators that demonstrates the tragedy of the anticommons. For strategic economic reasons, satellite operators – whether they are planning to launch a single satellite or an entire constellation – need to develop innovative technologies and obtain the best possible orbits. These orbits, which have become precious resources, are fiercely contested as they determine the quality and efficiency of the services provided by these satellites. To protect their market position and secure their competitive edge, operators are careful to keep their projects and technologies secret. Premature disclosure could allow competitors to capture the most strategic orbits or copy innovative business plans, jeopardizing their profitability and technological lead. Intellectual property plays a central role in the processing and valorization of data: In a context where considerable resources are invested in its collection and analysis, the data obtained, often through advanced technologies and sophisticated processing methods, have great value not only as economic assets but also as strategic tools for states. Because of their potential to influence economic prospecting and strengthen strategic positions, operators place a premium on protecting this data and the analyses derived from it, in order to maintain a competitive edge. Protecting intellectual property makes it possible to preserve the results of these efforts and investments, while limiting access by competitors or the general public to information likely to offer a competitive advantage or compromise national interests.

Operators, meaning to protect their investments and maintain a competitive edge, may be reluctant to share valuable data or participate in collaborative initiatives that could compromise their proprietary analyses. Although resources exist, their use is hampered by too many barriers to access them efficiently, reducing their overall usefulness. This phenomenon can lead to wasted opportunities for scientific

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advancement, economic decision-making, and collective security. To remedy this situation, collaborative regulations facilitating a balance between intellectual property protection and strategic data sharing are needed (Sankar et al. 2024; Seeds 2024). This would make it possible to utilize these resources optimally while preserving the competitive advantages and strategic interests of the various stakeholders.

There is a clear need for more space data sharing. The lack of a precise policy for data collection, sharing, and ensuring reliability poses a significant challenge to the management and regulation of space and technological information. The United Nations proposes general guidelines to states for operators' practices (United Nations Committee on the Peaceful Uses of Outer Space 2019). States and observers are also working on potential legal structures for activities in the exploration, exploitation, and utilization of space resources (United Nations Committee on the Peaceful Uses of Outer Space 2021). However, each actor, whether state or private, can adopt its own protocols for data collection and processing, leading to a heterogeneity that complicates international cooperation and transparency. The lack of specific standards on what is to be shared and how to certify data reliability and integrity raises crucial questions of trust and security (Baseley-Walker and Weeden 2010). Without harmonized certification and verification mechanisms, it is difficult for states and operators to guarantee the quality and relevance of exchanged data. This can lead to discrepancies in data interpretation and decision-making, potentially affecting national security and geopolitical stability.

## 6.3 Space Data, Space Knowledge, and the Essence of Data Sharing

### 6.3.1 *Space Data and Space Knowledge*

Access to space data benefits various stakeholders, including space operators, whether governmental or nongovernmental, to international organizations, agencies, academic institutions, and civil society (Reed et al. 2022). Until recently, data about objects located in space and activities conducted beyond the Earth's atmosphere has only been accessible to a small number of space operators, both governmental and nongovernmental. While users are not necessarily the ones collecting and analyzing space data, they benefit from it for various reasons, particularly the planning and management of their present and future missions in outer space and the long-term sustainability of space activities. Managing and governing space data raises several questions: What qualifies as space data (i.e., what information is relevant)? What are its origins (i.e., how is it collected)? Who are the users (i.e., who can access and process it)? How is it utilized (i.e., how is it employed)? And what are its applications (i.e., for what objectives)?

Under the knowledge commons literature, a meaningful distinction exists between data and knowledge. It takes a broad and inclusive view of "knowledge" for purposes of researching common governance, referring to human-generated

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material at any position that situates "data" at the lowest level, "information" and "knowledge" at intermediate levels, and "wisdom" at the highest level (Madison 2024, 320). This recognizes that knowledge is a product of what legal systems consider "counts" as a knowledge resource, and the character of cultural resources is frequently embedded in feedback loops at multiple levels (Madison 2024, 321).

Here, we distinguish between "space data" and "space knowledge." The term "space data" does not refer to the sensing of the Earth's surface, but rather to data relating to the space environment, including, but not limited to, natural resources characteristics and location and human-made objects' characteristics, orbital specifications, trajectories, and orbits. Space data ranges from raw information about outer space to the management, dissemination, preservation, and utilization of such data. Whether they generate such data or not, stakeholders need to access this resource and find a shared understanding of opportunities, benefits, and limitations regarding the joint use of this pool of information. Eventually, because of the multiplication of activities and the increasing need to coordinate between emerging and traditional actors, it may come to a point where the international community will have to address common management and governance. These resources are collected as a source of information about space-based natural elements, assets, and phenomena, as well as human activities and human-made objects, both functional and nonfunctional, including their components. Space data also relates to the mechanisms in place, starting with conversion of analog measurements to digital content, after data collection by relevant entities, to create information and share related knowledge, and also manage, disseminate, analyze, and preserve such data.

It is critical to note that the mere presence of data does not imply its active collection. Rather, sensing data is an activity that can only be carried out by a limited number of entities equipped with the necessary technical capabilities. Its processing and storage also rely on dedicated platforms, and compliance with existing transparency measures depends on states' willingness to share information about national space activities and assets with the international community (MITRE Corporation and Aspen Institute 2022, 5–6). For example, the Republic of Korea introduced plans to develop a space surveillance network combined with the KEPLER (Korea Enhanced Platform for Lowering spacE Risk) project, an advanced system that combines data from optical, radar, and laser sources to enhance situational awareness. During the 2025 United Nations Committee on the Peaceful Uses of Outer Space scientific and technical subcommittee session, the Republic of Korea unveiled the system's architecture, introducing Spacebook, a dedicated database for observing, collecting, analyzing, and managing space data. This platform is complemented by the Space Risk Warning Portal, designed to disseminate critical information to users (Choi 2025).

There are also initiatives to identify, label, and catalog natural resources and geological features regarding celestial bodies, including the Moon (Lunar and Planetary Institute, n.d.; Chinese Academy of Science 2024). Several projects initiated by

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private satellite operators and observers aim to better understand space (i.e., Space Data Association and Jonathan's Space Report) and states started to develop platforms to foster space situational awareness policies and develop STM mechanisms (Lal et al. 2018, 14–16).

The data can be analyzed and converted into valuable information, aiming to mitigate risks, reduce misperception and miscommunication between stakeholders, and anticipate critical scenarios. For example, they can be used to track the trajectory of objects in space and calculate the probability of collisions, thus contributing to the safety of space activities. In addition, these analyses can be used to identify the presence of specific resources on celestial bodies, facilitating the planning of future activities or the development of resource exploitation strategies (Clerc et al. 2025, 298–299). This transformation of raw data into usable information is fundamental to valorizing it and supporting strategic decisions that are both accurate and timely (Bonvino and Giorgino 2024).

After collecting data, identifying their type, and checking their reliability, the next step is to ensure relevance and focus on areas of mutual interest to stakeholders (Patriarca et al. 2019, 201–211). This process should integrate both protocols for data quality, interoperability, and formatting to ensure consistency and ease of use and tools for data import, analysis, and visualization, which allow contributors to upload data and users to interact with it meaningfully. Furthermore, knowledge gaps exist, as some operators prefer not to make public certain strategic and military uses of outer space. Thus, the objective here is not to list and classify all human-made objects and natural resources present in orbit or on celestial bodies, nor the space phenomena or activities conducted in orbits, but rather to identify how knowledge of these different elements is acquired, shared, and used, and to what purpose.

These resources, ranging from voluntary shared data to actively collected facts and measurements, have diverse characteristics. Despite the existence of transparency measures and incentives to exchange information, it is the detection of data through sensing technology and calculations that is of real interest. Ensuring access to accurate, complete, reliable, relevant, and timely data is made easier if all entities with sensing capabilities make space data available, so the resulting information is properly exploited. In addition, renewed interest in space operations and applications through the deployment of large satellite constellations in low Earth orbit (Blount and Cesari 2023, 147) and projects to extract natural space resources from celestial bodies (Guyomarc'h 2023, 6) are prompting states and various operators to carefully analyze the space environment before planning and designing their space projects and missions.

Generally, space data access and management tend to be more and more open to a larger part of the population. Being part of a community, as is the case with governmental entities or satellite operators in particular, facilitates access to this type of information. There are not necessarily any particular barriers to capturing data, apart from access to observation technologies (Ortega et al. 2023, 18–19). However,

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their analysis and the knowledge that can be derived from it may be subject to protection measures to prevent access by strategic competitors.

The development of space knowledge commons, as a whole, involves the collection and sharing of space data to support the safe and secure conduct of space activities, ensuring long-term sustainability. It relates to relevant information beneficial for projecting human activities and fostering the long-term sustainability of space activities (Porras 2019). For instance, knowing space objects' trajectory and orbital parameters is important for adequate coordination between operators operating satellites in orbit. Its goal is to mitigate risks of disruptions and incidents while reducing threats and misperceptions among space actors. Creating knowledge commons based on space data involves developing a shared, accessible resource that enables multiple stakeholders to contribute, access, and build upon collective knowledge. Because sensing space data requires having scientific instruments and observation tools such as optical telescopes or radars, all information about outer space is not necessarily accessible to the public (Weeden et al. 2010). However, as observation instruments become more affordable and accessible, and computers become more powerful and numerous, some information can be shared as open source, notably by online user communities and members of civil society, research centers, universities, and so on (Renault et al. 2022, 24; Ortega et al. 2023, 31–33).

### 6.3.2 *Data Sharing as an Essential Attribute of Knowledge Commons*

Knowledge commons is governance by a community or collective of shared knowledge, information, and data resources, searching out instances of shared knowledge, information, and data that prompt the need for governance (Madison 2024, 308). As explained by Madison, "Knowledge commons research begins with the assumption that sharing knowledge, information, and data effectively is both a substantial public policy challenge and an enormous policy opportunity, not only emerging from questions surrounding contemporary data, software, artificial intelligence, and the like, but also building on equivalent questions of long pre-Internet, even Homeric standing" (Madison 2024, 304).

Data sharing is an essential attribute of the governance of knowledge commons. Certain data collection instruments and pools of information exist to catalog the conduct of human-led activities in outer space or the presence and characteristics of space natural resources that could be of value to the market. Cataloging natural space resources is crucial for scientific purposes and improvement of research. It can also help operators know where these resources are to ensure successful missions and resource collection and plan how resources might be collected, managed, and utilized in outer space, particularly on celestial bodies (Clerc et al. 2025, 301–303). Space-data collection can serve to identify, describe, and possibly quantify resources in order to create a detailed map locating valuable materials on the Moon

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or other celestial bodies, for both scientific and economic purposes. Opening access to information on the state of celestial bodies, their composition, and the elements that make them up or are located on them may raise concerns about the uncontrolled and unrestricted extraction of natural resources for commercial purposes alone. Gathering and analyzing space-related data, and more specifically cislunar data, is important for states aiming to foster scientific research and future growth and economic activities.

From a space governance perspective, data sharing occurs in two contexts: first, among partners, and second, by making data accessible to the public.

#### 6.3.2.1 Data Sharing Among Partners

First, sharing related information with international partners not only improves global engagement and expands international cooperation but also enhances space situational awareness to maintain a foundation for responsible behaviors in space. Overall, it gives incentives to implement robust communication and navigational infrastructure to support safe and sustainable activities in space (White House 2022). On this basis, partners and competitors working on space mining activity can develop collectively understood norms with regards to acceptable, prohibited, or tolerated actions for stakeholders in specific situations, supported by enforcement measures and specific consequences in cases of noncompliance (Christensen et al. 2019).

Sharing space data efficiently and profitably requires the establishment of rigorous standards and coordination mechanisms. For these mechanisms to be reliable, rational, and usable, it is essential to establish a global normative policy defined by clear and commonly accepted standards. These standards may include guidelines on how to collect, process, and verify space data to guarantee both its quality and reliability. In the absence of such standards, publicly shared information may contain errors or be incomplete, which can undermine decision-making and trust between stakeholders.

It is, therefore, necessary to adopt certification mechanisms that guarantee the quality and integrity of space data before it is shared. This includes the introduction of international standards for data processing and dissemination, such as technical validation protocols and detailed documentation practices. In addition, enhanced coordination between the various players – be they governments, international organizations, or private entities – is crucial to ensure that space data is interpreted uniformly and that differences are minimized. This coordination can take the form of bilateral or multilateral collaborations, information-sharing forums, and the implementation of centralized platforms where verified space data can be deposited and consulted according to precise rules.

Ultimately, effective space data sharing, based on common standards and solid coordination, will not only promote better information use but also avoid the pitfalls

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associated with misinformation and errors of judgment caused by inconsistent or unverified data. However, for both public authorities and the private sector, data collection can be complex and costly. This difficulty stems largely from the technical and financial obstacles required to develop and maintain data collection infrastructures. Having one's own collection capabilities implies access to advanced technologies and substantial financial resources to build, operate, and update the necessary infrastructure. These include sophisticated sensors, robust communications networks, and high-performance data processing systems. The cost of research and development to remain competitive adds a further layer of complexity to the establishment of such an infrastructure.

Sharing and receiving space data from other operators requires integration into a network or group where trust and cooperation are established. Membership in these networks guarantees that data can be exchanged using common secure protocols. Membership in such groups implies commitments, such as compliance with sharing standards and protection of sensitive data, which can limit operators' freedom to manage information independently. Coordination and interoperability between different systems and collection methods are essential to ensure the consistency and efficiency of the space data exchanged.

Governance and sharing mechanisms are generally set up by both governmental and nongovernmental entities because exchange of information between operators and common governance reduces miscommunication, misperceptions, and mistrust. In that case, access to data can be granted to a part of the user community or be available to the general public so they can extract and use data (Hess and Ostrom 2007, 52). Companies, members of civil societies, state operators, and other stakeholders can use space data openly shared as nonrivalrous resources, even though not all information is shared, as some is kept secret for an operator's competitiveness for economic, strategic, or military reasons.

#### 6.3.2.2 Public Information

Publicly available information is a crucial mechanism for data sharing, contributing to the development of a space knowledge commons. Specific legal instruments, such as the Convention on Registration of Objects Launched into Outer Space (United Nations 1975), require states to provide information to the United Nations Office for Outer Space Affairs (UNOOSA) (United Nations Office for Outer Space Affairs 2024). States generally grant licenses to space operators who request them, authorizing them to launch objects to carry out their operations. Furthermore, the International Telecommunication Union (ITU) regulates spectrum and orbit for space radiocommunication services (ITU n.d.). To this effect, it records in the Master International Frequency Register frequency assignment and orbital information for space stations onboard geostationary and nongeostationary satellites used or intended to be used in order to ensure efficient, rational, and cost-effective utilization

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of orbital and spectrum resources, considered as limited resources (ITU n.d.). These transparency requirements proposed at the multilateral level help estimate the number of objects in the various orbits. However, this is a declarative mechanism, and many objects launched to outer space are not registered or information provided is incomplete or erroneous (Hertzfeld 2021, 241). While it is possible for states to share data related to their national space objects in the multilateral context to UNOOSA and ITU (Masson-Zwaan et al. 2024, 242–248), there is no real standard format or particular obligations regarding data quality, accuracy, or completeness. Furthermore, there is no obligation to share data about natural objects and phenomena in space or about how human activities alter celestial bodies (Chen).

Open access information or publicly available data, including that managed by the United Nations register, can serve as a valuable alternative or complement. With the growing presence of private actors, such disclosure is increasingly essential. These data enable operators to obtain information without incurring significant initial collection costs. However, its reliability and level of detail can vary. It often requires additional verification or cross-checking and trust between all stakeholders. Public space-related data plays a crucial role in informed decision-making but must be handled with care to avoid errors owing to outdated, unreliable, or inaccurate information. When space data is made public without the source being identifiable, it may include erroneous or poorly processed information. This may be due to differing collection methodologies, varying levels of accuracy, or failure to apply rigorous processing protocols. The absence of a common validation and certification policy also leads to differences in space data interpretation, making it difficult to align stakeholders on consistent conclusions or to develop harmonized policies.

Open access makes it possible to monitor and verify operators' compliance with national obligations, ensuring responsible behavior in outer space, in conformity with the licensing states' international commitments. In the event of an incident, such as a collision, more open access to data helps clarify the circumstances and facilitates access to redress for victims, enabling a fairer and more transparent resolution. Finally, for future exploration activities and scientific progress, open data is essential. It supports the building of a shared knowledge base about outer space, which is essential for understanding and exploring it more safely, securely, and sustainably. This international cooperation and knowledge sharing ensures that space resources are used responsibly, benefiting both current missions and future generations.

#### 6.3.2.3 Case Study: Space Traffic Management

STM serves as a compelling example of why data sharing is critical in space activities. In terms of regional STM, data plays a key role in the surveillance, tracking, and coordination of objects in orbit (Oltrogge and Kerr 2024). For example, the European Union is exploiting a network of terrestrial sensors, including radars and telescopes, to

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monitor and track space objects. This Space Surveillance and Tracking System (EU SST) aims to prevent the risk of collisions and track the trajectory of space debris to ensure the safety of satellites and space missions (McKnight 2019, 101–107).

Through this EU SST program, the European Union has also called for the development of space debris mitigation services for space safety and sustainability. (Committee on the Peaceful Uses of Outer Space Scientific and Technical Subcommittee 2023; Council of the EU 2023) By providing data and using its technological capabilities, the European Union seeks to enrich the pool of information available to the space community. These efforts aim to make monitoring services more transparent and accessible, aligning the European Union's approach through open public service (Moranta et al. 2020). This would enable private operators and space agencies from various countries to access the data they need to navigate safely in space, plan their missions, and avoid collisions (Moranta et al. 2020).

The integration of European efforts with other systems, such as that of the US, is an essential aspect of the overall STM coordination. The US, through the US Space Surveillance Network (Chatters and Crothers 2009, 249–258), manages a sophisticated network of sensors that continuously monitor space and provide critical data for STM. By working in partnership with players such as the European Union, the two systems can share complementary data, improving accuracy and global coverage (Stickings 2019, 8–9). Such collaboration also overcomes the geographical limitations of individual sensors, ensuring a more comprehensive and coordinated view of the space situation (Ortega et al. 2023). This articulation can be achieved through common platforms and bilateral or multilateral agreements, where data from both systems are exchanged according to defined protocols. Harmonization of data collection and analysis methodologies helps to enhance the reliability of shared information. Initiatives such as sharing best practices and developing common standards ensure that integrated data from European and American systems can be used consistently by all players in the space sector.

The ultimate aim of this international cooperation is to create a space situational awareness environment that is global and integrated, reducing the risks associated with space activities and supporting the sustainability of in-orbit operations (Oltrogge and Christensen 2020, 432–438). This could lead to better coordination for proactive debris mitigation, orbital conjunction management, and future space mission planning while promoting safer and more efficient use of space for future generations.

On the private sector level, the Space Data Association (SDA) plays a significant role in bringing together various satellite operators to encourage the sharing of data essential to the safety and integrity of the space environment. The SDA is a collaborative initiative that enables operators to share valuable information on satellite position, trajectory, and status to minimize the risk of collisions and disruptions in space. It emphasizes the sharing of reliable operational data and promotes best practices across the industry (Muelhaupt et al. 2019, 80–87).

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The SDA approach is distinguished by the fact that it is a closed service reserved for a limited number of operators who agree to participate on a reciprocal basis. This means that members must not only receive information but also contribute their own data concerning their satellite fleet, trajectories, and life expectancy, among other information, to enrich the collective knowledge base. This fosters an environment of mutual trust, where the exchange of information benefits all participants and helps to enhance the safety of space operations (Oltrogge et al. 2024, 342–361).

Participation in the SDA gives operators access to accurate, up-to-date data on space traffic, reducing the risk of collisions and enabling better maneuver planning for collision avoidance. In addition, this approach promotes the harmonization of STM methods in the private sector. It helps to complement the efforts of government systems such as those of the European Union and the US. By promoting best practices and facilitating secure and efficient data sharing, the SDA supports not only flight safety but also the long-term sustainability of the space environment.

This reciprocal sharing structure demonstrates the importance of private collaboration in STM, particularly when coordinated with public initiatives to create a more comprehensive and resilient surveillance ecosystem. The bottom line is that initiatives to share space data, whether from the public or private sectors or from collaboration between the two, highlight both considerable challenges and promising opportunities. On the part of public-led initiatives, the focus is on establishing robust infrastructures and open services to provide reliable data for safety and STM. However, the absence of common standards on an international scale complicates the coherence of exchanges and the quality of shared data while leaving the door open to divergent interpretations and the risk of errors (Stauch et al. 2016).

On the private side, the reciprocal and reliable sharing of data between operators can significantly improve space safety and coordination between satellite operators. However, these private initiatives remain limited in terms of access and participation and rely on trust and reciprocity, which may exclude important players that do not meet these criteria. The main challenges of these various initiatives include the need to develop harmonized standards, ensure data reliability and accuracy, and coordinate effectively between multiple stakeholders with varied interests. The issue of intellectual property and data protection also remains a major concern, influencing how and to what extent data can be shared.

At the same time, the opportunities offered by structured and coordinated sharing of space data are considerable. They include better management of space traffic, reduced collision risks, more efficient mission planning, and the possibility of developing global strategies for space debris reduction. Cooperation between public initiatives and private efforts could create an integrated and resilient space ecosystem. Such collaboration would be essential to ensure not only the immediate safety of space activities but also the long-term sustainability of outer space and, by extension, their security, a common asset essential to the continuation of space use and exploration. Because the space environment, particularly in low Earth

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orbit, can undergo rapid changes, space operators constantly need up-to-date information to be aware of a situation and conduct their activities safely, with a comprehensive repository of space data.

## 6.4 BUILDING A SUSTAINABLE SPACE KNOWLEDGE COMMONS

### 6.4.1 *Overview*

The purpose of the GKC framework is to prompt systematic study of resource-sharing practices, as the research program is pragmatic rather than ontological (Madison 2024, 317). The Ostrom literature makes an important distinction between a "framework," a "theory," and a "model." A framework identifies, categorizes, and organizes factors considered most relevant to understanding a phenomenon. A theory, in contrast, proposes general causal relationships among subsets of these variables or categories, designating certain factors as particularly significant while treating others as less critical for explanatory purposes. Finally, a model specifies the specific functional relationships among particular variables or indicators, hypothesizing their operation under well-defined conditions (McGinnis 2011, 170). The goal of the GKC framework is to invite researchers to explore knowledge commons governance by addressing clusters of interrelated questions, designed to be examined and answered systematically (Madison 2024, 308).

Different from the Institutional Analysis and Development (IAD) framework, "resources" in the GKC context are not tangible or "biophysical." Instead, the framework focuses on knowledge, or information that is non-depletable (Madison 2024, 309). It also does not make the assumption that "actors" are individuals operating on a rational decision-making basis (Madison 2024, 309). Generally, teams of experts are dedicated to the planning, management, and overall control of space activities, under the supervision of public authorities. The terminology in that schematic partially corresponds to the terminology developed by the IAD framework, particularly its emphasis on "rules-in-use" (referring to formal and informal rulesets that define the relevant community and its practices) and "action arenas" (contexts in which relevant actors repeatedly interact concerning shared resources) (Madison 2024, 309). However, a key difference lies in the interaction of various variables. Unlike the IAD framework, the outcomes of a given pattern directly influence the input variables, potentially leading to the destruction or sustainability of the resource (Strandburg et al. 2017, 15). These outcomes can also drive modifications to the rules-in-use if the community is dissatisfied with the results.

Overall, we advocate for space data-sharing policies to build various knowledge commons, where these different case studies can be effectively analyzed under the GKC framework. The creation, sharing, and maintenance of common resources and the structures controlling them or facilitating their appropriate use enable all stakeholders

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to ensure the smooth running of our activities. It also enables the development of rules or norms of behavior in the space environment. As such, the international community is already working on encouraging states to adopt responsible behavior in their use.

This is especially important because of the proliferation of private entities in space governance. Entities such as Starlink, Leolabs, Planet, Look Up Space, CFSCC, USSPACECOM, JSC Vimpel, and SeeSat-L have directly shared space data concerning space assets and activities on different platforms, either open such as Space Track or AstriaGraph or more confidential. Even though this practice might raise intellectual property concerns, this type of open access without costs or permissions does not prevent these platforms from retaining copyright over the work they provide (Wang et al. 2022, 13).

In addition to existing private initiatives, the European STM platform currently under development and mentioned earlier is supported by space-based data (Moranta et al. 2020). The US, meanwhile, has a legal structure for space situational awareness. This is also an opportunity for the military, which sees outer space as a strategic operational domain, important to their operations.

Information about the situation in orbit is useful for satellite operators to calculate collision probability or plan future operations. Generally, the analysis of space data enables better management of traffic, anticipation of collision risks, and identification of the areas in which operators can place space objects, especially in low Earth orbit and medium Earth orbit. Geostationary orbits have been under constant scrutiny ever since operators first realized their economic benefits: Placing an object in geostationary orbit means not having to move it, or reorient it frequently, because of its Earth-like orbit (Sato et al. 2021, 331–338). In nongeostationary orbits, it is more complex to identify the objects that are placed, and their trajectory, speed, altitude, and other characteristics linked to their placement (Borowitz et al. 2021). Moreover, not all satellites can be remotely piloted, some are no longer functional, and the presence of debris can cause damage to satellites (World Economic Forum 2021). Only some satellites or space objects can be maneuvered to avoid collisions or simply redirect their antennas to conduct their activities. Therefore, identifying the characteristics of different resources with as much space-related data as possible is essential for obtaining useful and reliable information. Increasingly, this information is being collected and analyzed by a number of categories of experts and researchers (i.e., Space Data Association and Jonathan's Space Report). Sharing space data therefore facilitates coordination between different space operators and, more generally, improves the efficient management of space traffic.

To date, mechanisms for collecting, sharing, and managing space-related data are used to assess the risk of in-orbit collisions in an efficient, temporal, and precise way, to reduce false alarms and missed events, and to reduce the time and resources devoted to this type of assessment by the various operators. This also minimizes the risk of confusion and conflicting decisions between operators while quickly finding

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solutions to avoid the risk of interference and collision (Silverstein 2023, 18–21). In terms of ensuring the investment of time and resources in this type of operation, opening up this information and access to a wider community of observers would perhaps enable greater efficiency and the development of best practices for stakeholders. Without such a mechanism, there is no standardized format for these data, analysis, sharing, and prevention of more reliable and accurate results.

### 6.4.2 *Building a Sustainable Space Knowledge Commons*

#### 6.4.2.1 The Boundaries of Space Knowledge: Strategic, Economic, and Scientific Considerations

One fundamental question when conducting GKC research is to define what constitutes knowledge commons. Intangible knowledge resources are not naturally defined by boundaries that limit their use. Instead, it is constructed, rather than discovered, and it operates through at least two resources – either embedded in the tangible form, or shaped and regulated through law and other social practices (Strandburg et al. 2017, 13–14). In the context of patents, for instance, the "claims" define the boundaries (Strandburg et al. 2017, 14). These boundaries are partly within and partly outside the control of members of a knowledge commons, giving rise to a series of social dilemmas (Strandburg et al. 2017, 14).

Space knowledge is inherently valuable but not neutral – it serves both scientific and strategic purposes. On the one hand, analyzing data and conducting research advances space exploration and science. On the other hand, leveraging data for strategic and economic considerations helps markets project revenues, assess investments, and evaluate associated risks (OECD 2024, 6–7). This is a question of social ethics that can be the subject of discussion and study to determine acceptable levels of safety for public expectations, while taking into consideration the desire of certain states to develop their space economy either with extraction technologies in their own way or with all the capacities and logistical systems that surround it.

Here, we utilize "sustainability" as a key term to draw the boundaries for space knowledge commons (Space Data Association 2024). In other words, sustainability becomes a primary goal for space data-sharing policies and serves as a determining factor in deciding what should or should not be shared. Sustainability is a major topic regarding the responsible use and exploration of outer space. It is intrinsically linked to space safety and security, as a debris-saturated and poorly managed orbital environment greatly increases the risk of collisions and accidents, jeopardizing not only ongoing space missions but also the infrastructures on which many terrestrial services depend. Relevant and reliable data on space situations and activities is essential to ensure a sufficient level of safety and security. This is where the concept of sustainability in our understanding of knowledge commons becomes relevant – space data, when shared and accessible for the purpose

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of space sustainability, can be considered as knowledge commons. The notion of sustainable space knowledge commons encourages the international community to share critical information that strengthens the coordination and collective management of outer space. Reasoned sharing of data on the position and trajectory of space objects, as well as on debris management, contributes to better risk anticipation and faster, more effective response to potential incidents (Space Data Association 2024).

The notion of "sustainability" should be a central aspect of various policies for space data sharing. Within the GKC framework, it serves as an important objective behind different rules-in-use. This concept implies that these data become collective resources, which, when properly managed and exploited, benefit the entire space community and beyond. The importance of knowledge commons for space data is threefold, covering strategic, economic, and scientific aspects.

From a strategic point of view, knowledge about the launch operation of a rocket and the encounter of space satellites should be shared, which gives an operator, whether governmental or nongovernmental, a complete and precise awareness of the situation around its assets. This knowledge is essential for ensuring the safety and integrity of space missions by making it possible to monitor nearby movements and operations and prevent incidents such as collision risks or unauthorized maneuvers, among which are threatening close approach (West 2023). This ability to anticipate and react proactively strengthens the operator's sovereignty and operational security. The goal is to prevent miscommunication, misunderstanding, misperception, and the rise of tensions between States. (United Nations Institute for Disarmament Research (UNIDIR) 2022).

From an economic point of view, access to space knowledge on space maneuvers, of the trajectory, and the position in orbit, is essential for investment planning and optimization. Private and public operators need reliable data to design missions, decide on the best orbits to use, and assess environmental conditions before launching satellites. Moreover, in the context of increasing competition for the exploitation of outer space, information on the distribution of debris or the viability of a future satellite's location can make the difference between a fruitful investment and a considerable loss. Concerning space resource exploitation, the availability of data about celestial bodies, such as the Moon or asteroids, can be used to assess the profitability and feasibility of extraction missions.

With regard to scientific exploration, shared space knowledge on specific celestial bodies in terms of the location and the chemical composition would create a collective knowledge base and facilitate international collaboration to understand outer space, celestial bodies, and improve the study of the universe. This includes the knowledge of specific celestial bodies in terms of the location and the chemical composition. States tend to address this from a scientific point of view – however, future discussions, informed by eventual technology developments, may lean towards an economic point of view. Identifying resources present on asteroids or

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other celestial bodies, detecting new objects, and analyzing their composition are essential elements for scientific research. These knowledge commons enable the scientific community to work more efficiently, exchange ideas, and push back the frontiers of space research. This stimulates innovation and fosters discoveries that can have beneficial applications on Earth, such as improving space technologies, understanding the universe or even technological spin-offs in medicine and engineering.

#### 6.4.2.2 Community

Managing and accessing space data as knowledge commons represents a crucial opportunity for strategic, economic, and scientific development. However, realizing this potential depends on stakeholders' ability to develop standards, share infrastructures, and strengthen international cooperation to ensure that these commons are sustainable and accessible while protecting the specific interests of each stakeholder.

Utilizing the GKC framework requires a comprehensive understanding of the community involved. Key questions include identifying community members, defining their roles, and assessing the degree of openness toward different stakeholders and the general public. Establishing standards to assess data quality and predict potential outcomes is crucial for organizing information and connecting it to the growing number of space activities (Hess and Ostrom 2007).

Overall, the community managing space data as a knowledge commons comprises space data providers, policymakers, users, space operators, civil society members, the scientific community, governmental organizations, private entities, international bodies, and technology developers, each contributing uniquely to ensuring sustainability, security, and accessibility. This diverse and interconnected network highlights the complexity of aligning interests, establishing governance frameworks, and fostering collaboration to address the shared challenges and opportunities of managing a sustainable space knowledge commons effectively.

The increasing accessibility of observation tools and computational power contributes to the rise of communities focused on outer space (Ortega et al. 2023). The growing awareness of the importance of space sustainability and safety has underscored the need for collaborative efforts. Space data – ranging from voluntarily shared information to actively collected measurements – possesses diverse characteristics. While transparency and information-sharing mechanisms exist, advanced sensing technologies and analytical tools play a crucial role in ensuring access to accurate, reliable, and timely data. Entities with sensing capabilities should make their data available to enable meaningful exploitation and support strategic planning. Recent developments, such as deploying large satellite constellations in low Earth orbit (Blount and Cesari 2023) and initiatives to extract resources from celestial bodies (Guyomarc'h 2023), have further

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highlighted the need for comprehensive data analysis to guide project design and mission planning.

State and private stakeholders are becoming more involved in space operations to ensure safety, security, and sustainability. Sharing data allows these parties to coordinate activities effectively, reduce collision risks, and contribute to a stable outer space environment while reaping strategic, scientific, and economic benefits (Foust 2019). For both state and nonstate actors, access to shared data promotes mutual understanding and facilitates cooperation on shared objectives.

Information providers, policymakers, and users all have important roles. Providers include those who collect, process, and disseminate data, as well as those offering supporting software, hardware, and infrastructure. Policymakers often operate within self-regulated communities, promoting transparency and encouraging information exchange among stakeholders (Hess and Ostrom 2007). Users range from individuals accessing digital content to organizations employing this data for operational purposes.

These interconnected groups typically function at different levels of the knowledge commons, where locally managed information pools are globally utilized. Ensuring that the data remains relevant requires proper categorization and classification, avoiding interference with trade secrets or sensitive military strategies.

In consideration of the law, international legal frameworks impose significant responsibilities on states for their space activities. Under the Outer Space Treaty (1967), states are internationally liable for damage caused by their space objects (Article VII) and must avoid interfering with the activities of other states (Article IX). National space laws further impose licensing conditions, including administrative, legal, financial, and technical obligations on operators. These regulations ensure smooth operations and minimize in-orbit risks.

Space operators, meanwhile, bear responsibility for minimizing their impact, coordinating with others, and contributing to the overall safety and sustainability of space. Given the rapid pace of developments, particularly in low Earth orbit, the creation of a comprehensive repository of space data is essential. Such repositories could enhance collision prevention and post-event analysis while supporting governmental and nongovernmental entities alike (Alfano et al. 2022).

While many platforms for sharing space environment data are developed by operators and entities directly using the information, other groups – such as civil society, scientific communities, and governmental organizations – play significant roles. These groups contribute to multilateral discussions by clarifying complex issues, conducting research, and reducing tensions in space (Cesari 2022). Their involvement helps ensure that space data is collected, analyzed, and shared to address emerging challenges and foster stability.

In conclusion, the effective management of space data as a knowledge commons relies on the collaboration of a diverse and complex community. This intricate network of stakeholders, each with unique roles and perspectives, underscores the importance of fostering cooperation, establishing clear standards, and

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maintaining transparent governance to ensure the sustainability, security, and accessibility of space data for the benefit of all.

## 6.5 CONCLUSION

Since the advent of space activities, various actors have strived to monitor activities in outer space to better anticipate future space missions and protect their assets from threats and operational risks. Nowadays, advancements in technology, including more optical telescopes, radar systems, and computing power. Space data collection tools involve diverse technologies, such as radars and tracking dishes, either based on Earth or placed in outer space.

As space-related data are exploited in pools of information by different stakeholders, they are shared differently depending on whether they relate to public operations or confidential and sensitive space missions. Community of users determine mechanisms for designing, sharing, and managing space data based on their characteristics and how this resource can serve different stakeholders, whether private or public, national, regional, transnational, or international.

Even though these technologies provide data that can be used to survey areas of interest, each of them has inherent limitations and biases and no single sensor provides an absolute and ubiquitous truth of the space situation. Furthermore, stakeholders and the general public cannot continuously and persistently observe every object all the time or share information about their objects in real time. However, despite these challenges, space-related data are very useful for various purposes, including the development of safety mechanisms and the planning of space mining activities. Therefore, aggregating data helps gaining a clear understanding of space activities. When the provision and management of space-related data have beneficial implications for all, it can lead to the qualification of knowledge commons.

In recognition of the rise of private actors in space, we are concerned about the potential occurrence of the tragedy of the anticommons, where information is withheld by private companies. We identify three key driving forces behind this phenomenon: national security and interests, intellectual property concerns, and the pursuit of strategic or economic advantages. We then explore the concept of knowledge commons, identifying what it means to share data and why it is important in the context of space data. To define the boundaries of space knowledge commons, we utilize the concept of sustainability and advocate for the development of a sustainable knowledge commons, emphasizing data-sharing policies. The GKC framework is flexible and well suited as an analytical tool for policies related to the collection, processing, and use of space data. The term "sustainability" should encompass economic, strategic, and scientific considerations, driving the rules-in-use within the framework. Furthermore, we outline the community involved, which can be effectively analyzed using the GKC framework to inform and enhance future policy analysis.

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If the provision and management of spatial data have beneficial implications for all, it can lead to the qualification of knowledge commons. Value is created by increasing the number of people who use the resource and join a community of users who benefit from data in various sectors, such as knowledge of space, planning of launches and space operations, and information relating to orbits, particularly with regard to the future challenges of their exploitation. Users can engage in governance, regulation, enforcement, education, or similar activities to conduct their space operations in a sustainable manner and foster mutual trust and understanding, ensuring peaceful and secure dynamics of interaction.

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