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ARTÍCULOS

Deep-black is the new green: Europe-India Innovation Pathways in Laser Systems for Space-Debris Reduction

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Abstract: The expansion of the new space economy has amplified the threat posed by orbital debris. This article maps the global value chains (GVCs) behind Europe's laser-based technologies for debris detection and mitigation, focusing on European Space Agency (ESA) and private sector systems. The analysis highlights Europe's dependence on semiconductor-based laser components. The article also examines the strategic potential of cooperation between ESA and the Indian Space Research Organisation (ISRO) in the fight against space debris. India's strengths in software development, systems integration, and cost-effective innovation complement Europe's hardware capabilities. The study concludes that strengthened ESA-ISRO collaboration could enhance debris-mitigation capacities while reinforcing the resilience of GVCs supporting laser-ranging technologies.
Keywords: Space debris; Laser technology; Global value chains; Europe-India cooperation

JEL codes: F14; L24; O32; Q55

ES El negro profundo es el nuevo verde: Vías de innovación Europa-India en sistemas láser para la reducción de desechos espaciales

Resumen: La expansión de la nueva economía espacial ha intensificado la amenaza que representan los desechos orbitales. Este artículo cartografía las cadenas globales de valor (CGV) que sustentan las tecnologías láser europeas para la detección y mitigación de dichos desechos, con especial atención a los sistemas de la Agencia Espacial Europea (ESA) y del sector privado. El análisis pone de relieve la dependencia europea de componentes láser basados en semiconductores. Asimismo, se examina el potencial estratégico de la cooperación entre la ESA y la Organización de Investigación Espacial de la India (ISRO) en la lucha contra los desechos espaciales. Las capacidades indias en desarrollo de software, integración de sistemas e innovación rentable complementan las fortalezas europeas en hardware. El estudio concluye que un fortalecimiento de la colaboración ESA-ISRO podría mejorar las capacidades de mitigación de desechos y reforzar la resiliencia de las CGV que sustentan las tecnologías de medición láser.
Palabras clave: desechos espaciales; tecnología láser; cadenas globales de valor; cooperación Europa-India

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Introduction[2]

This article suggests a research agenda which maps the global value chains (GVCs) put forward by the European Space Agency (ESA) in the development of laser ranging stations as a prime technology in fighting space debris and, ultimately, to protect active space assets. Situating the evolution of space-debris mitigation within broader debates on GVC governance (Gereffi et al., 2005), technological innovation systems (Lundvall, 1992; Edquist, 2005), and the strategic management of dual-use technologies (see, e.g., Stowsky, 2004; Mazzucato, 2013), the article argues that Europe's leadership in space sustainability depends not only on scientific capabilities but also on how effectively it shapes and leverages transnational production networks.

Since the launch of Sputnik by the Soviet Union in 1957, the North American Aerospace Defence Command (NORAD) has been compiling a Space Object Catalogue of satellites, shields, and booster rockets. Nowadays, the United States Space Surveillance Network (USSSN) is among the major actors tracking artificial objects orbiting Earth. At the time of writing this, the USSSN records about 35,310 objects in space –the cipher is likely to have increased since–, including satellites, rockets, and debris. Debris includes inactive satellites, abandoned vehicles, pieces of objects lost on a mission and fragments of the previous. Debris constitutes a relatively new source of environmental pollution.

The growth in debris has reached the critical threshold in the Low Earth Orbit (LEO), but also at higher altitudes. In the LEO, object decay is relatively faster compared to higher altitudes, because the closer to Earth an object orbits, the quicker it enters the atmosphere and burns up. Maximum debris levels are found between 800 and 1,000 km and at 1,400 km. (ESA, 2023). At higher altitudes, debris tends to decay much more slowly, because of the smaller gravity force attracting objects to the atmosphere. In both cases, debris can take decades or even longer to deorbit and burn up, hence representing a growing collision risk for active satellites, skyrockets, space stations and vehicles (ESA, 2021; NASA, 2021). The estimated number of break-ups, explosions, collisions, or other events resulting in fragmentations so far is above 640. These have led to the presence of 36,500 debris objects larger than 10 cm, one million between 1 cm and 10 cm, and 130 million between 1 mm and 1 cm. With about 110 yearly launches and 10 break-ups per year occurring at present, the number of debris objects is doomed to increase. This implies a cascade of debris due to debris collision, a phenomenon known as Kessler syndrome (Kessler and Cour-Palais, 1978). The phenomenon is accentuated by the increase in the number of payloads (space objects like satellites, for instance) per launch (OECD, 2022) (see Figure 1).

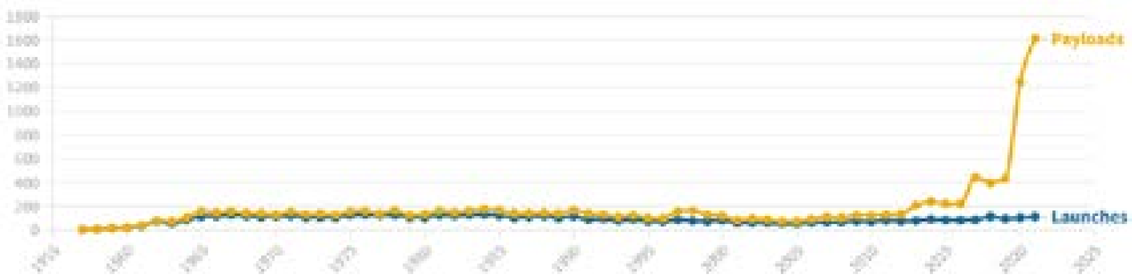

Figure 1. Exponential increase of payloads per launch

Source: OECD (2022).

Debris has thus become a new form of dangerous garbage, implying that pollution, and environmental protection, is no longer an exclusive sore of the "green" biosphere and "blue" hydrosphere, but increasingly extends to the "black" thermosphere and beyond. This evolving threat has transformed debris mitigation from a narrowly technical task into a challenge of "innovation-ecosystem coordination", where public agencies, private firms, and global suppliers jointly shape technological trajectories, a dynamic well recognised in the GVC and innovation-policy literature (see, e.g., Lema et al., 2015; OECD, 2021). For all this, the protection of space assets from debris becomes imperative, with the goal of guaranteeing the safety of the objects and the people sent to space. This can be achieved through new environmental space policies developed by major space agencies, national and international institutions, and the private sector (cf. Weinzierl & Rosseau, 2025).

In this regard, much is on progress to prevent debris formation, by means of regulation: for instance, by the United Nations Committee on the Useful Uses of Outer Space, the North American Space Agency (NASA), the U.S. Department of Defence, through US Air Force standard rules, ESA "25-year" rule, ISRO debris containment measures, national debris bond markets, etc. Plans are also being made to remove existing debris through operations in space. These include the development of electrodynamic tethers to slow the object and deorbit it at the end of its mission, deorbiting "sails", operations to hunt the debris and take it down to the atmosphere and, finally, laser beams installed on satellites. But, at the same time, China and Russia

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[2] A preliminary draft of this paper has been presented at the final symposium of CatChain project (European Union's Horizon 2020 research and innovation programme under Marie Skłodowska-Curie grant agreement No 778398), *Catching up and global value chains in times of transformation*, held at UNU-MERIT, United Nations University, Maastricht, The Netherlands, on February 19-20, 2024.

have in recent times used anti-satellite missiles (ASAT) to get rid of satellites that had become obsolete, thus increasing space junk (Defense Intelligence Agency (DIA), 2019).

The previous methods against debris imply a potential development of GVCs in many sectors, with the consequent economic and social impact on Earth and not just in terms of fight against debris. The focus of this paper, though, is on anti-debris lasers from Earth. Lasers, in fact, are becoming object of attention of public and private space stakeholders, as they can be used from Earth to make debris enter the atmosphere by altering its rotation angle, where it ultimately burns up. The paper analyses the convenience and viability of expanding the global value chain in the development of anti-debris laser technology through the cooperation between Europe and India.

Europe's most remarkable achievement to fight space debris using laser brooms from Earth is represented by Izaña-1 laser ranging station (IZN-1), ESA's laser station in Tenerife, Spain. IZN-1 is the result of testing and commissioning, thanks to the engagement with German firm DiGOS, which followed much of product development and on-site construction, placing Europe within a complex and geographically concentrated supply chain that resembles other strategic technological domains, including advanced semiconductors and digitalization (see, e.g., Baldwin, 2016; Sturgeon, 2019; Álvarez et al., 2024). This strategic dependence introduces vulnerabilities comparable to those observed in other dual-use technological fields, where military and civilian applications overlap and where value-chain chokepoints can constrain strategic autonomy.

As the risks associated to this type of technological application are damages to optical instruments and telescopes or pilots' distraction, the development of laser ranging stations implies the design and the production of sensors and software services aimed at avoiding contact between laser beams, manned vehicles, and instruments. In this regard, the Astrophysics Institute of the Canary Islands (IAC) has developed the Laser Traffic Control System (LTCS), to avoid that lasers and telescopes operate in the same target area. Therefore, stations like Izaña-1 will have an impact on global value chains, as they improve uses in various sectors, like the optical, the seismologic, and the engineering.

A clearer policy challenge underpins this study: how Europe can strengthen its technological resilience and strategic autonomy in space-debris mitigation by leveraging global value chains (GVCs) and targeted international partnerships, particularly with India. While space debris represents a fast-escalating environmental and security threat, Europe's ability to lead in mitigation technologies depends not only on scientific excellence but also on securing access to critical components, most notably semiconductor-based laser diodes, and on diversifying collaborative channels in an increasingly fragmented geopolitical landscape. By situating laser-based debris-mitigation systems within their global production networks, the paper identifies where Europe's vulnerabilities and strategic dependencies lie, and how these may be addressed through policy action.

To clarify its scope, the article positions itself as a hybrid contribution that combines a policy case study with a conceptual framework for GVC analysis in the space-debris domain. On one level, the paper offers an empirical case study centred on ESA's Izaña-1 laser-ranging station, DiGOS' SCOPE and RGG systems, and the upstream semiconductor components on which they rely. On another level, it translates these empirical observations into a broader conceptual and policy framework that can guide future research on how technological interdependencies shape Europe's strategic room for manoeuvre in space. This dual nature, case-specific analysis feeding into a generalisable framework, is deliberate, as Europe's response to space debris must combine operational solutions with long-term industrial-policy thinking.

Accordingly, the paper adopts a policy-oriented research agenda that addresses three interlinked issues. First, it examines which segments of the GVC for laser-ranging technologies present bottlenecks, risks of concentration, or exposure to geopolitical disruption. Second, it evaluates how cooperation with India could enhance Europe's resilience by integrating complementary capabilities: European strengths in hardware and India's strengths in software, systems engineering, and cost-effective R&D. Third, it outlines the implications for European industrial, innovation, and space-security policies as they confront the pressing challenge of ensuring sustainable access to orbital environments. This framing aims to make explicit the policy relevance of GVC mapping for Europe's leadership in debris-mitigation technologies.

The remainder is the following. At first, DiGOS' major systems are circumscribed, namely SCOPE and the Range Gate Generator (RGG), with a focus on their technical features and functions. Further on, the article suggests a mapping of the GVC in the production of the laser technology at the basis of SCOPE and the RGG. Such GVC is analysed in the context of the "new space economy" (see, e.g., D'Costa, 2025), i.e. the recent way of commercialising space products which are manufactured through COTS parts provided by private and public firms. Mapping GVCs in this sector may provide pivotal to avoid any bottleneck or cost inefficiency in any of the chains' parts. Lastly, attention is paid to the potential room for cooperation in the development of laser technology between the European Space Agency and foreign actors. In particular, the article suggests that cooperation with the Indian Space Research Organisation (ISRO) can complement European hardware strengths with India's well-documented capabilities in the space race, from software development to systems integration and frugal innovation (see, e.g., Mani et al., 2023). As the literature on global innovation networks suggests, such complementarities can enable latecomer and established actors to co-evolve capabilities through joint learning (Ernst, 2009; Pietrobelli & Rabellotti, 2011) and to catch-up with each other (Chaminade et al., 2019). Such cooperation can be contextualised as part of the current projects aiming at reducing space debris in different regions of the world. Also, it can be seen as an international effort to allow for Internet access on Earth through satellite laser communication, so much needed at these times of geopolitical tensions.

Space debris elimination in the context of Outer Space Economics

Economic activities related to outer space, for which we coined the term *Astronomics*, have reached an unprecedented global volume, having become one of the currently most significantly expanding sectors (OECD, 2019). Not only have public space budgets reached an estimated volume of USD +75 billion in 2018, the largest figure since the "Apollo era" in the 1960s, but in addition to that private investment has heavily joined the sector, both through the entrance of "big capital", such as the heavily advertised activities of Jeff Bezos's "Blue Origin", Richard Branson's "Virgin Galactic" and Elon Musk's "SpaceX", but also of many less iconic companies due to the steadily decreasing entrance costs. Hence, no wonder that already by 2022 OECD government space budgets had reached an estimated USD 75 billion, accounting for 0.1% of OECD GDP (OECD, 2023), with an upward trend.

However, this should not overshadow the fact that, although public-private partnerships are becoming increasingly relevant in the field, the leading agent in space economics is still the public sector, albeit private companies are increasingly taking over innovation leadership:

> The space companies at the forefront of this revolution are using innovative technologies and approaches to transform humanity's space future as well as life for all of us on Earth. Early leaders such as SpaceX have made access to Earth's orbit and beyond dramatically more affordable and routine, and hundreds of young companies have responded by developing technologies that take advantage of unique features of space as never before. The result: space is no longer just a site of geopolitical competition, scientific research, and exploration, though it remains that. It is becoming an ever-more-important site of value creation for businesses across industries and for society as a whole.
>
> (Weinzierl & Rosseau, 2025: 1)

According to the OECD (2019) the role of government investments in the development of space activities is a trend likely to continue in the coming decade, despite greater private sector participation (OECD, 2023), so that in G20 economies, government actors will continue playing a key role in the space economy as investors, developers, owners, operators, regulators, and customers. Recent attempts to land controlled vehicles on the moon by China, Japan, and India give a comprehensive example of this reality. But, as has already been stated, Governments are also increasingly partnering with the private sector (i.e. NASA with SpaceX), for the joint development of space products and services, funding basic and applied science as well as research and development and purchasing space products and services (OECD, 2023).

Although exact economic indicators regarding the outer space sector are not yet available for many countries, the median value of space budgets as a share of gross domestic product (GDP) amounted to 0,05% for G20 economies as a whole, with the United States and the Russian Federation investing more than 0,2% of GDP and France more than 0,1% (OECD, 2019).

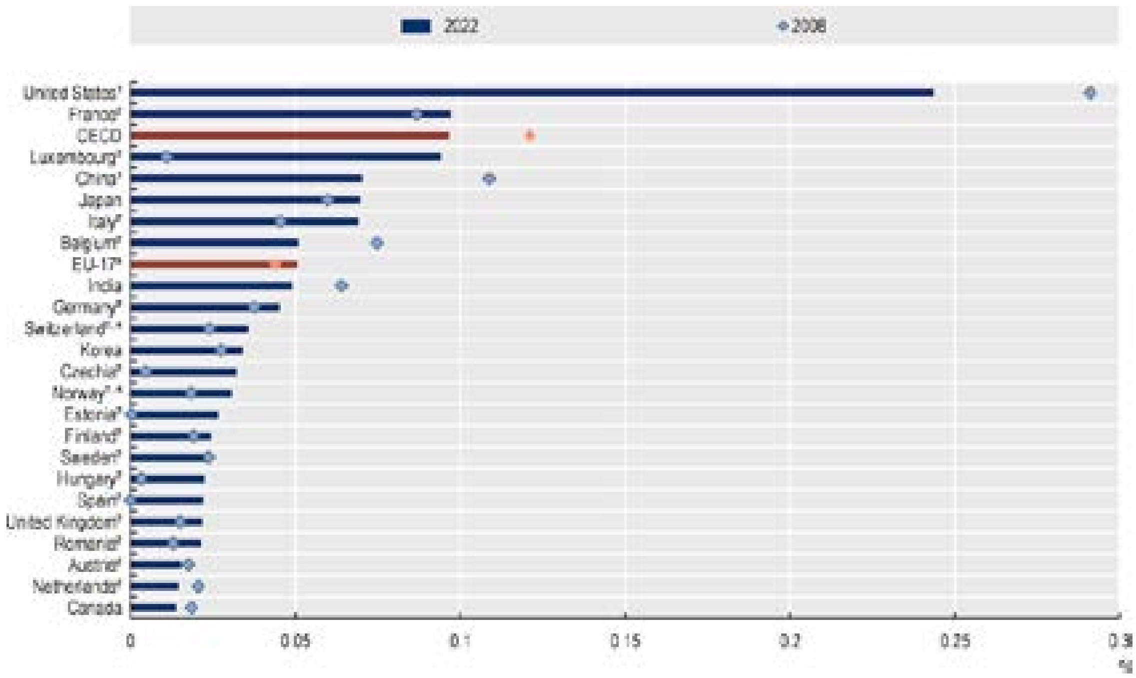

Figure 2. Selected government space budget estimates as a share of GDP (%)

Source: OECD (2023).

According to OECD (2021), these findings are comparable to those of previous years (a fact that may be explained because space programmes and projects tend to have long lead times), though Saudi Arabia is emerging as a notable new large investor. But also, other national space agencies, such the Chinese CNSA, the Japanese JAXA, the Indian ISRO, and the UAESA from the United Arab Emirates are intensifying their space efforts. However, the unexpected Covid-19 pandemic interrupted many of the ongoing programs, causing severe costs due to the forced halts, causing a damping effect in the short run (see Coz & Valiño, 2021).

Yet, recent data and advances in the space race reinforce the perception of an accelerated trend of public-private co-investments, partnerships and space commercialisation, as private sector capabilities mature and public organisations transfer more responsibilities and risks to non-government actors. This is associated with technological transfers to the private sector, deregulation, and more extensive space service buys (e.g., India and Korea are currently in the process of transferring technologies and know-how on satellite and launcher manufacturing to private actors, and also NASA is extending service buys to space exploration).

Hence, there is overwhelming empirical evidence showing that the space economy is one of the most dynamic and promising sectors in terms of economic growth and represents a strategically critical option for the development of advanced economies.

Consequently, in our immediate European context, the European Space Agency (ESA) has created a Space Economy unit, which has started working to improve economic measurement and collect and share best practices in socioeconomic impact assessment in cooperation with the OECD Space Forum, ESA member states and relevant government entities involved in economic analysis and statistics. And Spain has recently created its own (national) space agency.

Yet, it should be noted that *Astronomics* must be understood from its beginning as an interdisciplinary field of research, as it strongly overlaps with another area of analysis, namely defence and security. According to the report prepared by TEDAE on the Spanish space industry, 'Public Administrations dedicate resources close to 500 million euros per year in provision of services and development of space technology and infrastructures, of which the main items correspond to the Spanish contribution to ESA, the EU and the Ministry of Defence' (TEDAE, 2019:33; 2020). The space sector technical characteristics, the concurrence of institutions, and civil and military interests complicate space agent coordination, just as occurs both in the case of air and maritime space, only that more so. This dual-use technology becomes clear in the case of our object of study in this paper, as the same laser technology used to get rid of space debris might also be used to harm "enemy" satellites.

A case of study in laser technology: DiGOS' SCOPE and Range Gate Generator

DiGOS has surged as a reference developer of Satellite Laser Ranging (SLR) stations and Space Debris Laser Ranging (SDLR) stations. SLRs are built to detect satellites through lasers for several reasons, spanning from distance calculations to optical communication from earth. SDLRs specifically adopt laser beams to reach space debris and gently lead it back to the atmosphere. The development and post-installation support are made through designing and engineering activities on behalf of international clients, the most notable of which include the Japan Aerospace Exploration Agency and the European Space Agency. In Japan, DiGOs has been active since 2018, when it won a tender to build an LRS station for the Japanese Space Agency (JAXA) at the Tsukuba Space Center. In Europe, DiGOs has developed and installed Izaña-1. Located on Mount Teide, it is a vanguard station in the fight against space debris and likely the first of many to come.

DiGOS' major systems are two: SCOPE and the Range Gate Generator (RGG). They are based on laser technology that serves the scopes of SLR and SDLR stations, including the measurement of photons reflected from space debris and other objects.

As publicly stated by DiGOS (2024), scope is a software apt for command and control of laser systems and optical stations on Earth. It is the major system adopted by DiGOS at the German station in Potsdam, at the Spanish one in Tenerife, and at new installations. Specifically, SCOPE coordinates smoothly all subsystems involved in laser operations, from measurement to monitoring. The interface and the daemon software operate in real time through astrophysical algorithms, workflows, and monitoring. Support involves 'SLR system initialization, calibration, satellite & space debris tracking, star observation, planning, different operation modes, semi-automatic operation, etc.' (DiGOS, 2024). It is also apt for training, testing, and verification compatible with different hardware over day or night hours. It also serves as an efficient control system in laser communications. The system is being developed to operate in an automated mode. As regards its architecture, SCOPE works with C/C++, Python, and Doxygen. As regards the hardware, SCOPE relies on commercial-off-the-shelf (COTS) stations. Parts can be run on Linux.

The Range Gate Generator (RGG) generates triggers for lasers and detectors in satellite activities and operations with space debris. The latest version, RG2, 'is highly configurable, supports different operation modes, gate sizes, delay settings, etc. Its design is based on expertise from the previous RG1, developed in 2015 by DiGOS and the GFZ SLR team' (DiGOS, 2024). As features are concerned, RGG is made of a firmware written in C, has an emergency button to switch off the laser, and is supported by SCOPE.

Mapping the GVCs of laser technology as part of the "new space economy"

As stated by DiGOS, the German company develops laser stations based on state-of-the-art systems 'based on COTS components from the best European and international suppliers [...] and [...] operated with [...] [the] SCOPE control software' (2024). COTS components are commercial off-the-shelf hardware or software adapted by their purchaser for specific means. DiGOS' SCOPE, for instance, is developed through the best software and hardware in circulation at present. The use of COTS parts in the manufacturing of space products, on the one hand, has been avoided by the aero-space industry. In this regard, Gonzalez (2012) poses the question on whether COTS electric, electronic, and electromechanic (EEE) parts can be used in flight hardware systems. The question was a major focus of attention within the prime space agencies of the world, including NASA, obviously concerned with the security of space crews. In recent times, public space agencies have started their cooperation with the private sector, looking for high-quality and cost-effective products. Provided by private companies, COTS parts have thus become a common component of space products, including those adopting laser technology.

Public-private cooperation in the space industry has paved the way for the economics of space exploration. Space exploration is increasingly becoming the source of new profits for the manufacturers along the value chain of space products. The novelty, compared to the past, is that the State is no longer the unique economic agent involved in the production of space-related products, private companies and investors having entered the market, too. Remarkable in this regard is the fact that the consulting firm Morgan Stanley has even created its own Space Team, specifically devoted to activities and research about the space economy. 'Morgan Stanley's Space Team estimates that the roughly $350 billion global space industry could surge to over $1 trillion by 2040' (Morgan Stanley, 2024).

The traditional approach in the space sector was mostly upstream while the new space economy approach takes advantage of the downstream sector (e.g., see Moranta 2022; Bousedra, 2023).

> On a simplified linear space value chain, the space infrastructure industry is referred to as the "upstream", which corresponds with the series of economic activities leading to an operational satellite system in orbit, and the space services industry is referred to as the "downstream", which corresponds with all the subsequent economic activities related to the operation and exploitation of this satellite system for providing space-based products and services to end-users, including user equipment (e.g. satellite TV dishes, navigation devices, satellite phones).
>
> (Moranta, 2022: 7)

Nowadays, the upstream sector, namely the infrastructure industry, plays a smaller role than the downstream sector, namely the service industry, on the value chain. According to estimations (see Moranta, 2022: 7), the downstream sector accounts for 50-80% of the total space-related sales. The infrastructure sector, both public and private, provides 'spacecrafts, launchers and ground segment integrators', 'systems, sub-systems, equipment and components manufacturers', thanks in particular to launch services providers and space agencies (*ibid*.). The service sector consists instead of 'lease or sale of satellite capacity or data, ground support infrastructure manufacturing, ground support infrastructure operations', allowing for the exploitation of 'value added services [...] and consumer equipment and products' (*ibid.*) (see Figure 3).

The role of companies like DiGOS seems to be that of bridging the upstream and the downstream sectors, through the manufacturing of systems, the installation of ground support infrastructures, and a number of ground support operations. The way in which the manufacturing process is carried out, on a close look, is worthy of observation, as the final infrastructure product is more and more the result of a series of parts produced and assembled along global value chains. This is particularly true of the new space economy, which does not rely on the traditional approach of the past.[3]

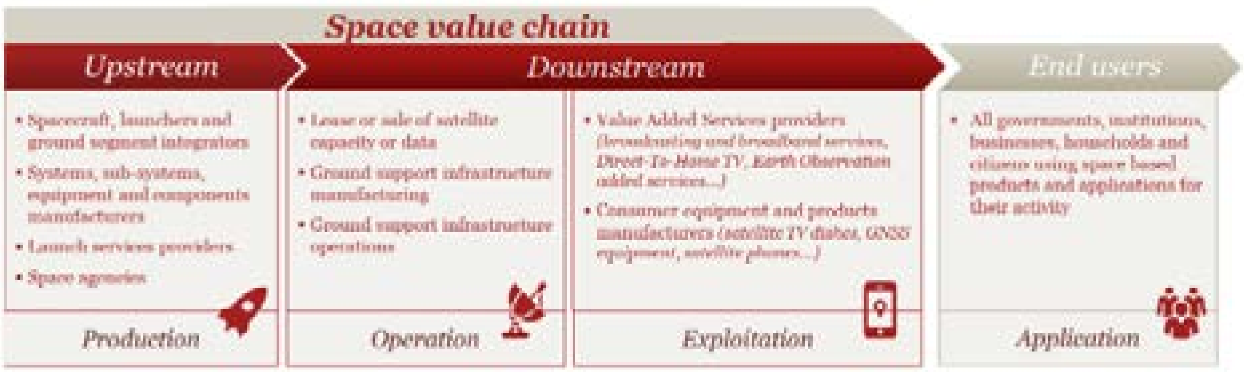

Figure 3. Space value chain: upstream and downstream

Source: European Commission/PwC in Moranta (2022: 7).

The new space economy is likely to have an impact on the global value chain of space products and guaranteeing a cost-efficient and continuing access to every component along the chain should be the prime goal of space agencies and service providers. Mapping the GVC of space products seems of a certain national interest. This holds true in the case of space stations like Izaña-1. The final SLR and SDLR installed by companies like DiGOS work through systems like SCOPE and the RGG that, on their part, are based on lasers. Now, a key component of the laser technology used to fight space debris, among other uses, consists of laser diodes. Mapping their origin may be required to guarantee a good screening and open access to their market.

[3] Following the traditional approach, a new component was initially designed and later produced in small units. If these passed test activities, they were used for space product manufacture. On its part, the new space economy mostly adopts a different approach. A component is designed for market uses and later produced on a large scale. Tests are regularly made on the aftersales market.

Laser diodes: major manufacturers by world region

Diode lasers are semiconductor devices that emit light photons when subjected to an electrical charge.[4] As depicted in Table 1, Europe and North America host the largest number of major producers of laser diodes, followed by Asian firms, mostly located in mainland China, Japan, and Taiwan.

Table 1. Major producers of laser diodes by world area

Region	*Country*	*Company*
Asia	China, Mainland	Daheng New Epoch Technology, Inc., Changchun New Industries Optoelectronics Tech. Co., Ltd.
	Japan	Ushio Inc., Hamamatsu Photonics K.K., Nichia, Sony Semiconductor Solutions, Rohm Co., Ltd.
	Taiwan	Appointech, Inc.
Europe	France	Imagine Optic
	German-speaking Austria and/or Germany	ams-OSRAM AG, Frankfurt Laser Company, SPI Lasers, Laserline GmbH, Sacher Lasertechnik GmbH, Laser Components Germany GmbH, PhotonTec Berlin GmbH, Omicron-Laserage Laserprodukte, Jenoptik AG, Innolume, Toptica Eagleyard
	Ireland	EBLANA Photonics Ltd.
	The Netherlands	Ushio Europe B.V.
	United Kingdom	Edinburgh Instruments Ltd.
North America	Canada	MPB Communications Inc., Egismos Technology Corporation
	United States	OSI Laser Diode, Inc., PRoPhotonix, IPG Photonics Corporation, Thorlabs, Inc., RPMC Laser, Inc., Blue Sky Research, Optilab, LLC., Advanced Photonic Sciences, Cutting Edge Optronics, Inc., Sheaumann Laser, Inc., SemiNex Corporation, Excelitas Technologies Corp., Aerodiode, Thorlabs Inc., U.S. Lasers, Arrow Electronics, Ushio America, Inc.

Source: Metoree (2024).

China, one of the most promising countries in the space race, is still very much dependent on imports of foreign semiconductors, which account for more than $300 billion every year (Brookings Institution, 2021). However, it is worth mentioning that the country seems to be willing to fill the gap in the near future. Indeed, new laser sources are currently being sought for by China. In particular, the country plans to create lasers through particle accelerators specifically aimed at producing advanced semiconductors that will be used, for instance, to develop Artificial Intelligence (AI). China, thus, is likely going to multiply its capacity as semiconductor producer, adding to the 30,000 particle accelerators distributed throughout the world, 97% of which is devoted to the production and commercialization of semiconductors (USEPA, 2023). It must also be observed that the Chinese desire to reinstate Taiwan into the Mainland (see Council on Foreign Relations (CFR), 2023) conceals the aspiration to control a great part of the world's semiconductor supply.

For these reasons, the maintenance of cutting-edge technology in the production of semiconductors, and in particular of laser technology, seems to be of the highest importance for Europe.[5] This could be achieved through the use of new materials along the value chain.[6] Silicon carbide, for instance, is a material made of silica sand and carbon that is increasingly being used in the production of semiconductors. It is in fact ten times faster as a semiconductor than silicon, traditionally used as band-gap semiconductor (see, e.g., EE Times, 2022). Cost-effective and state-of-the-art innovations may be the result, not just of Europe's own effort, but also of international cooperation.

As argued hereafter, India could play a major role in cooperation with the European Union as regards space technologies against debris. A justification for joint efforts would be based on India's demonstrated strengths in software development, systems engineering, cost-effective R&D, and operational experience with large-scale space missions. These capabilities directly complement the software-heavy architecture of

4 Diodes are the nuclear element of a chip or integrated circuit. The band gap of a semiconductor is the energy used to excite electrons between valence and conduction bands.

5 At the time being, Advanced Semiconductor Materials Lithography in the Netherlands is one of the major holders of advanced technology for the production of semiconductors.

6 Laser diodes are made of specific materials which include the following: indium gallium nitride (InGaN), aluminum gallium phosphide (AlGaInP), indium gallium phosphide (InGaP), aluminum gallium indium phosphide (AlGaInP), aluminum gallium arsenide (AlGaAs), indium gallium arsenide (InGaAs) and indium gallium arsenide phosphide (InGaAsP) (see, e.g., EE Times, 2022).

systems such as DiGOS' SCOPE and the integration-oriented nature of satellite-laser-ranging stations. Thus, India appears to be a potential, strategically relevant partner because of its proven excellence in systems integration, algorithmic optimisation, mission engineering, and affordable innovation.

Laser technology: ESA-ISRO cooperation amid geopolitical tensions

The fight against debris adopts a set of systems and technology that paves the way to communication uses, so much vital in daily life, at peace and at war. For instance, DiGOS' products are going to be used by the Galileo Laser Ranging System (GLRS) purposefully meant to improve the accuracy of Galileo's satellite navigation system. The products are also going to be used in Munich and Trauen, Germany, by the Bundeswehr University and the German Aerospace Center in two Optical Ground Stations meant for laser communication. These are just some of the applications exemplifying how laser technology serves communication needs. Lasers will increasingly be used for satellite communication. Major projects are under development for intelligence and surveillance, for instance. Starlink, the European Data Relay System, Backjack by the Defense Advanced Research Projects Agency and Amazon Kuiper are some examples.

Creating international alliances in the space sector seems a fundamental instrument to avoid potential isolation at times in which geopolitical tensions threaten to disrupt GVCs. One such cooperation may come, for instance, from the joint efforts of the European Space Agency (ESA) and the Indian Space Research Organisation (ISRO). The reasons for the European interest in a partnership with India may be justified by at least two factors: the technical knowledge of Indian scientists and the cost effectiveness of operations together with the Indian role as a common interlocutor between major Western and emerging geopolitical centres.

India has a well-established tradition in space cooperation (see Nair, 2023). The first launch of a Nike Apache rocket from Thumba, Kerala, dates back to November 21, 1963, thanks to synergies with the U.S. and the Soviet Union. Over the years, the launch of skyrockets from India was approved and aided by a number of countries. The UN General Assembly, for instance, became a sponsor of Thumba's launches in 1965. The first rockets made in India were licensed by the French Sud Aviation. In the past, India and Germany cooperated for instance in the development of experiments with sounding rockets. Another example worth mentioning is the cooperation with U.S. Ford Aerospace, which built a satellite designed by ISRO.

India has become a promising country in terms of space race (see Mani et al., 2023). In late 1967 the first Indian rockets, propelled by the indigenous Rocket Propellant Plant (RPP), were launched from Thumba and, later on, they were launched from Sriharikota, ISRO's station in East India. Today, Thumba and Sriharikota are still strategic launch centres. Over the years, ISRO has become more and more independent from foreign space products thanks to indigenous firms such as Mishra Dhatu Nigam, Midhani, Andhra Sugars Limited, Hindustan Organic Chemicals Limited, FACT, Oil and Natural Gas Corporation, Hindustan Aeronautics Limited, Godrej, MTAR, etc. (Nair, 2023). India has been capable of developing not only its own rockets, but also its own satellites, mostly for meteorological studies and research, together with propellant fuels and several software. Dr. Sarabhai, one of the masterminds of Indian space activities, strategically pursued leapfrogging to catch up with the most advanced countries in space exploration (Nair, 2023: 72). Leapfrogging, which has been implemented by a few countries to catch up at a faster speed with most developed countries (see Lee, 2023), helped India fulfil a number of goals, including, for instance, the development of indigenous Space Launch Vehicles (SLVs) in the 1970s and 1980s.

The expertise has been matched by competitive costs of space-related activities, making India an attractive partner for foreign public and private actors operating in the sector. The launch of the SRE capsule on January 10, 2017, for instance, attracted the attention of foreign players because of a cost as low as USD 10 million instead of the average USD 100 million needed abroad (Nair, 2023).

> Launching satellites for foreign countries and organisations, selling remote sensing data to them and leasing transponders for private users in India are some activities through which ISRO makes direct income. We are able to launch satellites at a low cost compared to the international market. By the beginning of 1990s, there was a directive that such purely commercial ventures must not be carried out by ISRO directly. Thus, an autonomous company fully owned by the Government of India called Antrix Corporation Private Limited was born on 28 September 1992 [...]. Remote sensing data from Indian satellites is sold to various countries, including the USA. Transponder capacity in satellites is leased for communication, TV broadcasting and for digital connectivity for businesses.
>
> (Nair, 2023)

The Chandrayaan programme, which landed Indian crafts on the Moon between November 14, 2008, and August 23, 2023, are likely the most notable examples of the cost effectiveness and scientific knowledge at ISRO. Such missions have been carried out with success at a very low cost compared to its foreign counterparts like ESA. India became the fourth country to land on the Moon (after China, the Soviet Union, and the United States) and the first ever to reach the lunar south pole.

Indians have also contributed to the research about space debris. The use of lasers, of a pulsed type rather than continuous-wave, to solve the debris problem, has been studied by Indian scientists on various occasions over the last decade (e.g. Thind and Lokesh, 2013). Concerned with debris, the Indian Space Research Organization has created the Directorate for Space Situational Awareness and Management and a project, the Network for Space Objects Tracking and Analysis (NETRA), to spot the presence of debris in space. Anti-debris lasers are not used yet in India, but radars and optical telescopes are employed to track debris. The current radar, known as Multi-Object Tracking Radar (MOTR) is based at Sriharikota, India's launch site in Andhra Pradesh, and detects objects up to 1,000 km. (see Nair, 2023). Compared to other space actors in different parts of the world, India has the strategic advantage of being relatively close to the equator, in the same way as Tenerife in Europe. This makes of India one of the best possible partners in the fight against debris.

Because of its special decade-long relationships with different countries, from Russia to the United States, from France to Germany, India could become an important player in the space sector. As remarked by G. Madhavan Nair, Chairman of ISRO between September 1, 2003, and October 29, 2009, India could serve as an international interlocutor about space debris:

> [w]hen discussing international relations in space, the organization called UN COPUOS needs to be mentioned. Headquartered in Vienna, it meets twice a year [...]. Most of the discussions are centred on the weaponization of space and the danger posed by defunct satellites and other space debris. India could play a major role as a moderator among the differing American and Russian blocs. [...] The international community meets in Paris quite often, and it is the place from where we coordinate with other European countries. ISRO has presence there in the form of the ISRO Technical Liaison Unit (ITLU), which works in association with the Indian embassy.
>
> (Nair, 2023: 268)

India, though –and this holds true for all countries involved in the space race–, has still an uncertain future on the path of international dialogue. So far, for instance, Indian-Sino relations on space matters have been limited. It remains to be understood to what extent China, an emerging player in space exploration, is going to be willing to interact with its foreign counterparts on space issues. The role of India, though, through ISRO, should not just be limited to the still strategic and prestigious role of an international interlocutor. An extension of GVCs in the fight against space debris, for instance, should be positively welcomed and fostered.

Given that India is not a major producer of laser diodes, the cooperation between Europe and India in the development of space technology should distinguish between hardware-critical products (e.g., semiconductor-grade laser diodes), of which the EU has already a certain degree of expertise, and software- and systems-level complementarities, where India provides strong comparative advantages. Such conceptual separation would allow the research agenda to focus on areas where European-Indian synergies are most plausible: automation, sensor-fusion algorithms, ground-station software, and low-cost testing infrastructures.

In spite of the high degree of secretiveness of national space programmes and technologies, Europe and India could mutually benefit from joint synergies in the production of laser-related products and facilities. Europe, through ESA and private companies, is a forerunner in the development and application of such technology, counting on highly skilled personnel and infrastructure. India, through ISRO, is still in an initial study of laser ranging technique, but it counts on a long history of space endeavours achieved at the most competitive price. As members of the Inter-Agency Space Debris Coordination Committee (IADC), ESA and ISRO could actively pursue GVCs in the production of anti-debris laser technologies and infrastructures. Europe and India would mutually benefit from increased skills and reduced production costs.

Actionable recommendations

Building on the previous analysis, several actionable recommendations emerge for the European Space Agency (ESA), European Union policymakers, and international partners such as ISRO. For ESA, a priority should be the establishment of a dedicated laser debris mitigation programme line. This programme should integrate systematic GVC monitoring for laser-related hardware, especially semiconductor-grade diodes, alongside coordinated R&D investments to reduce Europe's dependence on extra-European suppliers. ESA could also expand its existing partnership frameworks to include joint test campaigns, shared simulation environments, and co-developed software architectures with India, ensuring long-term interoperability and lowering duplication of efforts.

For EU policymakers, the analysis highlights the need to treat laser-based debris mitigation not merely as a scientific endeavour but as part of a broader industrial-security strategy. The EU should embed semiconductor-based laser components into the Important Projects of Common European Interest (IPCEI) framework,[7] encouraging risk-sharing and co-investment across member states. Additionally, the Union could create a space supply-chain observatory to monitor vulnerabilities in upstream and downstream components, mapping dependencies and preparing contingency responses to geopolitical disruptions. This observatory should work in tandem with ESA and the OECD Space Forum to align European industrial policy with the requirements of space safety.

For ISRO and international partners, the most effective contribution lies in deepening software-, systems-, and integration-focused collaboration. ISRO could work jointly with ESA to develop automated sensor-fusion algorithms, debris-tracking prediction models, and low-cost test facilities that support rapid prototyping of laser-ranging subsystems. Establishing a bilateral ESA–ISRO task force on space debris and laser

7 The Important Projects of Common European Interest (IPCEI) is an EU framework that allows Member States to jointly fund large, strategic, cross-border projects that are too risky or costly for a single country or company (see European Commission, 2025).

technologies would formalise these efforts and create a platform for mutual training, talent exchange, and coordinated standard-setting in laser-ranging operations. Such a task force would also strengthen India's role as a bridge between Western and emerging space powers in multilateral forums.

Taken together, these recommendations argue for a coordinated, multi-level approach: ESA should reinforce technological depth, the EU should secure industrial resilience, and ISRO should expand its systems-engineering and software contributions. By aligning these efforts, Europe and India can jointly establish a robust, globally relevant architecture for laser-based space-debris mitigation, one capable of sustaining both technological leadership and long-term orbital sustainability.

Conclusion

The exponential increase in skyrocket payloads which has taken place over the last few years shows the booming expansion of the new space economy, i.e. the commercialisation of space-related products and services. As human-made space products are doomed to multiply in the near future, major space actors, both public and private, must inevitably adopt measures to fight debris –from defunct satellites to damaged objects. The European Space Agency (ESA), through the German firm DiGOS, has installed the first Laser Ranging station in Tenerife, Spain, which is specifically built to detect debris and accompany it into the atmosphere, where it ultimately burns up.

Laser technology is likely to become a priority for any actor involved in reducing space pollution, which is a potential source of harm for man-made objects and manned missions in the space. Innovations in laser manufacturing for anti-debris purposes will also be of aid to other applications, such as laser communication among satellites and the Earth. Therefore, mapping the global value chains of this type of technology seems to be of pivotal importance for Europe, which, at present, is one of the most important actors in the space run. Mapping GVCs may provide of use to detect any weaknesses, from supply to power-related, along the chains.

DiGOS proves to be an interesting case of study, as its products –SCOPE and the RGG– and its services –station installations, system checks, etc.– are a bridge between the upstream and the downstream sectors of the space value chain. Relying on COTS parts, namely EEE parts provided by European and overseas firms, DiGOS seems to represent a good case for the exploration of the global value chains in laser products. As it turns out that laser technology is mostly based on laser diodes, a study of their sources and origin becomes imperative for Europe.

Laser diodes are produced by a number of large firms operating in the semiconductor industry. Most competitive firms at present are located in North America, Europe, and some parts of Asia (namely, China, Japan, and Taiwan). The United States appears to be a major producer of semiconductors and, so far, it is a major exporter of these products to other markets, including China. The Asian country, which depends on the imports of chips from the States and other parts of the globe, is now increasingly involved in space exploration programmes of its own, competing with the United States, Europe, Russia and India. For this reason, China is increasingly interested in producing semiconductors by its own, depending to a lesser extent on imports.

To face competition and to keep innovating in laser technology, Europe should seek cooperation with other partners. Cooperation, which could be sought for with the aim of fighting space debris, could be strengthened between the European Space Agency and the Indian Space Research Organisation (ISRO), which seems to be strategic for several reasons. Indeed, over the last decades India has proven to be a good partner on a number of joint projects with the United States, the Soviet Union, France and Germany, to mention the major ones. India has also ratified international treaties like the Outer Space Treaty, which was meant to regulate the peaceful use of the outer space. Its geographical position, close to the equator, makes of India a perfect partner to conduct the fight against debris. Also, Indian scientists have proven to be highly skilled and have carried out extensive research on laser technology. Last but not least, Indian space achievements have been made at very competitive costs.

The rationale for an ESA-ISRO partnership in the fight against debris would rest on Europe's role in the global laser-diode industry, together with India's established record in cost-efficient space operations, software innovation, and mission-integration capability. These attributes make India an attractive partner for co-developing algorithms, control software, data-processing pipelines, and testing infrastructures that underpin the performance of laser-ranging stations. Europe and India could benefit from mutual cooperation to keep the deep-black space green.

References

Álvarez, I., Marin, R., and Quirós, C. (2024). 'The dynamics of digital technologies in the strategies of MNEs', *Industry and Innovation*, online, 1-26.

Baldwin, R. (2016). *The Great Convergence: Information Technology and the New Globalization*. Harvard University Press.

Bousedra, K. (2023). 'Downstream space activities in the new space era: paradigm shift and evaluation challenges', *Space Policy*, 65, online.

Brookings Institution (2021). *Lagging but motivated: the state of Chinas semiconductor industry*, by C.A. Thomas, https://www.brookings.edu/articles/lagging-but-motivated-the-state-of-chinas-semiconductor-industry/

Chaminade, C., Lundvall, B.-Å., and Haneef, S. (Eds) (2019). *Advanced Introduction to National Innovation Systems*. Cheltenham, UK, and Northampton, U.S.: Edward Elgar Publishing.

Council on Foreign Relations (2023). *Confrontation over Taiwan*, Center for Preventive Action, https://www.cfr.org/global-conflict-tracker/conflict/confrontation-over-taiwan
D'Costa, A. (2025). *The Oxford Handbook on the New Space Economy.* Oxford: Oxford University Press.
Defense Intelligence Agency (DIA) (2019). *Report: Challenges to Security in Space.* January 2019, www.dia.mil/Military-Power-Publications
DiGOS (2024). *Laser Stations.* https://digos.eu/satellite-laser-ranging/
Edquist, C. (Ed.) (2005). *Systems of Innovation: Perspectives and Challenges*. London: Routledge. First published in 1997 by A Cassell imprint.
EE Times (2022). *SiC Semiconductors and the Future of the Industry,* by C.D. McGrady, https://www.eetimes.com/sic-semiconductors-and-the-future-of-industry/
Ernst, D. (2009). "A new geography of knowledge in the electronics industry? Asia's role in global innovation networks", *Policy Studies*, 54, 1-84.
ESA (2021). *About Space debris.* https://www.esa.int/Space_Safety/Space_Debris/About_space_debris
ESA (2023). *The latest figures related to space debris.* Darmstadt, Germany: Space Debris Office.
European Commission (2025). *Important Projects of Common European Interest (IPCEI).* https://competition-policy.ec.europa.eu/state-aid/ipcei/approved-ipceis_en
Gereffi, G., Humphrey, J., & Sturgeon, T. (2005). "The governance of global value chains", *Review of International Political Economy*, 12(1), 78-104.
González, O. (2012). *Use of commercial electrical, electronic and electromechanical (EEE) parts in NASAs commercial crew program (CCP)*, NASA/TM-2012-2175518, https://ntrs.nasa.gov/api/citations/20120006039/downloads/20120006039.pdf
Kessler, D. J., Cour-Palais, B.G. (1978). 'Collision frequency of artificial satellites: the creation of a debris belt', *Journal of Geophysical Research*, 83(A6), 2637-2646.
Lee, K. (2019). *The art of economic catch-up. Barriers, detours and leapfrogging in innovation systems*, Cambridge: Cambridge University Press.
Lema, R., Quadros, R., and Hubert, S. (2015). "Reorganizing global value chains and building innovation capabilities in Brazil and Indi", Research Policy, 44(7), 1376-1386.
Lundvall, B.-Å. (Ed.) (1992). *National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning*. Pinter Publishers.
Mani, S., Dadhwal., V.K., & Shaijumon, C.S. (2023). 'India's Space Economy, 2011-12 to 2020-21: Its Size and Structure', *Space Policy*, 64(May).
Mazzucato, M. (2013). *The Entrepreneurial State: Debunking Public vs Private Sector Myths*. Anthem Press.
Moranta, S. (2022). 'The Space Downstream Sector: Challenges for the Emergence of a European Space Economy', Études de *lIfri*, Ifri, March.
Nair, G.M. (2023). *Rocketing through the skies. An eventful life at ISRO*, New Delhi: Rupa Publications India.
NASA (2021). *Objects in Earth orbit including fragmentation debris.* NASA Astromaterials Research & Exploration Science – Orbital Debris Program Office (ODPO), https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv24i4.pdf
Metoree (2024). *Laser Diodes.* https://es.metoree.com/
Morgan Stanley (2024). *Global space economy.* https://www.morganstanley.com/Themes/global-space-economy
OECD (2019). *The Space Economy in Figures. How Space Contributes to the Global Economy*, Paris: OECD.
OECD (2020). *The impacts of Covid-19 on the space industry.* COVID-19 policy notes, Paris: OECD Publishing, https://read.oecd-ilibrary.org/view/?ref=135_135514-gg3eitmwa3&title=The-impacts-of-COVID-19-on-the-space-industry.
OECD (2021). *Space economy for people, planet and prosperity*, Paris: OECD.
OECD (2022). *Earth's Orbits at Risk. The Economics of Space Sustainability*, Paris: OECD Publishing, https://www.oecd.org/sti/inno/space-forum/earth-s-orbits-at-risk-16543990-en.htm
Pietrobelli, C., & Rabellotti, R. (2011). "Global value chains meet innovation systems: Are there learning opportunities for developing countries?", *World Development*, 39(7), 1261-1269.
Stowsky, J. (2004). "Secrets to shield or share? New dilemmas for military R&D policy in the digital age", *Research Policy*, 33(2), 257-269.
Sturgeon, T. (2019). "Upgrading strategies for the digital economy", *Global Strategy Journal*, 11(1), 34-57.
TEDAE (2019). *Sectorial Agenda of the Spanish Space Industry.* Madrid: TEDAE.
TEDAE (2020). *Anuario del Sector Espacial en España 2019.* Madrid: TEDAE.
Thind, M.K., & Lokesh, C. (2013). 'Removal of Space Debris Using Laser', *Advances in Aerospace Science and Applications*, 3(2), 107-112.
USEPA (2023). *Particle accelerators and radiation research.* United States Environmental Protection Agency, https://www.epa.gov/radtown/particle-accelerators-and-radiation-research#:~:text=According%20to%20the%20International%20Atomic,a%20component%20of%20computer%20chips
Valiño Castro, A., Coz Fernández, J.R., & Acosta Ortega, S. (2019). *Revista General de Marina*, July, 73-82.
Weinzierl, M. and Rosseau, B. (2025). Space to grow. Unlocking the final economic frontier. Boston (MA): Harvard University Press.

Selected bibliography

Back Impallomeni, E. (1983). *Spazio Cosmico e Corpi Celesti nell'Ordinamento Internazionale.* Padova: CEDAM.

Baslar, K. (1998). *The Concept of the Common Heritage of Mankind in International Law.* The Hague/Boston/London: Nijhoff.

Consejo de Europa (2016a). *Competitiveness Council, mayo de 2016. Principales resultados del Consejo de la Unión Europea sobre la Política del Espacio y el Mercado Interno*, Council of the European Union, https://www.consilium.europa.eu/es/meetings/ compet/2016/05/26-27/

Consejo de Europa (2016b). *Estrategia del Espacio de la UE, 2016*, Council of the European Union, https://www. consilium.europa.eu/es/meetings/compet/2016/11/28-29/

Consejo de Europa (2020a). *Cronología de la Política Espacial de la UE*, Council of the European Union.

Consejo de Europa (2020b). *Política espacial de la UE para una economía sostenible,* Council of the European Union, https://www.consilium.europa.eu/es/press/press-releases/2020/06/04/space-policy-for-a-sustainable-economy-council-adopts-conclusions/

Consejo de Europa (2020c). *Política espacial de la UE,* Council of the European Union, https://www.consilium.europa.eu/es/policies/eu-space-programmes

Consejo de Europa (2020d). *Long-term EU budget 2021- 2027. EU Leaders agree the long-term budget for 2021-2027 and the recovery plan*, European Union Council, https://www.consilium.europa.eu/en/policies/the-eu-budget/long-term-eubudget-2021-2027/

Copernicus (2020). *Copernicus - The European Earth Observation Programme.* European Commission, https://ec.europa.eu/growth/sectors/space/copernicus_en.

Coz Fernández, J.R., & Valiño Castro, A. (2021). 'The industrial and economic impact of space programs in Europe in the post-Covid-19: its implications for industrial policy', *Revista de Economía Industrial. Industrial Economy Magazine*, Monograph 420.

Desaussure, H. (1992). 'The freedom of outer space and their maritime antecedents', in Jasentuljiana, N. (Ed.) *Space Law: Development and Scope*, Westport, CT: Praeger.

Dreyfuss, J. (2020). 'Start-ups join Google, SpaceX and OneWeb to bring new technologies to space', January 12, Cnbc.com.

Egnos (2020). *The European Geostationary Navigation Overlay Service (EGNOS).* European Global Navigation Satellite System Agency (GSA), https://www.gsa.europa.eu/egnos/what-egnos

Esa (2017). '500 new European companies from space', *Technology Transfer*, 18 September, http://m.esa.int/Our_Activities/Space_Engineering_Technology/TTP2/500_new_European_co mpanies_from_space (accessed on 14 June 2018).

Esa (2020a). *ESA Technology Transfer Programme*, Esa.int.

Esa (2020b). *Sobre la ESA.* https://www.esa.int/Space_in_Member_States/Spain/Datos_de_la_ESA

Esa Council (2019a). 'Resolution on space: the five dimensions of space 4.0, adopted on 28 November 2019 by the ESA Council', ESA/C-M/CCLXXXVI/Res.1 (Final).

Esa Council (2019b). 'Resolution on the Scientific Programme ad the Basic Activities for Space19+. Level of Resources for 2020 - 2024, adopted on 28 November 2019 by the ESA Council', ESA/C-M/CCLXXXVI/Res.2 (Final).

Esa Council (2019c). 'Resolution on ESA programmes: addressing the challenges ahead, adopted on 28 November 2019 by the ESA Council', ESA/C-M/CCLXXXVI/Res.3.

Esa-Sdo (2020). *ESA's Annual Space Environment Report 2020*, ESA Space Debris Office.

Galileo (2020). *What is Galileo.* ESA, http:// www.esa.int/Applications/Navigation/Galileo/What_is_Galileo.

Govsatcom (2020). 'The Governmental Satellite Communications (GOVSATCOM)', European Defense Agency (EDA), https://www.eda.europa. eu/what-we-do/activities/activities-search/governmental-satellite-communications-(govsatcom).

Highfill, T., Georgi, P., & Dubria, D. (2019). 'Measuring the Value of the U.S. Space Economy', *The Journal of the US Bureau of Economic Analysis (BEA)*, December 2019, 99(12), 1-7, https://www.consilium.europa.eu/es/policies/eu-space-programmes/timeline/

Hobe, S. (2007). 'Adequacy of the current legal and regulatory framework relating to the extraction and appropriation of natural resources in outer space', *Journal of Space Law*, 32: 115-130.

Hobe, S. (2013). 'Moon agreement future perspectives', in Hobe, S., Schmidt-Tedd, B., and Schrogl, K.-U. (eds.) *Cologne Commentary on Space Law (CoCoSL)*, Vol. II, Cologne: Carl Heymanns Verlag, 423-426.

Iavicoli, V. (2015). 'The legal regime of outer space in light of the Law of the Sea', in S. Aricò (ed.) *Ocean Sustainability in the 21st Century*, Cambridge: Cambridge University Press, 249-274.

IISS (2019). *The Military Balance 2019.* International Institute for Strategic Studies. London UK.

IISS (2020). *The Military Balance 2020.* International Institute for Strategic Studies. London UK.

Kerrest, A. (2004a). 'Exploitation of the resources of the high seas and Antarctica: Lesson for the Moon?', Issues in IISL/ECSL Space Law Symposium 2004 on New Developments and the Legal Framework Covering the Exploitation of the Resources of the Moon (United Nations Doc. A/AC.105/C.2/2004/CPR.11, 1 April 2004), 33-38.

Kopal, V. (1992). 'Evolution of the doctrine of space law', in Jasentuliyana, N. (ed.). *Space Law: Development and Scope*, Westport, CT: Praeger, 17-32.

Luxembourg Space Agency (2020). *Luxembourg backs space technology venture capital fund*, Press release, January 16.

Marchisio, S. (2012). 'The legal dimension of the sustainability of outer space activities', in *Outer Space Activities: International Legal Aspects*, X Annual All-Russian Scientific Conference on Current Problems of Modern International Law, commemorating Professor Igor P. Blischenko. Abashidze, A., Zhukov, G., and Solntsev, A. (eds.), April 13-14, Moscow: PFUR, 157-177.

Marti Fluxá, R. (2020). 'El Espacio, Inspiración y Tecnología', *Anuario del Sector Espacial en España 2019*, Madrid: TEDAE, 4-5.

Martínez, I. (2019). *La quinta revolución industrial. Cómo la comercialización del espacio se convertirá en la mayor expansión industrial del siglo XXI.* Barcelona: Ediciones Deusto.

Mayo Muñiz, L. (2017). 'La industria nacional del sector aeroespacial', *Cuadernos de Estrategia*, 192, 185-226.

OECD (2007). *The Space Economy at a Glance 2007.* Paris: OECD Publishing.

OECD (2016). *Space and Innovation.* Paris: OECD Publishing, http://dx.doi.org/10.1787/9789264264014-en

OECD (2019). 'Remedying the gender gap in a dynamic space sector', in *The Space Economy in Figures: How Space Contributes to the Global Economy*, Paris: OECD Publishing, https://dx.doi.org/10.1787/9405a5a2-en

OECD (2023). *The Space Economy in Figures. Responding to Global Challenges.* Paris: OECD Publishing. https://www.oecd-ilibrary.org/science-and-technology/the-space-economy-in-figures_fa5494aa-en

Olivari, M., Jolly, C., & Undseth, M. (2021). 'Space technology transfers and their commercialisation'. *OECD Science, Technology and Industry Policy Papers*, 116, Paris: OECD Publishing, https://dx.doi.org/10.1787/0e78ff9f-en

Peterson, M. (1997). 'The use of analogies in developing outer space law', *International Organization*, 51 (2), 254-274.

UNDP (2020). *Objetivos de Desarrollo Sostenible.* https://www.undp.org/content/undp/es/home/sustainable-development-goals.html

Schneider, P. (2018). *Goldrausch im All.* München: Finanzbuch Verlag.

Space Foundation (2020). *Annual Report 2019*, Washington, D.C., USA.

SSA (2020). *Space Situational Awareness - SSA.* https://www.esa.int/About_Us/ESAC/Space_Situational_Awareness_-_SSA

Su, J. (2017). 'Legality of unilateral exploitation of space resources under international law', *International and Comparative Law Quarterly*, 66 (4), 991-1008.

Tuerk, H. (2004). 'The negotiation of the Moon Agreement', in *Space Law Symposium 2009*, 30th Anniversary of the "Moon Agreement": Retrospect and Prospect (available at www.unoosa.org/pdf/pres/lsc2009/symp00.pdf, last visited on 6 November 2014), 491-499.

UCSUSA (2020). *Union of Concerned Scientists – UCS Satellite Database, https://www.ucsusa.org/resources/satellite-database.*

UE (2019). *proposal by the European Parliament and Council*, Interinstitutional File 2018/0236 (COD), Brussels, April 12.

Undseth, M., Jolly, C., & Olivari, M. (2020). 'Space sustainability: the economics of space debris in perspective', *OECD Science, Technology and Industry Policy Papers*, 87, Paris: OECD Publishing, https://dx.doi.org/10.1787/a339de43-en