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Transitioning to a New Space Age in the 21st Century: A Systemic-Level Approach

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Abstract: Since the first launch of an artificial satellite—Sputnik 1—in 1957, space activities have played a significant role as a pioneering technological sector with a high impact on the international scenario. The space system has changed rapidly in the last 30 years, as a result of an intersystemic transition from a bipolar and simplified space system in the 20th century to a new and more complex space system in the 21st century. The post-Cold War space system has undergone multiple changes in its key system parameters—actors, interactions, processes, trends, etc.—that require new scientific approaches. Currently, there is extensive literature that attempts to address these changes, but it is an atomized and fragmented approach that focuses only on particular aspects of space activities, failing to provide a holistic perspective of the systemic changes. This article is analytical and is concerned with how space activities can be empirically examined using a systemic-level approach and systems models, and how the fundaments of systems science are a valuable methodological toolkit to be applied to the field of space studies. Therefore, the main objective of this research is to apply a systems architecture model—previously developed for the author—to the study of the key characteristics of the 21st century space age. The result is a systemic-level study of the new space age in the 21st century, which identifies and describes the intersystemic transition from the Cold War (1947–1991) to the post-Cold War period (1991 to the present), showing the profound changes in the main parameters of the space system and the emergence of new space actors, interactions, processes, and megatrends in space that have a significant impact on the entire world system.

Keywords: systems science; social systems; complex systems; systems architectural framework; systems thinking; systems model; complex system; international space relations; international relations; space studies; aerospace

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1. Introduction

Space activities played a significant role in the second part of the 20th century when the United States and the Soviet Union embarked on a competitive space race in the context of the Cold War. Since the first launch of an artificial satellite—Sputnik 1 in October 1957—the race for outer space between the two superpowers was fierce. From that point on, the development of space activities was exponential: artificial satellites, animals in outer space, men launched into space, multi-crew flights, spacewalks, missions to the Moon, Mars, and Venus, and the landing on the Moon on June 1969. Later, the competition continues with the development of the first space stations (Salyut, Skylab, and MIR) and the first reusables rockets (The Shuttle Space Program). Undeniably, space played a significant role in the 20th century as a pioneering technological sector with a high impact on the entire international system.

The disintegration of the Soviet Union in December 1991 and the collapse of the communist block deactivated the bipolar structure of the second part of the 20th century and opened the door for a profound reconfiguration of the international order. At the same time that the international system was changing, the space domain was also modifying its main systemic parameters. Essentially, the space system entered a vertiginous path of transformation, driven by multiple and profound processes. It is what the authors of [1] called a process of intersystem transition: "the period between the 'decadence' of a system and the 'emergence' of another". The typical bipolar structure of the space system that identified the Space Race and the Cold War period gave way to a new configuration that shows new characteristics. It is, therefore, the rupture of the previous structure and the emergence of new phenomena, trends, actors, interactions, and processes that are shaping a new space age. In the context of profound changes in the 21st century, space development has become a critical factor in the reconfiguration of the international system creating a new variety of issues with a high impact on the current global agenda and the entire world system.

The increasing relevance of space activities, the multiple empirical changes in space development, the transition toward a new space system, and the dawn of a new space age within the 21st century international system have stimulated academic study and analysis. Within the field of space studies, different social science subdisciplines have been addressing the changes in the space system in the last few decades.

Space security was a very popular subdiscipline during the Cold War because of the geopolitical relevance of the Space Race between the United States and the Soviet Union. Since we are moving to a new international system where new actors with global aspirations are emerging, generating a process of rebalancing of power, experts are now studying the impact of space activities on global security. The main focus is on the implications of new technological developments in military space programs, anti-satellite tests, new space propulsion techniques, and new space defensive systems [2–6].

From the subfield of space economy, experts study the role of space activities in the world economy. Mostly, these investigations are aimed at recognizing how the space industry and space business have evolved in the last few decades [7–11], the potential opportunities that offer the new space economic sectors (on-planet and off-planet industry) [12,13], and how this new space economic developments could affect the future economy on Earth [13,14].

Today, it is possible to observe an increasing number of scholars within the subdiscipline of space policy who are studying and analyzing the many new national space policies that have been drafted or updated in recent years, trying to understand their future impact on space development and highlighting the relevance of new local, regional, and international policies in the space sector [6,15]. At the same time, space law experts are making efforts to review the global space regulatory framework and offer alternatives for the global governance of space activities [16,17].

In particular, the subfield of study associated with space history has made considerable efforts to understand the historical evolution of space activities since the beginning of the 20th century and has attempted to provide an organized background for the study of people, events, and processes in the space domain since its origins [18–20].

Lastly, there are a reduced number of academics that have been trying to address the new space system from an interdisciplinary perspective trying to build bridges among the different social science disciplines [15,21,22]. These approaches have developed an innovative and necessary interdisciplinary perspective on the analysis of space activities, but they still lack the holistic and systemic-level view.

There is extensive academic literature on the changes in the space landscape in recent decades; however, unfortunately, much of the research on this topic has had as its main characteristic an atomized and fragmented approach to the phenomenon, focusing only on particular aspects of space activities, but failing to provide a holistic perspective on the transition from the bipolar space system of the 20th century to a new space system in the 21st century.

This article is analytical, and it is about how space activities can be empirically examined using systems models and demonstrate how the fundaments of systems science are a valuable methodological toolkit to apply to the field of space studies. It is crucial to be aware of the breadth and complexity of the subject of study and the empirical, disciplinary, and methodological limitations involved in a work of this caliber. The present essay intends to contribute through a systems approach to encourage academic research on the macrolevel analysis of complex problems.

This article raises the need for systems science approaches and macrolevel analysis to explain complex problems in space studies and to better understand the profound changes in the space system in recent decades. In this sense, systems science offers enormous potential to study complex issues within a complex social system like the international space system. Therefore, the main objective of this research is to apply a systems architecture model (SAM), previously developed for the author [23], to the analysis of the main characteristics of the 21st century space age. In this sense, this paper attempts to bring innovative perspectives to the study of the intersystemic transition that took place between the 20th and 21st centuries in the space domain. Methodologically, the SAM uses a variety of sources for data collection, including qualitative and quantitative indicators and an extensive literature review of the intersection between social science disciplines and space studies.

The result is a systemic-level study of the new space age in the 21st century, which identifies and describes the intersystemic transition from the Cold War (1947–1991) to the post-Cold War period (1991 to the present), showing the profound changes in the key parameters of the space system and the emergence of new space actors, interactions, processes, and megatrends in space that have a significant impact on the entire world order.

The essay proceeds in four stages. Section 2 explains the need for a systemic-level approach to analyze social complex systems such as the space system and describes how the SAM provides a comprehensive tool to study complex topics in the context of the world system. Section 3 applies the SAM to the 21st space system identifying and describing the main characteristics of the new space age. Lastly, Section 4 is a summary and highlight of the main findings, academic discussion, and conclusions.

2. Methods—A Systemic-Level Approach

2.1. The Need for Systems Approach

Over the past 30 years, we have witnessed numerous and profound changes in the space system. The traditional bipolar structure that characterized space during the Cold War is giving way to a new space age with new characteristics. This is known as a process of intersystem transition "the period between the 'decadence' of a system and the 'emergence' of another". This systemic reconfiguration and the definition of its main features is a historical process that can take decades to consolidate. The transition between different stages of history represents the exhaustion of an established order and the emergence of a new one, and it is characterized by the generation of structures in which the actors, phenomena, and interactions of the emerging order coexist with those of the decaying structure [1].

The space system, considered a subsystem of the broader international system, has suffered multiple changes in the post-Cold War order that require new and innovative analysis. The authors of [24] (p. 2) argued that "*we are living in an age of complexity; an age of interconnections, ambiguity, uncertainty, and various kinds of revolutions: military, technological, social, political, economic, and even philosophical*". In this new international environment, the emergence of new actors, types of interactions, processes, and a global agenda of issues that are more complex and interconnected has rendered traditional paradigms obsolete. In the context of increasing complexity, the traditional scientific analytical approach cannot provide the answers that researchers are looking for.

Unfortunately, even today, most researchers and scholars prefer to use a microlevel approach—focusing on the parts—which is surprising given the interconnectedness and interdependence of most of the critical issues on the international agenda, which require a holistic and systemic approach. The world system is more than ever a single system whose structure and dynamics can be fully grasped by a truly systemic perspective [25] (p. 4).

In his book "Open the Social Science", Wallerstein recognized the need to face new academic challenges in social science and analyze them in their whole complexity. The authors of [26] (p. 80) pointed out that "*major issues within a complex society cannot be solved by decomposing them into small parts that seem easy to manage analytically, but rather by attempting to treat these problems in their complexity and interrelations*". Murray Gell-Mann advocated for a transdisciplinary approach to address complex problems, emphasizing the need for "*a crude look at the whole*", as a way of acknowledging the difficulty of making an integrative study work. Global and complex problems cannot be considered in isolation; they require a systemic level of understanding. The authors of [27] called for a macrolevel analysis of the reality in science: "*We have to get rid of the idea that careful study of a problem in some narrow range of issues is the only kind of work to be taken seriously, while integrative thinking is relegated to cocktail party conversation*". Miller emphasized the need to start looking at whole pictures of complex systems, rather than individual parts that only make sense when we remember that they are part of larger systems. He criticized the way most social scientists address their work, using a reductionism approach—the idea that, to understand the world, we only need to study its parts—and also advocated for transcending the limits of reductionism to discover important new ideas at the systemic level [28].

Lastly, Bunge created the concept of "systemism" to address and analyze complex social systems. According to this notion [29–34], social science has developed a methodological approach that can be applied to any aspect of social life. Specifically, systemism can be considered a viable alternative way to make sense of a complex world [35] with great potential for application to analyze issues in the international system [36]. The relevance of systemism is its ability to admit and synthesize both levels: the microlevel of the individualist, and the macrolevel of the holistic. As suggested in [37] (p. 6), "*systemism allows for linkages operating at macro- and microlevels, along with back and forth between them*".

As a result, within the social science disciplines, some scholars are proposing to go beyond the traditional analytical thinking approach to examine complexity in the international system [24], and a respectable number of scholars are trying to make the case for embracing complexity [38].

2.2. Systems Architecture Model

According to the systems science tradition [29–34,39–45], systems models are a useful and reliable methodological tool for articulating theory and empirical facts through the schematization of a model of reality. Systems models are viewed as simplified versions of reality that researchers use to explore some aspects of the complex reality. Choi defined systems models as a simpler representation of the real-world problem [35] (p. 31).

Although there are existing systems models that are useful for capturing some of the empirical reality in international relations, these models do not allow for a comprehensive overview of the phenomenon such as space activities in the international system. The tradition of using systems science to analyze international affairs goes back many decades. Morton Kaplan (1957) was the first scholar to popularize the systems approach in international studies; since then, several scholars have used numerous models of the international system to analyze international relations (e.g., Kaplan, 1957; Deutsch, 1966; Singer, 1971; Braillard, 1977; Waltz, 1979; Wallerstein, 1982; Rosenau, 1990; Jervis, 1997; Wendt, 1999; Braumoeller, 2012, etc.) [14–19].

The epistemological discussion focuses on the debate between microlevel and macrolevel (systemic) approaches. The main difference is how to approach international relations issues, whether to study the structure (macro/systemic) or to focus on the parts (micro). Structural (macro/systemic) theories believe that international outcomes result from systemic constraints, while microlevel perspectives believe that these changes result from individual factors. Today, with very few exceptions [36,37], most scholars prefer to use a microlevel approach with very few exceptions. The result is the lack of a holistic perspective for the study of international phenomena.

For this reason, in a previous paper, the author proposed the creation of a broader and more holistic methodological framework [23]. Borrowing the concept from the field of engineering, the SAM responds to the conceptual and practical difficulties of the description and the study of complex systems such as the international system [46]. The development of an SAM offers a high-level perspective that views issues related to space (space subsystem) as being part of a larger overall system (international system), in interaction with other subsystems (political, technological, economic, etc.) and their environment, thus understanding the complexity of multicausal relationships among actors.

This new systemic framework named the systems architecture model (Figure 1) can be used as a methodological instrument to examine, study, and analyze in-depth a subsystem within a system, and it can be applied to all types of systems, at all levels, and in all fields of research [23].

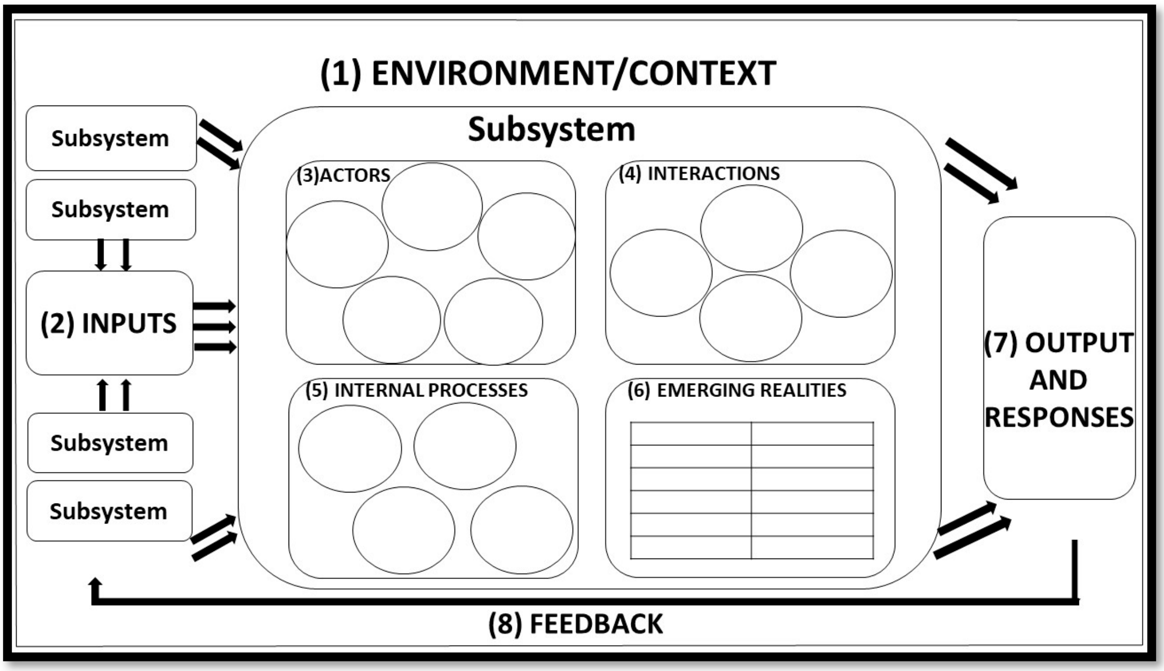


Figure 1. Systems architecture model. Source: Elaborated by the author.

Essentially, the systems architecture model is a methodological tool that is useful to examine and analyze issues within the international system. Even though a theoretical SAM can be applied to all systems, at all levels, and in all fields of study, it was conceived to apply to the study of interactions between scientific sectors and international relations. Figure 2 shows the SAM applied to science, technology, and innovation (STI) in the international system.

The use of the SAM requires following a precise methodological path in order to successfully apply the tool. Flowchart 1 shows how the systems architecture model should be applied. Following this methodological pathway to apply the systems architecture model allows one to address any case study and its impact on the international system using a systems tool.

The SAM is designed to represent reality in such a way that patterns, behaviors, properties, and structures of the subsystem within the larger international system can be identified, described, and analyzed.

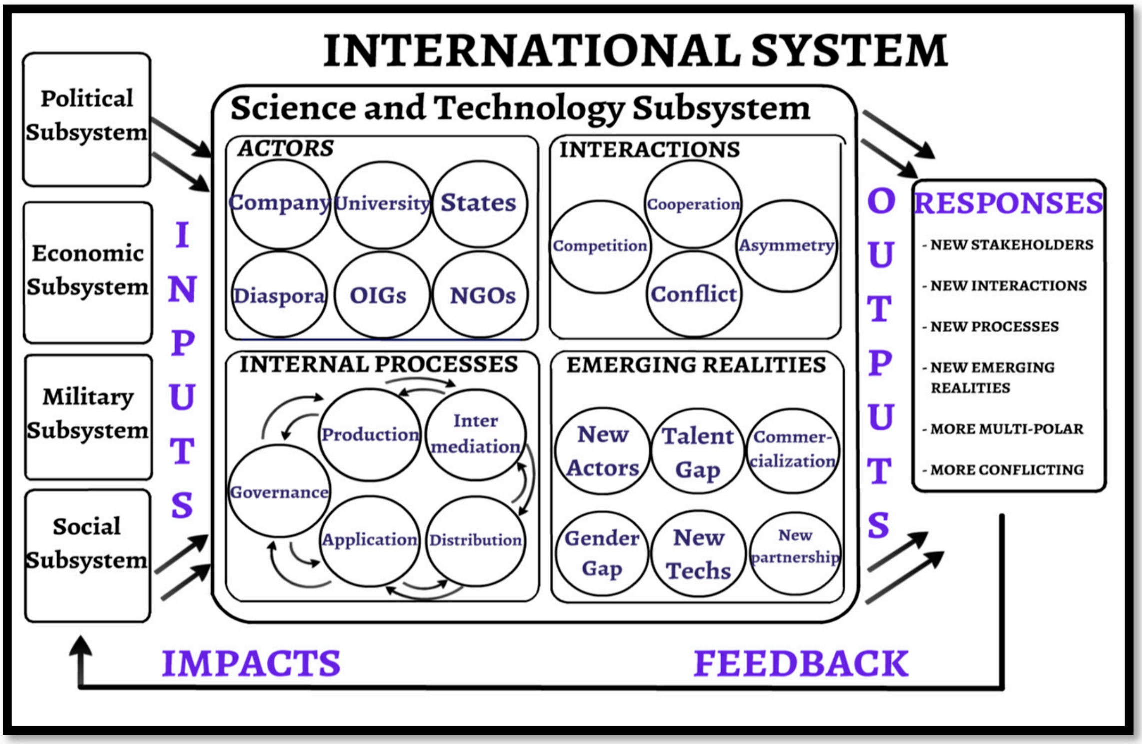
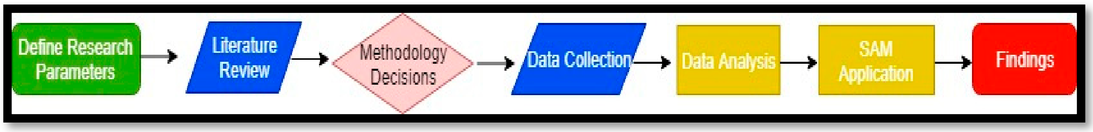


Figure 2. Systems architecture model applied to STI. Source: Elaborated by the author.

The use of the SAM requires that a precise methodological pathway be followed to successfully apply the tool. Scheme 1 illustrates how the SAM should be applied. According to this methodological pathway, this research follows a methodological process to apply the SAM to the study of space activities. The methodological path was applied as follows:

1. Define Research Parameters: The starting point is the definition of research parameters, including explanations of the research problem (lack of holistic perspective of the systemic changes in the space domain), the main objective (apply a SAM to the study of the key characteristics of the 21st century space age), and the case study (space system) in Section 1.
2. Literature Review: A preliminary approach to the subject of study (space activities) is taken through a literature review in Section 1 to identify the main research problems, gaps, and needs.
3. Methodology Decisions: Some key systemic methodological definitions are established in Section 2: (i) identification of the main system (international system) and subsystems (political, economic, technological, and social); (ii) definition of the actors taking into account their power, goals, and impact in the system (nation-states, private companies, higher education institutions, international organizations, and space hubs); (iii) identification of the main interactions (conflict, cooperation, competition, and asymmetries); (iv) identification of the main internal processes and mechanisms (production, governance, application, and use).
4. Data Collection: Information is gathered on dimensions and variables of interest using a combination of qualitative and quantitative methods. It is used as a mixed method of research combining insightful data with useful statistics. On one hand, in-depth research is conducted reviewing documents of other information sources related to the case study (space system), with more than 250 scientific articles and books reviewed, and more than 100 sources selected and used for this research project. On the other hand, statistical information is collected from international or national organizations (OECD, UN, NASA, DoD, etc.).

5. Data Analysis: A database is created in Excel structured according to the dimensions and variables selected in the SAM (actors, interactions, processes). This database allows making comparisons and classifying key information on the basis of the dimensions and variables previously selected. Founded on this database, a narrative is developed and included in Section 3.
6. Application of SAM: As part of the data analysis, SAM is applied, consisting of five steps: (i) identifying inputs from key subsystems and the entire environment (Section 3.1.1); (ii) identifying key actors (Section 3.2); (iii) examining interactions (Section 3.3); (iv) analyzing internal processes (Section 3.4); (v) identifying emerging realities, trends, and responses (Section 3.5).
7. Findings: Lastly, the results are presented with a systemic visualization at the end of Section 3, and a table/figure summarizing the key findings is included in Section 4.



Scheme 1. Methodological path. Source: Elaborated by the author.

To conclude this section, it could be said that SAM is applied to represent a new reality in the space domain in such a way that identifies, describes, and analyzes the patterns, behaviors, properties, and structure of the space system within the larger international system.

3. Results—Systems Analysis of the New Space Age in the 21st Century

The space sector can be considered as a subsystem within the general context of the international system; however, at the same time, it can be studied and analyzed as a system in its own right. The SAM was applied to the space system of the 21st century. Following the methodological path, data were collected, analyzed, and applied to the SAM. This process allowed us to identify and describe the main characteristics of the current space system in the context of the international space system of the 21st century. The main results of this scientific research are presented below.

3.1. Environment–International System

The international system can be understood as the environment or context in which the remaining subsystems interact [30] (p. 205), and it is defined as the context of the system that generates input, demand, or support for the subsystems. The international system is the larger system or supersystem that contains all subsystems: political, economic, social, technological, space, etc. The space system/subsystem, as part of this broader environment of the international system, receives demands, information, actions, and many other inputs that affect the subsystem.

In the last few decades of the 20th century, the international system has undergone a significant transformation, triggered by several deep global processes that have operated in parallel within the world order and have produced profound changes in the configuration of the international system and in each of the subsystems that compose it. These inputs also have a massive impact on the space system. The SAM makes it possible to identify the subsystems that have a greater impact on the space system and to describe the most important demands and trends coming from them.

3.1.1. Political Subsystem

Two major trends emanating from the political system affect the space system: the changes in the balance of power with the end of the Cold War and the challenge to the central role of the nation-states in the international system.

The first of these processes is the rebalancing of power in the international system. The end of the Cold War marked the end of the international order that prevailed from the end of the Second World War until the final dissolution of the Communist bloc in 1991. Throughout this period, the international system was dominated by the ideological conflict between two non-European superpowers (the United States and the Soviet Union), which represented antagonistic economic and political systems and maintained an indirect confrontation throughout the world map. The core of this process is the transition to a new order of the international system, in which global political power is redistributed differently with the rise of new nation-states with geopolitical aspirations and the conformation of a more multipolar international system, which necessarily creates a new polarization in the world system [47].

The second trend originating from the political subsystem is the erosion of the traditional role of the nation-state and the resulting changes in the international political order. The current systems of political organization are based on the principles of territoriality and sovereignty of the nation-state, which have been in force in the international system for the last 350 years since the Peace of Westphalia in 1648. The nation-state has begun to lose power within the world order because of a confluence of two main factors: the growing influence of the communications, information, and financial sectors that operate beyond the borders of the nation-state, and the rise of local and subnational identities. This new political phenomenon has stimulated a profound academic debate about the future role of nation-states in the international system. Some experts argue that nation-states have lost power, and that their role as the central actor of the international system is declining [48,49]. Meanwhile, other intellectuals believe that, despite global changes, nation-states still control their territories and borders and are still important as actors in international politics [47,50]. In any case, the post-Cold War era has shown the emergence of new actors at the international level that play a more relevant role, such as transnational corporations, intergovernmental organizations, nongovernmental organizations, and regional processes.

3.1.2. Economic Subsystem

Within the economic subsystem, two interrelated trends are affecting the space system: the changes in the capitalist system, and the rise of a knowledge economy.

The changes in the history of capitalism have always been among the most influential processes for the international system. The supremacy of capitalism throughout the 20th century was only possible because it mutated, transformed, and reconfigured itself several times during its historical evolution as an economic model. In the 20th century, one of the most important changes took place in the 1970s, when the economic guidelines established at Bretton Woods were modified toward a mode of subordination of national economies to the demands of the global economy. These changes gave rise to a new stage of capitalism [51,52]. The term "knowledge-based economy" or, more simply, "knowledge-economy" was popularized toward the end of the 1990s to describe the evolution of an economy based on production and industry to one based primarily on knowledge. According to [53], we can generally consider the knowledge economy to be based on the use of ideas rather than physical skills, the application of technology rather than the transformation of raw materials, or the exploitation of labor. The key to the emergence of a knowledge-based economy has been the newly acquired relevance of the economic competitiveness between the different actors of the international systems (and not only companies) and the role that scientific knowledge plays in this competition. The current international economic system requires competitiveness, as well as an increase in trade and investment, to ensure prosperity and economic growth. Today, the only competitive advantage comes from knowledge and innovation [54], where the ability to innovate is the cornerstone of competitiveness, and the enterprise becomes the mediator that transforms inventions (understood as the products of new knowledge) into innovations (understood as the economic valuation of said produced knowledge). The decisive dynamic of the system is scientific knowledge, which is adopted by companies and countries, as a decidedly endogenous growth factor, and which is translated into applied technologies (management, processes, and materials) through the sequence "Research, Development, and Innovation

(R&D&I)". As explained in [54], knowledge is being developed and applied in new ways, product life cycles are becoming shorter, and the need for innovation and competitiveness is increasing.

3.1.3. Scientific–Technological Subsystem

The scientific and technological domain has undergone a significant transformation in recent decades, with a profound impact on the entire international system, especially the space system. Historically, technological development has played a critical role in the international system with a significant and profound impact on the social, political, and economic domains. As the authors of [55] pointed out, the dynamics of technological change and military competitiveness have been the great driving force behind Europe's dominant position in international relations for many centuries.

In recent years, an unprecedented scientific and technological revolution has affected the international system and most especially the space sector. The terms "scientific and technological revolution", "technological revolution", "scientific and technical revolution", or "digital revolution" are concepts used to refer to the same phenomenon: the technical transformations (and their social and economic implications) that have taken place in the international system from the last quarter of the 20th century to the present. The relevance and impact of this scientific and technological revolution have led to the frequent use of expressions such as the "Third Industrial Revolution" and "Fourth Industrial Revolution" to compare them with the first two great transformations in human history that deserve the name of revolutions: the Neolithic Revolution and the Industrial Revolution.

Schwab [56,57] pointed out that there is clear proof to think that we are at the beginning of a Fourth Industrial Revolution, starting in the 21st century, building on the framework of the previous digital revolution. Following Schwab's arguments, what makes this new revolution different from the previous ones is the existence of new scientific and technological areas (such as AI, nanotechnology, or renewable power) that mix and interact, at the same time, in the physical, biological, and digital areas, which opens a wide and previously unthinkable array of possible applications. The application of emergent technologies in space could open new and unknown opportunities in space development with significant political, economic, and international impact.

This scientific and technological revolution generated incredible progress in communications and transportation systems, which has facilitated and promoted interactions, relations, and links among all areas of the planet and allowed the emergence of a new concept: the global village [58]. The end of the Cold War allows greater visibility of the globalization process of the international system, a long-term phenomenon that has accelerated in recent decades. In essence, globalization means the expansion and intensification of social, economic, and political relations across regions and continents. It is a multidimensional phenomenon involving many different processes and operating on many different timescales [59]. A more interconnected and interdependent world, at least in some areas (economic, financial, and communication) and in some specific geographical coordinates (developed countries) [60].

The concept of globalization is also associated with the confusion generated by the coexistence of contradictory megatrends within the same globalization phenomenon: on the one hand, the trend of economies toward globalization, the global governance of world politics, the homogenization and secularization of the cultural value systems; on the other hand, the trend of fragmentation in the resurgence of nationalism and populism, as well as the new rise of religious fundamentalism, ethnic protectionism, and cultural relativism [61].

3.1.4. Social Subsystem

Lastly, the social system has also changed dramatically in recent years, with implications for the space system. One major trend has emerged from the social system: the knowledge society. Essentially, the concept of the "knowledge society" or "knowledge-based societies" refers to a new type of society characterized by the intensive application of knowledge in all aspects of life, where knowledge becomes the main source of production, wealth, and power. This global phenomenon includes and transcends other emerging events in the international system, such as the knowledge economy or the information society. According to [62] (p. 16), "*the rise of the knowledge society is a global process that will not completely replace the old 'industrial society', but that will coexist in a spectrum of different situations over a long transitional period*".

In this context, the main demands from the social system are focused on the social use of the newly developed knowledge and improving the impact of STI on social life. This includes the use of scientific and technological solutions to tackle global challenges, where scientific knowledge is seen as a mechanism to successfully address the global agenda and achieve sustainable development for the entire international system. At the same time, this knowledge society also generates strong demands to spread technological innovations not only to the military and economic sectors but also to society as a whole, with concrete applications to basic tasks of daily life [62].

3.2. Actors

An actor is defined as anyone who is relevant in the dynamics of international relations, as well as the global agenda, and who influences the strategies of other actors [62] (p. 41). At the international level, not all actors are relevant. To be considered an international actor, it is necessary to have the capacity to generate or participate in relationships that are intentionally significant for the entire international system [63].

There is an extensive list of international actors within the international systems that actively participate in international events. In recent decades, there has been an increasing proliferation of different types of actors, e.g., transnational corporations, intergovernmental organizations (OIGs), nongovernmental organizations (NGOs), religious, ethnic, cultural, and social movements, regional processes, nationalist and/or separatist movements, international mafias, drug cartels, smuggling networks, hackers, and terrorist groups, Each with different capabilities, interests, influence, and power.

The SAM analysis focuses on the most relevant actors and describes their key characteristics, power, objectives, and strategies.

3.2.1. Nation-States

Space activities have followed a model of centralized, government-directed human space activity that emerged in the 1950s with the dawn of the space age. For this reason, nation-states have played a central role in the space domain since the beginning of space activities. Although this government-driven model has changed in recent decades with the gradual but persistent entry of private actors, nation-states are still key players in the 21st century space system.

While the number of nation-states involved in space activities was very small during the Cold War, the transition to a new space system in the 21st century has led to an increased interest in the space sector. As of January 2023, 90 different government space agencies are engaged in activities related to outer space and space exploration [64]. Eighty countries currently have registered a satellite in orbit [65], and at least eight of these 80 have full launch capability and can obtain orbital access.

Traditional nation-states involved in outer space activities have renewed their interest in space, while other nation-states are showing curiosity about outer space for the first time. To date, most of the national space programs have necessarily focused on activities of public interest, such as national security and defense, economic development and business, social applications and benefits, science and education, and national prestige.

In the space systems of the 21st century, governments play key roles as planners, manufacturers, investors, developers, owners, operators, regulators, and customers. Despite the growing number of new non-state actors involved in space activities, the government still plays a pivotal or catalytic role, articulating most of the activities in the space domain. This important role requires that space activities be carried out in many different parts of the government sector (e.g., defense, communications, transportation, and environment) and at different levels of government (federal, provincial, and local) [65] (p. 59).

In the last few years, we have witnessed renewed interest on the part of nation-states to define national goals in space. This interest has led to the establishment of new national space strategies that include comprehensive space plans, new space policies, new space agencies, and an increasing budget for space activities.

National Space Policy

Most of the space powers have updated their space policies in the last decade. In 2020, under the Trump administration, the United States released a new National Space Policy that advocated for expanding US leadership in space, encouraging private sector growth, expanding international cooperation, and establishing a human presence on the Moon with an eventual human mission to Mars. This space strategy was ratified by President Joe Biden with a new document entitled "The United States Space Priorities Framework", released in December 2021, which defines a similar space policy for the next 4 years.

Since Vladimir Putin became President of the Russian Federation in December 1999, he has identified space as a critical sector for restoring Russia's power and pride. Putin's space policy plans began with the First Federal Space Program (2006–2015), and then with the New Russian Federal Space Program (2016–2025). The FKP-2025 is a long-term roadmap that includes ambitious plans such as building a giant superheavy rocket that would enable Russia to land its cosmonauts on the Moon by the end of the 2020s and begin building a permanent base there. The Moon landing remains the strategic goal of the Russian manned space flight, but with a tentative launch date of 2030.

On 28 January 2022, China released a white paper entitled "China's Space Program: A 2021 Perspective", outlining its plans and priorities for the next half-decade of space travel and exploration. This is the fifth 5 year space exploration plan that China has released, following similar releases in 2000, 2006, 2011, and 2016, in which China introduces principles, policies, measures, and international cooperation in its space exploration.

The European Union (EU) has also been developing and updating strategic policies in space. In 2016, it published the "Space Strategy for Europe", which defines the main priorities: (i) maximizing the benefits of space for society and the EU economy; (ii) fostering a globally competitive and innovative European space sector; (iii) reinforcing Europe's autonomy in accessing and using space in a secure and safe environment; (iv) strengthening Europe's role as a global actor and promoting international cooperation. In April 2021, the Council and the European Parliament adopted a regulation establishing the new EU Space Program for the years 2021 to 2027. The program entered into force retroactively on 1 January 2021, promoting enhanced security and autonomy of the European Union, with a stronger role of the EU as a leading space power.

Japan revised its space policy by enacting the Basic Space Law in 2008, which broadened the interpretation of the concept of "exclusively peaceful purposes" and allowed Japan's space industry to engage in activities "to ensure international peace and security and also to contribute to our nation's security". It was a major shift in government policy to accept a wider range of space uses, including for defense. The Basic Space Law emphasizes the promotion of the civilian use of space, the strengthening of Japan's space industry, and its international competitiveness; furthermore, for the first time, it also mentions ensuring Japan's space security [66].

India, another traditional space actor, changed its space policy in 2003 when Indian Prime Minister Atal Bihari Vajpayee publicly challenged his country's scientists to work toward sending a man to the Moon. Immediately, the Chandrayaan program, India's lunar exploration program, led by the Indian Space Research Organization (ISRO), was announced. The program includes a lunar orbiter, impactor, soft lander, and rover spacecraft. Years later, a Mars exploration program called the Mangalyaan Program was announced. With this Mars program, India became the fourth country to reach Mars orbit, the first Asian nation to reach Mars orbit, and the first country to enter Mars orbit on its first attempt.

Additionally, in March 2019, India became the fourth country to successfully launch an anti-satellite (ASAT) missile after India's A-SAT missile shot down a live satellite in lower Earth orbit.

Most of the emerging and even small powers in space have developed new space policies in the last 20 years. Some good examples are Turkey (National Space Program, 2021), Pakistan (Space Program 2040, 2019), Brazil (The Brazilian National Plan for Space Activities—PNAE 2012–2021), and the United Arab Emirates (National Space Program, 2017), etc.

National Space Agencies

Over the past two decades, an increasing number of countries have become interested in space activities. In this sense, the rise of "nascent space powers" or emerging space powers in the space domain is one of the main features of the 21st century space age [67,68]. Typically, there are four main motivations for space development: national pride and international prestige; national security and defense; commercial development and applications; scientific exploration and social benefits. National space agencies play an important role in coordinating and overseeing national space activities. As pointed out in [67], the establishment of a national space agency office is the first step in developing a national space program.

The last two decades have seen an increased number of government agencies or offices dedicated solely to space activities, such as the UK Space Agency (UKSA), the Mexican Space Agency (AEM), and the South African National Space Agency (SANSA), all established in 2010. The United Arab Emirates established the UAE Space Agency in 2014 and the Mohammed Bin Rashid Space Center in 2016 (UAE Space Agency, 2016), with the aim of developing Earth observation satellites. Turkey established its own space agency in 2018. A respectable number of Eastern European countries are also establishing institutional frameworks for their space activities within their national strategies, often in combination with increasing cooperation with or adherence to the European Space Agency—ESA (Czech Republic, Estonia, Poland (2014)). Other relevant cases worldwide are in New Zealand (2016), Australia (2018), Luxembourg (2019), Portugal (2019), Costa Rica (2021), and Spain (2022).

In essence, the number of space agencies has increased significantly in recent years, signaling a growing need to coordinate national space activities and/or formulate integrated space policies.

National Space Budgets

The final element of the national strategy is the investment in civil and military space activities. The evidence shows that global government space budgets have continued to grow over the past decades. Government spending on space programs increased from 32 billion USD in 1990 to 62 billion USD in 2016 and 92 billion USD in 2021. Driven by space exploration and militarization, government space budgets will reach a record investment of 103 billion USD in 2022, an increase of 9% from last year. This growth is particularly pronounced in the defense sector, which will reach 16% in 2022 and set a new record at 48 billion USD.

The US government will spend nearly 62 billion USD on its space programs in 2022, making it the world's largest space spender. China followed the US, with government spending on space programs of nearly 12 billion USD, surpassing Russia for the very first time in 2021 [69]. While the United States remains, by far, the world's largest investor, its share of global spending declined from 76% in 2000 to 60% in 2022 as more and more countries joined the sector. In 2022, more than 90 countries are investing space activities, and all the regions have shown a particular dynamism in recent years.

3.2.2. Private Companies

The model of centralized, government-directed human space activity that emerged in the 1960s has given away over the past two decades to a new model, in which public initiatives in space increasingly share the stage with private priorities [9]. Most experts agreed on a new phase in the history of space activities since the beginning of the 21st century. This new phase (from 2000 to the present) has as its main characteristic a progressively higher participation of private companies in space activities [7,8].

This new role of the private sector in space activities has been fostered by a new form of public–private partnership, a collaboration in which governments provide initial support for the exploration and development of critical technologies (telecommunications and Moon–Earth navigation) and the construction of space infrastructure [8]. NASA has been at the forefront of this process, encouraging private companies to participate in various space activities over the last two decades (Commercial Crew Program, lunar exploration mission, construction of private space stations, etc.).

The private sector played an important but diminished role in space activities in the 20th century. Companies such as Lockheed-Martin, Boeing, and Northrop Grumman are considered the "old guards" of the space industry; as a result of that, they have some of the most mature space technology that has been developed over the past 50 years, in part thanks to their extensive experience working for the US government. The emergence of new private sector space companies has forced these traditional companies to adjust their commercial strategies and adapt to the new competition in the private sector. For example, in 2006, Lockheed-Martin and Boeing created a joint venture, the United Launch Alliance (ULA), to provide launch services for the US Air Force. The ULA has also developed a "Cislunar 1000 Vision" that aims to have 1000 people working in space between the Earth and the Moon by 2045 [70].

Since the late 1900s, the number of space companies has grown exponentially. Most began as small companies or startups, e.g., Bigelow Aerospace (1998), Blue Origin (2000), SpaceX (2002), Virgin Galactic (2004), and Rocket Lab (2006). These companies have begun to push the boundaries of the space industry, making it more affordable to launch rockets and developing new technologies that have dramatically changed the space business. There are also new entrants from other economic sectors—information and communications technology companies, including those involved in data analytics—such as Facebook, Google, Softbank, and Tencent.

Lastly, it is also possible to identify a new boom of space startups founded since the beginning of 2010. With the outbreak of the pandemic, the number of new companies decreased, but this does not seem to have changed the trend of the last decade, showing a significant increase in 2022 [71]. According to [72], about 265 billion USD has been invested in space startups since 2014. Half of this sum went to American companies and another 30% to Chinese companies. This new phenomenon presents some peculiarities: (i) American companies are still the majority, but this is a worldwide phenomenon of space startups with particular relevance in China, India, and Japan; (ii) these new companies are investing not only in on-planet space projects but also in the off-planet industry; (iii) the financing and entrepreneurial aspect is emphasized, which includes the entry of new large financial sectors and private-venture funds. As pointed out in [7], "*private companies, which act independently of governmental space policies and funding, target equity funding and promote affordable access to space and novel space applications*".

The growing importance of the private sector is changing the dynamics of space activities. Private companies are eager to put people in space to pursue their commercial interests and then meet the demand they create. This is the vision driving most of the new space companies that are pursuing their own goals. SpaceX is revolutionizing the rocket-launch industry with the goal of putting humans on Mars as early as 2029 as the first step in the slow colonization of the planet. SpaceX's CEO, Elon Musk, has a long-standing vision of building a city on the Red Planet that would be a self-sustaining Mars city of one million people by 2050. Jeff Bezos, the founder of Blue Origin, prefers to build giant orbiting cities near Earth to expand humanity. He had proposed that humans could live in a series of floating, spinning cylinders that could hold up to 1 million people and have rivers, forests, and wildlife. ISpace, a Japanese company founded in 2010, is working on the first step of the Moon Valley 2040 project, a community of at least 1000 people living and working on the Moon by 2040.

This is primarily an American phenomenon, where the private sector has traditionally been dynamic and highly innovative, but it should also be considered a global trend, given the increasing number of space companies in other countries. According to [71], there are now 5582 space companies in the United States. That is nearly 10 times more than in the next highest country by this indicator—Great Britain, where there are 615 of them. Even countries like China have begun to liberalize private investment in the space sector; over the past 5 years, more than 900 million USD in private funds have been invested in Chinese space development. With nearly equal investment from government sources, commercial companies have raised a total of at least 1.85 billion USD since 2014 [73].

3.2.3. Higher-Education Institutions

Since their beginnings 1000 years ago, universities have played a significant role in history. As mentioned in [62] (p. 42), "*the university has always been considered as a central institution in the international system [...] linked to a vast array of national and international actors at different levels, as well as to a diverse agenda of social, political, economic, educational, technological, and cultural issues*".

Essentially, universities perform two activities that have a significant impact on any economic and technological domain: the education and training of a specialized workforce and the conduct of high-quality research. Therefore, universities can be considered one of the most effective producers and suppliers of intellectual capital for the space industry [74]. In the current space system, higher-education institutions play a key role in space R&D in many countries and partner economies. As the OECD pointed out, "*they are a source of innovation, knowledge diffusion, and technological transfer for the sector, conducting basic and applied research, as well as publishing and patenting activities. Furthermore, many space economy startups originate in the higher-education sector*" [65] (p. 64).

In the United States, higher-education institutions have historically played an important role in the space industry. From the founding of the Jet Propulsion Laboratory (JPL) in 1936 by a group of Caltech researchers to the University of Arizona's leading role in the Phoenix Lander Project (an unmanned spacecraft that landed on the surface of Mars in May 2008) to the creation of a Graduate Program in space studies in 1986 at the University of North Dakota, the American higher-education system has been involved in space activities. In 2021, the recently created US Space Force launched the University Partnership Program (UPP), which involves more than 15 American universities. The UPP is designed to foster the development of synergies among America's top world-class research universities in the field of space activities and the public sector by identifying and pursuing areas of mutual interest, establishing scholarship, internship, and mentorship opportunities for university students, and recruiting and developing a diverse officer, enlisted, and civilian workforce.

ESA also recognizes that interactions among higher-education institutions and the public and private sectors are essential for the development of space activities, and it emphasizes both scientific and technological multidisciplinary innovative research, as well as the advancement of knowledge and education. The challenges of the space sector in the 21st century require creative and groundbreaking solutions to space science and engineering problems. The funding of activities in higher-education institutions to stimulate new ideas and stimulate subsequent innovative research and development is a necessary step in this direction [75].

China is also promoting a strategic partnership between the space sector and higher-education institutions as a result of the rapid and remarkable economic progress and acceleration of Chinese space activities. According to [74], China's university system currently provides intellectual capital to the Chinese space industry; however, as China continues to invest in strengthening its space industry and expanding its space ambitions, state resources, including the university system, would be mobilized.

Lastly, universities and research institutes serve as essential parts of the African space ecosystem, as they train and produce skilled personnel to participate in various sectors of the African space industry [76].

3.2.4. International Organizations

International or intergovernmental organizations are all those institutions that are constituted by nation-states. In this sense, two main types of organizations can be identified within the space system of the 21st century: global and regional.

At the global level, the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) is the most important organization related to space activities. It was originally established in 1958 with 18 members. In 1959, the General Assembly established COPUOS as a permanent body with 24 members. The main task of COPUOS is to review and promote international cooperation for the peaceful uses of outer space, and to maintain close contact with the main actors in the space domain. In addition, COPUOS oversees the implementation of five United Nations treaties and agreements related to outer space activities, including the Outer Space Treaty. The United Nations Office for Outer Space Affairs (UNOOSA) is the secretariat for the UN COPUOS and is responsible for the day-to-day operations and record-keeping of the Committee. During the Cold War period, COPUOS grew very slowly until it reached 53 members at the end of the century. Since then, the membership of COPUOS has grown more rapidly, reaching 102 members in 2022.

At least two other global organizations have a relative impact on the space system. The UN Institute for Disarmament Research works on the prevention of an arms race in outer space. Since the 1980s, a multilateral forum (with 65 members including the US, China, and Russia) has negotiated arms control and disarmament at the global level with few results. The International Telecommunications Union (ITU) is a specialized agency of the United Nations responsible for all matters relating to information and communication technologies. The ITU's Space Services Department is responsible for allocating the geostationary orbits used by telecommunications satellites and the radiofrequencies used for satellite broadcasting. Although the ITU operates under the umbrella of the United Nations, it is a separate legal entity with its own membership and funding.

The end of the Cold War led to the regionalization of space cooperation and the emergence of a new organization at the regional level. Most of these new regional processes have institutionalized cooperation and created new regional actors in the space system. The European Space Agency (ESA) established in 1975 with founding members was the first intergovernmental regional organization related to outer space activities. The end of the Cold War encouraged more countries, especially those from Eastern Europe, to join this European regional experience: the Czech Republic (2008), Romania (2011), Poland (2012), and Hungary (2015). Canada also sits on the Council and participates in some projects under a cooperation agreement. Slovakia (2022), Slovenia (2016), Latvia (2020), and Lithuania (2021) are associate members. Four other EU countries have cooperation agreements with the ESA: Bulgaria, Croatia, Cyprus, and Malta [77].

Based on the ESA model, many other regional space processes have emerged over the past 30 years. Among the most relevant are the Asia-Pacific Regional Space Agency Forum (1993), the Asia-Pacific Space Cooperation Organization (2005), the Latin-American and Caribbean Space Agency (2021), and the African Space Agency under the African Union (2022).

3.2.5. Space Hubs

In recent years, we have witnessed the emergence of a new and prominent actor in the space system: space hubs. Cities and regions have played an important role in world history as economic, political, and social actors; however, in the space domain in particular, cities and regions have been subordinated to national interests for most of the 20th century.

In the post-Cold War international system, cities and regions have acquired a special role in becoming more attractive geographic units for the development of STI, either because of their scientific installations and infrastructures or because of their global talent. Following the successful model of Silicon Valley/San Francisco in the United States, many cities are trying to copy the characteristics that made Silicon Valley into the paradigm of a high-tech and innovative city. This phenomenon has led to the concept of innovation hubs, understood as a community that enables the interactions among actors for the development of STI-related activities. The leading cities or regions are successful because they enable the exchange of knowledge between institutions and organizations in their environment, allow a higher concentration of talent, and can foster a more knowledge-intensive economy by providing an inviting place to work, invest, and research.

This model of innovation hub has been applied to the space sector in recent years, creating a new map of space hubs around the world. These space hubs are physical spaces that bring together, in a neighbor, city, or region, people, ideas, know-how, capital, funds, and investment to foster innovation processes in a particular economic sector. For cities and regions, space hubs represent an opportunity to create new sources of jobs, attract commercial investments, stimulate new research and innovation, attract and retain talent, support new businesses, and more.

The concentration of factories and industries in the aerospace industry is intended to create a synergistic effect through increased interaction and collaboration, creating a qualitatively new environment, and reducing the economic costs of the new businesses. Space hubs bring multiple, sustainable economic benefits to any geographic region; for this reason, several cities and regions recently stimulated this new paradigm of space hubs, including Moscow (Russia), Florida and California (USA), Seoul (South Korea), Guangdong and Beijing (China), the East of England (UK), and Southern Kanto (Japan) [12] (p. 35).

3.3. Interactions

The interactions are considered the relationships among the most relevant actors within the system/subsystem. In this sense, the space system can be defined as a vast network of interactions among different actors that can be identified, analyzed, and characterized. The SAM identified four potential types of interactions that are considered the most relevant interactions in international scientific relations: cooperation, conflict, competition, and asymmetries [23].

3.3.1. Cooperation

The political context of the Cold War allowed for very few instances of cooperation in space. On the contrary, the post-Cold War space system has shown an increasing number of cooperative activities among all the actors. Even though most nation-states consider space activities as a form of national security, there are still several reasons why countries are willing to cooperate in space. According to [78,79], space actors are inherently self-interested, and their activity in and use of outer space serve a particular goal—political, economic, scientific, or national security—that provides them with benefits, enables international competitive advantages, and justifies the costs and complexities of a space program. Even when space cooperation is pursued out of self-interest, the benefits that come from it are numerous and sometimes more attractive than those of unilateral action. These benefits include (i) reducing costs by spreading the burden to other nations, (ii) generating diplomatic prestige and developing “soft power”, (iii) increasing political sustainability, and (iv) a way to develop norms and international regime-building.

Since the end of the Cold War, space cooperation has increased intensely in all its forms: bilateral, multilateral, regional, global, and public–private. At the bilateral level, there has been an exponential increase in space agreements. One of the first and most important was the 1992 space agreement between the United States and the Russian Federation. This agreement called for the establishment of a joint space project in which an American astronaut would board the Russian MIR space station, and two Russian cosmonauts would board a Space Shuttle. From February 1994 to June 1998, space shuttles made 11 flights to the Russian space station MIR, and American astronauts spent seven stays aboard MIR.

Called "Phase 1", the Shuttle–MIR program paved the way for the International Space Station and began an era of cooperation and exploration, rarely seen in human history.

In the last few years, the United States has pursued a bilateral strategy in space, signing several bilateral agreements with countries such as South Korea, Japan, and India. In this sense, even the Artemis Accords were conceived as a set of bilateral agreements between NASA and the space agencies of other countries wishing to participate in the American Artemis program.

In the same vein, on 9 March 2021, the China National Space Administration (CNSA) and Roscosmos signed a bilateral agreement called the Memorandum of Understanding between the Government of the People's Republic of China and the Government of the Russian Federation. The main goal is to cooperate in the construction of the International Lunar Research Station (ILRS), which is planned to be operational in 2034. It should be noted that the International Lunar Research Station is open to all interested countries and international partners. Both countries have publicly declared their interest in cooperating with the Indian space agency in space exploration, and Russia is currently training four Indian astronauts.

In the post-Cold War era, a new multilateral model of space cooperation emerged with a singular case: the International Space Station (ISS). The ISS is considered the largest and most complex international cooperative science and engineering program ever attempted. Leveraging the technical expertise of participating countries, the ISS brings together scientists, engineers, and researchers from around the world to create a world-class orbiting research facility. The ISS is suitable for testing the spacecraft systems and equipment needed for possible future long-duration missions to the Moon and Mars. On 29 January 1998, senior government officials from five space agencies and 15 countries met in Washington and signed agreements establishing the framework for cooperation among the partners in the design, development, operation, and use of the space station. Construction began in 1998, the first crew arrived in 2000, and the space station has been continuously occupied ever since. In 22 years of continuous operation, the ISS has hosted 240 astronauts from 19 different countries. The US and Russia may not be able to reach an agreement on a range of geopolitical issues; however, in space, the two countries continue to work successfully together.

The Artemis Accords, originally signed by eight countries in October 2020, has expanded to the current 23 countries that have joined this multilateral space agreement. It is a legal instrument that provides a framework for NASA's most important space program since Apollo. The long-term goal of the Artemis program is to establish a permanent base camp on the Moon and to facilitate human missions to Mars [80]. This new space coalition includes relevant nation-states such as the United States, France, the United Kingdom, Japan, South Korea, and Brazil. Other relevant space powers such as China, Russia, and India have been invited to participate in the Artemis Accords, but they have not yet joined the multilateral space program.

The regional level has seen another boom in space cooperation in the last decades. This regionalization process can be broadly defined as a limited number of states linked by a geographical relationship and by a degree of mutual interdependence, which have decided to cooperate in a particular sector. Essentially, they form voluntary associations and pool together resources (material and nonmaterial) in order to create common functional and institutional arrangements. Although the first relevant process of regionalization in space was indeed the creation of the European Space Agency in 1975, the end of the Cold War busted the regionalization of space cooperation. The authors of [81] called this process "space blocs" and pointed out that international cooperation in space is increasingly defined by clusters of states. In essence, most of the regional integration processes are cooperating in the space sector, using space as a new tool or mechanism of space diplomacy. According to this model, the informal regionalization of space cooperation was later complemented by the creation of formal institutions and norms. In the post-Cold War context, the first experience was the creation of the Asia-Pacific Multilateral Cooperation in

Space Technology and Applications (APRSAF) in 1993, led by Japan and involving more than 50 states. The process of space regionalization has intensified with the formation of five new space blocs in the last two decades. These include the Asia-Pacific Space Cooperation Organization—APSCO (2008) with 10 states, the African Space Agency—AfSA (2018) with 55 states, the Arab Space Coordination Group—ArabSCG (2019) with 14 states, the Latin-American and Caribbean Space Agency—ALCE (2021) with 19 states, and the European Union Agency for the Space Program—EUSPA (2021) with 27 states.

Lastly, another type of space cooperation is public–private partnerships. Although history shows that there has always been some degree of cooperation between the public and private sectors, particularly in the US and in a few cases in Europe and Japan, this type of cooperation has developed strongly in the space system of the 21st century. Basically, these cooperative agreements between a public agency and a private entity allow for greater private participation in the implementation of space projects. In recent decades, the US government, in particular, has sought to expand its capabilities in various areas of space, recognizing the significant role that the private sector can play in providing these capabilities at reduced cost and risk. As recently as the early 2000s, the only way to launch payloads into space was to go through government agencies such as NASA, ESA, Roscosmos, and CNSA. Today, the US is leading the way in purchasing launch services from private companies (SpaceX, Boeing, and Blue Origins), while the private companies are working with other companies and investors to launch nongovernment payloads.

3.3.2. Competition

Competition between nation-states is a natural behavior in international relations, especially when this rivalry is over strategic resources. Typically, this type of interaction takes place in a peaceful context where the adversaries establish a set of rules to be followed and respected. In the second half of the 20th century, the US and the Soviet Union balanced between competition and confrontation in space exploration. With the transition to a new international system, the number of actors involved in space activities has also increased, as has the competition between them. In recent years, nation-states have begun to compete to develop their national space systems by designing complex public plans to invest in space R&D, infrastructures, and human resources.

In the post-Cold War era, more countries have decided to participate in this new space race. The traditional bipolar space system of the 20th century is transitioning into a multipolar system in which more and more nation-states are interested in space. By 2023, more than 90 countries will be involved in space activities; in addition to the United States and Russia, six other entities have developed full launch capabilities: China, ESA, India, Japan, Israel, and Iran [64]. This new space race seems to be just the beginning, considering that, in recent years, we have seen a growing interest in space with the creation of new government space agencies, the updating of national space policies, and the allocation of public funds to space activities.

The dynamics of competition among actors in the 21st century space system include new non-state actors such as corporations, international organizations, higher-education institutions, and space hubs. For companies, competition is a natural way of interacting with the rest of their peers and the normal process they use to achieve their economic goals. In essence, competition is what determines whether a company grows, develops, and succeeds or, conversely, fails and disappears. What is new in the 21st century space system is the economic value that is being placed on space activities, which is motivating the entry of new companies into the space industry. Traditional space companies in space such as Boeing and Lockheed-Martin now face fierce competition in the space industry. Founded at the beginning of the 21st century, SpaceX, Blue Origin, and Virgin Galactic have revolutionized the space industry with outstanding innovations in many areas of space, including launching, communication, and space exploration. At the same time, they are also competing for public funding, seeking to take advantage of the government's strategy of incentivizing the private sector through public contracts. In the United States, private space companies are competing for some of NASA's lucrative contracts to participate in the Commercial Crew program, the Artemis program, or the Developing Commercial Destinations in Space.

The number of space companies has grown exponentially over the past two decades. By 2021, there will be more than 10,000 space-focused companies worldwide [71]. American space companies lead this process with more than 50% of the total (5582 space-focused companies), but many other countries are stimulating their private sector to participate in the space industry. Skyroot Aerospace (India), I-Space (China), and I-Space (Japan) are some of the most notable examples of this growing phenomenon.

Competition within the space system goes beyond nation-states and corporations. Higher-education institutions are also competing for public and private funds, students, experts and professors, research opportunities, publications, patents, etc. Similarly, the recent phenomenon of space regionalization has triggered competition among regional organizations such as ESA, APSCO, and ALCE, which is also considered by some experts a new process of competition among space blocs [81]. Lastly, space hubs compete to attract talent, ideas, funding, and resources to develop these new space clusters.

3.3.3. Conflict

In the international system, power relations are natural behaviors, and conflictive and even violent interactions among actors are quite common. The history of international relations has been balanced between periods of peace and war, and space activities have played an important role in this dynamic. Since the military origins of space (the A-4/V-2 missile/rocket in October 1942), the space domain has always been a critical factor for national security and defense due to the relevant geopolitical value of outer space. Space activities have traditionally been used for military purposes, and most of the space actors have had specific military objectives to invest in space technology; therefore, national space policies have always pursued both political and economic objectives, taking into account fundamental security and military goals. Today, modern military forces rely on space, making it a key domain for any international actor with global aspirations.

Classical geopolitics focuses on how states should act in outer space to increase their influence in the international arena. According to the theories developed during the space race, whoever controls outer space controls the world [2–6]. In addition to the traditional dimensions of power, such as terrestrial, maritime, and aerial, the extraterrestrial dimension has become the fourth and most advanced element of power in international relations [6] (p. 3). According to this logic, the space race between the United States and the Soviet Union was an indirect conflict that used space activities as a mechanism of confrontation in the broader context of the battle for supremacy in the Cold War.

The post-Cold War international system has reduced the tensions between the two superpowers—with the collapse of the Soviet Union and the end of the bipolar dynamic—and allowed for the proliferation of new and more ambitious cooperative agreements in space, such as the Shuttle/MIR program (1992) or the historic agreement for the construction of the ISS (1998). However, a weak international legal framework, the lack of means of adequate enforcement by the global community, the absence of efficient global institutions, and the rise of new actors with global ambitions in the international system have encouraged national aggressive behaviors in recent years. In the last decade, geopolitical tensions have arisen between the United States and new contenders, especially China and Russia.

The space systems of the 21st century reveal a new balance of power in which the United States still maintains a privileged position as the number one space power, but its leadership is now threatened by new space actors such as China, India, the European Union, or Japan, which have shown remarkable space development over the last 30 years. The strategic importance of space as a theater of operations for hybrid warfare tactics has led governments to maintain their investments in traditional space activities such as telecommunications, navigation, and earth observation, but, more importantly, in space security and defensive systems to further protect their space assets.

In 2016, President Donald Trump declared that "*space is the world's new war-fighting domain*" [82] and established a Space Force in December 2019 to defend US interests in outer space. In the same line, former Chief of Space Operations, Gen. John W. Raymond, reiterated this notion, pointing out that he is "*not confident that we can achieve victory or even compete in a modern conflict, without space power*" [83]. Other countries are following this institutional model and creating new space branches within the national armed forces, such as South Korea or France.

In recent years, we have seen several emerging space powers, especially the fast-growing economies of China, India, and Japan, announce their intention to conduct military activities in space which many experts see as a new space race of the 21st century. The United States, Russia, France, Germany, Italy, Japan, China, India, and Israel have their own reconnaissance satellites that they use as observation or communication satellites deployed for military or intelligence purposes. All these space powers are investing more money in the space defense area, which has increased significantly in the last few years, reaching 16% in 2022 and topping a new record of 48 billion USD [69]. Even countries such as India or Japan, which have been reluctant to engage in any military-related use of space, have reviewed their space policies. Japan revised its space policy by enacting the Basic Space Law in 2008, which altered the interpretation of the concept of "*exclusively peaceful purposes*" and allowed the Japanese space industries to engage in activities "to ensure international peace and security and also to contribute to our nation's security". Many scholars and commentators have predicted that Japan will invest more aggressively in military space activities in the next few years [66].

Currently, almost 95% of satellites can be used for military purposes, and the idea that the space system is transitioning into an ongoing process of militarization of space is becoming more realistic.

3.3.4. Asymmetries

At the international level, asymmetries are those interactions among actors that establish links of hegemony and subordination. Historically, major international actors have established these types of asymmetric relationships by projecting their power to impose their particular goals and interests [62] (p. 97). In this sense, scientific and technological development has played a critical role in the international system to build political power [55] and legitimate geopolitical superiority and domination [84,85].

In recent decades, experts and intergovernmental organizations such as the United Nations have denounced the growing gaps and asymmetries between societies, and they have pointed out that the unequal distribution of science and technology has led to the emergence of new gaps in the international system, such as the "digital divide", the "cognitive divide", and the "scientific divide" [86,87].

Space has always been a strategic technology sector based on national priorities and geopolitical interests and that requires a huge amount of investment in order to be successful. During the 20th century, space activities were concentrated in the two superpowers (the United States and the Soviet Union), with very few other developments in a reduced number of countries. In this sense, the asymmetries and the geopolitical dominance in space were the norms in the space system.

The transition to a new space system after the end of the Cold War has configured a new international scenario in which inequalities and asymmetries still play a significant role, but differently than in the previous space system of the 20th century. Despite the increasing number of new actors (states and non-states) in the development of space activities in the last few decades, asymmetry is still one of the main characteristics of the space system in the 21st century. In 2019, more than 30 countries contributed to the global investment in space exploration, but just five of them accounted for 98% of the total, and the United States remains, by far, the largest global investor (71%). China (13%), the European Union (9%), Japan (3%), and Russia (2%) complete the top five [69]. Some regions have shown a particular dynamism in recent years; nevertheless, the asymmetries at the regional level are impressive. In 2020, North America will account for more than 53% of the global space budget, while Africa will account for 0.70%, Latin America and the Caribbean will account for 0.22%, and Oceania will account for 0.02% [88].

In addition to the gap between space powers and medium and small powers at the international level, there are also asymmetries within countries. In the last few years, we have witnessed the blossoming of space clusters or space hubs in many countries. These hubs are physical space that brings together researchers, creators, and innovators to nurture ideas into industry-changing products and services. This is a global phenomenon that has led to the development of space hubs in cities or regions around the world and has also contributed to the increasing gap between these geographic areas and the rest of the country, creating what many experts have called a "new geography of centrality and marginality of knowledge" [89–91].

The growing phenomenon of asymmetries in the space systems has encouraged intergovernmental organizations such as UNOOSA to promote more equitable cooperation in the use of outer space and to bring the benefits of space to all humanity. The Outer Space Committee proposed a new Space2030 Agenda in 2018, which aims to strengthen international cooperation for the peaceful uses of outer space and a more equitable distribution of the benefits of space activities. The new Space 2030 Agenda is working on strengthening the role of the space sector as a key driver of sustainable development, promote the societal benefits of space-related activities, and ensure that all countries have access to and can benefit socioeconomically from space development.

3.4. Processes

Processes are defined as the operational mechanisms that occur within a system/subsystem. Each system has specific methods of interconnection and interaction among its actors that generate specific internal mechanisms [23]. The SAM identifies and describes the key internal mechanisms that make the space system works. These processes describe and explain the life cycle of the space system from its creation, through its governance, to its final application and use.

All of these internal processes within the space system are part of a dynamic that is not linear, uniform, or progressive. On the contrary, these processes are highly interconnected and complex; in practice, it is an interactive mechanism that allows for a certain degree of overlap, where actors establish multiple interactions and perform many activities with different outcomes.

In the space system of the 21st century, it is possible to identify three main processes: production, governance, and application and use.

3.4.1. Production

The process of production of space technology is expanding globally, with a record number of countries and commercial companies investing and producing in space programs. Never before has there been so much interest in the space sector, represented by the increasing public investment in space activities worldwide and unprecedented levels of private investment in space ventures. All factors of space production have increased over the past 20 years: public investment, private investment, workforce, publications, and patents. In addition, we have seen a more diversified space production with more manufacturers and investors that are working in space.

In 2021, the global space economy generated revenues of approximately 469.3 billion USD, an extraordinary increase from 216.6 billion USD in 2009. In 2022, government spending on space programs worldwide amounted to 103 billion USD, an increase of almost 11.5% compared to the previous year. The United States has the highest budget in absolute terms, followed by China, Japan, and France. In 2021, NASA's approved budget amounted to approximately 23.3 billion USD [92].

The private sector is currently investing at record levels. Private-sector funding for space-related companies topped 10 billion USD in 2021. This is an all-time high and represents a tenfold increase over the past decade. Start-ups continue to emerge in all segments of the space sector, with small companies launched in recent years primarily in the United States, but also in Europe, Japan, China, and India, created in the past few years. Some of these newcomers aim to provide innovative products, services, and processes in space sectors such as launch, mining, or new forms of extraterrestrial life. Although many have yet to bring their products to market, one of their strongest impacts to date has been to spur innovation and encourage larger aerospace incumbents to begin adapting their business practices to the new environment [12].

The ongoing process of digitalization is increasingly affecting the entire space sector, from traditional companies to newcomers. All the processes of space production—science, research and development (R&D), manufacturing, and production processes—are affected and disrupted [12] (p. 28), provoking massive consequences in the reconfiguration of traditional space sectors (launch, communication, etc.) and the emergence of new ones (on-orbiting servicing, medicine, agriculture, etc.)

The authors of [93] described and analyzed very well the evolution of the new space economy sector and the development of new space sectors: "*Historically, much of the private funding—as well as government activity—has focused on satellite communications [. . .] Over the past 5–10 years, more space investment has gone to ventures in low-Earth orbit (LEO) [. . .] Overall, about 60–70% of space-company funding now goes to LEO efforts [. . .] These initiatives now account for about 10–15% of total private investment in space-related companies—about 1 billion USD—up from well under 5% just a decade ago. In 2021, private funding for lunar and beyond regimes exceeded funding for suborbital ventures for the first time*".

The rise and diversification of the production of space activities have also increased the interest in recruiting more workers. The space sector is characterized by a highly skilled workforce, often with graduate and postgraduate qualifications, which is a critical factor as a main resource for the creation of innovation.

The space workforce is growing rapidly internationally. The US space sector is composed of more than 198,500 individuals across the private sector and government agencies. Private sector employment in the US space sector continues a growth trend that began in 2016, adding approximately 3000 new workers from 2020 to 2021 to reach 151,797 individuals. The growth of the American space sector over the past 5 years has been strong, with employment increasing by 18.4% since 2016. Similarly, European space employment was 53,051 in 2021, an increase of 5.4% from a total of 50,317 in 2020. France continues to have the largest space workforce in Europe with 18,264 workers, followed by Germany with 10,300 employees. India's Department of Space had 16,786 employees as of October 2021, and the Japanese space sector employed 8527 people in 2020. Russia reported the largest number of space workers with 181,000 in 2020 [94].

The space sector is growing rapidly, and the major actors involved in space activities (government, companies, etc.) are struggling to recruit skilled workers because of the high demand for STEM skills. While some space sector companies require one or more specific space specialists, there is also a strong demand for general technical skills, and other skills such as 'agility' and communication and collaboration skills are becoming increasingly valuable to companies, along with commercial awareness and business acumen, such as data science, AI techniques, and software engineering [95].

Lastly, scientific papers and patents are considering another factor of production that shows the relevance of space production. The OECD has studied in depth the evolution of scientific production in the space domain, and it has concluded an increasing rise in specialized journals and conferences since the end of the Cold War. According to [12] (p. 32), "*this trend parallels the growing number of countries involved in space programs, especially from BRICS (Brazil, the Russian Federation, India, Indonesia, China, and South Africa). Traditional space actors continue to lead in terms of scientific publications in the space literature, but new countries are emerging. The United States has the largest share of publications, accounting for about 22% of the total. China and India have seen significant increases. China's scientific production increased* *tenfold between 2000 and 2016, making it one of the world's leading contributors, reflecting the growing interest in the space sector in China*".

As another proxy for innovation, patenting in the space sector is not as common as in other economic sectors, as commercial discretion and institutional secrecy are often still priorities for some space developments. Only a few hundred patents are granted each year. However, the number of space-related patents has nearly quadrupled in 20 years, as evidenced by the applications filed under the Patent Cooperation Treaty (PCT). As shown in the OECD report [12] (p. 33, 34), "*when comparing national patent applications for space-related technologies in 2002–2005 and 2010–2015, the United States still leads but its share has shrunk, while the European Union (EU28) grouping's share has increased. Several countries have seen their shares of worldwide patents grow in relative terms, notably France, Korea, Germany, China, and Italy*".

3.4.2. Governance

The governance of space activities is a mechanism through which space actors carry out tasks related to the planning, organization, and execution of public policies and private strategies for the development of space activities. Traditionally, control over space governance has been exercised by nation-states, the central actor in international relations, which, as sovereign and autonomous entities, designed public space policies through their internal agencies and establish international legal agreements in the space domain.

Throughout the 20th century, the United States and the Soviet Union have mostly been able to exert influence on this process primarily because of their status as space powers. Complex and costly space policies allow these two superpowers to maintain their privileged position at the international level. In this context, the two superpowers have been able to create an international space framework, a first attempt to develop global space governance at the international level. This global governance of space has two central elements: common institutions and regulatory agreements. The first was the creation of the Committee on the Peaceful Uses of Outer Space (COPUOS) and the United Nations Office for Outer Space Affairs (UNOOSA) under the auspice of the United Nations. The second was the signing of five international legal agreements, of which the Outer Space Treaty (OST), signed in 1967, was the first and most important. The OST was adopted under the United Nations General Assembly, and it is considered the foundation of modern international space law.

The end of the Cold War changed these basic parameters of the space system, which, in the 21st century, has shown a more diverse and complex matrix of governance where new actors, types of interactions, and levels or arenas of governance have emerged. In the current space system, the national level still plays an unquestionably leading role in the governance of space activities, planning, managing, and executing a large part of the activities in the space industry. Even though new actors become a very active part of the space business, governments are still a kind of catalyst in the planning process, on top of which the production of space activities revolves around the development of government-made public policies. Essentially, nation-states are key actors in the articulation of interests, the planning process, and the execution of space activities, where they become a kind of mediator in the discussions generated among other stakeholders pursuing their own interests. NASA's Commercial Crew Program of 2011 is an exceptional example. Today, most countries have ambitious public space policies to increase space activities, following the logic of considering outer space as a geopolitical and economic strategic factor in the 21st century international system.

The international regulatory framework for outer space remains quite similar to that established in the 20th century, based on few intergovernmental institutions and an ambiguous legal regime. Despite the many international space cooperative agreements we have seen since the end of the Cold War, the building of a more robust global legal framework for space activities is still a pending task.

In the last decades, most of the space powers have seemed to prefer a bottom-up rather than a top-down approach to building a global governance of space activities. Since most of the space actors have been reluctant to develop a global legal framework and make commitments on essential issues, they opted to build an international alliance or coalition through bilateral or multilateral agreements, hoping to expand the number of countries involved in the future. The Artemis Accords, based on the principles of the OST, was signed by nine countries in 2020, now counting 23 nations, and is open for new members. The 2021 Sino-Chinese agreement on cooperation for the construction of the International Lunar Research Station (ILRS) is open to all international partners, and negotiations are currently underway with Thailand, the United Arab Emirates, and Saudi Arabia.

Despite the lack of a consistent and comprehensive global legal framework, it is also true that there have been efforts to make modest progress on norms of behavior in space in recent years, with several initiatives at the global level. China and Russia have been working together in the "Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force Against Outer Space Objects" (PPWT). The PPWT was first proposed in 2008 and was reintroduced in a revised form in 2014. The proposed treaty was rejected by the United States due to the lack of verification mechanisms and restrictions on the development and stockpiling of ASAT weapons on the ground. The European Union introduced a separate proposal for a nonbinding "International Code of Conduct on Outer Space Activities" in 2008. The Code has been revised several times during numerous multilateral consultations involving more than 100 countries. Essentially, it is a voluntary agreement by signatory nation-states that builds on the foundation of the OST. The United Nations "Group of Governmental Experts on Transparency and Confidence-Building Measures in Outer Space Activities" (TCBMs) developed guidelines in 2013 based on recommendations from a group of experts from various countries. The voluntary guidelines outlined ways to build TCBMs that focus on transparency in space activities. Lastly, COPUOS developed a "Guideline for the Long-Term Sustainability (LTS) of Outer Space Activities" in 2016. The Guideline was written on the basis of feedback from four groups of experts nominated by each state and intergovernmental organization with permanent status in COPUOS. The final Guideline for Long-Term Sustainability was adopted by COPUOS in 2019. The guidelines are voluntary and nonbinding; therefore, they are not enforceable unless incorporated into national laws and regulations [96] (p. 10).

The space system of the 21st century also shows new levels or arenas of governance. The regionalization of space has created an intermediate level with a close relationship to the national and international arena, as well as reaffirmed its role as an independent arena for the decision-making process in space policy. Bilateral and multilateral cooperation have been transformed into a regional space process with the creation of institutions, policies, and common rules. At the same time, the local level should also be considered as a new arena of space governance, with the development of new space hubs in cities and regions that try to stimulate space activities in specific geographic areas.

3.4.3. Application and Use

Another key process within the space system is the application and use of space development. In this sense, it is possible to identify four basic areas in which space technology is currently applied and used: (i) the military sector; (ii) the economy; (iii) scientific exploration; (iv) society.

The Military Sector

The military sector has always been one of the main areas where new space developments are applied and used. The origin of space activities is inextricably linked to the military sector. The first space rockets were weapons developed by countries following their national security and trying to pursue their geopolitical interests (A4/V2, R7, or Redstone). Since then, the military sector has always been the first to use space technology. In the second half of the 20th century, the military application and use of space technology were the norm in the context of the space race between the two superpowers. Traditionally, most of the space developments have had a dual purpose: civil and military.

Even though the end of the Cold War was supposed to reduce global tension between countries, it did not change the main parameters of the international systems, where states remained the central actor of the space system, for which national security and defense are considered a top priority. In this sense, the space system of the 21st century maintains the same logic of the previous century, considering outer space as a strategic territory and a potential new battlefield, and applying and using new space technologies for military purposes.

In recent years, space powers have updated their national military space policies and have increased their investments in defense space assets and technologies. According to [69], government space budgets, driven by space exploration and militarization, hit a record investment of 92 billion USD in 2021, with 1 trillion USD projected over the decade.

The growth in space investment is particularly significant in the defense sector, with a 16% increase to a new record of 48 billion USD in 2022. One of the main reasons for the acceleration in the volume of government investment in the space sector is the growing geopolitical rivalries that are driving the militarization of space. Governments are spending on traditional space activities such as launch systems, ground control, remote sensing, or communications, but they are also investing in accelerated space defense systems to protect their assets in space [69].

The increasing tensions in the international systems of the 21st century among major nation-states have triggered the relevance of applications and use of new technologies for military space activities and the concerns about the geopolitical value of outer space as a potential battlefield. The United States has led this process in the last few years by developing a new military space policy, creating a new and dedicated space branch in the armed forces, and devoting more resources to the military space sector.

Since the beginning of the 21st century, the United States has increased its spending on military space. The evolution of the Pentagon's budget showed a more than twofold increase in the space budget from 2005 to 2022 [64]. This trend intensified under the Trump administration when military space spending increased by nearly 20%. US military space spending increased by 6.1% in 2020, reaching a new high of 26.6 billion USD, accounting for more than 80% of global military space spending. The United States released a National Defense Strategy in October 2022, which demonstrated the Pentagon's desire to rely on nimble space companies while monitoring and protecting commercial space ventures in orbit: "Space is vital to US national security and integral to modern warfare." According to the US Department of Defense, the 2023 budget supports a National Defense Strategy that recognizes China "as our key strategic competitor and Russia as an acute threat to the interests of the US and allies" [97].

This growth reflects the importance of space to the US military, even with the creation of the Space Force in December 2019, a new military branch that conducts military operations in outer space and space warfare. In the fiscal year 2022 budget request, the US Space Force received the largest increase over other armed forces. The administration requested 17.5 billion USD for the Space Force, a 13% increase over the FY21-enacted figure, and the FY21 itself grew 6% over the previous year. Estimates for FY24 could mark a new record of 30 billion USD. All of this growth occurred over a period where the overall DOD topline has only grown 4% in nominal terms [98].

Other space powers have also promoted the application and use of space technology in the military sector. China spends the second largest amount of money, 10.3 billion USD, as it supports a robust program of space activities including a low-Earth orbit space station and a lunar exploration program, as well as military activities. On 11 January 2007, China conducted an ASAT missile test from the Xichang Space Launch Center. Some reports suggest that China secretly conducted an ASAT missile test in May 2013. Russia also conducted a direct-ascent anti-satellite (DA-ASAT) test, destroying one of its own space objects, a defunct satellite, in low-Earth orbit on 15 November 2021. Space actors such as

India or Japan with a long tradition of developing peaceful space activities have shifted their national space policies in the last decades from a “nonmilitary” to a “nonaggressive” use of space in recent years. In March 2019, India tested an ASAT weapon that destroyed a target satellite in LEO, representing a shift in India’s space program. “A strong India can be a guarantor of peace in the region and beyond. Our strategic objective is to preserve peace, not prepare for war.” [99]. India is only the fourth country to use such a weapon. Iran successfully launched its first military reconnaissance satellite, the Noor-1 (“Light-1”), in April 2020. This satellite, mounted on the domestically built Qased rocket, now allows Iran to conduct reconnaissance operations and monitor Western forces, particularly American military bases and troops, in the Middle East and beyond. North Korea has been testing ICBMs since 1998 and recently tested the Hwasong-15, an ICBM with the potential to reach US soil.

Economy

A second area of application and use of space developments is the economic sector. In contrast to military use, the application of space development decreased in the 20th century, but increased significantly in the 21st century. Most experts agree on a new phase in the history of space activities since the beginning of the 21st century, where we are transitioning from a model of centralized, government-directed human space to a new model in which public space initiatives increasingly share the stage with private priorities [9]. The authors of [11] called this a shift in the space business model from a traditional model to a commercial model, which represents a revolutionary approach to government and commercial collaborations to advance space exploration.

In just 15 years, the scale of commercial activity has more than tripled, increasing from 110 billion USD in 2005 to nearly 357 billion USD in 2020. According to [64], the value of the global space economy reached 424 billion USD in 2020, an increase of 70% since 2010. Currently, commercial applications account for the largest share of the revenues (two-thirds), although military and institutional contracts still represent a significant share of the total revenues (one-third).

The world’s leading space consulting and market intelligence firm estimates that the global space market grew by 8% last year and is expected to reach more than 737 billion USD within a decade [69]. According to [70], the annual revenue of the space industry could exceed 1 trillion USD by 2040.

Economic applications are shifting from on-planet to off-planet industry, anticipating a revolution in the space economy. Currently, all returns from space commerce ultimately occur on Earth. This is what experts call a “space-for-earth economy”, i.e., goods or services produced in space for use on Earth. These space sectors include communications, remote sensing, launch services, and insurance. Although most of these space sectors began in the 20th century, we are experiencing in the 21st century space system a true revolution in innovation, applications, and new uses of space technology in the on-planet industry. Since 1997, when private investment in space communications exceeded government spending for the first time, the communications sector has continued to grow, with an estimated 57,000 communications satellites planned by 2029. At least 15 companies from eight different countries have declared interest in developing broadband satellite mega-constellations. SpaceX developed Starlink, a satellite network designed to provide low-cost internet and mobile phone service to remote locations. As of December 2022, Starlink consisted of over 3300 mass-produced small satellites in low Earth orbit (LEO), and the company hopes to eventually have as many as 42,000 satellites in this so-called mega constellation.

A similar revolution is taking place in the space launch sector. This is a critical sector of the space industry that has been undergoing a transformation in the last few years. Traditionally, access to space has been extremely expensive and limited to space powers. However, prices are coming down with each passing year as new technologies are developed and the sector becomes more commercialized. The introduction of “reusable” and “vertical landing” launch vehicles in recent years has arguably been the most significant factor in reducing costs. If the overall trend continues, access to space could become relatively affordable for most people in the second half of this century. This could be a game-changer in the space industry, opening the door to new applications and uses in space exploration. Similarly, new technological advances in remote sensing are enabling hundreds of new applications, from weather forecasting to GPS to reduce natural disasters, all of which have an enormous impact on our daily lives.

The off-planet industry or the "space-for-space economy" refers to goods and services produced in space for use in space, such as mining the Moon or asteroids for material to build in-space habitats or supply refueling depots. This opens up a new economy scale in terms of the opportunities that this new scenario offers for the application and uses of space technology. As pointed out in [100] (p. 82), if humans were ever able to get their hands on just one asteroid, it would be a game changer. That is because the value of many asteroids is measured in quintillions of dollars. As Neil deGrasse Tyson explained, "*the first trillionaire there will ever be is the person who exploits the natural resources on asteroids. There is this vast universe of limitless energy and limitless resources.*" [101].

There is now a broad consensus that the off-planet space industry will be a major driver of the future global economy. Valuations for 2040 range from 1.1 trillion USD (Morgan Stanley) to 2.7 trillion USD (Bank of America/Merrill Lynch) based on estimates that the minerals in the asteroid belt between Mars and Jupiter could be worth 700 quintillion USD [70]. Not surprisingly, there are a large number of newcomers to the space industry. Over the past few years, there has been a record number of new space companies and startups which are looking for new business and profitable economic areas within the space industry (10,000 space-focused companies worldwide in 2021) [71]. Many of them have been able to raise significant funding for new investors hungry for new profits. These companies are applying new technologies to a diverse group of space activities, including extraterrestrial resources, space mining, on-orbit satellite servicing, space stations, space debris, lunar and Mars missions, space colonization, and life off-planet.

Scientific Exploration

A third application and use of space activities is related to the scientific exploration of outer space. The application and use of space development for scientific purposes is remarkable in the post-Cold War space system. The United States and the Soviet Union made some notable scientific applications during the 20th century (exploration of the Moon, Mars, Venus, Jupiter, Saturn, Uranus, and Neptune), but now we are experimenting with an increasing interest in scientific applications and uses. The scientific community and, more generally, public opinion have been able to learn more about the planets of the Milky Way, the solar systems, and even beyond, thanks to this scientific exploration of outer space by spacecraft such as the Hubble Space Telescope.

NASA has a long tradition of the scientific exploration of outer space, which it considers to be one of its most important missions. The bipolar dynamics of the space system during the Cold War subordinated scientific missions to geopolitical goals; however, since the end of the Cold War, NASA has accelerated the scientific application of space activities and is conducting a wide range of scientific missions. In late 1990, NASA established the Discovery program to deepen human understanding of the solar system by exploring the planets, their moons, and small bodies such as comets and asteroids. Its major missions include the Lunar Reconnaissance Orbiter (2009—active), InSight (2018—active), MEGANE (2024), DAVINCI+ (2028–2030), and VERITAS (2028–2030). NASA's Solar System Exploration program consists of large, strategic missions designed to advance high-priority science objectives identified by the planetary science community. Key missions include DART (2021; the first successful mission to test an asteroid deflection technique), and JUICE, in partnership with the ESA (2023). Lastly, in 2003 the New Frontiers program was established to address specific solar system exploration goals identified as top priorities by the planetary science community. Major missions include New Horizon (2006; a close look at Pluto and its moons), JUNO (orbiting Jupiter since 2016), OSIRIX (2016; retrieving an asteroid sample and returning it to Earth for further study), and Dragonfly (2026; Saturn's moon Titan). In 2014, NASA decide to create the Planetary Missions Program Office to bring the different missions under a common management system. The missions in each series are independent, with their own unique science objectives.

The Hubble Space Telescope is another remarkable space exploration mission that has revolutionized astronomy since its launch in 1990. This space-based observatory was an international collaboration between NASA and the European Space Agency (ESA). Hubble has far exceeded its original goals, operating and observing the universe for more than 30 years. During its time in orbit, the telescope has made more than 1.5 million observations, and astronomers have used these data to publish more than 18,000 peer-reviewed scientific papers on a wide range of disciplinary topics. The James Webb Space Telescope (JWST) was created to replace the Hubble and is also known as the "Next-Generation Space Telescope". It is a space telescope being jointly developed by NASA, the European Space Agency (ESA), and the Canadian Space Agency (CSA). This telescope was launched in December 2021 and has been fully operational since June 2022. Essentially, JWST will allow observations of some of the most distant objects in outer space, opening up the possibility of collecting new and unknown data to analyze the universe.

Mars exploration has evolved greatly over the past few decades, with many NASA missions attempting to explore and learn more about the Red Planet. Since the 1990s, the missions have been numerous: Surveyor (1996), Pathfinder (1997), Spirit and Opportunity (2003), Phoenix (2008), Curiosity (2011), and Perseverance (2020). NASA's ongoing Mars Perseverance mission addresses high-priority science goals for Mars exploration, including key questions about the potential for life on Mars. Lastly, the scientific exploration of the Moon and Mars has entered a new and remarkable chapter with the launch of the Artemis Program in 2017. The ambitious goals of this space program include a manned return to the Moon, the establishment of a base camp on the lunar surface, a space station (the Lunar Gateway), and a first landing on Mars in 2030 [102].

Other countries have explored outer space scientifically in the last decades. The ESA has made many significant contributions to scientific exploration: Cassini-Huygens became the first spacecraft to orbit Saturn (2004); the Columbus science laboratory was attached to the ISS (2008); Rosetta made the first soft landing on a comet (2014); the launch of the ExoMars program (2016); the launch of the BepiColombo mission to Mercury in partnership with JAXA (2018). In parallel with the strong growth and development of the space program over the past 30 years, China has also made relevant contributions to scientific exploration. Chang'e Missions is an ongoing series of robotic lunar missions by the China National Space Administration (CNSA), with the ultimate goal of paving the way for a manned mission to the Moon. As a result of this mission, China was able to achieve a significant space milestone, when it made its first landing on the far side of the Moon in January 2019. In addition, in 2020, China announced the Planetary Exploration of China, an ambitious space program that aims to explore the planets of the solar system, starting with Mars and expanding to Jupiter and beyond in the future. Japan has a long and solid tradition of scientific exploration of outer space and a fruitful partnership with NASA and the ESA. In June 2010, Hayabusa became the first spacecraft to return to Earth with samples from an asteroid. India announced the launch of the lunar and Mars missions in the early 21st century. The Chandrayaan program, the Indian Lunar Exploration Program, is an ongoing series of outer space missions by the Indian Space Research Organization (ISRO) that includes a lunar orbiter, impactor, soft lander, and rover spacecraft. In October 2008, Chandrayaan-I found evidence of water on the lunar surface. Meanwhile, the Mars Exploration's Mangalyaan was launched into Earth orbit in November 2013 and entered Mars orbit in September 2014. It is India's first interplanetary mission, and it made India the first Asian nation to reach Mars orbit.

At the very least, but no less important, the ISS must be considered the largest and most complex international cooperative science and engineering program ever attempted. Since 2000, the ISS has brought together scientists, engineers, and researchers from around the world to assemble a premier research facility in orbit. During this time, researchers on the ISS have conducted approximately 3000 science experiments [103]. Research is conducted in a wide variety of fields, including such as, astronomy, physical sciences, materials science, space weather, meteorology, and human research, including space medicine and the life sciences.

Society

A fourth and final area where space activities have been applied and used is in society. Historically, space technology developments have had a strong social impact. In the 21st century, the unprecedented scientific and technological revolution is accelerating technological advances and their application and use in society. Space is a pioneering technology with further applications and impact on our society ranging from the prevention of natural disasters to the use of mobile phones, the internet, or GPS. Today, the space infrastructure enables the development of new services possible, which in turn enables new applications, in sectors such as meteorology, energy, telecommunications, transport, maritime, aviation, and urban development, leading to additional economic and societal benefits [12].

Communication satellites have had a major impact on society, allowing people to share information via mobile phones, personal computers, and other electronic devices. There are also hundreds of remote sensing applications (agriculture, crime, disasters, environment, mining, navigation, transportation, weather, etc.). At present, there are very innovative applications of space technology in the field of education (EDUSAT program), healthcare (ISRO's telemedicine program), and risk management (UN-SPIDER). Because of their unique characteristics, space applications could make a significant contribution to several long-term and enduring challenges of the 21st century: the environment, the use of natural resources, the management of natural disasters, international mobility, and the transition to a knowledge-based society.

Given the social impact of space applications and uses, and more importantly, the potential future impact of new space technologies, several initiatives in recent years have called for closer interaction between space activities and social development. The United Nations has been at the forefront of this process. UNOOSA has called for a broader application of space activities to support the UN 2030 Agenda for Sustainable Development Goals (Space4SDG—United Nations) [104]. While the space sector is currently making relevant contributions to society, the United Nations believes there is still room for a much broader and deeper role for space in support of the 17 SDGs. Another relevant initiative is the new Space2030 Agenda, proposed in 2018 by the Outer Space Committee, which aims to strengthen international cooperation for the peaceful uses of outer space and social applications. Among its key objective, it seeks to strengthen the role of the space sector as a key driver of sustainable development and promote the societal benefits of space-related activities. The Space2030 Agenda aims to ensure that all countries have access to and socioeconomic benefit from space activities [105].

3.5. Emergent Realities—New Trends in the 21st Century Space System

The application of the SAM to the study of the space sector in the 21st century allows us to identify the main characteristics, trends, and tendencies that are emerging in the space system in this new space age. These main characteristics define the space systems, as well as represent the trends, responses, and outputs of the space system to the other subsystems (political, economic, social, etc.) and the entire international system.

1. Demands on the Space System: The space system is a subsystem within the international system and, as such, receives demands and influence from many other subsystems. Since the end of the Cold War, the space system has received demands and influences from other subsystems, such as the political (end of the bipolar system and erosion of the nation-state), the economic (new capitalism and knowledge-economy),

the technological (4IR and globalization), and the social (knowledge society), which have a profound impact on the development of the space activities.
2. Increasing Number of Space Actors: The space system of the 21st century is characterized by a much larger number of space actors (both state and non-state actors). The interest of nation-states in space has grown in recent decades; today, more than 90 nation-states have space activities. At the same time, there is a growing number of non-state actors involved in outer space activities, playing a much more significant and powerful role (companies, universities, international organizations, and space hubs).
3. Central Role of Nation-State: In the current space system, nation-states still play an undisputed leading role in the governance of space activities. Even though new actors have taken a very active part in the 21st century space system, governments are still a kind of catalyst in the planning process around which the production of space activities revolves. Nation-states plan, organize, manage, and execute much of the activity in the space system through the development of national space policies, robust space budgets, and powerful national space agencies.
4. New Polarization: The balance of power among actors in the space system is changing. The traditional bipolar dynamic of the Cold War has given way to a multipolar system, with new space powers with global ambitions and a willingness to compete with the United States, as well as a new and diverse group of space coalitions and alliances. Although the United States remains the number one space power, new competitors have emerged in recent years, most notably China, which has made incredible strides in space.
5. The Rise of the Private Sector: One of the major trends in the 21st century space system is the growing role of private companies in space activities. The gradual entry of private companies into the space domain in the last three decades of the 20th century has increased exponentially in the 21st century (more than 10,000 space-focused companies worldwide in 2021) and now accounts for two-thirds of all space activities. While this is primarily an American phenomenon, it should also be considered a global trend given the growing number of space companies in other countries such as China, India, or Japan.
6. Intensification of Complexity: Another notorious feature of the post-Cold War space system is complexity. There has been a major transition from the simplified old bipolar system of two competing nation-states to a more intricate multipolar system in the 21st century. The growing number of actors has increased the number, types, and intensity of interactions among stakeholders, creating an extended network of relationships throughout the space system.
7. Simultaneous and Antagonistic Interactions: The acceleration of multiple interactions among actors in the space system also stimulates the coexistence of conflicting megatrends of relationships. In parallel, we have seen an intensification of conflictive, cooperative, competitive, and asymmetric interactions among space actors. There is a new context in which more actors are establishing multiple and simultaneous interactions that allow for some degree of overlap and from which they derive different outcomes.
8. Regionalization of Space: The regional level is a new relevant arena of negotiation and cooperation in the 21st century space system. The end of the Cold War led to the acceleration of space regionalization and the emergence of new space organizations. This process has intensified in the last two decades with the formation of at least five new space blocs (APSCO, ALCE, AfSA, ArabSCG, and EUSPA). Currently, nation-states are willing to cooperate in space activities with other regional countries and institutionalize this cooperation, thus creating new regional actors in the space system.
9. Lack of Global Governance: In a 21st century international system still dominated by nation-states, the space system lacks true global governance. Currently, the legal/regulatory space framework is outdated and inadequate, space treaties are weak

and insufficient, and the global community lacks the means to enforce them in a meaningful way. Despite numerous efforts in recent years to make progress on norms of behavior in space (PPWT, TCBMs, and LTS), there is still a lack of consensus among space powers to develop a true regulatory framework that would allow for global governance of space.

10. Multilevel Governance: The end of the Cold War changed the basic parameters of the space system, which, in the 21st century, has shown a more diverse and complex matrix of governance where new levels or arenas of governance have emerged. In the current space system, the national level still plays a key role, but new levels of negotiation and cooperation are gaining relevance. There are more public and private actors interacting in the space domain at different arenas or levels (local, state, national, regional, and international). This is a new process of space governance that is vertically open (not hierarchical or coercive) and more horizontally integrated (more interactions). Multiple arenas and multiple actors create a new and more complex multilevel governance of the space system.
11. Commercialization of Space: One of the most important current trends in the 21st century space system is the increasing commercialization of space activities. There is a shift in the space business model from a traditional government-centric model to a new commercial model. Over the past two decades, this process has accelerated with the gradual but persistent entry of private companies into the space sector, unprecedented levels of private investment in space ventures, and growing space industry revenues (commercial space activity has more than tripled in the last 15 years).
12. Space Economy: The privatization and commercialization of space activities are creating a new space economy that is seen as a major driver of the future of the global economy. The revolutionary technological advances in the on-planet industry (communications, launch, and remote sensing) are stimulating the expansion into new off-planet economic space sectors (mining, extraterrestrial resources, off-planet life, etc.), which anticipate a revolution in the space economy (a 2.7 trillion USD business by 2040). This opens up a new economic scale in terms of the opportunities for economic exploration of outer space, with an unprecedented impact on the world economy.
13. Militarization of Space: As all modern military forces rely on space, more nation-states are applying space in the context of national security and incorporating the outer space aspect into conventional military operations. More nation-states adhere to the classical geopolitical perspective of space as a potential battlefield and fear an escalation of an arms race in space. New and updated civil and military space policies show a strong interest in considering space activities as vital to national security. The development of new military space policies, the creation of new military space forces, the increasing budget for military purposes, and the development of new retaliatory weapons in outer space are accelerating the process of militarization of space.
14. Space Gap: The transition to a new space system after the end of the Cold War has configured a new scenario in which inequalities still play a significant role in the space domain. Despite the increasing number of new actors (states and non-states) in the development of space activities in recent decades, asymmetry is one of the main characteristics of the space system in the 21st century. Although there are more actors, cooperation, production, applications, and uses in the space sector, new space inequalities have emerged in recent decades, separating those actors with space capabilities from those without. This phenomenon could be observed at the international level (only five nation-states accounted for 98% of total space activities in 2019), but also within the countries, with the proliferation of space hubs creating new internal disparities.
15. Scientific Importance: More than ever in the history of the space age, scientific exploration of outer space is becoming an increasing trend in the space system, playing a more relevant role than in the 20th century. The application and use of space development for scientific purposes have been remarkable in the post-Cold War space system.

NASA, ESA, ISRO, JAXA, CNSA, and other national space agencies are showing an increasing interest in space exploration, and they are making some remarkable scientific applications that allow the scientific community and, more generally, the public opinion to learn more about the planets of the Milky Way, the solar systems, and even beyond.

Figure 3 summarizes the application of the SAM to the space system of the 21st century.

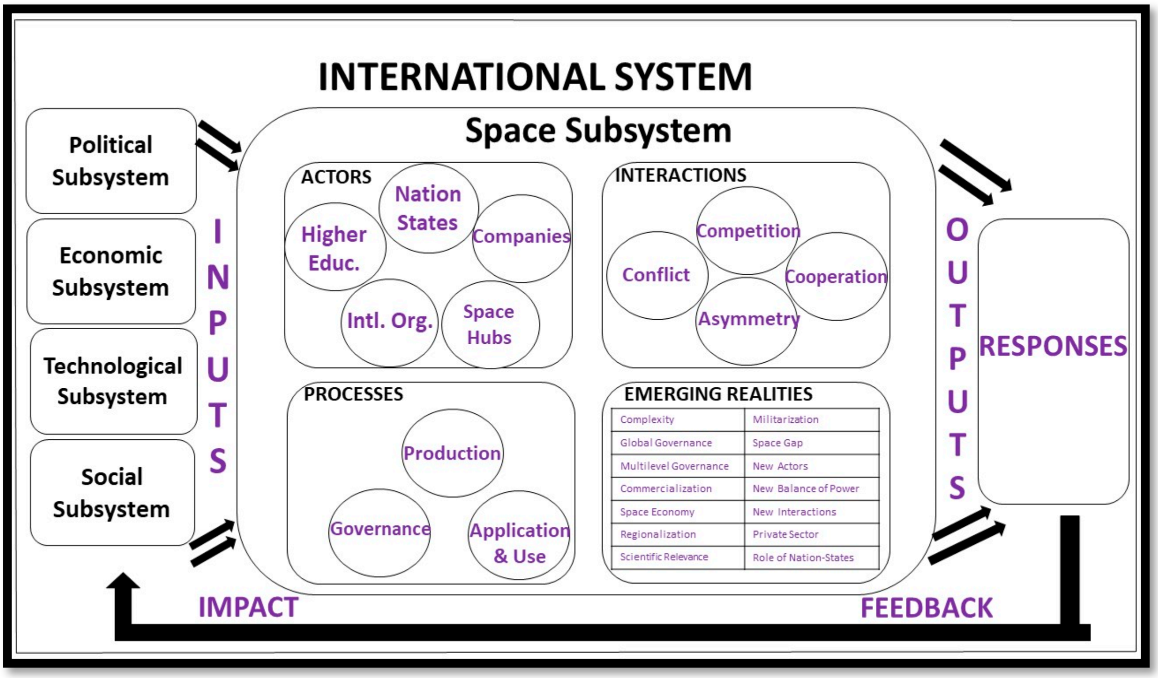


Figure 3. Visualization of the application of SAM to space system. Source: Elaborated by the author.

4. Discussion and Conclusions

The space system has changed rapidly in the last 30 years, as a result of an intersystemic transition from a bipolar and simplified space system in the 20th century to a new and more complex space system in the 21st century. The post-Cold War space system has undergone multiple changes in its main system parameters (actors, interactions, processes, trends, etc.), which require of new scientific approaches.

These structural changes in the space system have stimulated the academic debate on the need for new approaches that could provide a better understanding of the new complexity. There is a historical debate between microlevel and macrolevel (systemic) approaches. The main difference is how to address issues such as space activities, whether to study the structure (macro/systemic) or to focus on the parts (micro). Today, most scholars prefer to use a microlevel approach to studying the new space age. There is extensive academic literature on the changes in the space domain in recent decades; however, unfortunately, much of the research on this topic has had as its main characteristic an atomized and fragmented approach, focusing only on particular aspects of space activities, but failing to provide a holistic perspective on the transition from the bipolar space system of the 20th century to a new space system in the 21st century.

At present, a major academic challenge is to create, use, and apply new scientific tools to analyze the new global agenda of topics, particularly social complex problems. In this new context, the systemic approach can offer new solutions to scientific and academic challenges. Therefore, this essay raised the need for new approaches to the study of complex social systems, such as the space system, that holistically examine empirical changes and the great potential of systems models to provide reliable answers. This article introduced an original application of the systems architecture model that could identify and describe the key characteristics of the 21st century space system. The SAM identified, described, and analyzed the patterns, behaviors, actors, interactions, processes, emergent realities, and structure of the 21st century space system within the context of a larger international system.

The application of the systems architecture model allowed the study of several parts of the new space system in the 21st century: (i) identified certain aspects of the space system (space actors, types of interactions, internal processes, and emergent realities); (ii) found the main sources of change of the space system, examining the main demands and inputs from other subsystems of the international system (political, economic, technological, and social); (iii) recognized the main space actors, their historical evolution, and their main characteristics and interests (nation-states, companies, higher-education institutions, international organizations, and space hubs); (iv) examined the main types of interactions in the space system (cooperation, conflict, competition, and asymmetries); (v) explained the multicausal relations that occur within the space system as internal processes (production, governance, application, and use); (vi) identified emerging realities from the space system that represent key characteristics and main megatrends in the space system and play a role as a response and output to the international system (militarization, regionalization, commercialization, the role of the nation-states and the private sector, the space gap, etc.). Table 1 summarizes the application of the SAM to the space system of the 21st century.

Table 1. Summary of the main findings from the application of SAM to space system. Source: Elaborated by the author.

Context	Dimensions	Findings
Inputs from Interna-tional System	Political Subsystem	• Changes in the balance of power • Erosion of the traditional role of the nation-state
	Economic Subsystem	• Changes in the capitalist system • The rise of the knowledge economy
	Technological Subsystem	• The emergence of the fourth industrial revolution • The acceleration and intensification of globalization
	Social Subsystem	• Transition to a knowledge-based society • Promoting social benefits
Space System	Actors	Nation-States: • Revived interest in space activities • An increasing number of countries involved • New space policies, space agencies, and space budgets
		Private Companies: • Increasing role of corporations in space activities • Boom of new space startups • American phenomenon, but increasingly international • Promoting new space sectors
		Higher Education Institutions: • Training the space workforce • Conducting high-quality research in space
		International Organizations: • International institutions with global interests in space • Increasing processes of regionalization and formation of space blocs
		Space Hubs: • New actors at the local level, following the model of innovation hubs • Attract talent, ideas, and funding in the space sector • Promoting local economic and social development

Table 1. *Cont.*

Context	Dimensions	Findings
	Interactions	Cooperation: • Increase all forms of cooperation: bilateral, multilateral, regional and public-private
		Competition: • More competition between countries • New dynamics of competition among non-state actors
		Conflict: • U.S. leadership in space is threatened by new emerging space actors
		Asymmetries: • Widening gap between space powers and middle/small space powers
	Processes	Production: • Record levels of production in space activities (public & private) • Space production is disrupted by the technological advances • New financing and production in new space economic sectors • Space workforce is growing rapidly internationally • An increasing number of scientific publications and patents
		Governance: • National level still plays a leading role in the space governance • New levels of governance: local, regional, global • A bottom-up approach to building space governance • Lack of a solid international legal framework and global institutions
		Application and Use: • Increased application and use in the military sector • New space industries and commercialization of space • Off-planet space industry as a new driver of the future economy • Increased interest in scientific space exploration • Innovative application and use of space activities in society
Outputs/ Response to the International System	Emerging Realities	• Context: Increasing demands on the space system • Actors: Growing number of space actors; States are still key actors in space activities; New polarization of actors; Strong rise of the private sector; process of regionalization of space • Interactions: Simultaneous and antagonistic interactions in space; more cooperation but also competition and conflict. • Processes/Trends: Lack of global governance; new multilevel governance; expansion of the commercialization of space; rise of a new space economy; militarization of outer space; growing space gap between actors; more scientific relevance of space

Although the application of SAM can be understood as a useful methodological tool for studying complex social systems such as the space domain, it is also true that SAM has some concrete limitations that should be explicitly mentioned. First, SAM attempts to reduce the complexity of the international system, but the use of system models could also be considered a simplification of the international reality. Second, the subjectivity of the researcher developing the SAM should be taken into account. Third, the methodological choices made in the application of SAM imply the selection of dimensions, variables, and factors to be studied, as well as the elimination of others. Fourth, it is impossible to apply this model outside the context for which it was created. Fifth, SAM can identify, describe, and explain relationships among variables and even anticipate future trends and scenarios, but it could still be considered less predictive than other mathematical models.

Lastly, advances in the application of the SAM can include the study of specific actors such as nation-states, describing the evolution of the traditional space powers in recent years (US, China, Japan, India, etc.), as well as the rise of emerging powers (South Korea, Israel, Turkey, UAE, Brazil, etc.) and non-states that are playing a greater role in the 21st century (specific companies, higher-education institutions, intergovernmental organization, and space hubs); along with types of interactions (focusing on conflictive, competitive, cooperative, and asymmetric relationships among actors), processes (new mechanisms of productions of space technology, new forms of governance, and new applications and uses of space developments), and emerging realities (specific analysis of some of the new megatrends in the space system—global and multilevel governance, commercialization, militarization, space gaps, regionalization, etc.). It is expected that several applications in the field of space studies can contribute to finding new academic explorations, help to design public policies, and support planning strategies for the private sector.

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References

1. Dallanegra Pedraza, L. *El Orden Mundial del Siglo XXI*; Ediciones de la Universidad: Buenos Aires, Argentina, 1998.
2. Dolman, E. *Astropolitik. Classical Geopolitics in the Space Age*; Frank Cass: London, UK, 2002.
3. Moltz, J.C. *The Politics of Space Security: Strategic Restraint and the Pursuit of National Interests*, 3rd ed.; Stanford University Press: Stanford, CA, USA, 2011.
4. Colucci, L. *The United States Space Force: Space, Grand Strategy, and U.S. National Security*; Praeger: Santa Barbara, CA, USA, 2023.
5. Deudney, D. *Dark Skies: Space Expansionism, Planetary Geopolitics, and the Ends of Humanity*; Oxford University Press: New York, NY, USA, 2020.
6. Nucera, G. International Geopolitics and Space Regulation. *Oxf. Res. Encycl. Planet. Sci.* **2019**, 1–23. [CrossRef]
7. Peeters, W. Evolution of the Space Economy: Government Space to Commercial Space and New Space. *Astropolitics* **2021**, *19*, 206–222. [CrossRef]
8. Sommariva, A.; Gori, L.; Chizzolini, B.; Pianorsi, M. The economics of moon mining. *Acta Astronaut.* **2020**, *170*, 712–718. [CrossRef]
9. Weinzierl, M. Space, the Final Economic Frontier. *J. Econ. Perspect.* **2018**, *32*, 173–192. [CrossRef]
10. Barboraoux, P. The Metamorphosis of The World Space Economy: Investigating Global Trends and National Differences Among Major Space Nations' Market Structure. *J. Innov. Econ. Manag.* **2016**, *2*, 9–35. [CrossRef]
11. Heracleous, L.; Terrier, D.; Gonzalez, S. NASA's Capability Evolution Toward Commercial Space. *Space Policy* **2019**, *50*, 101330. [CrossRef]
12. Organization for Economic Cooperation and Development (OECD). Chapter 1. The ongoing transformation of the global space sector. In *The Space Economy in Figures*; OECD Publishing: Paris, France, 2019. Available online: https://www.oecd.org/innovation/the-space-economy-in-figures-c5996201-en.htm (accessed on 8 March 2023).
13. Bank of America Equity Research. *To Infinity and Beyond—Global Space Primer*; Bank of America Merrill Lynch: New York, NY, USA, 2017.
14. Satellite Industry Association (SIA). *The 2022 State of the Satellite Industry Report*; Executive Summary; SIA: Washington, DC, USA, 2022. Available online: https://sia.org/news-resources/state-of-the-satellite-industry-report/ (accessed on 8 March 2023).
15. Sadeh, E. *Space Politics and Policy. An Evolutionary Perspective*; Kluwer Academic Publishers: Dordreacht, The Netherlands, 2002.
16. Jakhu, R.; Pelton, J. *Global Space Governance: An International Study (Space and Society)*, 1st ed.; Springer: Cham, Switzerland, 2017.
17. Jakhu, R.; Dempsey, P. *Routledge Handbook of Space Law*, 1st ed.; Routledge: New York, NY, USA, 2017.
18. Launius, R. An unintended consequence of the IGY: Eisenhower, Sputnik, the Founding of NASA. *Acta Astronaut.* **2010**, *67*, 254–263. [CrossRef]
19. Logsdon, J. Why did the United States retreat from the moon? *Space Policy* **2015**, *32*, 1–5. [CrossRef]
20. Lambright, W. Administrative Leadership and Long-Term Technology: NASA and the International Space Station. *Space Policy* **2019**, *47*, 85–93. [CrossRef]
21. Cheston, T.S.; Chafer, C.M.; Chafer, S.B. *Social Sciences and Space Exploration*; NASA: Washington, DC, USA, 1984.
22. Berea, A.; Denning, K.; Vidaurri, M.; Arcand, K.; Oman-Reagan, M.P.; Bellovary Aydinoglu, A.U.; Lupisella, M. The Social Sciences Interdisciplinarity for Astronomy and Astrophysics—Lessons from the History of NASA and Related Fields. *Bull. Am. Astron. Soc.* **2019**, *51*, 142.
23. Del Canto Viterale, F. Developing a Systems Architecture Model to study Science, Technology, and Innovation (STI) within the international system. *Systems* **2019**, *7*, 46. [CrossRef]

24. Orsini, A.; Le Prestre, P.; Haas, P.M.; Brosig, M.; Pattberg, P.; Widerberg, O.; Gomez-Mera, L.; Morin, J.-F.; Harrison, N.E.; Geyer, R.; et al. Forum: Complex Systems and International Governance. *Int. Stud. Rev.* **2020**, *22*, 736. [CrossRef]
25. Albert, M.; Cederman, L.; Wendt, A. (Eds.) *New Systems Theories of World Politics*; Palgrave MacMillan: London, UK, 2010.
26. Wallerstein, I. *Open the Social Sciences: Report of the Gulbenkian Commission on the Restructuring of the Social Sciences*; Stanford University Press: Stanford, CA, USA, 1996.
27. Murray, G.M. *Thinking about the Future—The Big Picture*; Distinguished Lecture Series, the 2004–2005 Pardee Visiting Professor of Future Studies, Pardee Center for the Study of the Longer-Range Future; Boston University: Boston, MA, USA, 2005. Available online: https://www.bu.edu/pardee/9-27-05/ (accessed on 9 March 2023).
28. Miller, J.H. *A Crude Look at the Whole the Science of Complex Systems in Business, Life, and Society*; Basic Books: New York, NY, USA, 2016.
29. Bunge, M. A general black-box theory. *Philos. Sci.* **1963**, *30*, 346–358. [CrossRef]
30. Bunge, M. *Treatise on Basic Philosophy. Volume 4: Ontology II: A World of Systems*; D. Reidel Publishing: Dordrecht, The Netherlands, 1979.
31. Bunge, M. *Finding Philosophy in Social Science*; Yale University Press: New Heaven, CT, USA, 1996.
32. Bunge, M. Systemism: The alternative to individualism and holism. *J. Socio-Econ.* **2000**, *29*, 147–157. [CrossRef]
33. Bunge, M. Emergence and the mind. In *Scientific Realism: Selected Essay of Mario Bunge*; Mahner, M., Ed.; Prometheus Book: Amherst, NY, USA, 2001; pp. 75–89.
34. Bunge, M. *Emergence and Convergence: Qualitative Novelty and Unity of Knowledge*; University of Toronto Press: Toronto, ON, Canada, 2003.
35. Choi, H. Systemism. In *21st Century Political Science*; Ishiyama, J., Breuning, M., Eds.; SAGE: Los Angeles, CA, USA, 2011; Volume 1, pp. 29–33.
36. James, C.; James, P. Systemism and Foreign Policy Analysis: A New Approach to the Study of International Conflict. In *Advancing Interdisciplinary Approaches to International Relations*; Yetiv, S., James, P., Eds.; Palgrave Macmillan: Cham, Switzerland, 2017.
37. James, P. What do we know about crisis, escalation, and war? A visual assessment of the International Crisis Behavior Project. *Confl. Manag. Peace Sci.* **2019**, *36*, 3–19. [CrossRef]
38. Boulton, J.; Allen, P.; Bowman, C. *Embracing Complexity: Strategic Perspectives for an Age of Turbulence*; Oxford University Press: Oxford, UK, 2015.
39. Bertalanffy, L. *General System Theory*; George Braziller: New York, NY, USA, 1969.
40. Kaplan, M. *System and Process in International Politics*; John Wiley and Sons: New York, NY, USA, 1957.
41. Braillard, P. *Théories des Relations Internationals*; Presses Universitaires de France: Paris, France, 1977.
42. Jervis, R. *System Effects: Complexity in Political and Social Life*; Princeton University Press: Princeton, NJ, USA, 1997.
43. Wallerstein, I. *Geopolitics and Geoculture: Essays on the Changing World-System*; Cambridge University Press: Cambridge, UK, 1991.
44. Rosenau, J. The complexities and contradictions of Globalization. *Curr. Hist. J. Contemp. World Aff.* **1997**, *96*, 360–364.
45. Braumoeller, B. *The Great Powers and the International. System Systemic Theory in Empirical Perspective*; Cambridge University Press: New York, NY, USA, 2012.
46. Jaakkola, H.; Thalheim, B. Architecture-driven modeling methodologies. In *Proceedings of the 2011 Conference on Information Modelling and Knowledge Bases XXII*; Heimbürger, A., Kiyoki, Y., Tokuda, T., Jaakkola, H., Yoshida, N., Eds.; IOS Press: Amsterdam, The Netherlands, 2011; pp. 97–116.
47. Halliday, F. Global Governance: Prospect and Problems. *Citizenship Studies* **2000**, *4*, 19–33. [CrossRef]
48. Keohane, R.; Nye, J. Power and Interdependence in the Information Age. *Foreign Aff.* **1998**, *77*, 81. [CrossRef]
49. Strange, S. *The Retreat of the State: The Diffusion of Power in the World Economy*; Cambridge University Press: Cambridge, UK, 1996.
50. Haass, R. Deglobalization and Its Discontents. *Project Syndicate*, 12 May 2020. Available online: https://www.project-syndicate.org/commentary/deglobalizaton-discontents-by-richard-n-haass-2020-05?barrier=accesspaylog (accessed on 9 March 2023).
51. Stiglitz, J. *The Globalizations and Its Discontents*; W.W. Norton: New York, NY, USA, 2002.
52. Porter, M. *The Competitive Advantage of Nations: Creating and Sustaining Superior Performance*; The Free Press: New York, NY, USA, 2011.
53. Foray, D. *The Economics of Knowledge*; The MIT Press: Cambridge, MA, USA, 2006.
54. Porter, M. *Clusters and the New Economics of Competition*; Harvard Business Review: Boston, MA, USA, 1998; pp. 77–91. Available online: https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition (accessed on 9 March 2023).
55. Kennedy, P. *The Rise and Fall of the Great Powers: Economic Change and Military Conflict from 1500 to 2000*; Vintage Books: New York, NY, USA, 1987.
56. Schwab, K. *The Fourth Industrial Revolution*; Crown Business: New York, NY, USA, 2016.
57. Schwab, K. *Shaping the Fourth Industrial Revolution*; World Economic Forum: Geneva, Switzerland, 2018.
58. Mc Luhan, M. *War and Peace in the Global Village: An Inventory of Some of the Current Spastic Situations That Could Be Eliminated by More Feedforward*; McGraw-Hill: New York, NY, USA, 1968.
59. Held, D. Regulating Globalization? The Reinvention of Politics. *Int. Sociol.* **2000**, *15*, 394–408. [CrossRef]
60. Keohane, R.; Nye, J. Power and Interdependence Revisited. *Int. Organ.* **1987**, *41*, 725–753. [CrossRef]
61. Rodrik, D. Why Does Globalization Fuel Populism? Economics, Culture, and the Rise of Right-Wing Populism. *Annu. Rev. Econ.* **2021**, *13*, 133–170. [CrossRef]

62. Del Canto Viterale, F. *International Scientific Relations*; Anthem Press: London, UK, 2021.
63. Dallanegra Pedraza, L. Escenarios sobre el orden internacional. *Reflexión Política* **2012**, *14*, 18–38.
64. Space Foundation. *The Space Report 2022 Q4*; Space Foundation: Colorado Springs, CO, USA; Arlington, VA, USA, 2022. Available online: https://www.spacefoundation.org/ (accessed on 9 March 2023).
65. Organization for Economic Cooperation and Development (OECD). Chapter 3: Monitoring the evolving cast of space actors. In *OECD Handbook on Measuring the Space Economy*; OECD Publishing: Paris, France, 2022. Available online: https://www.oecd.org/publications/oecd-handbook-on-measuring-the-space-economy-2nd-edition-8bfef437-en.htm (accessed on 8 March 2023).
66. Suzuki, K. The contest for leadership in East Asia: Japanese and Chinese approaches to outer space. *Space Policy* **2013**, *29*, 99–106. [CrossRef]
67. Wood, D.; Weigel, A.D. A framework for evaluating national space activity. *Acta Astronaut.* **2012**, *73*, 221–236. [CrossRef]
68. Shabbir, Z.; Sarosh, A.; Nasir, S.I. Policy Considerations for Nascent Space Powers. *Space Policy* **2021**, *56*, 101414. [CrossRef]
69. Euroconsult. New Record in Government Space Defense Spending Driven by Investments in Space Security and Early Warning. 15 December 2022. Available online: https://www.euroconsult-ec.com/press-release/new-record-in-government-space-defense-spendings-driven-by-investments-in-space-security-and-early-warning/ (accessed on 9 March 2023).
70. Spudis, P. Cislunar Space: The Next 30 Years. United Launch Alliance has a Vision. *Smithsonian Magazine*, 22 February 2017. Available online: https://www.smithsonianmag.com/air-space-magazine/cislunar-space-next-30-years-180962249/ (accessed on 9 March 2023).
71. SpaceTech Analytics. Space Tech Industry 2021/Q2. *Landscape Overview*, May 2021. Available online: https://analytics.dkv.global/spacetech/SpaceTech-Industry-2021-Report.pdf (accessed on 9 March 2023).
72. Fleck, A. The U.S. and China Lead the Space Race 2.0. *Statista*, 7 November 2022. Available online: https://www.statista.com/chart/28667/countries-are-leading-the-space-race-20/ (accessed on 9 March 2023).
73. Euroconsult. Private Investment Fuels China Commercial Space Sector Growth, Alongside State-Backed Investment. 4 June 2020. Available online: https://www.euroconsult-ec.com/press-release/private-investment-fuels-china-commercial-space-sector-growth-alongside-state-backed-investment/ (accessed on 9 March 2023).
74. Li, X.; Niu, W. Support potential of elite civil universities for China's space industry: Higher educational mobilization capacity for China's space ambition. *PLoS ONE* **2020**, *15*, e0243456. [CrossRef] [PubMed]
75. Raitt, D. Academic and Industrial Cooperation in Innovative Space Research. ESA Bulletin 98—June 1999. Available online: https://www.esa.int/esapub/bulletin/bullet98/RAITT.PDF (accessed on 23 February 2023).
76. Moyo, R. The Role of Universities in Building A Resource–Dependent Space Industry. *Space in Africa*, 23 February 2023. Available online: https://africanews.space/the-role-of-universities-in-building-a-resource-dependent-space-industry/ (accessed on 9 March 2023).
77. The European Space Agency (ESA). Member States & Cooperating States. *ESA Corporate News*. Available online: https://www.esa.int/About_Us/Corporate_news/Member_States_Cooperating_States (accessed on 9 March 2023).
78. Broniatowski, D.A.; Faith, G.R.; Sabathier, V.G. *The Case for Managed International Cooperation in Space Exploration*; Center for Strategic & International Studies: Washington, DC, USA, 2006. Available online: https://www.csis.org/analysis/case-managed-international-cooperation-space-exploration (accessed on 9 March 2023).
79. Knipfer, C. International Cooperation, and Competition in Space (Part 1) How—And Why—Should the United States Proceed? *The Space Review*, 20 November 2017. Available online: https://thespacereview.com/article/3376/1 (accessed on 9 March 2023).
80. The Artemis Accords Principles for Cooperation in the Civil Exploration and Use of the Moon, Mars, Comets, and Asteroid for Peaceful Purposes. 2020. Available online: https://www.nasa.gov/specials/artemis-accords/img/Artemis-Accords-signed-13Oct2020.pdf (accessed on 14 February 2023).
81. Ben-Itzhak, S. Space Blocs: The future of international cooperation in space is splitting along lines of power on Earth. *The Conversation*, 21 April 2022. Available online: https://theconversation.com/space-blocs-the-future-of-international-cooperation-in-space-is-splitting-along-lines-of-power-on-earth-180221 (accessed on 9 March 2023).
82. BBC. Trump: 'Space is the world's newest war-fighting domain'. *BBC News US & Canada*, 21 December 2019. Available online: https://www.bbc.com/news/av/world-us-canada-50875940 (accessed on 8 March 2023).
83. Lopez, T. Space Force Chief: U.S. Doesn't Want War in Space, Must be Prepared for It. *DOD News*, 15 September 2020. Available online: https://www.defense.gov/News/News-Stories/Article/Article/2348614/space-force-chief-us-doesnt-want-war-in-space-must-be-prepared-for-it/ (accessed on 9 March 2023).
84. Habermas, J. El valle de lágrimas de la globalización. *CLAVES Razón Práctica* **2001**, *109*, 4–10.
85. Marcuse, H. *One-Dimensional Man: Studies in the Ideology of Advanced Industrial Society*; Beacon Press: Boston, MA, USA, 1964.
86. UNESCO. *Towards Knowledge Society*; UNESCO Publishing: Paris, France, 2005. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000141843 (accessed on 9 March 2023).
87. UNESCO. *UNESCO Science Report: Towards 2030*; UNESCO Publishing: Paris, France, 2015. Available online: https://uis.unesco.org/sites/default/files/documents/unesco-science-report-towards-2030-part1.pdf (accessed on 9 March 2023).
88. Space in Africa. Global Space Budgets—A Country-Level Analysis. *Space in Africa*, 10 March 2021. Available online: https://africanews.space/global-space-budgets-a-country-level-analysis/ (accessed on 9 March 2023).
89. Van Dijk, J. *The Deeping Divide: Inequality in the Information Society*, 4th ed.; SAGE Publications: Los Angeles, CA, USA, 2020.
90. Sassen, S. *Sociology of Globalization*; W.W. Norton: New York, NY, USA, 2007.

91. Innerarity, D. *The Democracy of Knowledge*; Continuum/Bloomsbury: New York, NY, USA, 2013.
92. Burgueño Salas, E. Turnover of the global space economy 2009–2021. *Statista*, 5 November 2022. Available online: https://www.statista.com/statistics/946341/space-economy-global-turnover/ (accessed on 9 March 2023).
93. Brukardt, R.; Klempner, J.; Stokes, B. Space: Investment Shifts from GEO to LEO and Now Beyond. *McKinsey & Company*, 27 January 2022. Available online: https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/space-investment-shifts-from-geo-to-leo-and-now-beyond (accessed on 21 February 2023).
94. Borowitz, M. Europe Continues to Lead in Global Workforce Job Growth. *The Space Report Online*. Available online: https://www.thespacereport.org/resources/europe-continues-to-lead-in-global-workforce-job-growth/ (accessed on 9 March 2023).
95. Green, A. Meeting the Skills Needs of the Space Sector. *City REDI Blog*, 15 September 2021. Available online: https://blog.bham.ac.uk/cityredi/meeting-the-skills-needs-of-the-space-sector/ (accessed on 7 March 2023).
96. McClintock, B.; Feistel, K.; Ligor, D.C.; O'Connor, K. *Responsible Space Behavior for the New Space Era Preserving the Province of Humanity*; RAND Corporation: Santa Monica, CA, USA, 2021. [CrossRef]
97. White House—Office of Management and Budget. Budget of the U.S. Government Fiscal Year 2023. Available online: https://www.whitehouse.gov/wp-content/uploads/2022/03/budget_fy2023.pdf (accessed on 9 March 2023).
98. U.S. Department of Defense. The Department of Defense Releases the President's Fiscal Year 2023 Defense Budget. Statement by Secretary of Defense Lloyd J. Austin III on the President's Fiscal Year 2023 Budget. 28 March 2022. Available online: https://www.defense.gov/News/Releases/Release/Article/2980014/the-department-of-defense-releases-the-presidents-fiscal-year-2023-defense-budg/ (accessed on 9 March 2023).
99. India Today. *Mission Shakti: Read PM Narendra Modi's Full Speech Announcing How India Took Down Satellite*; India Today Web Desk: New Delhi, India, 27 March 2019. Available online: https://www.indiatoday.in/india/story/mission-shakti-narendra-modi-full-speech-1487838-2019-03-27 (accessed on 8 March 2023).
100. James, T. *Deep Space Commodities. Exploration, Production, and Trading*; Palgrave Macmillan: Cham, Switzerland, 2018.
101. CNBC. Build the economy here on Earth by exploring space: Tyson. *CNBC on the Money*, 3 May 2015. Available online: https://www.cnbc.com/2015/05/01/build-the-economy-here-on-earth-by-exploring-space-tyson.html (accessed on 9 March 2023).
102. National Aeronautics and Space Administration (NASA). *Artemis Plan—NASA's Lunar Exploration Program Overview*; NASA: Washington, DC, USA, 2020.
103. Witze, A. Astronauts have conducted nearly 3000 science experiments aboard the ISS. *Nature*, 3 November 2020. Available online: https://www.nature.com/articles/d41586-020-03085-8 (accessed on 27 February 2023).
104. United Nations Office for Outer Space Affairs. Space Supporting the Sustainable Development Goals. Available online: https://www.unoosa.org/oosa/en/ourwork/space4sdgs/index.html (accessed on 9 March 2023).
105. United Nations Office for Outer Space Affairs. The "Space2030" Agenda: Space as a Driver of Sustainable Development. *Resolution Adopted by the General Assembly*, 25 October 2021. Available online: https://www.unoosa.org/oosa/oosadoc/data/resolutions/2021/general_assembly_76th_session/ares763.html (accessed on 8 March 2023).