ESPI

European Space
Policy Institute

ESPI Yearbook 2021

SPACE POLICIES, ISSUES AND TRENDS

Report:
Title: "ESPI Yearbook 2021 – Space policies, issues and trends"
Published: July 2022
ISSN: 2218-0931 (print) • 2076-6688 (online)

Editor and publisher:
European Space Policy Institute (ESPI)
Schwarzenbergplatz 6 • 1030 Vienna • Austria
Phone: +43 1 718 11 18 -0
E-Mail: office@espi.or.at
Website: www.espi.or.at

Cover design: www.rainfall.ro
Internal layout design: www.copylot.at

Table of Contents

Foreword ....

About ESPI Space Sector Watch ....

1 Policy & Programmes 1

1.1 Space Policy Highlights and Trends 1

1.1.1 ESA and EU seek new impetus for European space activities 1

1.1.2 New realities for international cooperation in human spaceflight & space exploration .. 7

1.1.3 Governments eager to boost space commercialisation and business development 9

1.1.4 STM and responsible behaviour: priorities for the global space sustainability agenda 12

1.1.5 G7 and G20: space issues rose in the high-level geopolitical agenda 15

1.1.6 Space defence: expanding international partnerships amidst evolving doctrines 17

1.1.7 New developments in national space policy and space law 20

1.1.8 Other outstanding policy developments 23

1.2 Major Space Programme Developments 28

1.2.1 Access to space 28

1.2.2 Application programmes 34

1.2.3 Space science and exploration programmes 44

2 Industry & Innovation 52

2.1 Space Industry Highlights and Trends 52

2.1.1 Defying the odds: new steps in space tourism 52

2.1.2 Cloud companies affirming their role in the space sector 57

2.1.3 Unprecedented development of communication constellations 66

2.1.4 Notable developments in quantum encryption for protecting communications 75

2.1.5 Increasing development of in-orbit operation technologies 80

2.1.6 Developments and demonstrations of new and improved propulsion technologies... 85

2.2 Other Outstanding Developments 91

2.2.1 Nuclear power sources enabling faster & longer missions deeper into the universe ... 91

2.2.2 Industrial and innovative developments for a responsible space sector 94

2.2.3 The interwoven development of micro launchers and spaceports in Europe 97

2.2.4 Promises of fully reprogrammable satellites 100

2.2.5 Rising interest in commercial SIGINT solutions 102

2.2.6 Increased relevance of SAR technologies and services ... 105
2.2.7 Progress in habitats and life support for exploration ... 108

3 GLOBAL SPACE ECONOMY ... 110
3.1 Overview and Main Indicators ... 110
3.1.1 Commercial satellites and launches ... 114
3.1.2 Commercial launches ... 115
3.1.3 Commercial satellite manufacturing ... 116
3.1.4 Ground stations and equipment ... 117
3.1.5 Space products and services ... 118
3.1.6 Space insurance sector ... 120
3.2 Institutional Space Budgets ... 123
3.2.1 Global overview and evolution ... 124
3.2.2 Space budget per country ... 126
3.3 European Space Budgets ... 131
3.3.1 Consolidated European space budget ... 131
3.3.2 National space budgets ... 132
3.3.3 European Space Agency ... 133
3.3.4 European Union ... 136
3.3.5 EUMETSAT ... 140
3.4 European Space Economy Statistics ... 142
3.4.1 European space manufacturing industry ... 142
3.4.2 European remote sensing industry insights ... 146
3.4.3 European GNSS and EO sector ... 148
3.5 Global Private Space Investment ... 150
3.5.1 European private space investment ... 150
3.5.2 European investment in a global context ... 151
3.5.3 Regional differences in investment ... 153

4 LAUNCHES & SATELLITES ... 155
4.1 Global Space Activity Evolution 2000-2021 ... 155
4.1.1 Launch activity evolution by country ... 156
4.1.2 Spacecraft orbit and mass ... 158
4.1.3 Space missions and markets ... 161
4.1.4 Spacecraft manufacturing and procurement by country ... 165

4.2 **Global Space Activity in 2021** **171**

4.2.1 Launch activity in 2021 171

4.2.2 Spacecraft launched in 2021: customers and manufacturers 174

4.2.3 Spacecraft launched in 2021: missions and markets 175

4.3 **Launch Log and Activity Highlights** **177**

4.3.1 ESPI launch log 2021 177

4.3.2 ESPI Database definitions 189

4.4 **Space Activity Highlights in 2021** **190**

AUTHORS **196**

ABOUT ESPI **198**

Foreword

Dear members and readers,

I am happy and proud to introduce to you this 2021 edition of our ESPI Yearbook. This long-established annual publication has gained along the years a solid reputation of being a reliable source of information and a useful tool for monitoring the development of the European space policy in a global context.

With this new issue we tried to better meet the expectations of our readers and we paid substantial efforts to ensure a consistent overall coverage of the 2021 space activities and business.

We do not pretend establishing with this yearbook THE reference document describing and analysing the evolution of the global space sector. Some other publications have such ambition, but none of them has such a strong and permanent focus on the situation of Europe. And this is exactly the purpose we pursue with this publication, highlighting the position of Europe on the space international stage and putting forward the trends at work that deserve being considered in the further development of the European space policy.

This approach builds on the permanent "Space Sector Watch" effort that we initiated three years ago with our new ESPI Insights monthly publication structured along four major areas of interest to our members:

- Policy & Programmes, where we report on the latest developments of space public, governmental and institutional affairs,
- Industry & Innovation, where we gather prominent announcements related to space industry evolutions worldwide and technology's most promising progress,
- Economy & Business, which is based on a collection of indicators relevant to the global space economy and markets,
- Launches & Satellites, which presents some exploitations of our in-house databases related to launch site activities worldwide over the past year.

2021 has been quite remarkable regarding the development of space policy-related matters with:

- Adoption of the EU Space Programme Regulation and creation of EUSPA.
- New realities for international cooperation in human spaceflight and space exploration.
- Changes in Europe's institutional space leadership,
- Notable developments in international norms creation regarding space sustainability.
- New developments in approaches to space and defence with a growing presence of space in the global defence agendas,

Regarding space industry, 2021 has also been quite dense with the advent of major initiatives that might have disruptive consequences in the medium term:

- The emergence of space tourism.
- Cloud Companies affirming their role in the space sector.
- Unprecedented development of communication constellations.
- Increasing Maturity of In-Orbit Operation Technologies.
- Developments in quantum encryption for protecting communications.

I hope you will enjoy going through this publication as much as we did in preparing it and that you will share with us the need to fill-in a gap with solid Europe-centered socio-economic indicators to support the further development of the European space policy in order to best foster effectiveness of public expenditures, business development and investment.

I would be more than happy to receive feedback on ways we could further tailor this publication to your needs.

In the meantime, I remain,

Sincerely yours,

Jean-Jacques Tortora

Director of the European Space Policy Institute

ABOUT ESPI SPACE SECTOR WATCH

As part of its mission, the European Space Policy Institute (ESPI) continuously monitors international space affairs and tracks a selection of indicators in proprietary databases. The ESPI Yearbook series is part of this broader ESPI Space Sector Watch that includes complementary publications.

ESPI Yearbook

The ESPI Yearbook is an annual publication of the providing an overview of major developments and trends in space policy, industry, programmes, economy and overall worldwide space sector activity over the year.

The Yearbook is organised in four complementary chapters:

- **Policy & Programmes:** space policy highlights and trends, major space programme developments
- **Industry & Innovation:** launcher and satellite industry developments, selected company infosheets
- **Economy & Business:** global and European space economy indicators (turnover, budgets, investment)
- **Launches & Satellites:** space activity statistics, mission highlights and ESPI launch log

The ESPI Yearbook does not aim to be comprehensive but rather to provide useful information, data and insights on a selection of topics expected to shape the future of the global and European space sector.

ESPI Yearbook 2021 is the 3rd edition of the new ESPI Yearbook series, available for free on ESPI website. Previous editions are available in eBook and Hardcover format on Springer website.

ESPI Insights

ESPI Insights is a monthly overview of major developments in the global space sector. The publication provides a digest of top space news and useful links to official documents, public reports, web articles or conference websites.

The ESPI Insights series was designed to be complementary to the ESPI Yearbook series and both series follow the same structure.

You can sign up to ESPI Newsletter in ESPI website to receive ESPI Insights directly in your mailbox every month. All previous editions are also available for free on ESPI website.

ESPI Executive Briefs

ESPI Executive Briefs are short papers published every month that provide the views of the Institute on outstanding space policy topics.

Recent topics include for example:

- The urgent need for sustainable EU-UK relations in space (ESPI Brief 58, June 2022)
- The War in Ukraine and the European Space Sector (ESPI Brief 57, May 2022)
- ESA Accelerators: challenges and opportunities (ESPI Brief 56, April 2022)

All ESPI Executive Briefs are available for free on ESPI website.

1 Policy & Programmes

1.1 Space Policy Highlights and Trends

1.1.1 ESA and EU seek new impetus for European space activities

In January 2021, the **13th European Space Conference** in Brussels brought together European space stakeholders, including high-level EU executives, whose speeches testified the increasing ambitions on **accelerating European investment and competitiveness in the global space sector,** as well as to guarantee Europe´s strategic autonomy.

During the year, both the EU and ESA have unveiled new initiatives nested in a common objective to foster new ambitions for Europe. The year was marked by several major developments including, among others, the adoption of the EU Space Programme Regulation and official establishment of EUSPA, the release of ESA Agenda 2025, the endorsement of the new Financial Framework Partnership Agreement (FFPA), the launch of the EU secure connectivity initiative, and the preparation of ESA Accelerators and Inspirators. Together, these developments underline the willingness of European institutions to raise the level of ambition for space in Europe and to pave the way for a new European approach to space.

Adoption of the EU Space Programme Regulation and creation of EUSPA

On January 1st, the EU Regulation establishing the **EU space programme for the period 2021-2027** entered into force after a lengthy trilateral negotiation process between the European Parliament, the Council of the European Union and the European Commission.

The regulation follows the new **EU Space Programme Multiannual Financial Framework (MFF) 2021-2027**, which was agreed upon in December 2020. The MFF secured a €14.8 billion envelope for the EU space programmes, confirming the important role that space would play for the next 7 years in Europe.[1] The overall space envelope has risen in comparison to the previous MFF 2014-2020 (€11.1 billion, current), underlining a growing interest and investment of the EU in the space sector.

The EU Space Programme created a single programme, comprising Galileo/EGNOS, Copernicus and SSA/GOVSATCOM, with the aim to secure EU leadership in space activities, foster innovative industries, safeguard autonomous access to space and simplify governance.

EUSPA logo (Credit: EUSPA website)

The Space Programme regulation also formally transformed the former European GNSS Agency (GSA) into the **EU Space Programme Agency (EUSPA).** The regulation enlarges the responsibilities previously held by the GSA to all components of the EU Space Programme. Among the new responsibilities, EUSPA will be tasked with managing the increasing exploitation of EU's space-enabled services, with a focus on Copernicus, Galileo and EGNOS and it will be responsible, with collaborating Member States, to coordinate user-related aspects linked to the implementation of GOVSATCOM. EUSPA was

[1] Council adopts position on €14.8 billion EU space programme for 2021-2027, Council of the Eu, 2021

officially created on May 12th, 2021 and will remain operational beyond the 7-year framework of the Regulation.

New EU initiatives to foster investment and entrepreneurship

In 2021, several initiatives have been established to further foster the New Space sector. During Thierry Breton's speech at the 13th European Space Conference, the Commissioner highlighted that the EU Space Programme is complemented by the launch of the €1 billion **Competitive Space Start-ups for Innovation (CASSINI) initiative** to boost European start-ups in the space sector. As part of the InvestEU programme, CASSINI was created in partnership with the European Investment Bank (EIB) and the European Investment Fund (EIF). As a successor to the InnovFin space equity pilot, the initiative intends to make the EU an anchor customer for European space start-ups as well as an essential promoter of their growth through an acceleration programme.[2]

Officials from the European Commission, the EIB and EIF signed the establishment of the CASSINI in January 2022. The initiative will be managed by the Directorate-General for Defence Industry and Space. Furthermore, the Horizon Europe research and innovation funding programme was established in April 2021, with a budget of €86.1 billion in current prices for the period of 2021-2027. The programme has a component dedicated to space-related projects, under Pillar 2 "Global Challenges and European industrial competitiveness" within its Cluster 4 denominated "Digital, Industry and Space".[3]

Under the umbrella of Horizon Europe, the European Commission carried out its first ever direct equity investment in 42 highly innovative European start-ups through the **European Innovation Council (EIC) Fund** (EIC) in March 2021. EIC has a budget of €10 billion (current prices) for 2021-2027. This initiative, established, provides blended finance to start-ups and SMEs, and small mid-caps.[4] The 2022 EIC Programme establishes a budget of €1.7 billion, including **EIC Accelerator** (€1.16 billion), **EIC Pathfinder** (€350 million), and **EIC Prizes**.

EU Secure Connectivity Initiative

Over the last years, the EU has shown a growing interest in playing a more active role in the domain of secure space communication. Following preparatory studies and activities, a new component named GOVSATCOM was included in the EU Space Programme to address user needs for secure and cost-effective governmental satellite communication.

The **Action Plan on synergies between civil, defence and space industries** initiated the development work on a new EU space-based global secure communications system.[5] The initiative aims to develop a new multi-orbit connectivity system to complement GOVSATCOM preliminary services. The goal of the system is to provide an integrated, secure, autonomous and cost-effective governmental connectivity to support the protection of critical infrastructures, external actions and crisis management, maritime and air space surveillance and more, and to enable high-speed broadband availability throughout Europe. The initiative would also promote innovative quantum cryptography technologies in relation with the EuroQCI (Quantum Communication Infrastructure) initiative.

After a call for tenders for the execution of a preparatory study, a consortium of nine European companies (gathering major actors for a unique bid) was awarded a €7.1 million contract in

[2] Europe can become an innovative space technology hub, says Thierry Breton, The parliament Magazine, 2021
[3] European Commission, Space Research and Innovation (available at: https://ec.europa.eu/defence-industry-space/eu-space-policy/space-research-and-innovation_en)
[4] European Innovation Council Fund: first equity investments of €178 million in breakthrough innovations, EC, 2021
[5] Action Plan on synergies between civil, defence and space industries (COM/2021/70 final)

December 2020. The study has been led by established leaders of the European space industry such as Eutelsat, SES, Airbus and Thales Alenia Space. In August 2021, the EC published the Inception Impact Assessment and opened a public consultation for the roadmap of the EU space-based secure connectivity initiative. 13 stakeholders provided comments.[6]

Later in the year, European Commissioner Thierry Breton called for a **new study led by start-ups and small companies** that are part of the "**European New Space ecosystem**", to explore potentially more innovative solutions. Two contracts, each worth €1.4 million, were subsequently awarded to:

- The New Symphonie consortium co-led by UnseenLabs and Euroconsult, including 22 companies in total (e.g. AVIO, Anywaves, Exolaunch, Exotrail,Loft Orbital…),[7]
- The UN:IO consortium, co-led by Reflex Aerospace, Mynaric and Isar Aerospace.[8]

In October 2021, the Draft Impact Assessment Report was submitted to the Regulatory Scrutiny Board and received a negative opinion in November 2021. The impact assessment was resubmitted by the Commission in December 2021. Notwithstanding the subsequent negative opinion by the Board in January 2022, the European Commission realised the document Proposal for a Regulation establishing the Union Secure Connectivity Programme for the period 2022-2027 (accompanied by the executive summary of the impact assessment report) in February 2022.[9]

On April 2022, the European Parliament Committee on Budgets released a **draft opinion on the Secure Connectivity Programme (2023-2027)** for the EP Committee on Industry, Research and Energy.[10] The Committee welcomed the new initiative, while highlighting that funding from other programmes should not be cut, reduced or redeployed to this new initiative.

The main features include,

- Multi-orbital, benefiting and using assets in Europe,
- Integrating military needs,
- Improving and expanding the capabilities and services of EU Space Programme components,
- Governance and eligibility conditions to avoid any dependencies on third parties,
- Expertise of EU industries, including New Space,
- Allow connectivity over geographic areas of strategic interest (Africa, Arctic).

The EU is planning to start building an EU space-based global secure connectivity system in 2022. The initiative would represent a new pillar in the EU space programme, complementing Galileo/EGNOS satellite navigation systems and the Copernicus EO system, to further establish the EU in the space telecommunication domain and ensure that the EU maintains its global space leadership.

Increased focus on safety, security and defence in EU space policy

2021 has been a worthwhile year in terms new additional policy instruments dealing with aspects related to safety, sustainability and security.

---

[6] EU space policy - space-based secure connectivity initiative, EC, 2021
[7] New Symphonie takes collaborative approach to European Commission call for connectivity, Euroconsult, 2021
[8] EU selects 2nd New Space consortium for constellation study as established-space group divides in two after conflicts, Space Intel Report, 2021 (grant agreement no DEFIS/2021/OP/0005/2).
[9] European Commission, Proposal for a REGULATION establishing the Union Secure Connectivity Programme for the period 2022-2027
[10] Draft opinion on the Secure Connectivity Programme (2023-2027)

In February, the EC published **"Action Plan on synergies between civil, defence and space industries",** aiming to enhance Europe's technological edge and support its industrial base through:[11]

- Enhancing the synergies between EU programmes to increase their added value,
- Promoting the value of spin-offs stemming from EU funding in R&D,
- Assisting the creation of spin-ins from the civil industry to the defence and space industries, in particular for civil applications that require low technology readiness levels.

In the Action Plan the European Commission presented an **EU strategy for STM, alongside space-based global secure connectivity system and EU drone technologies** to be the three forthcoming flagship projects.

The Action Plan also notably highlights the role the **European Defence Fund (EDF)** will play to support disruptive technologies. The European Commission (formally) launched the EDF in June 2021 with a budget of €7.95 billion for the 2021-2027 period. Among other topics, the initial 23 EDF calls for proposals indicated support to two space-related themes with overall estimated budget of €50 million:

- Space and ground-based navigation warfare (NAVWAR) surveillance (Development), and
- European protected waveform and accompanying technologies for resilient satellite communications against jamming (Development).[12]

In March, the EC published the **2021 DG DEFIS Management Plan,** acknowledging the overarching political priorities of the European Commission (green, digital, stronger Europe). The document also sets out the 10 main priorities of the DG for 2021, which chiefly include objectives related to the adoption of the EU Space Programme, the deployment of new initiatives such as the European Defence Fund, the GOVSATCOM component and new support mechanisms for space innovation and entrepreneurship.

In February 2022, in the occasion of the informal EU Competitive Council Meeting on Space, followed by an ESA Council Meeting at the ministerial level, the European Commission adopted a space and defence package, including:

- The **Proposal for a Regulation establishing the Union Secure Connectivity Programme** for the period 2023-2027; and
- A **Joint Communication on Space Traffic Management**, called **"**An EU Approach for Space Traffic Management - An EU contribution addressing a global challenge**"** (non-legislative, with EU's HRVP) to outline future EU efforts in the increasingly critical policy domain of STM.

Finally, in March 2022, the Council of the EU approved the Strategic Compass. The document outlines a plan to strengthen the security and defence policy of the EU by 2030 and sets out concrete priority actions in four work strands: act, secure, invest and partner.

New ESA DG and a new high-level Agenda for ESA

Starting from March 2021, **Josef Aschbacher** took over the leadership of ESA as the **new Director-General** for a period of 4 years.[13] On April 7th, the new DG presented the **ESA Agenda 2025** outlining the main short-term objectives and challenges for ESA in the next years. The document is a short-

[11] EU industry: Commission takes action to improve synergies between civil, defence and space industries, EC, 2021
[12] Factsheet on EDF calls 2021, European Commission, 2021
[13] ESA Council appoints Josef Aschbacher as next ESA Director General, ESA, 2020

term roadmap with long-term implications, highlighting the main objectives that the agency will prioritise during Joseph Aschbacher's mandate in the next four years: [14]

1. **Strengthening ESA-EU relations**
2. **Boosting space commercialisation for a green and digital Europe**
3. **Developing space for safety and security**
4. **Addressing critical programme challenge**
5. **Completing the internal transformation of ESA**

ESA's DG Josef Aschbacher presenting Agenda 2025 (Credit: ESA / V. Stefanelli)

In this context, ESA has reorganised its Directorates on Procurement and Industrial Policy into a Directorate on "Commercialisation, Industry and Procurement (D/CIP)". The new organisation aims to support and reinforce the objectives that were set in the ESA Agenda 2025 with a particular emphasis on the priorities related to the goal of boosting space commercialization highlighted in the document. Starting from November, Géraldine Naja was appointed as new Director of Commercialisation Industry & Procurement.

In addition, ESA's Agenda 2025 outlines a clear roadmap to reinforce ESA-EU relations centered around two priorities: establishing a high-level political dialogue to define a common vision for Europe in space and developing a concrete proposal to strengthen the current cooperation model. In particular, the agenda proposes to organise a European Space Summit in 2022, gathering top European decision-makers to define Europe's ambition in space for the next decade. On the 16th of February 2022, the Space Summit was held in Toulouse, France.[15] During the Summit, ESA DG was mandated by ministers to initiate a discussion on a human exploration "inspirator".

High-Level Advisory Board calls for new Accelerators and Inspirators

In the summer 2021, at the request of ESA DG, a High-level Advisory Group convened to discuss ways to accelerate the use of space in Europe. In its report, this expert group recommended[16] ESA to adopt a new approach, called "Accelerators", to address urgent and unprecedented social, economic and security challenges. Following this, three Accelerators were identified:

- **Accelerator 1 - Space for a Green Future**, using advanced space data, science & technology for sustainable life on Earth, including the development of digital twins of our planet to support society and decision makers to reach carbon neutrality by 2050.
- **Accelerator 2 - Rapid and Resilient Crisis Response**, for enabling security stakeholders to ensure rapid provision of information, hence allowing quick response to crises facing Europe.
- **Accelerator 3 - Protection of Space Assets**, to ensure resilient availability and functioning of space infrastructure on which Europe's economy and society relies for day-to-day life.It is envisioned that these Accelerators will be implemented through a joint architecture and cooperative approach (with a strong user engagement), and their objective is to strengthen European leadership in their areas of action as well as to benefit society and the economy in Europe.

[14] Introducing ESA Agenda 2025, ESA, 2021
[15] N° 4–2022: Decisions from the 2022 Space Summit, ESA, 2022
[16] HIGH-LEVEL ADVISORY GROUP ON ACCELERATING THE USE OF SPACE IN EUROPE, Final report (October 2021)

This approach was endorsed by ESA Member States during an Inter-ministerial Meeting in November 2021, which resulted in the unanimous adoption of a **Resolution called "Matosinhos Manifesto**".[17]

In addition to accelerators, ESA Council also noted that European leadership in science, technology development and inspiration could be reinforced in particular by 'Inspirators', such as an icy moon sample return mission and human space exploration.[18]

EU and ESA sign a new seven-year Financial Framework Partnership Agreement

A joint letter sent to Member States by EU Commissioner Thierry Breton and ESA DG Josef Aschbacher in March 2021 outlined a shared political willingness from ESA and EU to reinforce their relationship.[19]

On June 22nd, the **EU and ESA signed a new seven-year FFPA** that will govern the relationship between the two institutions throughout the 2021-2027 MFF, including with the newly created EUSPA. Since the first Framework Agreement in 2004, which drew the legal basis for cooperation between the EU and ESA, the FFPA has laid out the principles for the financial and administrative cooperation between the two institutions. It specifies the responsibilities and the sharing of costs for EU flagship programmes.[20]

The **EC is set to delegate approx. €9 billion to ESA** in the framework of the FFPA, in particular for activities concerning the EU Space Programme for which ESA remains the prime contractor. Specifically, the FFPA gives a clearer oversight over the governance of the EU's Galileo, Copernicus and EGNOS and supports new initiatives in the fields of space commercialisation, secure connectivity and R&D.

Signing ceremony of the new EU-ESA Financial Framework Partnership Agreement (Credit: ESA)

ESA and EDA seek to further collaborate to protect critical space infrastructure

In October 2021, ESA and the European Defence Agency (EDA) agreed to deepen their cooperation in cyber resilience and security to strengthen Europe's capacity to protect critical space systems and networks.[21] ESA and EDA will continue to share information and capabilities, enhance cyber-resilience training, facilitate access to expertise, and infrastructure, and expand cooperation with other key European actors such as the EC, the External Action Service (EEAS), the EU Satellite Centre, EU Agency for Cybersecurity (ENISA), or the European Cybersecurity Competence Centre and Network.

[17] Council Resolution on "Accelerating the Use of Space in Europe (ESA/C(2021)176), ESA, 2021
[18] Ibid.
[19] Messrs Breton and Aschbacher want to move forward with EU-ESA cooperation, agence Europe, 2021
[20] ESA and EU celebrate a fresh start for space in Europe, ESA, 2021
[21] EDA and ESA deepen cooperation on cyber resilience, EDA, 2021

1.1.2 New realities for international cooperation in human spaceflight & space exploration

A great deal of space-related developments in 2021 concerned human spaceflight and space exploration, thus testifying a rapid evolution towards a new set-up for this area in the international landscape. While the era of the ISS as the only permanently inhabited orbital outpost is coming to an end, an increasing focus on lunar missions emerges in parallel with a growing appetite for the development of new orbital stations, either governmental or private.

The future of permanent human presence in Low Earth Orbit and the plans for new space station

Part of the developments are related to the future of **permanent human presence in Low Earth Orbit** in the face of an ageing ISS and **new emerging and planned space stations**.

China successfully launched first modules of its new Space Station:

The long-pursued Chinese effort towards sustained human presence in LEO achieved a major milestone on April 29th, when **the heavy-lift Long March 5B put the 22-ton core module of the new Chinese space station Tianhe into orbit.**[22] 11 launches will follow to complete the assembly of this 66-ton, three-module station, which will be larger and more complex infrastructure than Tiangong-1 and 2 stations operated by China in the 2010s. 2 cargo deliveries (Tianzhou 2 and 3) and 2 crew missions (Shenzhou 12 and 13) followed to the station later in 2021, beginning its construction and starting first crewed operations.

Breakdown of the China Space Station, when completed, and a related infrastructure (Credit: CGTN, China Manned Space, China Academy of Space Technology)

China, in collaboration with UN Office for Outer Space Affairs, has also set up **international partnerships on scientific experiments onboard its new space station**. It was reported that scientific experiments from 16 countries[23] (France, Germany, Italy, Spain, Poland, Netherlands Norway, Belgium, Russia, Japan, India, Saudi Arabia, Kenya, Mexico, Peru), had been accepted to be conducted on board the station. In a similar **scientific diplomacy** approach, China has also initiated international collaborations on its new state-of-the-art FAST radio telescope, opening a call for scientific proposals from foreign astronomers.[24]

[22] China launches Tianhe space station core module into orbit, SpaceNews, 2021
[23] Graphics: China marches a step closer to its future space station, CGTN, 2021
[24] In China, a Telescope Offers Cosmic Data Amid Earthly Tensions, UNDARK, 2021

Russia announced plan to leave the ISS programme post-2025:

In mid-April **Russia announced plans to leave the ISS by 2025, to focus instead on the development of its own new orbital station**. The Russian modules would remain at the ISS and would be either transferred over to other partners or offered for a commercial take-over. For the new station, it was already reported that the Energia Rocket and Space Corporation was tasked with preparing the first station module - the science and energy module that was previously planned for launch to the ISS in 2024.[25]

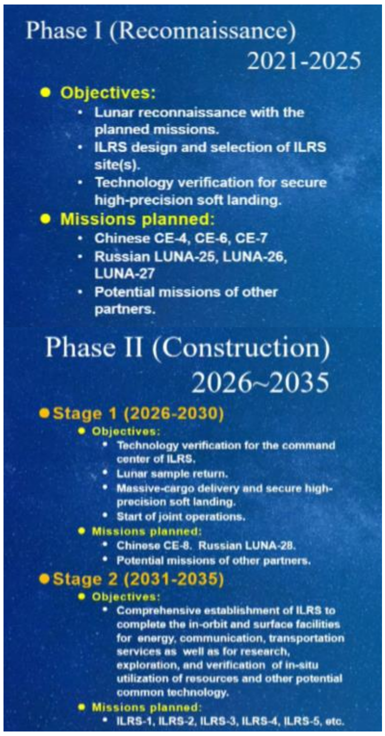
The Russian announcement has major implications for the future of the ISS, which has already been subject to termination talks. According to Director of Roscosmos, Dmitry Rogozin, Russia would leave the ISS gradually in a coordinated manner with the ISS partner nations. Mr. Rogozin also noted, U.S. sanctions on the Russian space industry adds to Russian considerations of discontinuing the ISS partnership.[26]

Regarding the ISS, in July and November, **Russia successfully launched two new modules to the ISS** – the **MLM Nauka** science module, which replaced the long-serving Pirs docking module, and the spherical **Prichal** module with 6 docking ports to accommodate for future visiting spacecraft.

Moon and beyond: next steps towards the shaping of international cooperation for future space exploration

The growing interest in space exploration missions to Moon, Mars and beyond impacts the emergence of broader international coalitions. In 2020, the announcement of first signatories of the Artemis Accords were one of the key developments in space exploration, with impacts beyond programmatic cooperation. **During 2021, the list of Artemis Accords signatories grew by 5 countries** – Brazil, South Korea, New Zealand, Poland and Mexico, and one self-governing British Crown Dependency, the Isle of Man. It was also reported France was considering joining the club of signatories.

In parallel to U.S.-led Artemis Accords, **Russia and China have joined forces in a new partnership on the "International Lunar Research Station"** (ILRS). The two countries signed a MOU in March, and in June, the China National Space Administration (CNSA) and Roscosmos released the International Lunar Research Station Roadmap (V1.0) and Guide for Partnership (V1.0).[27] According to CNSA, the ILRS announcement introduces the definition, scientific objectives, implementation and international cooperation principles of ILRS to all interested countries, international organizations and international partners.[28]



ILRS Roadmap (Credit: CNSA & Roscosmos)

The ILRS is envisioned to be a complex set of research facilities on the lunar surface. It will initially have robotic components and there are plans for crewed missions in the utilisation phase, after 2036. Concerning international partnerships, at the time of announcement, it was reported that discussions had taken place with the ESA and CNES of France, while Thailand, Saudi Arabia and the

[25] Russian orbital station may become prototype for new ISS — Roscosmos CEO, Tass, 2021
[26] Russia threatens to leave International Space Station program over US sanctions: reports, Space.com, 2021
[27] International Lunar Research Station (ILRS) Guide for Partnership, CNSA, 2021
[28] China, Russia jointly release road map on lunar station program, emphasizing openness to intl partners, GT, 2021

United Arab Emirates had expressed interest in the project.[29] In the context of an evolving U.S.-led Artemis partnership, the ILRS signals the progressive bifurcation of the international space community around two contending pathways for future space exploration activities.

1.1.3 Governments eager to boost space commercialisation and business development

New public initiatives launched around the world in 2021 to foster space commercialisation and business development underline **a global trend toward a growing institutional focus on boosting the private space economy and commercial ventures**.

Moving beyond the more traditional space programmes management and procurement, space agencies and other public institutions are actively exploring new incentives and support mechanisms taking the forms of:

- technology incubation,
- financial subsidies,
- new procurement models,
- business acceleration,
- competitions & challenges,
- streamlining of regulatory requirements.

The list below outlines several specific developments from China, Australia, India, USA, France, UK, Austria-Slovakia in line with this observation. The list is non comprehensive.

China: provincial governments continue to invest in and partner with private space ventures

Commercial space ventures in China are growing in prominence, partly due to a noticeable interest of public stakeholders, who increasingly recognise the value of commercial space endeavours in the national economy.

Whereas much of the support is coming from the central government and the CNSA, **regional governments have also recently enhanced their efforts to support the growing industry** through massive investments, notably in spaceports and space industrial clusters:

- The city of Ningbo in eastern Zhejiang province has committed a total investment of 20 billion yuan (€2.8 billion) to establish a spaceport at Xiangshan.[30]
- The southernmost Hainan Province announced increasing its support for the development of the Wenchang International Space City concept to meet the needs of the commercial space industry.[31]
- The city of Guangzhou has announced steps towards the development of a major space cluster, attracting companies engaged across the satellite value chain.

In January 2022, the State Council Information Office of the People's Republic of China published a white paper titled "China's Space Program: A 2021 Perspective". The document shows the increasing promotion commercial use of satellite, thus expanding the applications market for enterprises and individuals. The white paper noted the theme of "encouraging commercialisation" among its policy priorities related to modernising space governance.

[29] China, Russia reveal roadmap for international moon base, Spacenews, 2021
[30] Zhejiang wants to build a commercial space launch center with a total investment of 20 billion yuan, Future aerospace, 2021
[31] Ningbo, Wenchang to construct Chinese commercial spaceports, Spacenews, 2021

Australia – The government launched the A$150 million "Moon to Mars Initiative"

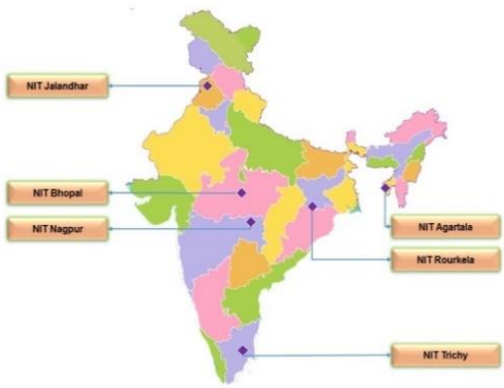
The new governmental initiative aims **to fund industrial development and foster participation of Australian companies in U.S. lunar efforts.** With the aim to accelerate the growth of Australia's space industry, the initiative offers different investment programmes. First grants to Australian companies have been already provided later in 2021. The $150 million Moon to Mars initiative is part of over A$700 million invested by the government into the Australian civil space sector since 2018.

India - ISRO created three new Space Technology Incubation Centres to bring the total amount to six

The incubation centres hosted by three technology institutes will be responsible for the Western, Eastern and Central regions. This step follows the establishment of three previous Space Technology Incubation Centres (S-TICs) set up in 2018 and 2019.

S-TICs are an ISRO-conceived concept to encourage space entrepreneurship and to develop the academia–Industry ecosystem for space technology in the country.

On top of that there were additional public policy developments.

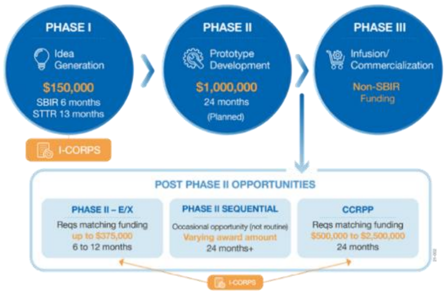


Locations of ISRO's Space Technology Incubation Centres (Credit : ISRO)

- At the inauguration of the Indian Space Association, Indian PM Narendra Modi stressed the vision of Indian government capable of fostering and commercializing private actors in India's space sector.[32]
- It was also announced that a new Committee for a single regulatory clearance of satellite-based networks is being set up, a move deemed to facilitate commercial perspectives of Indian space companies.[33]

USA – NASA and U.S. Space Force invests more than $130 million into SBIR programmes

In the past several years U.S. public stakeholders has developed and implemented various new measures for an improved cooperation between public and private space stakeholders and for support to space commercialisation. The year 2021 continued in this policy trend.



NASA's SBIR/STTR programmes (Credit: NASA)

In May, NASA provided 140 new awards for a total of $105 million in the framework of its **Small Businesses Innovation Research** (SBIR) programme's Phase II.[34] As part of DoD's Space Force Phase II SBIR programme, the U.S. Space Force awarded $32 million in contracts to 19 companies.[35]

[32] PM launches Indian Space Association, Prime Minister's Office, Government of India, 2021
[33] Indian Government Sets Up Committee for Clearance Of Satellite Networks, Telecomtalk, 2021
[34] NASA Invests $105 Million in US Small Business Technology Development, NASA, 2021
[35] Space Force Selects 19 Small Business Projects for SBIR Phase 2 Effort, ExecutiveBiz, 2021

NASA also awarded $500.000 to 13 companies as part of its Break the Ice Lunar Challenge, which seeks to develop system architecture for the collection & transportation of regolith from the Moon's South pole.

France – CNES approves government subsidy agreement for space stimulus plan

In March, CNES approved the new subsidy agreement between the French government and the agency. **As part of the competitiveness component of the Recovery plan, €365 million in new funding will stimulate the French space industry.** The funding is composed of a €165 million envelope dedicated to launcher programmes and an additional €200 million envelope allocated to support innovation in France. [36]

In November, CosmiCapital, a venture capital fund initiated by CNES and managed by Karista, closed its first funding round at €38 million, supported in particular by CNES and public investment bank Bpifrance. In addition, CNES and Germany's Bundeswehr University Munich launched a space tech start-up accelerator titled SpaceFounders. This new programme seeks to support leading space start-ups in Europe and is essentially focused on providing non-financial support. [37]

Austria – New Austrian Space Strategy

In October 2021, the Austrian Space Strategy was published by the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) and the Austrian Research Promotion Agency (FFG), the two main actors responsible for Austria's space affairs. Among the six strategic goals, one is dedicated to the vision for a "competitive space sector with high added value and sustainable jobs in Austria", underlining the growing importance given to commercial space.

UK government progresses towards an adapted regulation of commercial spaceflight services

The UK government announced it expects to enact a new legislation, addressing results of the commercial spaceflight consultation survey. The new regulation would complement both the Space Industry Act of 2018 and new National Space Strategy with the objective of increasing the UK's share of the global space market to 10% by 2030 and supporting the development of new commercial activities.[38]

Slovakia – New space incubator has been established to foster space ecosystem development

As one of its first major initiatives, the newly established Slovak Space Office has launched the first Slovak space incubator (3 locations around the country in partnership with private sector and academia), aiming to foster development of a local space industry ecosystem through improving access to facilities, mentoring, financing and through facilitating feedback from technical experts.[39]

[36] France Relance: the first winners of the space component, Air & Cosmos International, 2021
[37] Karista's NewSpace Fund, CosmiCapital, Closes with 38 Million Euros with CNES and Bpifrance Via FNA 2, Parabolic Arc, 2021
[38] UK one step closer to spaceflight launches as government publishes environmental consultation response, Gov.uk, 2021
[39] Slovak Space Incubator, Slovak Space Office, 2021

1.1.4 STM and responsible behaviour: priorities for the global space sustainability agenda

Throughout the past decade, the long-term sustainability of space activities has clearly emerged as a top international space policy domain, with a major impact on multilateral space diplomacy as well as policymaking at national level. **Space sustainability issues remained high in policy agendas also in 2021,** with notable developments in international norms creation and space traffic management.

New UN resolution on norms of responsible behaviours in space

Resolution 76 /231 convened the Open-ended Working Group on Reducing Space Threats, which met for the first time in May (Credit: UNODA)

In December, the UN General Assembly adopted seven resolutions related to outer space.[40] Among the annually discussed resolutions such as the one on the Prevention of an Arms Race in Outer Space (PAROS) or on the No First Placement of Weapons in Space, **the new resolution A/RES/76/231 "Reducing space threats through norms, rules and principles of responsible behaviours"** represents a novel element in the modus operandi that has thus far prevailed in tackling space security issues within the UN.[41] Specifically, the resolution supported a shift in approach to consider and value behaviours - instead of technological capabilities - as the basis for international norm-setting. As a concrete measure, the resolution decided to convene an **Open-Ended Workng Group (OEWG) meeting twice in 2022 and 2023**, to take stock of existing international normative frameworks and to make recommendations on possible norms of responsible behaviour.

The new UN resolution builds on the process initiated in 2020 by the UK, which sponsored a resolution on reducing space threats through norms, rules and principles of responsible behaviours. Overall, while the resolution obtained the overwhelming majority of votes, it also received non-negligible objections by some important space powers, notably China and Russia. The new resolution explicitly acknowledges the importance of legally binding measures and verification mechanisms, thus meeting to some extent, the preferences of China and Russia. While the efforts are far from finished, **the preparation and a subsequent voting on the resolution can be valued as a step forward for norms creation**.

Space Traffic Management: new initiatives amidst converging views calling for a broad international approach

In the past years, the concept of space traffic management (STM) has gradually evolved from mostly conceptual discussions to practical policy making. Some of these milestones include the inclusion of STM as an agenda item of UN COPUOS Legal Subcommittee in 2015 or the release of the U.S. National STM Policy in 2018. However, the implementation pace of the U.S. STM policy since its publication has been rather slow, marked by burdensome efforts to secure appropriate funding for DoC's Office of Space Commerce.

The lack of major progress in 2021 has led to vocal criticism from lawmakers in both chambers of U.S. Congress.[42]

---

[40] Resolutions of the 76th Session, UNGA, 2021
[41] UN resolution on norms of responsible behaviours in space, ESPI Brief, 2021
[42] Senators Decry Weak Implementation of Space Traffic Management Policies, Potomac Officers Club, 2021. Also, House committee presses NOAA on commercial weather data and space traffic management, Spacenews, 2021

U.S. developments in 2021 also brought about a first of a kind bilateral STM-like agreement between a public actor and a private operator. In March, **NASA and SpaceX signed a spaceflight safety agreement on coordination of operations of the ISS and other NASA spacecraft with SpaceX's Starlink constellation**, whereby SpaceX agreed to move its satellites should they come close to a NASA spacecraft.[43]

EU – Major interest in STM embodied in multiple parallel lines of action

Perhaps the most dynamic STM agenda in 2021 was pursued in the EU. At the member states level, governments followed in the footsteps of Germany's EU Council presidency in the 2nd half of 2020 and dramatically stepped-up considerations regarding STM. In particular, the Slovenian presidency in the latter part of 2021 declared STM as one of its priorities. In July, Slovenia hosted a European wide STM Conference. A new report issued by Slovenian presidency in November 2021[44] indicated a growing convergence in the deliberations of EU member states on the topic of STM.

The European Commission also greatly addressed STM. Besides the European Parliament STM Pilot Project, two independent consultative projects on STM by large European consortia were launched in January (EUSTM and Spaceways), relying on funding through EU's R&D Framework Programme Horizon 2020. In a policy document "Action Plan on Synergies between civil, defence and space industries" released in February, the Commission presented STM as one of three forthcoming flagship projects (alongside space-based connectivity system and drone technologies).[45] In October, the Commission opened a public consultation for an initiative "Space traffic management – development of an EU strategy for safe and sustainable use of space", outlining that a formal EC communication on STM is envisioned for release in first part of 2022.[46]

This momentum for STM in Europe has also spurred consolidation of industrial positions. Eurospace, the trade association of European space manufacturers issued in March a position named "Manifesto for a European Global Answer on STM" calling European institutions to be at the forefront of the discussions on the topic of STM.[47]The foreseen Joint Communication on STM was realised in February 2022 as part of a comprehensive Defence and Space package.[48] The policy document includes 10 STM-related actions (i.a. assessing the STM civil and defence requirements for the EU, enhancing EU operational capabilities to support STM in terms of services and technologies, fostering STM regulatory aspects culminating in relevant legislation, and promoting the EU STM approach globally).

The relevance and interest in furthering the STM agenda has also been observed in Japan.[49] The Japanese government continued a 2020-outlined policy approach, which explicitly aimed to foster STM-rule making both domestically and internationally, putting the spotlight on missions related to space-debris mitigation and on-orbit servicing. A detailed formal action program is expected to be released soon.

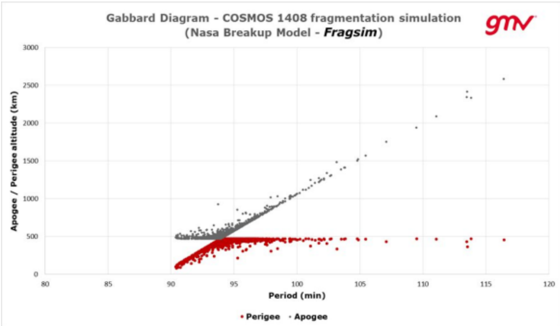
A panel of head of agencies at the U.S. Space Symposium in April showcased that while the high-level speakers from Germany, France, Italy, USA, Canada and ESA generally agreed on the

[43] NASA, SpaceX Sign Joint Spaceflight Safety Agreement, NASA, 2021
[44] Preparation of the Competitiveness Council on 26 November 2021, STM, Presidency Report, Council of the EU, 2021
[45] EU industry: Commission takes action to improve synergies between civil, defence and space industries, EC, 2021
[46] Space traffic management – development of an EU strategy for safe and sustainable use of space, EC
[47] STM: An opportunity to seize for the European space sector, Eurospace Position Paper
[48] JOIN(2022) 4 final
[49] Keynote Speech by Mr. Matsuo, DG of the NSPS at the 6th NSPS, Cabinet Office, 2021

importance of advancing STM, there remains a lack of consensus on appropriate implementation and of a shared STM vision.[50] This lack of consensus and sensitivity of the STM subject was also observed in November 2020 at the International Organisation for Standardisation (ISO), when the first major voting on definition of a new ISO standard on space traffic management and coordination was unsuccessful.[51]

Other notable developments in space sustainability

Russian ASAT demonstration in Low Earth Orbit triggered international criticism



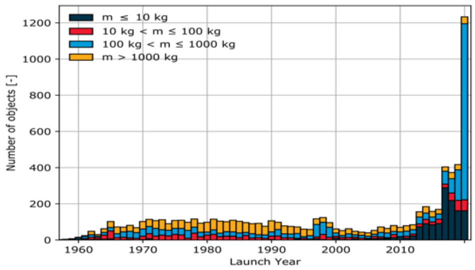
Simulation of space debris produced by Russian ASAT test from November 2021 (Credit: GMV)

The Russian MoD launched an anti-satellite missile on November 15th, which intercepted a defunct Soviet satellite (Kosmos 1408), producing a cloud of debris in an already saturated orbital environment - a highly inclined orbit at approx. ~480km altitude - potentially endangering the ISS and other satellite operations in the long run.[52] The USA was the first country to condemn Russia's action. France, UK, and Germany followed, as well as other spacefaring nations, including Japan, South Korea, and Australia. China did not release any official statements. The EU statement[53] condemned the Russian ASAT demonstration as a clear act of irresponsible behaviour".

U.S. DoD issued a memo on responsible behaviour in space, identifying 5 "tenets"

These 5 tenets of responsible behaviours include: Operate in space with due regard to others, limit the generation of long-lived debris, avoid the creation of harmful interference, maintain safe separation and trajectory, communicate and notify actions to enhance safety and stability of the domain.[54] This first-of-its-kind memo was welcomed by many experts, arguing it would allow the U.S. to lead by example.

2021 edition of ESA's Space Environment Report assessed the behaviour in space as unsustainable.



Evolution of launch activity to LEO (Credit: ESA)

ESA's annual assessment of space debris in Earth orbits[55] underscored the steadily increasing amount of objects in space (in particular in LEO), a changing nature of missions fuelled by the miniaturisation and deployment of large constellations, and, overall, an insufficient compliance with best practises aimed at increasing space safety and long-term space sustainability.

[50] 2021 Space Symposium | Heads of Agency, NASA Video, 2021
[51] Brief Overview of the Current Status of Space Traffic Management, Christophe Bonnal (CNES), 2021
[52] Russian anti-satellite missile test was the first of its kind, Space.com, 2021
[53] Statement by the High Representative of the Union for Foreign Affairs and Security Policy on behalf of the EU on the Russian anti-satellite test on 15 November 2021, Council of the EU, 2021
[54] Tenets of Responsible Behavior in Space, US Secretary of Defence, 2021
[55] ESA'S ANNUAL SPACE ENVIRONMENT REPORT, ESA, 2021

International consortium finalises the definition of "Space Sustainability Rating"

An international consortium established in 2019 (WEF, ESA and MIT, in cooperation with UT Austin, and Bryce) was tasked to develop a rating to measure how well satellites comply with space sustainability practises and guidelines finalised its work and definition of the Space Sustainability Rating (SSR) tool. Switzerland-based EPFL's Space Center (eSpace) was selected to lead the implementation phase.[56]

White House released Orbital Debris R&D Plan and NASA created new debris-focused Working Group

The White House document[57] presented a national plan of R&D to support essential elements of orbital debris risk management. The new NASA working group will examine how the agency could take a larger role in efforts to mitigate and remediate orbital debris.[58]

1.1.5 G7 and G20: space issues rose in the high-level geopolitical agenda

The significance of space as a major geopolitical topic was manifested by the inclusion of space-related issues in the agenda of major international events, such as G7 and G20.

G7 Meeting in Cornwall on the 11-13 June 2021

In June, the 47th G7 summit took place in Carbis Bay and, **for the first time in the twenty-first century, space-related issues were specifically addressed in the G7 final document and extensively discussed during the Summit.** The Group of Seven (DE, CAN, USA, FR, IT, JPN, UK and EU as Observer) recognised the need to use space in a safe and sustainable manner and the importance of cooperation in addressing space issues in order to continue benefitting from it, as space was referred to as one of the "future frontiers of the global economy and society".

Family photo of the G7 leaders, incl. EU representatives, at the 2021 G7 summit (Credit: Government of Japan)

In this year's G7 Final Communique,[59] the **G7 leaders specifically expressed their commitment to the "safe and sustainable use of space** to support humanity's ambition now and in the future", and addressed two space-related topics:

- "The importance of developing common standards, best practices and guidelines" to make space operations safe and sustainable,
- "The need for a collaborative approach for space traffic management and coordination".

The question of **space debris mitigation** was an important issue addressed during the summit. In the communique, the G7 welcomes "the UN´s Long Term Sustainability Guidelines and calls on others to join in implementing" them, and on all interested parties, public and private, to collaborate in researching and developing potential solutions.[60]

[56] A universal definition of space sustainability is hard to find, EPFL, 2021
[57] 2021 NATIONAL ORBITAL DEBRIS RESEARCH AND DEVELOPMENT PLAN, US, 2021
[58] NASA team to study new roles for the agency in addressing orbital debris, SpaceNews, 2021
[59] Our Shared Agenda for Global Action to Build Back Better, CARBIS BAY G7 SUMMIT COMMUNIQUÉ, 2021
[60] G7 nations commit to the safe and sustainable use of space, UKSA, 2021

Furthermore, cooperation was a major keyword of this G7 summit. Space geopolitical balances are shifting and **G7 leaders underlined that commitment and political leadership at international level are needed to effectively address safety and sustainability challenges in the space sector**. On the other hand, the G7 statements are not binding and the summit´s documents have no legal value. In addition, the leaders made no pledge to take action to address space-related topics and to find concrete solutions to increasingly serious and pressing problems.

Instead, the G7 leaders called on nations to cooperate through the appropriate international fora. They called on "all nations to work together, through groups like the United Nations Committee on the Peaceful Uses of Outer Space, the International Organization for Standardization and the Inter-Agency Space Debris Coordination Committee, to preserve the space environment for future generations."

G20 Space Economy Leaders Meeting takes place at ASI headquarters

The G20 leaders met at the end of October in Rome to discuss "People, Planet and Prosperity".[61] Although the economic themes have maintained a particular importance, the topics address by the G20 have significantly expanded over the years prior to the Summit, the Italian Space Agency (ASI) hosted the "**G20 Space Economy Leaders Meeting**".[62] The initiative was firstly launched and organized by the Saudi Space Commission (SSC) under the Saudi Arabia G20 Presidency in 2020.[63] Participants included heads of the space agencies of the G20 countries, ESA, the European Commission, UNOOSA, OECD and other international organizations. The OECD Space Forum developed a background paper for this meeting, providing "new evidence on how space technologies can promote growth and well-being in G20 economies and beyond".[64]

The representatives of space agencies of G20 members: [65]

- **Agreed to continue the Space Economy Leaders' Meetings** launched by the Saudi Space Commission in 2020, and to discuss the item "Space Economy" on future G20 agendas,
- **Agreed to establish an informal Space Economy Leaders Advisory Group**, composed of representatives of the G20 countries,
- **Reaffirmed the necessity to address the growing hazard of space debris** and the increasing congestion in Earth's orbit and encouraged efforts to support the implementation of the Guidelines for the Long-Term Sustainability of Outer Space Activities.

During the event, the ASI president said that "space activities will play a key role in the coming years, in terms of strengthening the foundations of these three pillars" and for this reason "this year's Space Economy Leaders Meeting was a perfect opportunity to raise the level of attention towards the role that space, and the 'Space Economy' can provide to the G20 goals and the future of our society. And the G20 countries can act as ambassadors for Space also in developing and emerging countries which, however, haven't had the chance yet to seize the opportunities of this industry to build a sustainable future".

Furthermore, particular emphasis was put on space applications toward climate and sustainable development, especially in the preparation of the COP26 meeting chaired by Italy and the UK.

[61] G20 Leaders' Summit 2021, IISD, 2021
[62] ASI opened the doors to the "G20 Space Economy leaders meeting", ASI, 2021
[63] G20 Voices on the future of Space Economy, Space20
[64] G20 Space Economy Leaders Meeting 2021, ESA, 2021
[65] G20 Space Italy, MarketScreeener, 2021

1.1.6 Space defence: expanding international partnerships amidst evolving doctrines

The participation of a broad range of international military space representatives at the U.S. Space Symposium highlighted a **trend of increasing military space cooperation**. Stakeholders from 23 nations, primarily U.S. allies, called for further military space collaboration beyond information sharing to include joint exercises, wargames and network integration. Stakeholders also emphasised outstanding needs, in particular with regards to compatible doctrines, interoperable procedures and capabilities, collaboration on equipment programmes or shared space domain awareness.[66]

In regard to new military collaborations with the U.S., significant developments occurred in 2021:

- Across the Pacific, a new Space Security Partnership was launched between USA and South Korea,[67]
- In a similar format, the U.S. Space Command also expanded space defence ties with Japan68 and the U.S. Space Force committed to further expand officer exchange partnerships,[69]
- The U.S. Space Force and the Israeli Air Force engaged in their first Space Engagement Talks,[70]
- In Europe, USA expanded the network of SSA sharing partners with a new collaboration with Ukraine,[71]
- Already in late 2020, the U.S. Space Force with the Space Command initiated first steps towards greater space defence collaboration six Latin American countries.[72]

At the multilateral level, countries of the **Quadrilateral Security Dialogue (Quad) — Australia, India, Japan, and USA — issued a joint statement, addressing, for the first time, a space-related partnership**, noting the will to consult on "rules, norms, guidelines and principles for ensuring the sustainable use of space."[73]

In addition to these and other U.S.-led collaborations (e.g., Combined Space Operations Centre or Global Sentinel), in 2021 **France hosted a military space exercise AsterX for the first time**. Germany, Italy and USA participated at this week-long exercise and France announced that next iterations will include more invited nations.[74] Later in the year, France and India agreed to start a bilateral space security dialogue, focusing in particular on the protection of space assets.[75]

AsterX military space exercise (Credit: Jean-Luc Brunet/Air and Space Force)

Also concerning non-U.S. collaborations, **Japan and Vietnam signed an agreement to cooperate in space defence** and cybersecurity[76] and it was also reported that the UAE and Israel are considering setting up military space cooperation.[77]

[66] Linking allied military space capabilities, SpaceNews, 2021
[67] US, South Korea Formalize Space Security Partnership, ExecutiveGov, 2021
[68] SPACECOM To Tighten Ties To Japan, BreakingDefence, 2021
[69] Space Force Increasing International Outreach as the Service Grows, Airforcemag, 2021
[70] U.S., Israel expand cooperation to the space domain, Space Force, 2021
[71] Ukraine and the United States signed an agreement on the basics of defence partnership, UATV, 2021
[72] New International Partnerships Could Spur Hosted Payloads: Gen. Thompson, Breaking Defence, 2021
[73] India, the Quad, and the Future of Outer Space, Carnegie India, 2021
[74] « Aster X 2021 » : Premier exercice spatial en Europe, French Governemnt, 2021
[75] India-France Agree on Space Security Dialogue, ORF, 2021
[76] Japan, Vietnam look to cyber defense against China, japanetoday, 2021
[77] Potential for Middle East space force collaboration with Israel and UAE, jpost, 2021

Furthermore, space continues to rise in the NATO agenda. **NATO named space as one of its top seven priorities for emerging and disruptive technologies** in the 2020-2040 timeframe.[78] The alliance also finalised **NATO's overarching space policy**, of which the public version was published in January 2022.[79] The policy stated that attacks to, from, or within space could lead to the invocation of Article 5 of the North Atlantic Treaty.

National developments in space defence in Europe in 2021 in Europe

The French Ministry for the Armed Forces updated its 2017 Defence and National Security Strategic Review. Space developments are widely acknowledged in the document. The Ministry recalls various strategic threats, which include the "irresponsible" or dangerous behaviour, "unfriendly" activities or demonstrations (ASAT launches, proximity manoeuvres, jamming of PNT systems, etc.)" of some states in outer space. The document also notes that space is now a warfighting domain.[80]

Germany[81] and the UK[82] establish new Space Commands, following in the footprints of U.S. and French actions in 2019, while preparations of the establishment of an Italian "Joint Command for Space Operations" progressed.[83]

In Italy, ASI and the Italian Army signed a collaboration agreement in the space sector. The agreement formalises a long-existing partnership. It aims at optimising public investment and maximising defence capabilities through increasing "synergies of national programs, resources and professional skills".[84]

In the UK, the new UK Space Strategy also committed to deliver the U.K.´s first Defence Space Portfolio which will lead the government to invest an additional £1.4 billion to ensure UK capabilities to support defence operations in the modern age. [85] The UK's new "Defence Space Strategy: Operationalising the Space Domain", published in early 2022 provides more details for this funding, which will be used primarily to:[86]

- Enhance UK's military's satellite communications (Skynet 6 programme).
- Develop independent space domain awareness capabilities,
- Build and deploy a small constellation of ISR satellites.

In the Netherlands, it was reported that the **Royal Netherlands Air Force is considering to further expand its space capabilities,** including through combined partnership with the U.S. and NATO allies.[87] In addition, **the first Dutch military satellite (BRIK II) was successfully launched** onboard Virgin Orbit's LauncherOne. The satellite, A 6U cubesat, is an experimental project of the Royal Netherlands Air Force to demonstrate the potential of nanosatellites for military and civilian use.[88]

At the EU level, efforts continued to support space defence-related research, capacity development and European cooperation, through new projects launched under the European Defence Fund and Permanent Structured Cooperation.[89]

---

[78] Emerging and disruptive technologies, NATO, 2021
[79] NATO's overarching Space Policy, NATO, 2021
[80] Defence – 2021 strategic renewal, France Diplomacy, 2021
[81] Germany establishes new military space command, defencenews, 2021
[82] UK Space Command, UK Government, 2021
[83] The italian Space Operations Command is getting ready, aresdifesa, 2021
[84] Firmato L'accordo Esecutivo Tra Esercito E Agenzia Spaziale Italiana, ASI, 2021
[85] New UK space strategy sets the stage for defense investments, Defense News, 2021
[86] Defence Space Strategy: Operationalising the Space Domain, Gov.uk, 2022
[87] The Netherlands Ministry of Defence, SMC Officials meet to discuss space cooperation, U.S. Space Force, 2021
[88] First Dutch military nanosatellite launched successfully, Defensie.nl, 2021
[89] PESCO: EU Council launches 4th European defence cooperation wave, Insight EU Monitoring, 2021

Developments in space defence in the rest of the world

In the USA, **various reports suggested that U.S. military space and intelligence organisations** (namely the U.S. Space Force, Space Development Agency, Defense Advanced Research Projects Agency, National Reconnaissance Office and National Geospatial Agency) increasingly **explore options to further exploit and integrate space capabilities offered by commercial providers**.[90,91] While commercial services have long played a major role in U.S. military's launch and satcom enterprises, these recent announcements show a more comprehensive evolution of the U.S. approach to space capability development.

South Korea committed to invest 16 trillion Won (€11.8 billion) over the next 10 years in space defence capabilities.[92] In September, South Korea's Defense Acquisition Program Administration (DAPA) issued a more detailed roadmap geared primarily towards achieving self-reliance in the space defence sector.[93]

Australia announced assembling of a space division within its armed forces, which will comprise military officers from the army, navy and air force targeting to better protect satellites from an attack.[94]

Japan announced it will set up its second space defence squadron within the next 18 months to improve capabilities in protecting the country's space assets. Japan's first space defence squadron was set up in 2020.[95]

Egypt, as part of a broader military equipment deal with France, **bought a new remote sensing satellite**, which will be produced by Airbus. The deal follows previous agreements with European countries, namely France and Italy, which also included purchases of military satellites, built by Airbus or Thales.[96]

Iran has reportedly increased activity at the Shahrud complex, which is central to the IRGC's solid-fuel space-launch and missile development activities. The complex has undergone a comprehensive expansion over the course of 2021.[97]

Signing of a new space defence MoU between U.S. and South Korean militaries (Credit: Republic of Korea Air Force)

[90] The US military wants to plug commercial satellites into its orbital networks, C4ISRNet, 2021
[91] NRO to tap commercial industry for space-based radar data, SpaceNews, 2021
[92] South Korea to invest $13.6 billion to bolster defences capabilities in outer space, SpaceNews, 2021
[93] South Korea outlines plan to grow space-defence capability, Janes, 2021
[94] Australian military to set up space division with $7bn budget, The Guardian, 2021
[95] Japan to launch 2nd space defence unit to protect satellites from electromagnetic attack, SpaceNews, 2021
[96] Egypt to buy spy satellite, MRTT aircraft from France, Daily News Egypt, 2021
[97] Iran's Military Space Program Picks up Speed, Newlines Institute, 2021

1.1.7 New developments in national space policy and space law

In 2021, close to 20 countries went through major updates with regards to national policies, organisational frameworks or laws related to space activities.

European Developments

The UK releases its first civil and defence national space strategy: In September, the U.K. Department for Business, Energy & Industrial Strategy and the Ministry of Defence released the first ever National Space Strategy of the UK. The new strategy "sets out the government's ambitions for the U.K. in space, bringing together civil and defence policy for the first time" and "pursues a bold national vision". The strategy outlines 4 pillars which will support the achievement of that ambition: [98]

1. Unlocking growth in the space sector
2. Collaborating internationally
3. Growing the UK as a science and technology superpower
4. Developing resilient space capabilities and services

In Scotland, the newly published Scottish Space Strategy [99] is intended to be consistent with the broader UK Space Strategy. The overarching goals of the space strategy include positioning Scotland as a leader in commercial space, establishing launch sites, transitioning towards an environmentally friendly space industry and increasing economic opportunities.

Germany's new government's (SPD, FDP, and Green Party) coalition agreementincludes provisions on space. The section dedicated to aerospace and aviation highlights the following priorities: [100]

- The importance of space and new space for key future technologies
- Germany's intentions to strengthen the National Space Programme and contribution to ESA
- Development of a new space strategy, with a focus on avoidance and removal of space debris

In December, the Federation of German Industries (BDI) launched the "New Space Initiative", gathering 5 other associations as well as 28 space and cross-sectoral industry start-ups and companies.

French Economy Minister Bruno Le Maire presented the new French space policy ambitions, noting decisions taken to support reusable mini launchers (to be developed at a rapid pace, with first flight by 2026), reusable micro launchers (smaller than mini launchers), NewSpace ecosystem, satcom constellations, space situational awareness or in-orbit servicing.[101]

[98] National space strategy, UK Governments, 2021
[99] A Strategy for Space in Scotland, 2021
[100] MEHR FORTSCHRITT WAGEN, BÜNDNIS, 2021
[101] France's version of New Space is top-down, with government funding to develop reusable mini- and micro-launchers, Space Intel Report, 2021

Space funding in recovery and resilience funds (RRFs) of multiple EU member states

In 2021, France was one of the EU member states, which allocated portions of new funding streams under the NextGenerationEU recovery plan to space technologies and capabilities. Under the €30 billion "France 2030" investment plan, France is set to invest €500 million to New Space actors, €200 million to reusable micro-launchers, and €500 million to the financing of a satcom constellation. Two thirds of the €1.5 billion space funding under the "France 2030" plan will be dedicated to SMEs and start-ups.[102]

Other countries with notable space funding lines in their national RRFs include e.g., Italy (more than €2 billion), Belgium, Greece, Luxembourg, Portugal or Poland.

Hungary adopted its first national space strategy, presenting the following priorities:[103]

- Making Hungary a player in the global space industry and a regional leader in certain areas.
- Ensuring "a constant supply of multidisciplinary specialists" to support the production of "highly innovative products and services, as well as the development of domestic space competencies".
- Boosting "competitiveness through the space industry" to improve quality of life.

The government will also invest up to €100 million over 5 years to double the number of local space firms.

Austria released its new Space Strategy 2030+[104], emphasising sustainable development, scientific excellence, socio-economic benefits of space, and space workforce. Space is tied to Austria's climate action and to the country's goal of being climate neutral by 2040. In addition, the strategy also underlines Austria's commitment to long-term sustainability in space, in line with UN LTS Guidelines.

In Denmark, the new National Space Strategy[105] follows in the footsteps of Denmark's previous space strategy (2016). prioritising the role of space in societal development. The priorities listed focused on utilising space solutions in support of green, climate and environmental related goals.

In Slovakia, a new unit, the Slovak Space Office (SSO), was set up to foster the development of space ecosystem and international space engagement. SSO is based on a partnership between the Ministry for Education, Science, Research and Sport and the Slovak Investment and Trade Development Agency.[106]

Also in central Europe, the new **Memorandum of Understanding on "Enhancing Cooperation in the Field of Space Research and Peaceful Uses of Outer Space"** was signed by prime ministers of countries from the Visegrad Group (**Czech Republic, Hungary, Poland, Slovakia**).[107]

The principality of Monaco established an Office for Outer Space Affairs in October: The Office aims to serves as a single-entry point to support the growth of businesses in the space sector.[108]

Lithuania signed an Association Agreement **to become and ESA Associate Member state:** The agreement was signed in April 2021 and entered into force in May for a duration of seven years.[109]

[102] Présentation du plan France 2030, Élysée, 2021
[103] Government approves Hungary's national space strategy, About Hungary, 2021
[104] Österreichische Weltraumstrategie 2030+, Austrian Parliment, 2021
[105] Denmark's national space strategy, The Danish Government, 2021
[106] https://spacegeneration.org/regions/europe/slovakia
[107] SGAC Slovakia, SGAC, 2021
[108] Monaco strengthens its space program, Monaco Tribune, 2021
[109] Lithuania becomes ESA Associate Member state, ESA, 2021

Non-European Developments

In the USA, the White House released the "United States Space Priorities Framework"[110], a first comprehensive space policy effort by the new administration. It outlines several priorities that are grouped into two overarching categories (maintaining a robust and responsible U.S. space enterprise and preserving space for current and future generations).

U.S. VP Kamala Harris at the National Space Council meeting (Credit: NASA/Joel Kowsky)

The 7-page document does not go as far as to offer detailed implementation steps. Vice President Harris' speech at a subsequent National Space Council meeting was the first under the new administration and put a particular emphasis on national security, climate and education related issues.[111]

The Parliament of Japan officially adopted the **Law Concerning the Promotion of Business Activities Related to the Exploration and Development of Space Resources** in June**.** The country thus became the fourth country following the U.S., Luxembourg, and the United Arab Emirates to adopt a national regulation allowing for the commercial exploitation of extracted space resources.[112]

In India, the Department of Space continued a major space policy reform process which started in 2020, drafting 10 unique space policy documents[113], some of which were already released for public consultation (the adoption process of all the policies and an overarching legislation should be finalised in 2022):

1. Satellite communications policy
2. Space-based remote sensing policy
3. Technology transfer policy
4. Humans in space policy
5. Satellite navigation policy
6. Space transportation policy
7. FDI policy for the space sector
8. Space exploration policy
9. Space situational awareness policy
10. National space policy

Vietnam unveiled a new strategy for the development and application of space science and technology by 2030. Acknowledging the major role of space in support of security and socio-economic interests, the strategy focuses primarily on capability development in space applications (EO, satcom, PNT).[114]

In Taiwan, a new space development act was passed, laying the legal foundation for the further development of Taiwan's space programme, encouraging the development of technologies to enhance the competitiveness of space-related industries. The new legislation also covers registration of launch and space vehicles or establishment, operation and management of launch sites.[115]

[110] US SPACE PRIORITIES FRAMEWORK, White House, 2021
[111] Harris calls for new international rules for space after Russia blows up satellite, Politico, 2021
[112] Japan: Space Resources Act Enacted, Library of Congress, 2021
[113] 3 key Space policies to go to Cabinet soon; 7 more in pipeline; key launches delayed, Times of India, 2021.
[114] Strategy issued for space science-technology development, application, Vietnam News, 2021
[115] Space development act passes final reading in Taiwan's Legislature, Taiwan Today, 2021

In Turkey, president Recep Tayyip Erdoğan unveiled a 10-year Turkish space programme, a first for the country, presenting a roadmap with ambitious national goals in the space domain, including launching a Moon mission by 2023, sending Turkish astronauts into space and building a Turkish spaceport.[116]

Live televised ceremony of the release of Turkey's first space programme (Credit: Anadolu Agency / Youtube)

The Rwandan Chamber of Deputies approved the establishment of the new Rwanda Space Agency (RSA).[117] The RSA is entrusted with administrating the national spatial data and imagery, advising the government on new national and international space policies and implementing existing programmes.

The African Union Executive Council has approved the structure of the African Space Agency (AfSA), moving closer to establishing the agency, which is expected to start operations in 2022.[118]

A new Costa Rican Space Agency (AEC) was set up in March,[119] with the objective of coordinating the country's activities in the space sector.

Nicaragua created the Ministry for Extraterrestrial Affairs to ensure the country's compliance to international space law commitments, as well as to execute national policy initiatives in the field.[120]

1.1.8 Other outstanding policy developments

Changes in Leadership: New appointments at key positions in agencies and institutions

ESA	Starting from March 2021, **Josef Aschbacher** leads ESA as the **new Director-General** for a period of 4 years.[121] On October 21, the ESA Council appointed three new ESA directors: • **Géraldine Naja** as Director for Commercialisation, Industry and Procurement, • **Simonetta Cheli** as Director of Earth Observation Programmes, • **Francisco-Javier Benedicto Ruiz** as Director of Navigation.
NASA	In March, President Joe Biden's nominated **Bill Nelson as new NASA administrator**.[122] In addition, a few other appointments occurred during the year: • **Pam Melroy** was nominated as deputy administrator of NASA,[123] • **Bhavya Lal** has been nominated as head of newly created NASA Office of Technology, Policy, and Strategy;[124] In September, NASA split the Human Exploration and Operations Mission Directorate into two new entities: the **Exploration Systems Development Mission Directorate (ESDMD)** and **Space Operations Mission Directorate (SOMD)**.[125] NASA also established a new position of **senior climate adviser**.[126]

[116] Erdoğan unveils 10-year Turkish space programme, The Guardian, 2021
[117] Rwandan legislature approves law establishing Rwanda Space Agency, Space in Africa, 2021
[118] African Union Executive Council Approves African Space Agency Structure, Space in Africa, 2021
[119] Alvarado firma Ley de Creación de la Agencia Espacial Costarricense, elmundo.cr, 2021
[120] Nicaragua creará secretaría para asuntos relacionados con el espacio ultraterrestre, Asemblea Nacinal Nicaragua, 2021
[121] ESA Council appoints Josef Aschbacher as next ESA Director General, ESA, 2021
[122] Former Senator Bill Nelson Sworn in as the 14th NASA Administrator by Vice President Kamala Harris, NASA, 2021
[123] Statements on Pam Melroy's Senate Confirmation as NASA Deputy Administrator, NASA, 2021
[124] NASA creates new technology and policy office in leadership reshuffle, SpaceNews, 2021
[125] NASA splits human spaceflight directorate into two new branches, Space.com, 2021
[126] NASA creates climate adviser position, SpaceNews, 2021

CNES	**Philippe Baptiste** was appointed as the new President of CNES following the parliamentary approval given in April.[127]
UK Space Agency	In September, **Dr Paul Bate** has started his work as the CEO of the UK Space Agency.[128] Paul Bate has been approved by Science Minister Amanda Solloway in June.
UAE Space Agency	The UAE has appointed **Salem Butti Salem Al Qubaisi** as the new Director-General of UAE space agency - in a reshuffle executed by a federal decree issued in October by President Sheikh Khalifa bin Zayed Al Nahyan.[129]
NASRDA	In April, **Halilu Shaba Ahmad** has been appointed as the substantive Director-General of Nigeria's National Space Research and Development Agency (NASRDA).[130]
EUMETSAT	**Phil Evans** became new Director General of EUMETSAT in January[131]
NOAA	**Rick Spinrad** was sworn in as NOAA administrator and as undersecretary for oceans and atmosphere at the Department of Commerce.[132]
FCC	Biden administration nominates **Jessica Rosenwocel** as permanent Chair of the FCC in October, making her the first woman to Head the Commission.[133]
Italy	Italian PM Mario Draghi delegated the coordination of space policies and aerospace programmes to **Vittorio Colao**, the Minister for Tech. Innovation and Digital Transition.[134]

New bilateral collaborations signed in 2021

The table below summarises major bilateral cooperation agreements on space activities signed in 2021, including both new partnerships and expanded collaborations between countries already working together. Two specific collaboration frameworks are summarised outside of the list below:

- **Artemis Accords** – the list of signatories (bilateral agreements with the USA) grew with Brazil, South Korea, New Zealand, Poland and Mexico, and the Isle of Man.
- **Space Climate Observatory (SCO)** – the CNES-led effort enlarged the list signers of SCO's Declaration of Common Interest with institutions from Morocco, Norway, Saudi Arabia, South Africa and Slovakia.

January	Netherlands – Norway	The Netherlands Space Office and the Norwegian Space Agency agreed to place Dutch cutting-edge technology on Norway's new national satellite (NorSat-TD).
February	France – South Africa	CNES and SANSA signed an implementing arrangement to the 2019 framework agreement to enhance interoperability capabilities for climate monitoring constellations.

[127] Centre national d'études spatiales, Senat, 2021
[128] Paul Bate appointed as UK Space Agency CEO, UK Government, 2021
[129] UAE Space Agency, 2021
[130] Nigerian Space Agency appoints new Director General, Space Watch Africa, 2021
[131] EUMETSAT welcomes its new DG: Phil Evans, EUMETSAT, 2021
[132] Richard W. Spinrad sworn in as NOAA administrator, NOAA, 2021
[133] Jessica Rosenworcel confirmed by Senate to lead the FCC, The Verge, 2021
[134] Italy invests 1,29 billion in space economy, miprons, 2021

	ESA – Japan	ESA and JAXA signed a collaboration agreement (part of a broader agreement) for HERA and MMX missions.
	UK – Australia	UK and Australia signed the Space Bridge Framework Arrangement to increase investments, industrial cooperation and knowledge sharing between the two countries.
	Australia – India	Australian Space Agency and ISRO signed an MoU, to open opportunities for Australian organisations to work closely with Indian entities under the country's space programme.
March	Japan – India	JAXA and ISRO signed an Implementing Arrangement for collaborative activities on rice crop area and air quality monitoring using satellite data.
	Japan – Paraguay	JAXA and the Paraguayan Space Agency (AEP) signed a Letter of Intent, to start dialogues to explore possibilities of cooperation in space activities for peaceful purposes.
	Russia – China	China and Russia signed a MoU for a collaboration in the development of an International Lunar Science Station (ILRS).
	France – Italy	Italy and France signed a joint declaration on the future of European space launchers, covering the creation of a high-level working group on launchers and their exploitation.
	France – Egypt	The Egyptian Space Agency (EgSA) and CNES signed a space cooperation protocol for satellite developments, training and exploration of outer space.
	Singapore – UAE	Singapore's National Space Office and the UAE Space Agency signed a Letter of Intent to collaborate in the areas of space technologies, space law and human capital development.
April	France – India	ISRO and CNES signed an agreement for cooperation for the India's first human space mission "Gaganyaan", enabling Indian flight physicians to train at French facilities.
	Japan – USA	Japan Air Self Defense Force and U.S. Space Command signed new arrangement, assigning a Japanese liaison officer to the command.
June	France – Luxembourg	France and Luxembourg signed a Letter of Intent on exploration and space resources, represented by CNES, the Luxembourg Space Agency (LSA), ESRIC, and Air Liquide.
	Japan – UK	JAXA and UKSA signed a MoC, to promote cooperation in R&D, space science and exploration, EO and satellite applications, and the sustainable and safe use of orbits.
	Japan – Philippines	JAXA and Philippine Space Agency (PhilSA) signed a Memorandum of Cooperation on Space Development and Application.

July	US – Japan	JAXA and NASA signed a MoU on the cooperation on the launch and data exchange for the two JAXA CubeSats on Artemis I.
August	USA – Ukraine	The State Space Agency of Ukraine (SSAU) and U.S. DoD signed a MoU on cooperation in safety of spaceflight and the provision of SSA services and information.
	USA – South Korea	The U.S. Space Force and ROK Air Force agreed to strengthen space security cooperation.
	Russia – South Africa	SANSA and Roscosmos agreed to build the PanEOS antenna to track space debris.
September	UK – UAE	The UK and the UAE signed a bilateral Memorandum of Cooperation on Industrial and Advanced Technologies Collaboration in several areas, including space.
	Russia – Kazakhstan	Russia and Kazakhstan signed an agreement for the construction of a Soyuz-5 launch complex at the Baikonur Cosmodrome.
	USA – Peru	The US and the Republic of Peru formalised a partnership (Memorandum of Agreement) to facilitate cooperative research in Earth Observations and technology development.
October	Russia – UAE	Roscosmos and the UAE Space Agency signed agreed to expand ties in GNSS and remote sensing, space debris monitoring, satellite telecomms and human spacefliglht.
	Germany – Norway	DLR and The Norwegian Space Agency (NOSA) have renewed their framework agreement on space surveillance, tracking and microlaunchers.
	Germany – South Korea	DLR and KARI extended existing cooperation. Since 2016, KARI and DLR have been collaborating in satellite exploitation, space exploration and space robotics.
	Italy – Luxembourg	ASI and LSA signed a MoU to strengthen cooperation, in space exploration, sustainable use of space resources, science, technology, and applications.
	Italy – Canada	ASI and CSA signed a MoU to facilitate information exchange, joint activities in space sciences and technologies, development of space exploration systems and training.
	UK – South Africa	UKSA and SANSA signed an MoU on space applications, space science and technology, support to space businesses and national infrastructure development support.
	UK – Canada	UKSA and CSA signed an MoU on joint activities in the areas of space science, technology and applications, space policy, law and regulation and human capital development.

	UAE – Israel	The UAE Space Agency signed a MoU with the Israel Space Agency to enhance cooperation in scientific research, space exploration and knowledge transfer.
	ESA – UAE	The UAE's MBRSC signed a Memorandum of Intent (MoI) with ESA on the establishment of a long-term collaboration in the areas of human spaceflight and exploration activities.
	Slovakia – Taiwan	Taiwan and Slovakia signed an agreement to deepen two-way exchanges in various areas.
November	Italy – France	France and Italy signed a bilateral treaty (Quirinal treaty) a bilateral launcher agreement on the level of the responsible ministries.
	Russia – Zimbabwe	The Zimbabwe National Geospatial and Space Agency (ZINGSA) has signed a MoU with Roscosmos to foster collaboration in remote sensing trainings.
December	Egypt – Ukraine	The Egyptian Space Agency and the State Space Agency of Ukraine signed an MoU to expand bilateral cooperation in space
	India – Russia	India and Russia signed an agreement to deepen collaboration in the space sector, including in the human spaceflight programme.
	South Korea – Australia	South Korea and Australia signed a MoU to cooperate on space exploration, launch services, satellite navigation, EO, SSA and STM.
	South Africa – China	SANSA and China Satellite Navigation Office (CSNO) signed a MoU for cooperation in satellite navigation.

Table 1: New bilateral collaborations signed in 2021 (Source: ESPI database)

1.2 Major Space Programme Developments

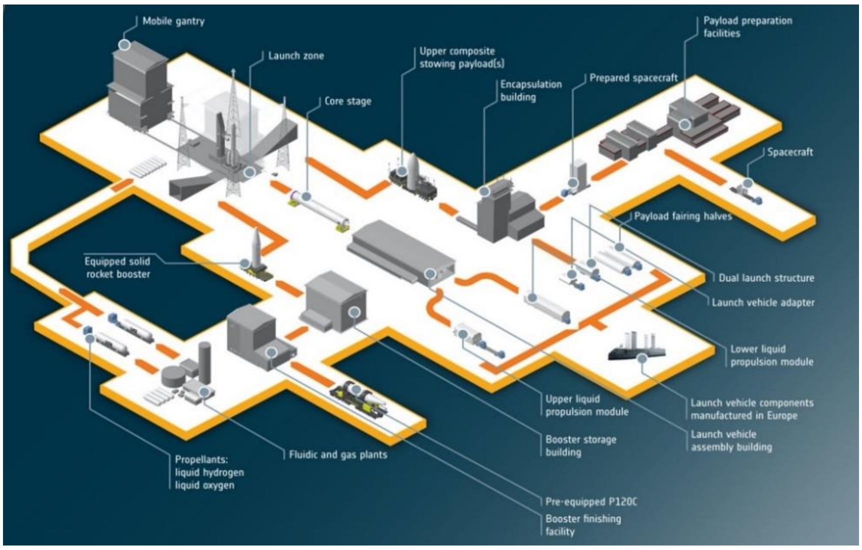
1.2.1 Access to space

Europe – Growing public support for new initiatives amidst ongoing work on new launchers and spaceports

In parallel to operational Ariane 5 and Vega, Ariane 6 and Vega-C rockets are the core public European space transportation programmes under development. Facing delays, both launchers now have their **maiden flights scheduled for 2022**.

In August, ESA Council adopted a resolution outlining the future of the agency's launcher support policy. The **resolution defines minimum institutional demand** of 4 and 2 yearly launches guaranteed for Ariane 6 and Vega C respectively. If the minimum institutional launch demand is not met, industrial contractors will be compensated. The resolution awaits formal approval at the 2022 ESA Ministerial Council.

In September, a major milestone for Ariane 6 programme was reached – a **new launch complex for Ariane 6 rocket was inaugurated** at Europe's Spaceport in French Guiana.[135] Also in September, Europe's Spaceport hosted the first combined test in preparation for the inaugural flight of Ariane 6.[136]



Ariane 6 launch complex at Europe's Spaceport in French Guiana
(Credit: CNES, ESA, ArianeGroup, Arianespace)

In November, **Italy and France signed an agreement to strengthen cooperation on space launchers** as part of a broader bilateral treaty. The two countries agreed to work together on liquid and solid propulsion and pressed ahead with the development of launchers Ariane 6 and Vega C.[137]

Earlier, in April, CNES, DLR and ArianeGroup inaugurated the **expansion of the European research & technology test bench P8.3**. Announced as an important building block for future European launch vehicles, this liquid propulsion research test stand offers an R&I environment for liquid propulsion and promotes the fast industrial application of innovative technologies for future propulsion systems.[138]

[135] Ariane 6 launch complex inaugurated at Europe's Spaceport, ESA, 2021
[136] Combined tests start for Ariane 6 at Europe's Spaceport, ESA, 2021
[137] Italy and France sign agreement on space launchers, euronews, 2021
[138] Third Test Cell for the European Research and Technology Test Bench P8, Parabolic Arc, 2021

For the Vega launcher, ESA decided to award new €188.8 million contract to Vega's manufacturer Avio for the continuous development of a new Vega launch vehicle called Vega-E, beyond 2025.[139]

While most of public funding in Europe goes to Ariane and Vega programmes, under ESA framework, **other space transportation initiatives in Europe increasingly receive support from public actors**.

In the EU Industrial Strategy updated in May 2021, the European Commission considered the preparation of a **European Alliance on Space Launchers**.[140] In November it was reported that ESA and CNESare exploring the possibility to create a **European Space Transportation Hub** located in Paris region.[141] More details on both visions are yet to be presented.

ESA has also issued **two contracts worth €150 million to ArianeGroup for two flagship space transportation demonstration projects** on future disruptive technologies:

- €135 million to advance development of **Prometheus**, a reusable rocket engine,
- €14.6 million for finalisation of **Phoebus**, a highly optimised upper stage.[142]

ESA and DLR moved ahead in implementation of support schemes to new launcher programmes. The German Government and DLR awarded Isar Aerospace with €11 million contract through its C-STS programme, which is run by ESA and designed to strengthen commercial space transportation services in Europe. A follow-up co-funding contract of €11 million as part of ESA's Boost! programme was awarded to Isar Aerospace in November for flight demonstration of the Spectrum launch vehicle.[143] Another Germany-based launch service provider, Rocket Factory Augsburg extended its contract in Boost! signed in 2020, relying primarily on financial support of the Portuguese Space Agency.[144]

ESA's Boost! programme (Credit: ESA)

Finally, in previous years, several independent spaceport initiatives emerged in different European countries, with varying level of governmental support. During 2021, **European governments took additional steps, mostly regulatory clearances, to advance the development of new spaceport initiatives**:

- **United Kingdom** – the new legislation "Space Industry Regulations 2021" represented a major milestone in facilitating space launches from three upcoming UK spaceports in Cornwall, Wales and Scotland, in formally enabling the licensing and regulation of spaceflight activities and spaceports.[145]
- **Norway** – the Norwegian government gave the green light to establish a launch site for small satellites in Andøya, approving a funding of approx. €36 million to launch the site operator Andøya Space. [146]
- **Germany** – the federal government endorsed the plan of a small-satellite launch platform aboard a ship in German territorial waters in the North Sea, refusing to provide direct funding

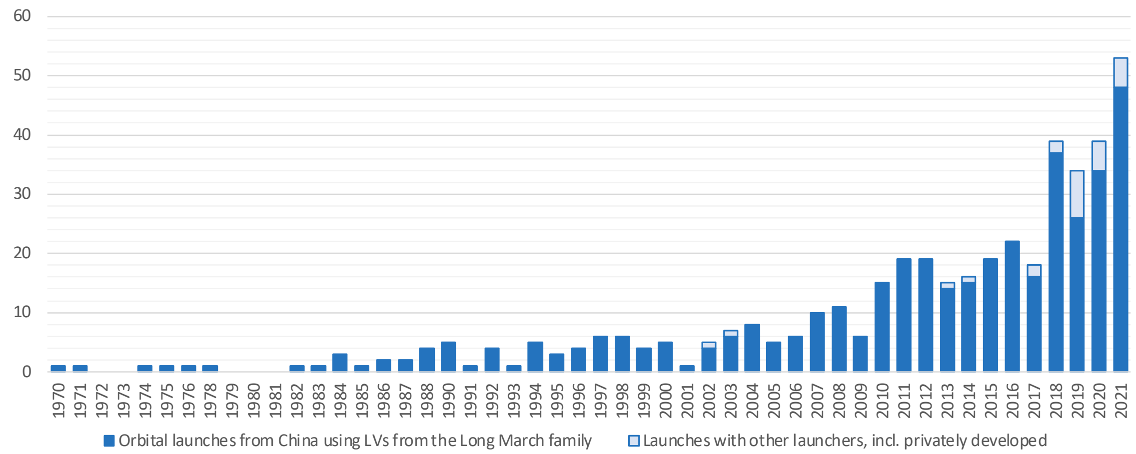
[139] ESA advances Vega rocket evolution beyond 2025, ESA, 2021
[140] Updating the 2020 Industrial Strategy: towards a stronger Single Market for Europe's recovery, EC, 2021
[141] ESA and CNES plan European Space Transportation Hub, space watch europe, 2021
[142] New ESA contracts to advance Prometheus and Phoebus projects, ESA, 2021
[143] ESA Boost! contract for flight demonstration of Spectrum launch vehicle, ESA, 2021
[144] Rocket Factory receives Portuguese support to extend ESA Boost! Contract, IRFA, 2021
[145] Spaceflight legislation and regulations, UK Civil Aviation Authorithy, 2021
[146] GREEN LIGHT FOR SATELLITE LAUNCH SITE IN NORWAY, Kongsberg, 2021

but agreeing to partially reimburse the German Offshore Spaceport Alliance in the regulatory approval process.[147]

- **Portugal** – the Portuguese Space Agency confirmed it is looking at building a spaceport on the Azores islands[148], however no additional formal details has been announced.

China – A milestone year for Long March rockets

In 2021, China reached a major space milestone in conducting the **400th orbital launch using launch vehicles of the Long March (Chang Zheng - CZ) rocket family.** A few additional launches in late December 2021 brought the total launch count at the end of 2021 to 405. The Chinese space programme has notably increased launch rate of CZ launch vehicles over time. While it took 37 years to conduct the first 100 orbital launches, the last 100 launches were performed in less than 3 years.



Timeline of China's 405 orbital launches with Long March rockets (Source: ESPI database)

In March, the newest variant from the Long March rocket family, **Long March 7A, performed its first successful flight,** launching a classified experimental satellite called Shiyan-9. The first launch attempt of a Long March 7A failed in March 2020. With payload capacity of 7 metric tons to GTO, the new rocket is intended to replace China's workhorse Long March 3B rocket for GTO launches.[149] The second successful launch of Long March 7A followed in late December 2021.

In April, a **Long March 6 mission was the first rideshare mission under the new Long March Express service** launched by the China Great Wall Industry Group Company, a subsidiary of China Aerospace Science and Technology Group.[150]

During 2021, additional details emerged on China's future heavy-lift launchers:

- In February, it was reported **China has officially approved the development of a super heavy-lift Long March 9**, with a lift capacity of 140 metric tons (50+ metric tons to lunar transfer orbit). Its first flight is expected in 2028-2030 timeframe.[151]
- In December, it was reported that a slightly smaller **new-generation crewed launch vehicle** (27 metric tons to lunar transfer orbit) **would launch for the first time around 2026**. This launcher was first presented as a concept in 2018 and will likely borrow technology and tooling from Long March 5.[152]

[147] German government gives benediction to North Sea orbital spaceport, but won't finance its development, SIR, 2021
[148] Portugal envision building a spaceport on the Azores islands, Room, 2021
[149] China's Long March 7A rocket launches on 1st successful flight, Space.com, 2021
[150] Long March 6 Launches 9 Satellites into Orbit, Parabolic Arc, 2021
[151] China officially plans to move ahead with super-heavy Long March 9 rocket, Ars Technica, 2021
[152] China's new rocket for crewed moon missions to launch around 2026, SpaceNews, 2021

With regards to spaceports, it was reported that **China is constructing a specially designed ship for space launches** from the seas, boosting its capacity to launch satellites and recover rocket stages.[153] The ship is expected to enter service in 2022. To further support perspectives of the space launch sector, the cities of Ningbo and Wenchang committed to the construction of new commercial spaceports.[154]

Russia – Transition to new launch vehicles underway

Major 2021 developments in the Russian space launch sector included the third Angara A5 test flight, R&D progress on new launch vehicles and multiple spaceport evolutions.

Russian launch vehicles

- In December, **Russia conducted the third Angara A5 demonstration mission**. The launch was not 100% successful, due to engine failure of a new Persei upper stage and could prompt additional test flights.[155] The troubled development of the Angara rocket family, envisioned to become a workhorse of Russian launch, was reported in a December newspaper article on the poor health of Russia's space sector. The article notes that while the Khrunichev Center agreed to deliver 10 booster cores for the Angara A5 rocket five years ago, the first five cores were delivered only in March 2021.[156]
- In September, the **development of the Yenisei super-heavy launch vehicle was suspended**. It was reported that work was stopped at the technical design stage and may be resumed in the future.[157]

Designs of selected Russia's launch vehicles (Credit: Ministry of Defence of the Russian Federation)

- **Russian MoD revealed initial technical specifications of a future small launch vehicle Irkut**, expected for maiden launch in the 2024-2026 timeframe from Plesetsk. The new rocket should be available in both expendable (23 metric tons) and reusable (25 metric tons) configurations, with maximum payload capacity of approx. 600kg to LEO.[158]

---

[153] China is building a new ship for sea launches to space, Space.com, 2021
[154] #SpaceWatchGL Column: Dongfang Hour China Aerospace News Roundup 5 April – 11 April 2021, Spacewatch.global, 2021
[155] Russia launches third and final Angara A5 demonstration mission, NASA Spaceflight, 2021
[156] A domestic newspaper warns of the Russian space program's "rapid collapse", Ars Technica, 2021
[157] Russia halts development of lunar super-heavy rocket, Yahoo News, 2021
[158] Russian "Irkut": will the new launch vehicle make it possible to impose competition on the West?, Top War, 2021

- **Roscosmos has completed the conceptual design of the Amur rocket**, a partially reusable and Russia's first methane-fuelled launch vehicle.[159] Reports suggested that cost for development and series of flight tests for the Amur launcher could reach up to $1 billion.[160]
- Following a series of static tests of the fuel tanks of the first stage[161], it was reported that **conceptual design of the next-generation medium-lift launcher Soyuz-5 has finished**, moving the project to next development phase.[162] The maiden launch of Soyuz-5 is expected in 2023-2024 timeframe.

Russian spaceports

- For future usage of Soyuz-5 and Soyuz-6 rockets, Russia and Kazakhstan agreed to build a new launch complex at the Baiterek launch facility at the Baikonur Cosmodrome.[163]
- Also concerning Baikonur, the Parliament of Kazakhstan has approved an extension on Russia's lease on the Baikonur space launch facility through to 2050, but with additional provisions to improve environmental aspects of spaceport utilisation.[164]
- At the Vostochny Cosmodrome, new work has been announced to adapt the launch pad and related facilities for future launches of the crewed Oryol spacecraft.

USA – First SLS launch postponed to 2022

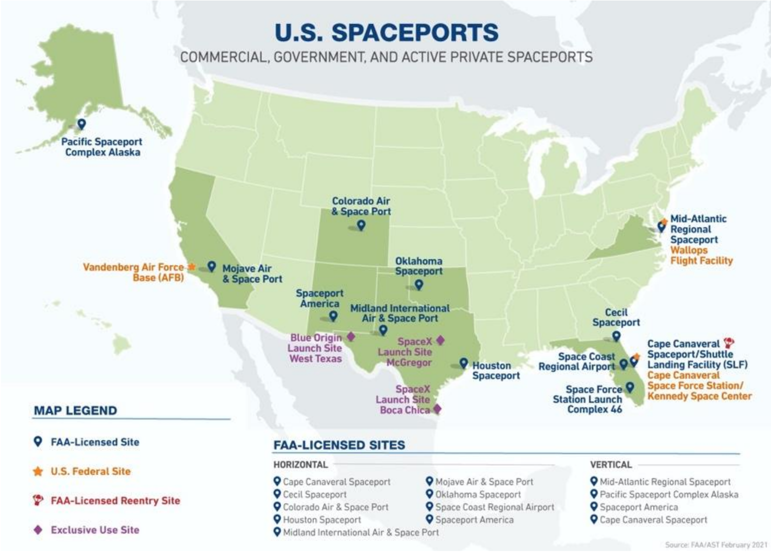
In March, NASA's upcoming giant rocket dedicated to the Artemis programme, the Space Launch System (SLS), was stacked up with all its major components for the first time.[165] Despite plans to conduct the first test flight in 2021, **the maiden launch of SLS was eventually postponed to mid-2022,** due to COVID-related delays and technical problems with the system's avionics.[166]

On the military side, the U.S. Space Force enlarged the list of companies eligible for responsive launch contracts within the **Orbital Services Program (OSP)-4**. ABL Space Systems Corp, Astra Space and Relativity Space were added to Aevum, Firefly, Northrop Grumman, Rocket Lab, SpaceX., ULA, VOX Space, and X-Bow Launch. OSP-4 is a follow-up to the OSP-3, with a $986 million envelope through 2028.[167]

On the regulatory side, **the Federal Aviation Administration (FAA) released launch and re-entry regulations**, with the goal streamline the licensing process for private sector launch and re-entry operations. The new rule arose from a directive of the National Space Council and aims to support greater innovation, flexibility and efficiency in commercial space operations.[168] After setting up a new spaceport office to support the growing number of launch sites in 2020, the FAA issued a new launch site operators license, also known as a spaceport license, to Camden County, Georgia, for the proposed Spaceport Camden.[169]

---

[159] Russia's new Amur rocket to embrace composites, 3D-printing and bionic design, TASS, 2021
[160] Russia To Spend $1 Billion On Reusable Methane-Powered Rocket, Aviation Week, 2021
[161] RCC Progress Completed Tests of Soyuz-5 First Stage, Parabolic Arc, 2021
[162] Conceptual design of future Soyuz-5 rocket finished in Russia, TASS, 2021
[163] Russia, Kazakhstan Sign Agreement to Build Soyuz-5 Launch Complex at Baikonur, Parabolic Arc, 2021
[164] Kazakhstan: Russia to keep using Baikonur until at least 2050, Eurasia.net, 2021
[165] NASA's new moon rocket, the Space Launch System, takes shape in giant hangar, Space.com, 2021
[166] The launch of NASA's titanic SLS rocket slips toward summer 2022, Ars Technica, 2021
[167] Air Force selects eight launch providers to compete for $986 million worth of orders, SpaceNews, 2021
[168] New Era of U.S. Commercial Space Transportation Begins, FAA, 2021
[169] FAA issues license for Georgia spaceport, SpaceNews, 2021



Spaceports in the USA, excluding newly licensed Spaceport Camden (Credit: FAA)

Japan – New reusable rocket project initiated

JAXA has initiated work on a new reusable rocket to reduce launch costs and increase competitiveness. More than 30 Japanese companies and institutions are taking part in this initiative. Maiden launch of this new launcher is anticipated in 2030.[170] In parallel, Japanese company Honda announced it is also developing a partially reusable launcher for small satellites with a test launch scheduled for 2030.[171]

India – Launch sector impacted by Covid-19, forcing delays

For the second year in a row, India struggled with conducting space launches, delaying scheduled missions due to Covid-19 restrictions. Both 2020 and 2021 saw only two launch attempts from India's Satish Dhawan Space Centre. In August, the second Indian orbital launch of 2021 (the first mission of GSLV Mark 2 in more than 2 years) ended in failure due to Cryogenic Upper Stage ignition error.[172]

The delays also moved the maiden launch of India's upcoming launcher, the "Small Satellite Launch Vehicle" (SSLV) from 2021 to the first half of 2022.[173] SSLV is in final stages of development and intended to serve the PSLV family, more specifically the on-demand, launch of small satellites. ISRO developed the SSLV with 500kg payload capacity to mid-inclination LEO, and 300kg to SSO.

Ukraine & Canada – Joint spaceport agreement

The two countries have initiated **the construction of a joint Ukrainian-Canadian spaceport in the Canadian province of Nova Scotia**. The partnership is implemented by the Canadian company Maritime Launch Services and involves the use of the Ukrainian carrier rocket Cyclone 4M.[174] The first launch from the new spaceport is expected in 2023.

South Korea – First flight of the domestic Nuri rocket

In October, South Korea **launched the Korean Satellite Launch Vehicle II (KSLV 2), known as Nuri, for the first time.** An anomaly resulting in third stage shut-off prevented the rocket to reach orbital velocity. Nuri is South Korea's first domestically developed space launch vehicle. Its development

[170] Japan launches reusable rocket project, chasing Musk's SpaceX, Nikkei, 2021
[171] Japanese carmaker Honda developing reusable rocket for LEO satellites, SpaceNews, 2021
[172] GSLV-F10 / EOS-03, ISRO, 2021
[173] ISRO developing SSLV with pvt participation, to be launched in Q1 of 2022, Business Standard, 2021
[174] Canada and Ukraine launch construction of spaceport, UKRINFORM, 2021

costs are estimated at approx. $1.5 billion, it uses liquid fuel and has payload capacity of 2.6 metric tons to 300km LEO.[175]

First launch of South Korea's Nuri rocket (Credit: KARI)

It was reported that **South Korea is also pursuing the development of an indigenous solid-fuel orbital launcher** for small and medium payloads, with envisioned first launch around 2024.[176]

Iran – Suborbital test launch of a new launch vehicle

The new launcher, Zoljanah, is a three-stage rocket based on the Sejil SRBM solid fueled missile, with two solid propulsion stages and one liquid one, and can be launched from a mobile platform.[177]

Brazil – Virgin Orbit to handle launches from the Alcântara spaceport

The Brazilian Space Agency (AEB) and Brazilian Air Force selected Virgin Orbit to bring orbital launch capability (Virgin Orbit's LauncherOne system) to the Alcântara Launch Center on Brazil's northern coast near the equator. The AEB expects the first launches to take place in the first half of 2022.[178]

1.2.2 Application programmes

Positioning, Navigation and Timing

Galileo and EGNOS

In January, the **European Commission selected Thales Alenia Space and Airbus Defence & Space to design and build the first batch of Galileo 2nd Generation satellites (G2G),** shutting out the incumbent manufacturer OHB, responsible for 34 of the 38 first-generation Galileo satellites.[179] After OHB's appeal and subsequent court procedures, ESA eventually signed contracts with both winners, awarding:

- €770 million to Thales Alenia Space for six G2G satellites,
- €700 million to Airbus Defence & Space for six G2G satellites.

Galileo satellites 27 and 28 in their launch configuration onboard Soyuz-2 (Credit: ESA)

In December 2021, **Galileo satellites 27 and 28 were launched** from Europe's spaceport in French Guiana, using the Soyuz-2 launcher. These two satellites are the first of a total of twelve Galileo 'Batch-3' satellites, manufactured by OHB. The satellites are operated by SpaceOpal for EUSPA and will act as backups and spares.[180] In November, a first prototype satellite for Galileo, GIOVE-A, has been formally decommissioned after 16 years of operational lifetime.[181]

In late 2020 and throughout 2021, **Galileo started testing the Open Service Navigation Message Authentication (OSNMA),** an authentication mechanism that allows a GNSS receiver to verify the authenticity of the GNSS information.[182] The official provision of OSNMA is expected for 2022-2023. In March, EUSPA published the Galileo High Accuracy Service (HAS)

[175] South Korea launches first homegrown space rocket Nuri, BBC, 2021
[176] (LEAD) S. Korea to launch homegrown solid-fuel space rocket by 2024, Yonhap News Agency, 2021
[177] Iran launches new rocket on suborbital test flight: report, Space.com, 2021
[178] Virgin Orbit selected to bring orbital launch capabilities to Brazil, Virgin Orbit, 2021
[179] Galileo Second Generation, ESA, 2021
[180] Arianespace launches Galileo navigation satellites in final mission before Webb, Spaceflight Now, 2021
[181] Galileo prototype GIOVE-A switched off after 16 years in orbit, ESA, 2021
[182] Galileo OSNMA position opens, TeleOrbit authenticates with Goose, GPS World, 2021

Information Note, detailing main characteristics and features of Galileo HAS, which is expected to be fully operational by 2024.[183]

Addressing a long-term outlook, in May, the European Commission awarded two contracts to consortia led by Thales Alenia Space (€320,000) and GMV (€350,000) **to assess the feasibility of an integrity service to complement the High Accuracy service of the European Global Navigation Satellite System** (Galileo + EGNOS).[184] This complementing integrity service is implemented on top of baseline EGNSS services in the 2030+ timeframe. Its main objective is to cover the evolving needs in autonomous transport.[185]

Finally, concerning EGNOS-specific developments in 2021:

- Iceland (not an EU member state) joined the EGNOS Programme, as a new participating State.[186]
- **EUSPA awarded a 15-year €100 million contract to Eutelsat to develop and operate the next-generation EGNOS satellite navigation overlay service**. The new service (EGNOS Version 3) will make several improvements, including integrating signals from Galileo in addition to GPS signals. The payload will be hosted on Eutelsat's Hotbird 13G, whose launch was postponed to 2022.[187]
- **EGNOS ground segment sites (in Spain and Italy) underwent a major modernisation of processing facilities** to ensure further robustness and integrity of EGNOS services.[188]

GPS

The U.S. programme added **one new satellite to orbit in 2021, GPS III SV-05**, which was declared operational in September.[189] Its launch in June provided by SpaceX's Falcon 9 marked the first-time that a reused booster has been used for a National Security Space Launch (NSSL) mission.

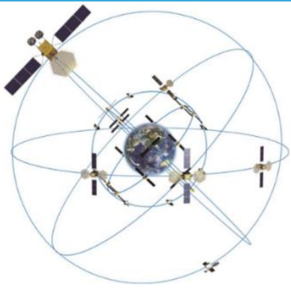
A few major contracts were awarded to the U.S. industry for the further development of the GPS system:

- In May, the U.S. Space Force awarded a **$228 million to Raytheon Intelligence** and Space for the development of the operational control ground systems for the latest generation of GPS 3 satellites.
- In November the U.S. Space Force exercised its contract option valued at approximately **$737 million to Lockheed Martin** for the procurement of three additional GPS IIF satellites.[190]
- In December the U.S. Space Force awarded **$329.3 million to Boeing** to support operations of Global Positioning System satellites for the next 10 years.[191]
- In May and December, The Defense Logistics Agency (DLA) awarded **2 contracts worth $641 million to BAE Systems** for advanced M-Code (military signal) GPS devices, for the U.S. DoD and its allies.[192]

---

[183] Galileo High Accuracy Service (HAS), EUSPA, 2021
[184] Thales Alenia Space to assess feasibility of EGNSS integrity service, GPS World, 2021
[185] ITHACA Integrity Service Complementing EGNSS High-Accuracy, EUSPA, 2021
[186] EGNOS: an evolving satellite navigation system that anticipates user needs, EUSPA, 2021
[187] Eutelsat awarded €100m contract for next-gen European navigation overlay service, SpaceNews, 2021
[188] EGNOS improves its robustness and efficiency with modernized processing facilities, EUSPA, 2021
[189] GPS III SV05 Receives Operational Acceptance, U.S. Space Force, 2021
[190] U.S. Space Force contracts Lockheed Martin for 3 more GPS IIIF satellites, GPS World, 2021
[191] Boeing wins $329 million contract to support orbiting GPS satellites, SpaceNews, 2021
[192] $316 million contract to deliver hardened military GPS modules, BAE Systems, 2021

BeiDou



Structure of the BDS-3 constellation (Credit: Jun Xie & Chengbin Kang[196])

No major infrastructure-related developments on China's BeiDou GNSS system in 2021 have been publicly advertised. China has reached a major BeiDou milestone a year ago, in 2020, by completing the deployment of the 3rd generation of its BeiDou system (BDS-3), improving the service availability and precision. **The current BDS-3 infrastructure consists of a total of 30 satellites**, including 24 MEO satellites, 3 GEO satellites and 3 inclined-GSO satellites.[193]

In September a status update by a senior Chinese official[194] revealed that:

- Since its formal commissioning in 2020, "BDS-3 has maintained steady operation and top-class service performance"
- aside from standard PNT service, BDS-3 also "offers global and regional short message communication, international search-and-rescue, precise point positioning, satellite-based augmentation and ground-based augmentation services."

On the diplomatic front, China organised two events to increase the international uptake of BeiDou:

- **3rd China-Arab States BeiDou Navigation Satellite System (BDS) Cooperation Forum**, welcoming representatives of 17 Arab Nations and 4 international organisations.[195]
- **1st China-Africa BDS Cooperation Forum**, welcoming representatives of nearly 50 African nations, as well as the African Union. One of the outcomes of the forum was a joint agreement to take advantage of the BeiDou system to enhance Africa's social, economic, and environmental developments.[196]

GLONASS

In 2021, Russia started a new federal program for developing a **GLONASS dual-use satellite navigation system**. Its main goal is to develop a new structure of the GLONASS system, increasing the system's reliability and accuracy for the Eastern Hemisphere. The launch of the first spacecraft is estimated in 2025, while the full deployment the constellation is expected by the end of 2027.[197]

The GLONASS constellation currently consists of spacecrafts of the GLONASS-M generation and of new-generation GLONASS-K.[198] Russia plans to deploy remaining GLONASS-K satellites and 15 GLONASS-K2 satellites by 2030.[199] **The launch of the first Glonass-K2 satellite has been postponed to 2022.**[200] News also indicated a continued GNSS cooperation between Russia and China.[201] Roscosmos will install a ground monitoring station in Shanghai, while China will likely place equivalent stations in Russia.[202]

[193] Jun Xie, Chengbin Kang.Engineering Innovation and the Development of the BDS-3 Navigation Constellation[J].Engineering,2021,7(5):558-563.
[194] China's Beidou system offers 7 different user services, China Daily, 2021
[195] China, Arab states to boost collaboration on Beidou, China Daily, 2021
[196] China and Africa to Strengthen Collaboration on Beidou Satellite System, Space in Africa, 2021
[197] GLONASS Program for 2021–2030, Defence Club, 2021
[198] GLONASS constellation status, Roscosmos, 2021
[199] Николай Тестоедов: ИСС им. Решетнева полностью обеспечено заказами на 2020 год, TASS, 2021
[200] Launch of first Glonass-K2 satellite postponed until 2022, GPS World, 2021
[201] China and Russia cooperate on rival to GPS, The Diplomat, 2021
[202] Russia Will Install GLONASS Monitoring Stations In China; China to Reciprocate, Inside GNSS, 2021

Status and progress of other space-based PNT initiatives around the world

After scrubbing the ambitions of a national PNT system in 2020, **the UK continued with a few initiatives**:

- A UKSA-funded "UK SBAS TESTBED" project was launched under ESA's NAVISP programme to "establish and operate a new national (SBAS) capability" with Inmarsat as the prime contractor.[203]
- As part of UKSA's Space-Based PNT Programme, £2 million was awarded to 6 companies to enhance national PNT solutions and to reduce the country's dependence on external solutions.[204]

Notable developments in other countries included the following:

- **Japan** launched QZS-1R satellite to its QZSS constellation, replacing QZS-1, in orbit since 2010.[205]
- **Turkey**'s new national space programme notes that Turkey will develop a regional PNT System.[206]
- **India**'s Draft Satellite Navigation Policy 2021 showed that India seeks to greatly foster global availability and usage of its NavIC regional satellite navigation system.[207]

Finally, concerning Satellite-Based Augmentation System (SBAS) - **as of 2021, there are four operational SBAS** with plans for continued improvements, and **five SBAS in various phases of development**:[208]

Operational SBAS	SBAS in development
1. (U.S.) Wide Area Augmentation System (WAAS) 2. (Europe's) Geostationary Navigation Overlay Service (EGNOS) 3. (Japan's) Quasi-Zenith Satellite System (QZSS) 4. (India's) GPS Aided Geostationary Earth Orbit (GEO) Augmented Navigation (GAGAN)	5. (Russia's) System of Differential Correction and Monitoring (SDCM) 6. (China's) BeiDou Satellite Based Augmentation System (BDSBAS) 7. (Korea's) Augmentation Satellite System (KASS) 8. (Australia's) Southern Positioning Augmentation Network (SouthPAN) 9. SBAS for Africa & Indian Ocean programme

Remote Sensing

European developments (Copernicus, EUMETSAT, ESA's EO programmes)

In EU's flagship Earth Observation programme, **Copernicus**:

- The European Centre for Medium-Range Weather Forecasts (ECMWF) renewed an agreement with the European Commission to **continue implementing Copernicus' Climate Change Service (C3S) and Atmospheric Monitoring Service (CAMS)** for the next seven years.[209]

[203] 019 - UK SBAS TESTBED, ESA, 2021
[204] Britain charts a new course for satellite navigation, SpaceNews, 2021
[205] Japan launches H-IIA with QZS-1R satellite, NASA Spaceflilght, 2021
[206] Turkey Unveils National Space Program, Anadolu Agency, 2021
[207] India seeks global adoption of its NavIC system, GPS World, 2021
[208] SBAS Worldwide, Federal Aviation Administration, 2021
[209] ECMWF and European Commission renew contract for Copernicus services, ECMWF, 2021

- Negotiations on UK's participation in the Copernicus programme post-Brexit continued throughout the year, however without conclusive settlement as of end of 2021, leading to the threat of more than €700 million gap in funding envisaged for the programme in the 2021-2027 timeframe.[210]
- Finnish firm ICEYE became a new Contributing Mission partner to the programme. [211]
- **EUMETSAT signed a 7-year, €735 million Contribution agreement with European Commission** (Copernicus 2.0 agreement). The agreement will entrust EUMETSAT with continued operations and utilisation of the existing Copernicus Sentinel satellite series 3, 4, 5 and 6.

Concerning **EUMETSAT**, there were additional developments in 2021:

- In September, **EUMETSAT released its new long-term strategy "Destination 2030"**, presenting following core objectives: 1) to deploy the next-generation meteorology satellites in GEO (MTG) and polar (EPS-SG) orbits, 2) to continue and strengthen cooperation with the EU and space agencies worldwide allowing access to more data and analysis, 3) to strengthen EUMETSAT´s flexibility, efficiency, and innovative spirit in order to be ready for the challenges ahead.[212]
- Following the launch of a **new pilot programme, EUMETSAT made its first commercial data acquisition**, contracting Spire Global for access to company's radio occultation data. [213]
- EUMETSAT Council approved a €58 million investment (2022 – 2027) to increase societal benefits of its satellite data through better services.[214]

Within **ESA's Living Planet Programme** of "Earth Explorers", and "Earth Watch" class of missions: [215]

- The Harmony mission (two satellites that orbit in formation with one of the Copernicus Sentinel-1 satellites) was pre-selected for the tenth Earth Explorer mission, to be confirmed in 2022.
- The selection process for Earth Explorer 11 was narrowed down to 4 final proposals.

ESA also awarded **OHB Sweden a €32 million contract for its Arctic Weather Satellite**. The upcoming mission will ensure almost instant weather forecasting updates in the Arctic region, with the agency potentially projecting to build a constellation of satellites for this purpose.[216] During the COP26, **ESA and the EU revealed plans for a new satellite-enabled comprehensive tool to track human-made greenhouse gas emission**, expected to be fully operational by 2026.[217]

EUMETSAT's new long-term strategy (Credit: EUMETSAT)

[210] Commission urged to bridge funding gap for 'green' space missions, ENDS Europe, 2021
[211] ESA to Integrate Iceye's SAR Data into Copernicus Mission, Satellite Today, 2021
[212] EUM control room Challenge of protecting against extreme weather shapes new EUMETSAT strategy, EUMETSAT, 2021
[213] In a first, EUMETSAT will buy meteorological data from a commercial supplier, EUMETSAT, 2021
[214] €58 million for innovative satellite data applications, EUMETSAT, 2021
[215] ESA picks next Earth Explorer mission: Harmony, UN, 2021. Also, 4 mission ideas to compete for Earth Explorer 11, ESA, 2021
[216] OHB und ESA unterzeichnen Vertrag über Arctic Weather Satellite, OHB, 2021
[217] Europe announces new satellite constellation to track human-made greenhouse gas emissions, Space.com, 2021

Notable 2021 launches

The table below lists publicly owned or funded remote sensing satellites that were launched in 2021.

Satellite name	Country involved	Description
Arktika M-1	Russia	The first of a new line of HEO-operating meteorology satellites (~2,100kg) designed to provide persistent weather data on the Arctic.[218]
Amazônia-1	Brazil	The first EO satellite to be completely designed, integrated, tested and operated by Brazil. [219] It works in visible and NIR spectra, has a mass of 637kg and its primary objective is to monitor deforestation.
CAS500-1	South Korea	The first of two 500kg spacecraft and country's first fully domestically developed mid-sized multi-purpose EO satellite.[220]
CERES (1, 2 & 3)	France	CERES is the first operational ELINT system for the French defence agency DGA. The three satellites launched have each mass of 446kg.[221]
Landsat 9	USA	NASA's most recent addition to its long-existing Landsat program. The 2,711kg spacecraft will replace the Landsat 7 satellite and continue the program's role of monitoring & managing land resources,[222]
NorSat-3	Norway	A 16.5kg satellite which will enhance Norway's monitoring of maritime traffic. Similarly, to its predecessors, it is equipped with an AIS receiver to detect signals from ships at sea.[223]
Pion NKS	Russia	The first of Russia's new-generation naval intelligence satellites, part of the Liana programme. With estimated mass of ~6,500kg, it is equipped with both passive and active reconnaissance systems.[224]
SDGSAT-1	China	A 740kg satellite developed by Chinese Academy of Sciences will use thermal infrared, low light level and multispectral cameras to collect data to help evaluate the Sustainable Development Goals indicators.[225]
TROPICS (Pathfinder)	USA	A 3U pathfinder for a constellation of 6 cubesats that will measure temperature and moisture profiles and precipitation in tropical systems with unprecedented temporal frequency.[226]

Table 2: Notable remote sensing satellites (publicly owned, funded or developed) launched in 2021

In the USA, 2021 also saw two classified launches for the National Reconnaissance Office (NRO): missions L-82 and L-111. In India, the GSLV launch of the EOS-03 satellite ended in a failure.

[218] Soyuz launches first Arktika-M satellite, Russian Space Web, 2021
[219] About the satellite, INPE, 2021
[220] CAS500 marks South Korea's first all-Korean mid-sized practical satellite, Korea Herald, 2021
[221] CERES 1, 2, 3, Gunter's Space Page, 2021
[222] NASA launches powerful Landsat 9 satellite to monitor climate change, forest cover and more, Space.com, 2021
[223] Norway's new satellite detects radar signals from ships, Norwegian Space Agency, 2021
[224] Russia's Soyuz launches Pion-NKS naval intelligence satellite, NASA Spaceflight, 2021
[225] China launches sustainable development satellite SDGSAT-1 to study Earth from space, Space.com, 2021
[226] TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats), eoPortal, 2021

New China's remote sensing satellites in orbit

As part of China's impressive launch cadence in 2021 (53 orbital launches), **China's civil and military institutions deployed more than 40 remote sensing satellites**, with an overarching majority of them falling within Gaofen, Fengyun, Shijian, Tianhui, TSJW, Yaogan and Ziyuan satellite families:

Family	Description	Satellites launched in 2021
Gaofen	A series of various high-resolution and very high-resolution imaging satellites (optical, multispectral, hyperspectral, SAR) for the state-sponsored program China High-resolution Earth Observation System (CHEOS).	• Gaofen 3-02 (Nov) • Gaofen 5-02 (Sep) • Gaofen 11-03 (Nov) • Gaofen 12-02 (Mar) • JILIN-1 Gaofen 02D (Sep) • JILIN-1 Gaofen 02F (Oct) • JILIN-1 Gaofen 03D x 3 (Sep)
Fengyun	China's meteorology satellites, both in SSO and GEO variants	• Fengyun 3E (Jul) • Fengyun 4B (Jun)
Haiyang	A series of ocean monitoring satellites in SSO	• Haiyang-2D (May)
Shijian	Believed to be a SIGINT SSO constellation (Shijian-6)	• Shijian-6 05A & O5B (Dec)
Tianhui	Multiple series of LEO satellites operated by PLA, with various capabilities (e.g., Tianhui 1– visible and IR mapping, Tianhui 2 – radar surveying (InSAR))	• Tianhui-1D (Jul) • Tianhui-2 02A & 02B (Aug) • Tianhui-4 (Dec)
TSJW	Highly classified GEO satellites believed to have SIGINT / early warning capabilities for detection of missile launches	• TJSW 6 (Feb) • TJSW 7 (Aug) • TJSW 9 (Dec)
Yaogan	A comprehensive remote sensing satellite family mainly used for a wide range of applications (e.g., science, land survey, crop yield assessment, or disaster monitoring). Depending on individual mission, Yaogan satellites carry various types of sensors and operate from different LEO orbits. Analysts perceive Yaogan satellites serve both civil and military users.	• Yaogan 30 08A, 08B & 08C (May) • Yaogan 30 09A, 09B & 09C (Jun) • Yaogan 30 10A, 10B & 10C (Jull) • Yaogan 31 02A, 02B & 02C (Jan) • Yaogan 31 03A, 03B & 03C (Feb) • Yaogan 31 04A, 04B & 04C (Feb) • Yaogan 32A & 32B (Nov) • Yaogan 34 (Apr) • Yaogan 35A, 35B & 35C (Nov)
Ziyuan	Different-purpose satellites (some together with Brazil), including with hyperspectral capabilities.	• Ziyuan I-02E (Dec)

Table 3: China's launch cadence of remote sensing satellites in 2021 (Source: ESPI Database)

Other news related to remote sensing programmes (upcoming or newly announced)

China started work on a new **constellation of 36 LEO remote sensing satellites** for forecasting natural disasters and monitoring urban emergencies. The full deployment is expected in 2023.[227]

BRICS countries (Brazil, Russia, India, China, South Africa) **signed a new agreement to establish a network of remote sensing satellites** to help better deal with societal challenges and crises.[228]

Canada's government published a strategy for satellite Earth observation titled "Resourceful, Resilient, Ready", to guide Canada's actions related to EO data, technology, and partnerships.[229]

The Polish armed forces created a consortium to build three nanosatellites, with a 5m spatial resolution. Leading the consortium is Creotech Instruments. The project is valued at $18 million and is expected to be deployed in orbit in 2024, in the framework of the Polish Imaging Satellites (PIAST) project.[230]

The **U.S. Air Force**, through its AFVentures Strategic Funding Increase program, **awarded a $19.3 million contract to Tomorrow.io to fill in critical weather sensing gaps** through company's EO constellation.[231]

Satellite communications programmes

Governmental actors increasingly pursuing or supporting LEO constellation initiatives

Governmental actors around the world have stepped up their support to large LEO constellation initiatives, using different mechanisms.

The European Commission advanced the development of its secure connectivity system

For details on the emerging EU's space-based connectivity initiative, see section 1.1.1 of this Yearbook.

China established a state-owned company to develop and operate broadband mega constellation

In May, the Chinese State-Owned Assets Supervision and Administration Commission (SASAC) created the China Satellite Network Group, a company tasked with developing and operating a LEO broadband constellation.[232] The news comes a few months following the submission of an ITU filing from China for spectrum rights for two constellations totalling 12,992 satellites.

China's actions are in line with government's efforts to insert satellite broadband into broader objectives under the Belt and Road Initiative and 14th Five-year Plan. It is believed that the national LEO constellation initiative has superseded the previously announced Hongyan and Hongyun LEO constellation projects by CASC and CASIC (infrastructure from these constellations may form part of the new national project).

Canadian government provided C$1.44 billion stimulus to Telesat's Lightspeed LEO constellation

The funding will be composed of a C$790 million loan and C$650 million in preferred equity. In exchange, Telesat has committed to invest C$1 billion in capital expenditure for the constellation and to increase its number of employees in Canada.[233]

[227] China to build satellite constellation for natural disaster observation, China Daily, 2021
[228] BRICS to set up remote-sensing satellite network, China Daily, 2021
[229] Canada's Strategy for Satellite Earth Observation, Government of Canada, 2021
[230] Polish Armed Forces enlist industry consortium for imaging nanosatellites, SpaceNews, 2021
[231] USAF contracts Tomorrow.io for spaceborne weather data, Air Force Technology, 2021
[232] China establishes company to build satellite broadband megaconstellation, SpaceNews, 2021
[233] Government of Canada announces $1.44-billion investment in Telesat, Government of Canada, 2021

Canada's minister of innovation, science and industry announcing country's investment in Lightspeed (Credit: Twitter)

In addition to financial support provided by the federal government:

- The Government of Ontario invested C$109 million to Lightspeed in return of an investment by Telesat of C$20 million for the expansion of its Ontario facilities and an increase of its staff in the province. [234]
- The Government of Québec signed an MoU with Telesat, providing an investment in Lightspeed worth C$400 million.[235]

Rwanda files application with ITU to license 327,320 satellites

Rwanda filed an application with the ITU to license two fleets of LEO satellites named Cinnamon 217 and 937, counting a total of 327,320 spacecrafts. The Rwanda Space Agency noted it is "a necessary step for any nation hoping to become operational in space". Rwanda's filing has surprised some Heads of State in the African Union as well as the South-African space agencies who were not solicitated for support.[236]

Germany's Federal Network Agency files ITU application for Kepler's Aether-C

The submission outlines Kepler's plans to develop approx. 114,582 S-band satellites. Kepler CEO noted the ITU filing is a result of several years of cooperation with the German regulator.[237]

The table below provides a summary of major governmental actions in support of LEO constellations:

Country	Description of support measures
Canada	Federal government is investing C$1.44 billion in Telesat Lightspeed
China	The government has added satellite internet to a list of "new infrastructures" required for China's national development. A new state-owned company was also established to oversee the development of domestic LEO broadband constellation
European Union	European Commission has pushed for EU's own, independent, multi-orbit satcom constellation initiative that would serve various user needs. The project will probably become another component of EU's Space Programme.
Germany	Telecommunications regulator Federal Network Agency filed an ITU application for Kepler's Aether-C communication hardware.
Russia	Russia's federal government provides co-funding for the Sfera constellation project, currently under development by Roscosmos.
Rwanda	Rwanda Space Agency has filed an ITU-application for two satellite constellations.

[234] Ontario Partners With World-Class Satellite Operator to Bring High-Speed Connectivity Across Province, Ontario, 2021
[235] Telesat Lightspeed to Receive $400 Million Investment from the Government of Québec, Telesat, 2021
[236] African Union, South African space agencies: We were blindsided by Rwanda's 327,000-satellite ITU filing, SIR, 2021
[237] Kepler Communications CEO Mina Mitry, Acast, 2021

UK	UK government has become one of the co-owners of the OneWeb constellation through a $500 million investment.
USA	Pentagon's Space Development Agency is developing a comprehensive National Defense Space Architecture in LEO, aiming to deploy multiple constellations that collectively could amount to thousands of satellites.

Table 4: Selected Governmental support schemes to large LEO constellations

Other news concerning satellite communications programmes

France's Syracuse 4A was successfully launched

In October, France launched its new state-of-the-art Syracuse 4A military communications satellite (will be complemented by 4B and 4C satellites in the future). Syracuse 4A is designed to be compatible with the existing infrastructure, while also delivering **expanded capacity and new functions for armed forces, greater throughput, capacity and flexibility, along with a broader coverage zone**.[238]

Syracuse 4A illustration (Credit: Thales Alenia Space)

Earlier in the year, the French Ministry of the Armed Forces contracted Thales (prime contractor for Syracuse 4A satellite) to supply the second part of the ground segment of the Syracuse 4 communications system (the first part was agreed already in 2019).[239] In addition, Airbus has also won a ground segment-related contract worth approx. €100 million.[240]

Indonesian government secured $545 million financing for Satria-1 satellite

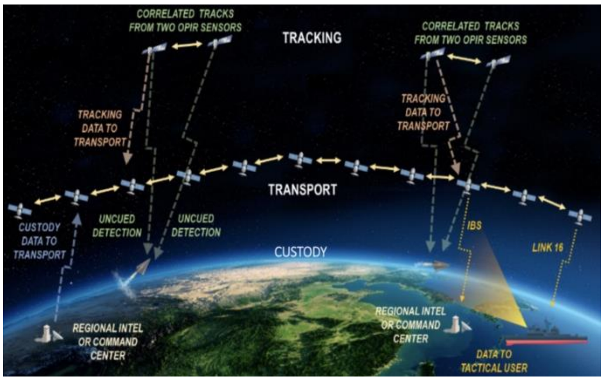
The Indonesian government completed the financing of the Satria-1 broadband satellite after a one-year delay due to Covid-19. The government received financing from institutions such as Bpifrance, Banco Santander, the Korean Development Bank and the Asia Infrastructure Investment Bank. The financing is composed mainly of loans worth approx. $431 million with a second tranche of $114 million in equity. Satria-1 will supply broadband services over the entire Indonesian territory with the aim of also bridging the digital divide in the country. The broadband satellite is projected to be manufactured and delivered by Thales Alenia Space, following a contract award completed in 2019, and launched by SpaceX in 2023.[241]

U.S. Space Development Agency launches procurement for new batch of LEO satellites

SDA has progressed in implementing the vision of National Defense Space Architecture, launching a call for proposals from satellite manufacturers to compete for contracts to build as many as 144 satellites, to constitute a proliferated broadband constellation known as the Transport Layer.[242]

[238] Two Communications Satellites Built By Thales Alenia Space Now In Orbit, Thales, 2021
[239] French Armed Forces To Rely On Thales Expertise To Expand Their Secure Satellite Communication Capabilities, Thales, 2021
[240] Airbus wins its first Syracuse IV ground segment programme contract, Airbus, 2021
[241] Indonesia completes $545M financing for Satria-1 Ka-band broadband satellite; ITU deadline extension expected, SIR, 2021
[242] SDA wants 3 bidders to develop $2B, 144-satellite Transport Layer LEO constellation. Deadline: Oct. 1, Space Intel Report, 2021

The procurement was relaunched in October after a protest raised by Maxar. In December, SDA initiated another procurement, issuing a draft solicitation outlining plan for 28 missile-tracking satellites under Tracking Layer. These Tranche 1 satellites, to be launched in 2024, would complement the Tranche 0 batch of 8 satellites, currently under development by L3 Harris.[243]



National security space architecture concept (Credit: Space Development Agency)

The Spanish Council of Ministers approves a €32.4 million allocation for SECOMSAT

The Spanish Council of Ministers authorised a Framework Agreement to support the Spanish Military Communications Satellite System (SECOMSAT). The €32.4 million funding is projected to be used for the maintenance of the satellite terminals as well as to ensure the operational availability of SECOMSAT. The system allows deployed forces to access their command and logistical support organisations through the joint military telecommunications system (SCTM).[244]

G7 countries and other partners agreed to develop quantum encryption satellite network

At the G7 summit in Cornwall, an international consortium of governments and private organisations was formed to develop a Federated Quantum System (FQS), based on the one British start-up Arqit is developing for its customers. On top of G7 countries (Canada, France, Germany, Italy, Japan, UK, USA), the governments of Japan, Canada, Italy, Belgium and Austria are also partnering on the initiative. [245]. **UK Space Agency (UKSA) awards £32 million to support development of beam-hoping satellite.**

UKSA awarded £32 million to an industrial consortium led by OneWeb to develop a new generation of satellites capable of switching its coverage area in real time.[246] The funding was awarded in the framework of ESA's Sunrise programme and aims to advance technologies to better adapt to possible surges in demand in different areas. The first "JoeySat" demonstration satellite will be launched in 2022.

1.2.3 Space science and exploration programmes

Successful launch and deployment campaign of the James Webb Space Telescope

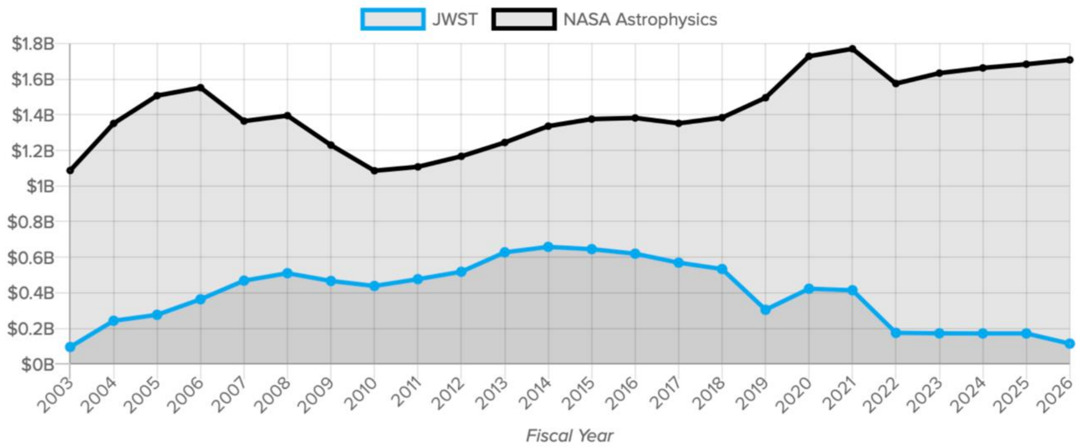
After major delays and cost overruns, the long-awaited James Webb Space Telescope (JWST) was finally launched on Christmas Day onboard the Ariane 5 rocket from the European spaceport in French Guiana.[247] The new space-based infrared observatory will conduct its operations from Sun-Earth L2 point. Webb's science goals range from observing the early universe and mapping

JWST (Credit: NASA)

[243] Space Development Agency to acquire 28 missile-tracking satellites to launch in late 2024, SpaceNews, 2021
[244] Autorizado el acuerdo para el sostenimiento de SECOMSAT, Actualidad Aerospacial, 2021
[245] Governments ally for federated quantum encryption satellite network, SpaceNews, 2021
[246] UK companies join forces to build revolutionary beam-hopping satellite, Gov.uk, 2021
[247] NASA, ESA, CSA successfully launch the historic James Webb Space Telescope, NASA Spaceflight, 2021

lifecycles of stars and galaxies to studying habitable exoplanets orbiting nearby stars.

JWST is an international partnership led by NASA in collaboration with ESA and CSA. The estimated development cost has dramatically increased since programme inception in late 1990s, reaching approx. $11 billion (adjusted for inflation), with €700 million in ESA contributions and a C$200 million CSA contribution, including 5 years of operations costs.[248] The astronomy community's high science expectations are based on telescope's unprecedented mirror size (6.5 metres) and 4 state-of-the-art scientific instruments, two of which (NIRSpec & MIRI) have been developed or co-developed by ESA. In years leading to the launch JWST also underwent turbulent periods in the development phase, including concerns of cancellation. Over more than two decades, JWST absorbed a major portion of NASA's astrophysics budget.



Evolution of JWST cost compared to NASA's total astrophysics spending (Credit: Planetary Society)

New strategic outlooks for European and U.S. space science endeavours.

On June 11th, ESA published the **final report of the Voyage 2050 Senior Committee**[249] to guide the selection of Agency's science missions for the timeframe 2035-2050. The key themes selected by the Committee for ESA's core large-class missions are focused on:

- Moons of the Giant planets,
- Temperate exoplanets,
- New physical probes of the early Universe.

The missions that will be undertaken in the framework of the plan will be selected following the issue of individual calls for proposals.[250] The Committee also identified technologies such as cold atom interferometry, or improved power sources that are posed to play a major role in missions beyond 2050.

In the USA, **"Pathways to Discovery in Astronomy and Astrophysics for the 2020s," colloquially known as the decadal survey[251],** was released in November, continuing in the tradition of decadal exercises across multiple science themes, to guide future efforts of NASA, NSF or other U.S. institutions. Recommendations from decadal surveys are often translated into NASA activities for the forthcoming years.

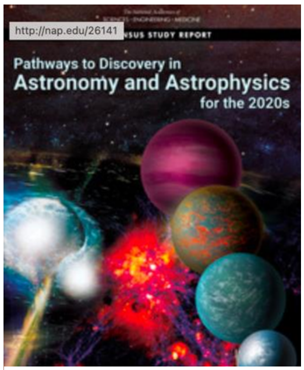
[248] How much does the James Webb Space Telescope cost?, Planetary Society, 2021
[249] Voyage 2050 Final recommendations from the Voyage 2050 Senior Committee, ESA, 2021
[250] "Call for Membership in the Expert Committee for the Large Mission Covering the Science Theme "Moons of The Giant Planets" published in December initiated first steps towards this theme as the first of proposed Voyage 2050 priority domains. This is in line with announcing of the Icy Moons sample return theme of under the concept of Inspirators, unveiled by ESA DG also in 2021.
[251] Decadal Survey on Astronomy and Astrophysics 2020 (Astro2020), NASEM, 2021

The 2020 astrophysics decadal survey identified 3 priority science areas:[252]

- Pathways to habitable worlds,
- New windows on the dynamic universe,
- Unveiling the drivers of galaxy growth.

The Report recommended technologies and programmes to address these scientific goals:[253]

- Continue existing programs and those under active development[254]
- Develop a 6-meter telescope capable of detecting biosignatures in the atmospheres of roughly 100 Earth-sized exoplanets, launching by the mid-2040s,
- Initiate a new Great Observatories Technology Maturation Program to lower the risk and cost of future space telescope programs,
- Begin a new "mid-sized" ($1.5 billion) space telescope programme, launching one per decade,
- Complete at least one extremely large ground-based telescope currently in development,
- Invest in the scientific community, and improve efforts to recruit a more diverse workforce.



2020 Astrophysics Decadal Survey
(Credit: NASEM)

Three new Venus missions selected by NASA and ESA

Dedicated space missions to Venus have been rather rare in the past decades. This has changed in 2021 with the selection of three new missions to explore and better understand Venus. In a final selection from 4 concepts under the Discovery Program, **NASA has selected two Venus missions** (first NASA missions to the planet since the 1980s), both expected to launch in the 2028-2030 timeframe:[255]

- **DAVINCI+ (Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging)** mission, relying on an atmospheric probe to measure the composition of Venus' atmosphere to understand how it formed and evolved, as well as determine whether the planet ever had an ocean.
- **VERITAS (Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy)** orbiter to map Venus' surface to determine the planet's geologic history, to map Venus's rock type, and to determine whether active volcanoes are releasing water vapor into the atmosphere.

At ESA level, the Agency has selected EnVision Venus orbiter as the fifth medium-class mission in ESA's Cosmic Vision plan, targeting a launch in the early 2030s. EnVision will investigate Venus from its inner core to upper atmosphere to determine how and why Venus and Earth evolved so differently.[256]

Three successful arrivals at Mars and a new Chinese Mars sample return mission in sight

All three Mars missions launched in 2020 (NASA's Mars 2020 mission, China's Tianwen-1 mission and UAE's Hope probe) **have successfully reached the red planet in early 2021** and began their science missions in orbit and/or on the surface. Major achievements included successful flight demonstrations of NASA's Ingenuity Helicopter or the first non-U.S. soft landing and operation of a Martian rover by China with its rover Zhurong. Later in the year **ESA and CNSA collaborated on**

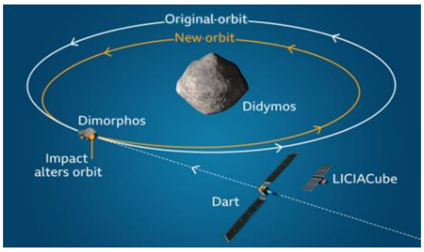
[252] Pathways to Discovery in Astronomy and Astrophysics for the 2020s, NASEM, 2021
[253] Your Guide to the 2020 Astrophysics Decadal Survey, Planetary Society, 2021
[254] With the exception of SOFIA infrared observatory
[255] NASA Selects 2 Missions to Study 'Lost Habitable' World of Venus, NASA, 2021
[256] N° 17–2021: ESA selects revolutionary Venus mission EnVision, ESA, 2021

experimental communications tests using ESA's Mars Express to collect data from the Zhurong rover and relay it to Earth.[257]

Also in 2021, more details emerged on **China's planned Mars sample return mission for 2028.** The mission has passed a milestone review. From the technological perspective, China will build on its already developed and demonstrated capabilities on the Moon and Mars. China will likely conduct two launches within the same launch window using Long March 3B and Long March 5 launch vehicles.[258]

The "selfie" of China's Zhurong rover and its landing platform was one of the most shared space photos of 2021 (Credit: CNSA)

Landmark launch of a first dedicated planetary defence mission



DART's asteroid deflection goal (Credit: BBC, NASA, JHU APL)

A first-of-its-kind planetary defence endeavour, the **Double Asteroid Redirection Test (DART) mission** launched on 24 November 2021. In September 2022, it will deliberately crash into the minor-planet moon Dimorphos of the asteroid Didymos to assess viability of kinetic impactor technique of asteroid deflection.[259]The cost of the entire DART mission of $330 million makes it notably "cheaper" than other NASA's planetary probe projects. DART is a joint project between NASA and the Johns Hopkins Applied Physics Laboratory (APL). The Italian Space Agency also contributed to the mission by providing a LICIACube cubesat built to carry out observational analysis of the Didymos asteroid binary system after DART's impact. **ESA, for a follow-up mission, is developing Hera**, a spacecraft that will be launched to Didymos in 2024 to conduct a detailed reconnaissance and assessment.

Updates on ongoing and new Lunar programmes

News related to the NASA's Artemis programme

- **Delays to Artemis programme schedule –** In November, **NASA announced the postponement of the first human lunar landing to 2025 at the earliest**. NASA also delayed Artemis 2 to as late as May 2024 noting Covid-19 and increasing development costs of Orion slowing the progress. In late December, after facing an issue with RS-25 engine of the SLS launcher, **NASA's uncrewed Artemis 1 mission was also delayed to March 2022**.[260]
- **Japan's participation to Lunar Gateway –** NASA and the Government of Japan finalised the partnership agreement, under which Japan will provide several capabilities for the Gateway's International Habitation module.[261]
- **Selection of SpaceX's Starship for the Human Landing System (HLS) –** In April, NASA selected SpaceX as the sole winner of the HLS Option A procurement, issuing a $2.89 billion contract to develop a landing system to transport astronauts from the Orion spacecraft to the lunar surface. In August, NASA paused the work on HLS following Blue Origin's appeal at the Court of Federal

[257] Europe's Mars orbiter relays data from Chinese rover back to Earth, Space.com, 2021
[258] China is planning a complex Mars sample return mission, SpaceNews, 2021
[259] Double Asteroid Redirection Test (DART) Mission, NASA, 2021
[260] NASA's Artemis 1 Moon mission delayed to March 2022, The Tribune, 2021
[261] NASA, Government of Japan Formalize Gateway Partnership for Artemis Program, NASA, 2021

Starship in the HLS variant (Credit: SpaceX)

Claims. The Court eventually dismissed Blue Origin's claim and the work resumed in November.[262]

- **New CLPS contracts -** NASA continued with the implementation of the Commercial Lunar Payload Services (CLPS) program, which since 2018, contracts companies to deliver robotic payloads to the moon's surface. In 2021, Firefly Aerospace and Intuitive Machines[263] were awarded new contracts and NASA also selected three new scientific payloads.[264]

Other lunar programmes and initiatives

- **Russian Chinese partnership on the International Lunar Research Station (ILRS)** – More information on the ILRS, including the envisioned timeline, is provided in section 1.1.2 of this Yearbook.
- **Russia's Luna 25 mission delayed to 2022** – The new Russian lunar lander was postponed until May 2022 at the earliest due to problems encountered with the spacecraft during crucial tests.[265]
- **China working on a lander for crewed moon missions** – A report from Xiamen University School of Aeronautics and Astronautics revealed ongoing work on crewed lunar landing and ascent system. The report refers to the landing project as a "national strategy".[266]
- **Acceleration of schedule for UAE's first Moon mission –** MBRSC partnered with Japan's ispace to send a rover to the moon by 2022[267], rather than 2024 as initially planned. UAE has also expanded cooperation with Israel, incl. collaboration at Israel's Beresheet 2 lander, to be launched in 2024.[268]
- **South Korea to attempt a lunar landing by 2030** – President Moon Jae-in has vowed to launch the nation's first robotic lunar lander on a domestic rocket by 2030.[269] South Korea's KPLO lunar orbiter is scheduled for launch in 2022 and country has signed the Artemis Accords in 2021.
- **ESA's new industrial contracts for different components of its lunar exploration efforts:**
- **A new lunar logistics vehicle**–Airbus and Thales Alenia Space were contracted for concept studies on a Cis-Lunar Transfer Vehicle (CLTV), a versatile logistics vehicle, which would also complement the European Large Logistic Lander (EL3), currently in development.[270]
- **Satellite infrastructure in lunar orbit**–Under the Moonlight Initial contracts were awarded to Telespazio, Surrey Satellites and Thales Alenia Space.[271] EECL and SpacePNT were awarded a contract to manufacture, test and deliver a Moon satellite navigation system module.[272]
- **Resources utilisation capabilities**–European industrial teams were selected to compete in designing a compact plant to demonstrate the manufacture of oxygen on the Moon.[273]
- **U.S. Air Force to fund development of lunar "GNSS"** – Masten Space Systems was awarded a Phase II SBIR contract through the Air Force Research Laboratory to develop and demonstrate a lunar positioning and navigation network prototype.[274]

[262] Court Report Details Why Blue Origin Lost Hls Case Against Nasa, Space Policy Online, 2021
[263] Firefly selects SpaceX Falcon 9 rocket to launch NASA-chartered moon lander, Spaceflight Now, 2021
[264] NASA selelcts new science investigations for future Moon deliveries, NASA, 2021
[265] Russia's Luna-25 mission postponed over 'problems during testing', ROOM Space Journal, 2021
[266] China is working on a lander for human moon missions, SpaceNews, 2021
[267] Emirates moon mission preps for 2022 landing, Wired, 2021
[268] Israel-UAE joint space projects include new lunar mission, spacewatch.global, 2021
[269] South Korean leader vows 'landing on the moon by 2030', SpaceNews, 2021
[270] Airbus studies "Moon Cruiser" concept for ESA's cis-lunar transfer vehicle, Airbus, 2021
[271] ESA advances its pllan for satellites around the Moon, ESA, 2021
[272] First 'GPS on the Moon' contract awarded to EECL, Electronic Specifier, 2021
[273] Competing companies developing payload to make air from moondust, ESA, 2021
[274] Masten Awarded Contract to Develop Positioning and Navigation Network for the Moon, Masten Space Systems, 2021

ISS, CSS, and other human spaceflight programmes

In late December, the U.S. administration committed to further extend ISS operations[275] – the station would operate until 2030 if approved by international partners and funded by the U.S. Congress. Russia's reflections of leaving the ISS in favour of a new national station puts the future of the Station in question.

2021 witnessed a few infrastructure and logistics-related evolutions in the ISS programme:

- Russia **successfully launched two new modules to the ISS** – the **MLM Nauka** science module, which replaced the long-serving Pirs docking module, and a new **Prichal** docking module.[276]
- In July, the **European Robotic Arm** was launched and integrated with the ISS, complementing the already operational ISS robotic arms provided by Canada and Japan.[277]
- Within NASA's **Commercial Crew Program**, SpaceX successfully executed the 2nd and 3rd operational mission of its Crew Dragon spacecraft. On the other hand, the first test flight of Boeing's CST-100 Starliner crew vehicle slipped from 2021 to 2022 due to valve problem.[278]

Multiple ISS partners have also initiated or finalised **new astronaut selection processes**:

- ESA has launched a call for new astronauts for the first time in 11 years, receiving over 23,000 applications. A multi-stage selection process will run until late 2022.[279]
- Similarly, and for the first time in 13 years, JAXA has also initiated recruitment of new astronauts to support future missions. The final section of candidates is planned for February 2023.[280]
- In the USA, NASA has finalised the selection 10 new astronaut candidates from a field of more than 12,000 applicants.[281]

Live broadcast of Chinese taikonauts of the Shenzhou 13 mission onboard the CSS (Credit: CGTN)

2021 was also a milestone year for China's human spaceflight. **In April, Long March 5B successfully launched 22-ton core module of the new Chinese space station (CSS), Tianhe, into orbit.**[282] 11 launches will follow to complete the assembly of this 66-ton, three-module station. 2 cargo deliveries (Tianzhou 2 and 3) and 2 crew missions (Shenzhou 12 and 13) followed later in 2021, beginning the construction and first crewed operations. CNSA also reiterated the interest to welcome international astronauts onboard the new station in the future.

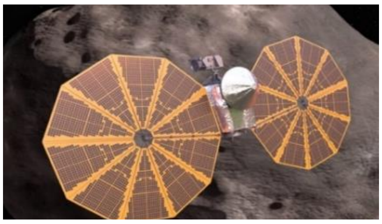
In Europe, new activities have been initiated by ESA management to **increase the ambition of Europe in its human spaceflight capabilities**.[283] Human space exploration was one of two long-term "inspirator" initiatives endorsed by ESA members at the Intermediate ESA Council Meeting in November.[284] A more detailed implementation plan remains subject to future agreement.

[275] Biden-Harris Administration Extends Space Station Operations Through 2030, NASA, 2021
[276] Russia launches new docking module to ISS, Phys.org, 2021
[277] European Robotic Arm is launched into space, ESA, 2021
[278] Boeing Starliner test flight delayed until 2022, The Verge, 2021
[279] ESA Astronaut Selection, ESA, 2021
[280] Japan to recruit first new astronauts in 13 years to support Artemis program, SpaceNews, 2021
[281] NASA Selects New Astronaut Recruits to Train for Future Missions, NASA, 2021
[282] China launches Tianhe space station core module into orbit, SpaceNews, 2021
[283] Prepare the future of space, ESA, 2021
[284] ESA looks to space summit to endorse human spaceflight efforts, SpaceNews, 2021

In India, the launch of country's first indigenous human spaceflight mission, Gaganyaan, was further delayed from August 2022 to 2023, mostly due to Covid-19 restrictions. Two major uncrewed test missions prior to the launch are envisioned to be executed in 2022.[285]

Other space exploration and space science news

- **Extended missions for NASA's Juno probe and NEOWISE telescope** – NASA extended the Juno mission (launched in 2011) until 2025, expanding the probe's study of Jupiter, including flybys of moons Ganymede, Europa and Io.[286] For Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE), the 2-year extension will continue the telescope's hunt for asteroids and comets.[287]
- **New calls for ESA's future science missions** – The ESA Director of Science has launched calls for proposals for both a "Fast" mission opportunity (to be launched in the 2030-2031 timeframe) and for a "Medium" mission opportunity (to be launched around 2037).[288] The call does not include opportunities for other two types of ESA science missions (Large and Small class).
- **China's long-term plans contemplate exploration missions further in the Solar System**–In addition to China's goals on the Moon and Mars and with the future Chinese Space Station Telescope, CNSA outlined multiple additional and comparably ambitious long-term projects:[289]
    - a **Jupiter probe**, possibly with a lander on Jupiter's moon Callisto, to be launched around 2030,
    - an **asteroid sample return mission** from the small near-Earth asteroid Kamo'oalewa, in collaboration with Russia and possible launch date of 2025,
    - a pair of Voyager-like **deep space probes** for the head and tail of the heliosphereincluding flybys in the outer Solar System.
- **India's two space observatories delayed for 2022 launch** – India's second and third space telescopes, a solar observatory Aditiya-L1 and an X-ray polarimetry satellite XPoSat, were further postponed from their 2021 launch dates and will likely launch in late 2022.[290]
- **Launch of Lucy, an asteroid probe to study Trojan asteroids** – Lucy, a mission under NASA's Discovery program, embarked on a 12-year mission to study two different clusters of asteroids around Jupiter known as Trojans. The total cost of the Lucy mission is estimated at $990 million.[291]
- **Launch of IXPE, a new X-ray space observatory** – The joint NASA-ASI "X-ray Polarimeter Explorer" (IXPE) telescope is the first space observatory dedicated to studying the polarization of cosmic X-rays of black holes, neutron stars, and pulsars.[292] Conceived as one of NASA's "Small Explorer" missions, IXPE's design and scientific capabilities are constrained by strict cost limits.



Lucy probe's unique solar panel design (Credit: NASA)

- **Bigger international footprint on NASA's IMAP mission scheduled for 2025** – Poland's Ministry of Science[293] and UKSA[294] joined NASA on its Interstellar

[285] ISRO Says Gaganyaan Mission Will Finally Take Off in 2023 After COVID-19 Delay, Gadgets360, 2021
[286] Juno mission extended, will now study Jupiter's moons and rings, Astronomy Now, 2021
[287] Asteroid-Hunting Space Telescope Gets Two-Year Mission Extension, NASA, 2021
[288] Call for missions 2021, ESA, 2021
[289] China to launch a pair of spacecraft towards the edge of the solar system, SpaceNews, 2021
[290] Space science missions ISRO will launch in the near future, Jatan's Space blog, 2021
[291] NASA launches robotic archaeologist Lucy on ambitious mission to Trojan asteroids, Space.com, 2021
[292] IXPE X-ray observatory completes commissioning, eyes Cassiopeia A for calibration, NASA Spaceflight, 2021
[293] NASA, Poland Sign Agreement to Build Instrument to Study Interplanetary Space, NASA, 2021
[294] UK and NASA join forces on new mission to study 'magnetic bubble' around Sun, Gov.uk, 2021

Mapping and Acceleration Probe (IMAP) mission to study and map the heliosphere and solar wind.

- **Low-cost TOLIMAN telescope to aid in the hunt for exoplanets** – An international team of scientists from Australia and USA began work on an unusually small space telescope (30cm), which will look for habitable planets in the Alpha Centauri system. TOLIMAN could launch in mid-2020s.[295]
- **Formal establishment of the Square Kilometre Array Observatory (SKAO)** – SKAO is the world's second intergovernmental organisation to be dedicated to astronomy, with the objective to construct and operate the largest radio telescope in the world. The creation of SKAO in February followed a decade of engineering work, scientific prioritisation, and policy development under its predecessor, the SKA Organisation.

Composite image of the SKA combining all elements in South Africa and Australia (Credit: SKAO, ICRAR, SARAO)

- **Interstellar Probe detailed mission concept proposed by Johns Hopkins University Applied Physics Laboratory (APL)** – Designed and proposed in part to be a successor to Voyager 1 and 2 missions, the Interstellar Probe concept (850kg probe equipped with sensors to measure parameters such as charged and neutral particles, magnetic fields and dust) could find its way in the recommendations of the upcoming Solar and Space Physics Decadal Survey.[296]
- **ESA's upgrades to deep space ground stations to increase science data return by 40%** – Enhanced cooling for antennas in Spain and Argentina will increase station downlink capacity and thus enable greater science value of upcoming missions such as BepiColombo or JUICE.[297]
- **New European and U.S. funding to foster space nuclear power & propulsion** – ESA awarded a contract to Belgian company Tractebel to evaluate the possibility of producing plutonium-238 (Pu-238) for use in space exploration.[298] In the USA, multiple contracts were awarded to industry by NASA, Department of Energy and DARPA, with the objective to advance nuclear thermal propulsion R&D.[299]
- **ELT's first light confirmed for 2027** – European Southern Observatory's upcoming ground-based "Extremely Large Telescope" will be the largest optical telescope in the world. ELT is now expected to deliver the first scientific observations in September 2027.[300]
- **First-ever detection of gamma-ray bursts by a cubesat** – GRBAlpha, a 1U demonstrator for a future constellation developed by an international team from Slovakia, Hungary and Japan has demonstrated the viability of nanosatellites as platforms for specific space science objectives.[301]

---

[295] Is there life at Alpha Centauri? New space telescope to seek out habitable planets around sun's neighboring star, Space.com, 2021
[296] U.S. and Chinese Scientists Propose Bold New Missions beyond the Solar System, Scientific American, 2021
[297] Cool tech to almost double deep space data, ESA, 2021
[298] European and US nuclear companies contribute to space work, World Nuclear Association, 2021
[299] NASA Announces Nuclear Thermal Propulsion Reactor Concept Awards, NASA, 2021
[300] ESO's Extremely Large Telescope planned to start scientific operations in 2027, European Southern Observatory, 2021
[301] Slovenská družica ako prvý CubeSat na svete detegovala záblesk gama žiarenia, živé.sk, 2021

2 Industry & Innovation

2.1 Space Industry Highlights and Trends

2.1.1 Defying the odds: new steps in space tourism

An economically viable and sustainable space tourism industry has long intrigued entrepreneurs and the space sector at large, as it (*i.a.*) implies significantly lower launch costs and would provide ripple effects throughout the space-industry supply chain. Pioneering steps were already taken in the first decade of the 21st Century with seven space tourists visiting the International Space Station. These trips, at an estimated cost between $20-30 million were brokered by a private company (Space Adventures, Inc.) but relied on Roscosmos for the provision of the seats on board the launch vehicle and all mission-related formalities.

It was however in 2021 that the suborbital/space tourism market made a considerable leap forward, enabled by three U.S. private companies, namely Virgin Galactic, Blue Origin, and SpaceX.

- On 11 July 2021, the 22nd test flight of **Virgin Galactic's VSS Unity** was also the first test flight with a full crew in the cabin, including the Company's founder, Sir Richard Branson, reaching an altitude of about 86 km. This was considered the final step before the company's first commercial flight, now **scheduled to take place in Q4 2022**.
- July 2021 also saw the launch of **Blue Origin's New Shepard** launch vehicle, carrying four private citizens, including the company's founder Jeff Bezos alongside Oliver Daemen, the **first ever commercial astronaut to purchase a ticket and fly to space on a privately funded and licensed space vehicle from a private launch site.** The passengers reached an approximate altitude of 107km, reaching beyond the elusive Kármán line according to the FAI, before immediately returning to Earth. The first flight was followed by two subsequent flights in October and December 2021, carrying 2 (out of 4) and 4 (out of 6) commercial passengers respectively.
- In September 2021, **SpaceX,** added another milestone to its records when its Crew Dragon capsule hosted 4 commercial passengers (procured by Jared Isaacman, who took the role of mission commander) while reaching orbit. The Inspiration4 mission **orbited Earth for three days, using an orbit at approximately 585 km**, before returning back to Earth.
- In December 2021, **after a 12-year hiatus**, the Russian Soyuz spacecraft carried two Japanese space tourists to the International Space Station where they spent 12 days. The deal, brokered by Space Adventures is said to cost approximately $50-60 million per seat. Earlier in 2021, **Glavkosmos, the commercial arm of Roscosmos**, announced it will enter the space tourism market on its own, with a minimum of four Soyuz seats available for commercial passengers in 2022 and 2023.[302]

The nature of the services and the related costs currently offered by these three companies is noticeably different, and it is hard to establish whether they act as competitors or whether they cover complementary segments of the space tourism market.

Rough estimates of the current offer for aspiring space tourists (limited to companies with a proven track record) is provided below and is based on publicly accessible sources and estimates by various industry experts and media outlets:

[302] Glavkosmos to sell seats on Soyuz missions, SpaceNews, 2021

Service Provider	Type of Mission	Estimated Price (per seat)
Virgin Galactic	Suborbital flight	\$300,000 - \$400,000[303]
Blue Origin	Flight beyond the Kármán line	\$400,000 – \$1M[304] Seats auctioned as high as \$28M
SpaceX	Multi-day stay in-orbit	\$30M-\$40M[305]
Space Adventures	Multi-day stay on board the ISS	\$20M - \$30M (historic) \$50M-\$60M (current)[306]
Axiom Space	Multi-day stay on board the ISS	\$55M[307]

Generally, market estimates are forecasting a steady increase but do not foresee exponential growth, with the market assessed at roughly \$400M in 2021 and **not expected to grow beyond \$600 million by 2030** in an analysis produced by **NSR**.[308] The long-term prospects and the economic viability of the space tourism market as a whole remain uncertain, with the Virgin Galactic share price **slumping over 80%** since its July 2021 value. Moreover, in October 2021, Space Adventures announced it is no longer planning a multi-day orbital mission using SpaceX's Crew Dragon flights, due to a "**mix of price, timing and experience**" that did not suit prospective customers.[309] Similarly, back in 2019, **Bigelow Space Operations** cancelled plans for private missions to the ISS using SpaceX service. Moreover, in March 2021, **Orion Span** announced it is cancelling its Aurora Space Station project due to a lack of necessary funding. Outside the US, Russia's first private venture, **Kosmokurs**, that planned to sell (suborbital) space tourism services and operate a private cosmodrome has scrapped the project and ceased operations in 2021.[310]

Moreover, the omnipresent backlash in both traditional outlets and on social media towards the set of space tourism activities in 2021 adds a layer of uncertainty and scepticism towards the market as societal and environmental issues are becoming increasingly important in public and corporate policies.

On the other hand, new opportunities are presenting with launches from outside the U.S., with an announcement of an agreement **between Blue Origin and the United Arab Emirates** entering into a space tourism partnership.[311] Furthermore, in December 2021, NASA cleared the crew for 1st private mission to International Space Station that will be **operated by SpaceX on behalf of Axiom Space** and is expected to launch in March 2022, with Axiom seemingly securing enough commercial interest for both its maiden flight as well as several subsequent missions in 2022 and 2023.

With the ISS currently representing the only fully-deployed long-term orbital outpost, the focus is turning towards its increased commercialisation and the long term transition from the ISS to

[303] Virgin Galactic sells 100 tickets to space at higher price after reopening sales, The Verge, 2021
[304] What a Ticket on Jeff Bezos' Rocket Will Cost You, Slate, 2021 ; Eric Berger, Twitter, 2021
[305] After Inspiration4, SpaceX sees high demand for free-flyer missions, Arstechnica, 2021
[306] First space station tourist in ten years docks at ISS, CNN, 2021
[307] Axiom names first private crew paying \$55 million for a trip to the ISS, The Verge, 2021
[308] Orbital Space Tourism: Where Are We?, NSR, 2021
[309] Space Adventures no longer planning Crew Dragon flight, SpaceNews, 2021
[310] Russia's First Space Tourism Company Closes, The Moscow Times, 2021
[311] UAE and Blue Origin enter into space tourism partnership, Room, 2021

commercial space stations with the US, the station's main international partner, only extending ISS operations until 2030. NASA published a call for the Commercial Low Earth Orbit Destinations and received 11 proposals by various industrial actors/consortia.[312]

In December 2021, NASA awarded over $400 million to three industrial consortia to advance developments on commercial space stations, namely:[313]

- A **$160 million** award for **Nanoracks, Voyager Space and Lockheed Martin** for their space station called **Starlab**, whereby Nanoracks will be prime contractor Voyager handling strategy and investment and Lockheed Martin the manufacturer and integrator. Initial operational capability is foreseen as soon as 2027.
- A **$130 million** award for a team led by **Blue Origin** along with **Boeing, Redwire and Sierra Space**, for their **Orbital Reef space station,** referred to as a multi-purpose business park in space. Their goal is for initial operations to start in the latter half of the 2020s.
- A **$125.6 million** award, worth $125.6 million, for **Northrop Grumman's** concept, supported by Dynetics (with other partners to be announced) and building on top of developments for the Cygnus spacecraft, the Mission Extension Vehicle and the Habitation and Logistics Outpost.
- Generally, across all received proposals, the business plan evaluation resulted in fairly low scores, with concerns related to **unrealistic revenue estimates**, even among the winning proposals. The technical approach evaluation only yielded slightly better results.
- Additionally, plans are in place for the **Axiom space station**, designed to begin its operations as a module added to the ISS that would be built upon and eventually detached after the ISS's retirement. Axiom Space **raised $130 million in February 2021** to further develop the modules. Axiom later signed a contract with **Thales Alenia Space** to provide two key pressurised modules of the Axiom Space Station.
- Another U.S. company, **Varda Space**, raised $42 million through Series A with an aim of building a **space station with industrial use**, planning to tap into markets for semiconductors, fibre optic cables, and pharmaceuticals. Other proposed commercial space stations, such as **Orbital Assembly Corporation's** artificial gravity space station seem to be even further away in terms of their development cycles.
- Despite the prospects offered by these commercial endeavours, and their ambitious timelines, NASA's Inspector General is wary of potential delays in development of commercial space stations, which "heightens the risk of a gap in low Earth orbit destinations" (such a gap would leave the Chinese Tiangong space station as the only habitable LEO destination) and subsequently threatening the collapse of the LEO commercial space economy. According to the NASA Inspector General "a commercial platform is not likely to be ready until well after 2030". Interestingly, in late February, **NASA significantly increased prices for commercial uses of the ISS**, notably for marketing, advertising, or entertainment purposes. The price for sending 1kg of cargo increased from $3,000 to $20,000 and an hour of crew time increased from $17,500 to $130,000, now better reflecting the actual cost of such services.[314]

Regardless of these warnings, the space tourism sector at large (including spaceports, suborbital flights, in-orbit stays) continues to spur interest and new entrants are betting on the prospects of this future market not only in the United States, but also in Europe (admittedly only in the realm of spaceports), China, Russia, and Japan. These companies are addressing different segments of the

[312] Relativity and SpaceX bid on NASA commercial space station competition, SpaceNews, 2021
[313] NASA awards funding to three commercial space station concepts, SpaceNews, 2021
[314] NASA hikes prices for commercial ISS users, SpaceNews, 2021

market, and are currently at different stages of development, have made relevant announcements during 2021:

Company	Country	Type of product / service	Developments in 2021
PD AeroSpace	Japan	Suborbital spaceplane (Suborbital flight)	Announced first launch from Shimojishima Spaceport by 2025
RSC Energia	Russia	Suborbital spaceplane (Suborbital flight)	Announced a patent for a spaceplane.
CAS Space	China	Launcher + Capsule (flight beyond 100km)	Announced the beginning of space tourism services in 2024
Space Transportation[315]	China	Suborbital spaceplane (Suborbital flight + P2P travel)	First launch (2024) and first crewed flight (2025) announced

Notably, the lack of development of space tourism ventures in Europe (beyond developing spaceport facilities and ancillary services) is clear. Whether this is based on cultural, entrepreneurial, financial or other reasons can be discussed. Upon reflection, one must nevertheless conclude that any integrated ambition related to human spaceflight in Europe seems to be firmly under the responsibility of public actors, as private ventures are not taking flight, despite declaratory support to private ventures related to space tourism as far back as 2008.[316]

Moreover, a number of stratospheric balloon companies (reaching approximately 40 kilometres in altitude, admittedly well below the edge of space under any of its definitions) is taking off with a number of companies in the United States and Europe driven by the prospects of a wider addressable market due to the lower costs compared to spaceplanes and vertical take-off launches:

- **Space Perspective (USA)** raised $40 million in its Series A funding round early in 2021 and formally opened ticket sales (priced at $125,000) days after its first test flight in July.
- **Zero 2 Infinity (Spain)** announced it already secured "*the capsules, the permits, the insurance, and the flight centre*" and is now only in need of additional funding (approximately €2M) before first operations begin.
- **World View (USA)** announced that it expects to operate its first commercial flights in early 2024 and foresees pricing at roughly $50,000 per person.
- **EOS-X (Spain/UAE)** announced it intends to operate its first commercial flights as early as 2023 and predicted to host 10,000 passengers by the end of the decade.
- **AVA Space (Romania)**, a Sibiu-based company with limited publicly available information, announced its plans to attract $2 million in seed round investment through a tokenization process.[317]

[315] Chinese space plane company targets suborbital tourism, point-to-point travel by 2025, space.com, 2022
[316] ESA's position on privately-funded suborbital spaceflight, 2008 (Link)
[317] FOTO AVA Space, indicată drept prima companie de turism spațial din România, vrea să atragă o finanțare de 2 milioane dolari și țintește o evaluare de 1 miliard de dolari pe viitor, Profit, 2021

Finally, the prospect of an awakening space tourism market also enables a number of adjacent products and services leveraging the ripple effect made by recent successful launches, with examples such as travel insurance for space tourists by **Battleface (Belgium)**, training programmes for potential space tourists offered by **Orbite (USA)** as well as new competitors to existing mission management and travel agencies (e.g. **Rocket Breaks (UK)** and **Stellar Frontiers (UK)).**

With the global market seemingly on the rise, the coming years might provide to be decisive with regard to its long-term trend and economic viability. Nevertheless, novel concepts and any notable cost reductions can have a positive impact on the space sector at large, irrespective of the prospects of the space tourism market itself.

2.1.2 Cloud companies affirming their role in the space sector

Over the past years, digital giants such as Amazon, Microsoft, and Google have entered the space sector by leveraging their digital infrastructure to integrate space assets in the ground, space, and user segments into the cloud. Space companies are adopting new business models such Ground Station-as-a-Service or Satellite-as-a-service, in which users do not develop or own space infrastructures but only pay for the service used, following the pay-as-you-go principle.

Ground Segment-as-a-Service:

The GSaaS model has continued to develop in 2021, driven in particular by the increasing digitalization of space systems and the emergence of start-ups, which do not necessarily have the financial means to develop their own ground infrastructure.[318] GSaaS enables satellite operators and start-ups to allocate most of their capital to the development of their specific services or missions.[319]

According to Euroconsult's 2021 Ground Segment Market Prospects report, **the number of active antennas owned by GSaaS companies is likely to double in the next five years**, as the demand for their services continues to grow.[320] **Several types of actors in the GSaaS market have emerged:**

- Digital giants, which provide the cloud infrastructure and build their own antennas while also relying on existing networks of ground stations established by traditional space companies. They can offer large capacities to a large pool of customers (e.g., Amazon).
- Space companies (often start-ups), which develop their own ground stations and offer GSaaS based on their capacities (e.g., Leaf Space).
- Traditional space companies, which have ground stations and rent their spare capabilities to GSaaS providers.
- Companies, which create cloud-based software platforms and only act as brokers between ground station owners and customers without building or operating ground stations themselves (e.g., Infostellar).

The emergence of GSaaS has allowed new actors such as start-ups and IT providers to complement the services offered by traditional Ground Segment service suppliers.

Space-as-a-Service

Space-as-a-Service can be considered as an umbrella term for several new business models. The terminology is not clearly defined and often used differently by start-ups, researchers, and institutions. The following terms can be identified:

Infrastructure-as-a-service: a service where the provider owns space systems and enables users to control the spacecraft, retrieve space data, or process them from the cloud.

- **Ground Segment-as-a-Service:** a cloud computing service that enables satellite operators to use a network of ground stations to control their satellite and retrieve and process the data on the cloud.
- **Satellite-as-a-Service:** a service that enables to place a payload on a satellite or use and control a satellite through the cloud without developing or owning the satellite itself.

Software-as-a-Service: a cloud-based service that enables users to use a software online instead of hosting it on their servers.

Space Data-as-a-Service: a service where a satellite operator operates and control a satellite and only sends the data required by the client through the cloud.

Edge computing: Cloud-based storage and computing/processing solutions where the data is being produced, whether it is next to ground stations or on-board of satellites.

[318] NSR White Paper: Satellite Ground Network Virtualization, Northern Sky Research, 2021.
[319] Market Perspectives of Ground Segment as a Service, PwC, 2020.
[320] Ground Segment Manufacturers Face Changes to Leverage Constellation Potential, Satellite Today, 2021.

Amazon Web Services (AWS) consolidates its position in the cloud ground station market

Amazon's Ground Station (Credit: AWS)

AWS continued to consolidate its position in the cloud ground station market in 2021 by forming new partnerships with space companies as well as by extending its services to public actors. Following the establishment of AWS Ground Services in 2019, the company has quickly turned itself into one of the market leaders in the field of GSaaS and cloud ground stations.

In 2020, the company ramped up the development of its cloud ground station services with the establishment of an Aerospace and Satellite solutions team, the signing of agreements with more than nine space companies, and the extension of its services to the Africa and Asia Pacific regions. AWS also completed the rollout of 6 of its planned 12 ground stations during the year. While the company had originally planned a fast rollout of all its stations, it decided to halt its plans in order to better meet customer demand with regard to the locations of its stations. AWS currently has ground stations in 9 different locations around the globe.[321]

One of the main developments for AWS in 2021 was the partnership it formed with Seraphim Capital to launch its AWS Space Accelerator for space stat-ups.[322] In particular, the two companies collaborated to create a four-week programme focused on helping space companies enhance their services using AWS's services. Notably, the company aims to help space start-ups better manage the large amounts of data ensuing from their operations by leveraging its cloud computing solutions. The accelerator programme is open to all start-ups, with AWS and Seraphim Capital selecting two European companies as part of its first cohort, as both Satellite Vu and D-Orbit took part. In addition, Cognitive Space, Descartes Labs, Edgybees, HawkEye 360, LeoLabs, Lunar Outpost, Orbital Sidekick, and Ursa Space Systems were selected.[323]

On top of its initiatives to strengthen its relationship with space start-ups, AWS also furthered its partnerships with larger space companies:

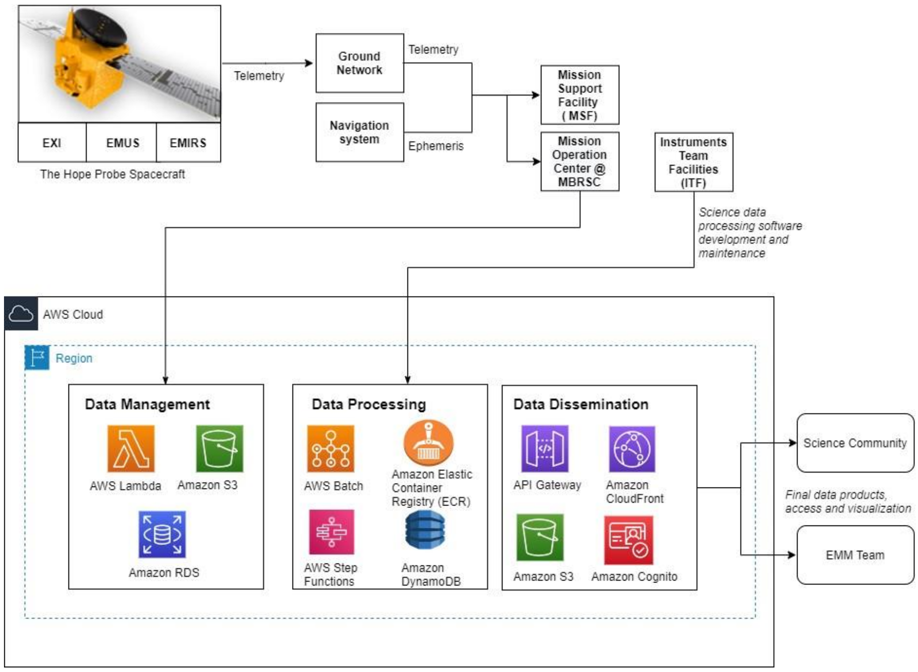
- In June, **SES** extended its partnership with AWS by becoming the first satellite operator to achieve the status of AWS Direct Connect Partner status.[324] By joining AWS's Direct Connect Delivery Partner programme, SES aims to provide its customers with connectivity solutions from remote locations, in particular through AWS's cloud-based application. SES plans to connect its customers to AWS data centres through its Cloud Direct service, which will also be available on its next generation 03b MEO constellation. The service would allow its customers to establish a connection to AWS at speeds ranging from 50 Mbps to 100Gbps.
- In April, **Telespazio** furthered its collaboration with AWS by supporting its solutions through its own "ENABLE" cloud-based service platform. The collaboration between the two companies aims to provide customers with access to an expanded network of ground stations in addition to AWS services for storage, analysis, and data processing. In the scope of the partnership, Telespazio customers will be able to access all AWS Ground Station services.[325]
- AWS also formed a partnership with Argentina-based Earth Observation company **Satellogic** in September.[326] The extended collaboration with Satellogic represents an important

[321] AWS Ground Station Locations, Amazon Web Services, 2021.
[322] Announcing the AWS Space Accelerator for startups, Amazon Web Services, 2021.
[323] Amazon CTO announces the 1st AWS Space Accelerator cohort delivered by Seraphim, Seraphim Capital, 2021.
[324] SES Expands Cloud Leadership as Amazon Web Services Direct Connect Partner, SES, 2021.
[325] Telespazio announces support for AWS Ground Station with its cloud-based service platform ENABLE, Telespazio, 2021.
[326] Satellogic Uses AWS Ground Station to Scale Services and Deliver Insights to Customers Faster, Satellogic, 2021.

development for AWS as it is currently competing with Microsoft's Azure Orbital to sign new customers planning to launch satellite constellations. Satellogic currently has 17 satellites in orbit and aims to launch more than 300 by 2025 to complete its Earth Observation constellation. In the scope of their agreement, the company will leverage AWS's Ground Stations to scale its satellite data acquisition processes quickly and cost-effectively. By transferring the collected data directly to AWS for processing and analysis, Satellogic will also enable its customers to take fast decisions based on its data.

In addition to its partnerships with member of the industry, AWS also reached important milestones with regard to the adoption of its space-related services with public entities:

- In February, AWS supported UAE's Hope Mars mission through a customised suite of its cloud services. The Hope probe is principally managed by the Mohammed Bin Rashid Space Centre (MBRSC) and became the UAE'S fist successful interplanetary mission when it started orbiting Mars in February. While the MBRSC selected NASA's Deep Space Network as the sole-source Ground Station Communication Network, it uses AWS's services to host the mission science data centre responsible for processing and analysing the data collected by Probe on the Martian atmosphere.[327]
- In August, AWS signed a Statement of Strategic Intent with **the Ministry of Digital Government and the Ministry of Development and Investment of Greece.** The cooperation is part of the country's digital transformation goals and has the objective of supporting the creation of a regional space hub in Greece. In particular, it includes access to AWS's Activate programme for all Greek space start-ups looking to work with qualified space-related data.[328]



The Hope probe's spacecraft architecture (Credit: AWS)

[327] UAE Mars mission uses AWS to advance scientific discoveries, Amazon Web Services, 2021.
[328] Government of Greece and AWS sign Statement of Strategic Intent to accelerate the formation of regional space hub, Amazon, 2021.

Start-ups ramp up efforts to deploy their GSaaS solutions

Important GSaaS developments also took place in the start-up ecosystem in 2021, with companies forming new partnerships and raising additional funding to expand their ground station services.

This was the case notably for the Italian start-up Leaf Space, whose GSaaS runs on Google Cloud:

Leaf Line Network (Credit: Leaf Space)

- The company successfully raised additional funds in January following a €5 million Series A round co-led by Primo Space and Whysol Investments. The latest round brought the total funding raised by the company to over €10 million since its inception and enabled its considerable growth this year.[329]
- In particular, the company was able to build upon the success it encountered in Europe and announced its expansion to the U.S. market. Its market expansion allows Leaf Space to propose its solutions to U.S. customers including Momentus, Kleos Space, Swarm, and Kepler communications.[330]
- Leaf Space also announced a significant expansion of its network of ground stations this year by planning to add 8 stations to Leaf Line Network.[331] Following its addition of stations in Sri Lanka, the Azores and Scotland, the company announced it would also build stations in South Australia, British Columbia, Iceland, and Bulgaria. The supplement to its network allows the company to provide its GSaaS solutions to a growing list of international customers seeking additional global coverage for their mission, as well as increased capacity and reduced latency. The company will now operate a set of 15 ground stations and projects to activate new ones in Q1 2022.[332]
- The company also announced additional partnerships with other start-ups this year. Notably Leaf Space concluded a partnership with Luxembourg-based start-up Odysseus Space in October to develop the first global hybrid ground station network.[333] Specifically, the aim of their partnership is to develop a ground station network that is optimised for both optical and RF communications, leveraging Odysseus Space's expertise in end-to-end laser communication systems for satellite missions. By offering a hybrid station solution, the companies intend to enable an added degree of flexibility for companies seeking to benefit from the much higher data rate capacity made possible by optical communication. The project is supported by ESA as wells as the Luxembourg Space Agency, and the network is currently scheduled to be completed by 2024.

In addition to Leaf Space, other GSaaS start-ups have also remained active this year:

- The Japanese start-up **Infostellar** also received additional funding this year, raising a $6.2 million Series B round in October. The Series B round brings the total funding raised by the company to approx. $17 million. Infostellar projects to use the new funding in order to continue increasing the number of ground stations included in its StellarStation platform as well as to

[329] Leaf Space Reaches €10 Million Funding, Leaf Space, 2021.
[330] Leading Ground Segment as-a-service Provider Leaf Space Announces U.S. Expansion, Leaf Space, 2021.
[331] Leaf Line is the company's GaaS distributed ground station network. It aims to ensure a tailored solution to customers.
[332] Leaf Space Adds Five New Ground Stations to Global Network, Increases Capacity to Address Growing Customer Demand, Leaf Space, 2021.
[333] Leaf Space Partners with Odysseus Space to Develop Optical Ground Terminals and Build First Ever Global, Hybrid Ground Station Network, Leaf Space, 2021.

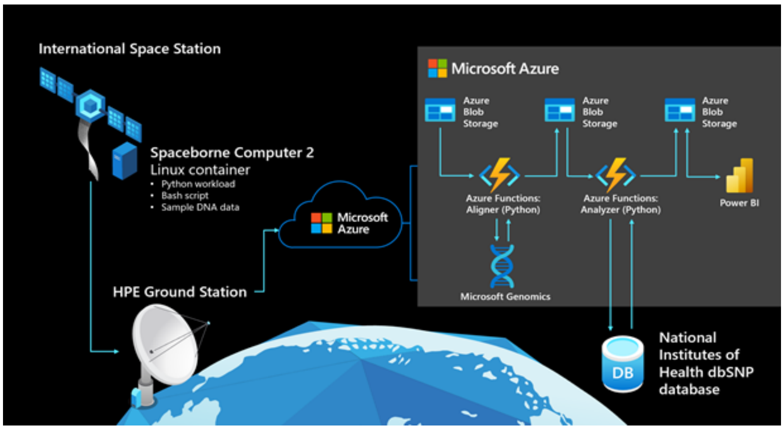
expand its activities to the U.S. market.[334] In addition, the company also concluded an agreement with AWS Ground Station. The partnership represents an expansion to its services as it enables all Infostellar customers to have access to AWS Ground stations.[335]

- Italy-based **D-Orbit** and the Canadian company **SkyWatch** have strengthened their partnerships with **AWS** Ground Services this year. D-Orbit signed an agreement with AWS in order to integrate the cloud-company's Ground Stations solutions to its AURORA cloud-based mission control software. The aim of the agreement is that of enabling the management of increasingly complex missions D-Orbit's ION Satellite Carrier while also allowing bi-directional communication between satellites and AURORA in addition to the downlink and processing of data.[336]
- **SkyWatch** reinforced its collaboration with AWS by becoming an Independent Software Vendor (ISV) Partner in the AWS Partner Network (APN).[337] Through the agreement, the company's TerraStream platform will provide satellite operators with immediate access to scalable data storing, cataloguing, processing, and distribution of Earth observation data via AWS Ground Station, combining Platform-as-a-service and GSaaS. The partnership with AWS followed SkyWatch's €17.2 million Series B round of funding in June. [338]

Developments in edge computing and satellite-to-cloud data processing

Companies are now looking to develop **edge computing in space, which can be defined as the deployment of cloud-based storage and computing solutions where the data is produced, whether it is next to ground stations or on-board of satellites.** Edge computing projects usually consist of edge devices such as sensors, satellites, or other objects that collect large amounts of data, which are then sent to a backend cloud application to process the data. Edge computing enables to process data faster and reduce latency. It may also facilitate future space exploration missions as it will enable astronauts to process and analyse data collected in space without sending information back to Earth for analysis.[339]

Experiments conducted this year on the ISS by NASA, Hewlett Packard Enterprise, and Microsoft have demonstrated the possibility to develop edge computing in space and link it to the cloud:



Spaceborne Computer-2 (Credit: Microsoft)

[334] Infostellar raises ￥700M ($ 6.16M USD) in 1st round of Series B Financing, Infostellar, 2021.
[335] Infostellar to Integrate AWS Ground Station into StellarStation mission control software, Infostellar, 2021.
[336] D-Orbit announces AWS Ground Station integration with AURORA mission control software, D-Orbit, 2021.
[337] SkyWatch Achieves Independent Software Vendor (ISV) Partner Status in the AWS Partner Network, SkyWatch, 2021.
[338] SkyWatch raises $17.2M for its Earth observation data platform, Techcrunch, 2021.
[339] Mission to Mars: How edge computing will make it possible, HPE, 2021

- In February, **Hewlett Packard Enterprise's** Spaceborne Computer-2 (HPE SC-2) was successfully launched to the ISS on the 15th Northrop Grumman cargo resupply mission. HPE SC-2 is an updated version of the original Spaceborne Computer, which was sent to the ISS in 2017. HPE SC-2 is designed to process data from various space systems (satellites, instruments, etc.) and is based on HP's Edgeline EL4000 Converged Edge System.
- In August, **Microsoft** and **HP** announced that they successfully connected HPE SC-2 to Microsoft's Azure cloud.[340] Microsoft and NASA are conducting an experiment using the HPE SC-2 and Azure cloud to sequence DNA data from astronauts' blood samples collected in the ISS. It enables NASA to monitor the consequences of exposure to radiation on astronauts. Gene sequencing is generating a large amount of data that needs to be compared against a large database. HPE SC-2 is able to conduct in-orbit data processing of the gene sequences and only offload data containing anomalies or selected interesting bits to HPE ground station, which is then sent to Microsoft's Azure cloud.[341]

The project aimed at overcoming the limitations in bandwidth between the ISS and the Earth and demonstrating the efficiency and utility of in-orbit supercomputers linked to the cloud, accelerating data processing from months to minutes on the ISS.[342]

Similarly, in May, **Google** signed a deal with **SpaceX** for a period of seven years to provide cloud services to Starlink customers and install Starlink terminals at Google's data centres around the world in order to provide high-speed and low-latency connectivity. The agreement plans to use Google Cloud as well as AI capabilities to enable satellites to make decisions about what parts of datasets should be sent to Earth.[343] Customers may use Starlink to connect edge devices to the internet and send the data they collect to Google Cloud.[344]

Furthermore, space start-ups are also looking to develop edge computing solutions: the American company LEOcloud is providing space-based cloud infrastructure and services. LEOcloud is looking to develop cloud edge computing services at ground stations operated by partners and launch a constellation of data centers.[345] In 2021, the company establish signed several partnership agreements to reach this goal:

- In March, **LEOCloud** and **Leaf Space** announced that they signed a Memorandum of Understanding (MoU) to deliver space edge cloud services. The two companies agreed to develop a strategy that will enable end-users to connect to satellite data suppliers and operate in a hybrid cloud environment.[346]
- In June, **LEOcloud** announced that it signed a Memorandum of Understanding (MoU) with the Canadian company **Exodus Orbital** to deliver a cloud framework for satellite-hosted applications. The two companies are looking to create a space-based and terrestrial cloud framework that will enable users to develop, integrate and test their satellite-hosted applications.[347]
- In July, the American company **LEOcloud** announced it signed a partnership to develop a satellite-based cloud computing system with the supercomputer company Ramon.Space.

[340] Spaceborne Computer-2 shows results on space station, SpaceNews, 2021
[341] Genomics testing on the ISS with HPE Spaceborne Computer-2 and Azure, Azure, 2021
[342] Spaceborne Computer-2 shows results on space station, SpaceNews, 2021
[343] SpaceX's Starlink internet satellites to connect with Google Cloud systems, Space.com, 2021
[344] Google Cloud and SpaceX will provide satellite connectivity for enterprises, SiliconAngle, 2021
[345] LEOcloud establishes partnerships for satellite-based cloud computing, SpaceNews, 2021
[346] Leaf Space And LEOcloud Collaborate To Deliver Space Edge Cloud Services, LeafSpace, 2021
[347] LEOcloud and Exodus Orbitals Collaborate To Deliver Seamless Cloud Framework For Satellite-Hosted Applications, ExodusOrbital, 2021

LEOcloud plans to build a constellation of data centres and will integrate Ramon.Space computing solutions, which will offer their customers cloud edge computing services.

- In November, **LEOcloud** signed a partnership agreement with **Orbital Assembly** to enable public cloud edge computing services hosted on Orbital Assembly's Gravity Ring and Pioneer Stations. [348]

Other start-ups are developing edge computing solutions and reached some milestones in 2021:

- In May, the American company **Loft Orbital** announced that it was awarded a small business innovation research (SBIR) contract from **the U.S. Space Force**, which accounts for $1.5 million, to develop an edge computer processor in space. The edge computer will be able to conduct on-board data analysis, enabling to increase data processing without sending it to a server on the ground. Loft Orbital outlined that the edge computer will be able to connect to the cloud. The end goal for Loft Orbital would be to send the Space Force a space infrastructure as a service package, in which the Space Force would fly its payloads aboard its satellite buses and would use the edge computer to operate their payload, as well as to collect and analyse the data.[349]
- In July, the Australian company **Spiral Blue** successfully launched its space edge computer, Space Edge Zero (SEZ), onboard of Virgin Orbit's LauncherOne. SEZ is a hosted payload on the Polish satellites STORK-4 and STORK-5. SEZ is a prototype that aims at demonstrating on-board data processing of satellites images and ensuring that only the necessary data is sent back to Earth in an effort to only deliver actionable information.[350]

Server room (Credit: ECSA)

Finally, in November, several space start-ups and companies founded the "Edge Computing in Space Alliance", which is a working group that aims at promoting edge computing in space, the Satellite-as-a-service (SaaS) business model as well as fostering cooperation between the IT and space sector. The Alliance gathers companies such as Exodus Orbitals, Orbital Transport, ModularitySpace, LEOcloud, Copernicus Space, EXO-Space, Orbits Edge, Skywatch, Spiral Blue, Deploy Solutions, Ramon.Space, KP Labs, Ibeos, Spacelinks, Little Place Labs, Zephyr Computing Systems, 3K SpaceTech, CySec, Pandio, Sfera Technologies, and Skudo.[351]

While the use of *cloud for space* is becoming more common place, the use of *cloud in space* is emerging with edge computing and in-orbit data centres. For instance, the launch of data centres in orbit is increasingly seen as a promising business by several space companies as they hold the promises of reducing the environmental impact of data centres on Earth (e.g, cooler temperatures, abundant solar energy, etc.), enabling cost reductions between 3.3% and 66.3% on average. Space-based data centres are also expected to reduce latency by 45.7% on average.[352] For instance, in 2021, the Japanese companies NTT and SKY Perfect JSAT announced plans to jointly build a computing networking in space, which would include in-orbit data centres, with an expected deployment by 2025.[353]

[348] LEOcloud to Offer Space Edge Cloud Services on Orbital Assembly Space Stations, SpaceRef, 2021
[349] Loft Orbital wins Space Force contract for edge computing in space, SpaceNews, 2021
[350] Loft Orbital wins Space Force contract for edge computing in space, SpaceNews, 2021
[351] Edge Computing in Space Alliance is Launched!, Spacequip, 2021
[352] Space-Based Data Centres: A Paradigm for Data Processing and Scientific Investigations, Springer, 2019
[353] NTT to launch data centres into space within five years, Telecoms, 2021

The integration of cloud computing into the user segment

Public and private actors are also increasingly looking to use cloud computing to easily store, process, and disseminate space-based data. Several developments took place in 2021:

- In March, **NASA** announced that it has been working with **Raytheon** to develop a cloud-based platform to help the agency store, disseminate, and archive space-based data from the Sentinel-6 satellite. The platform was developed under NASA's Earth Science Data and Information Systems project. This cloud-based platform is expected to be made available to the public, in an effort to make climate data available to all.[354]
- In March, the Italian company **Telespazio** announced that it transferred the Payload Data Processing System of Copernicus' Sentinel-3 satellites to the cloud. The company outlined that using cloud computing would optimise the use of its computing resources by 40%, facilitate access to data, and increase the reliability and resilience of the system.[355]
- In May, **Airbus** transferred the operations of the two Copernicus Sentinel-1 satellites to the cloud following a request of ESA to digitalise Sentinel satellites.[356]
- In October, **CNES** selected the French telecommunication company **Orange Business Services** to lead a new consortium to design, deploy and maintain a modern storage solution for scientific and spatial data. The consortium aims to help CNES to fully modernise its storage facility, in order to make the use of its satellite data easier. Orange Business Services will design, install, and maintain the operations. The more cost-effective data cloud (data lake) will be capable of hosting 100 petabytes of spatial data and is expected to facilitate in the use of visualisations, cross-referencing, and information sharing.[357]

Space companies, usually telecommunication companies, are also signing partnership agreements with cloud service providers to host their infrastructures on the cloud. According to NSR, the delivery of cloud services via telecommunication satellites is expected to generate the largest revenue potential among all satellite cloud service revenues, from around $200 million in 2019 to more than $1.8 billion in 2029.[358]

- In February, **cegedim.cloud** announced it signed a partnership with the French company **Kinéis** to host all the IT infrastructure of their nanosatellite constellation dedicated to the IoT on a private cloud, which will be able to handle 100 times more data than the current local IT infrastructure cegedim.cloud will provide a hybrid public/private cloud infrastructure, ultra-secure connection points, dual-site production environment, a digital disaster recovery plan, and dedicated secure platforms to Kinéis in order to transfer the entire ground segment to the cloud. Cegedim.cloud will also provide simulators to Kinéis to test technologies and services related to the constellation.[359]
- In March, the Canadian company **Telesat** announced it signed an agreement with the software company **CloudOps** in order to build the Telesat Lightspeed Cloud, which will consist of a cloud infrastructure and cloud-native data platforms for Telesat.[360]

[354] Raytheon, NASA Build Cloud Platform to Store Sentinel-6 Satellite Data; David Appel Quoted, ExecutiveBiz, 2021
[355] Telespazio transfers the Payload Data Processing System of the European Copernicus programme's Sentinel-3 satellites to public cloud, Telespazio, 2021
[356] Airbus takes Sentinel-1 data from orbit to Earth…and into the cloud, Airbus, 2021
[357] French Space Agency chooses Orange Business Services to help transform and shape its data-centric strategy with cloud-based data lake, Orange, 2021
[358] Cloud Computing: Ratcheting The Satellite Industry Forward, NSR, 2021
[359] cegedim.cloud announces an inventive partnership with Kinéis to host all IT infrastructure for the first European nanosatellite constellation dedicated to the internet of things, GlobalNewswire, 2021
[360] Telesat Selects CloudOps to Develop Cloud Infrastructure for Telesat Lightspeed LEO Network, Telesat, 2021

In addition, some space companies are now specialising in the development of cloud-based software and analytics services as well as of downstream applications. This can be compared to the business model of Software-as-a-service, in which customers access a software through a web application and through a subscription instead of downloading and storing the software and the related data on their own systems. Several space companies have entered this market:

- The American company **LeoLabs** established a cloud-based analytics platform that processes data from the company's global network of phased array radars, which tracks space objects in LEO. The platform enables customers to search for satellites, monitor traffic patterns and receive alerts when spacecraft are at risk of colliding.[361]
- The American company **BlackSky** developed the Spectra AI platform, which serves as an analytics engine that merges multiple data sources of information with its geospatial imagery from BlackSky's constellation. Through a subscription-based software-as-a-service (SaaS) model, the Spectra AI platform delivers real-time geospatial intelligence products to customers.[362] BlackSky has been in a partnership with Amazon Web Services since 2018 to its services through AWS cloud infrastructure and use AWS Ground Station services.[363]
- In August, **Planet and Google Cloud** have expanded an existing partnership on data analysis. The companies announced Wednesday an agreement to create joint solutions with Planet satellite imagery and Google Cloud's cloud-based infrastructure. Under the agreement, government and enterprise customers will be able to use Google Cloud's infrastructure and BigQuery data warehouse to process large volumes of Planet data. The companies said this renewed partnership reflects growing demand for planetary-scale satellite data analysis, powered by the cloud.[364]

Overall, cloud computing is a major trend, which will have considerable impact in the ways space operations are conducted and in the ways space-based data is distributed, processed, and stored. The use of cloud computing in the space sector seems to be a representative case of the trend in which there is an increasing demand for space-based data and space systems are becoming simple tools at the service of the Big Data market. However, European cloud computing companies have limited capabilities, shrinking market shares and they have not yet entered the space sector to offer dedicated services.

[361] Software-as-a-Service model takes the space sector by storm, SpaceNews, 2021
[362] BlackSky achieves world's highest revisit, time-diverse dawn-to-dusk satellite constellation with three successful launches in three weeks, Geospatial World, 2021
[363] BlackSky Geospatial Solutions Achieves AWS Advanced Consulting Partner Status, BlackSky, 2021
[364] Planet and Google Boost Data Analysis Partnership, ViaSatellite, 2021

2.1.3 Unprecedented development of communication constellations

Developments during the past year in terms of proposed business plans, filings and deployments of satellite communication constellations have raised considerable interest from both the space community as well as from the general public at large. Considering the stakes and the scale of many of these constellations this comes as no surprise, since the dynamics and prospects of these developments continue to catalyse strategic reflections in the space industry both for manufacturers, launch providers and operators alike.

Operator	# of Satellites Launched	Business Case
Starlink	989	B2C &B2B Broadband
OneWeb	284	B2B Broadband
Swarm	76	IoT / M2M
Astrocast	10	IoT / M2M
Kepler	10	IoT / M2M

Operators launching 10 or more communication satellites in 2021 (Source; ESPI Database)

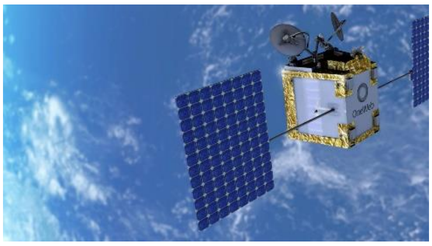
SpaceX and OneWeb leading the charge

The largest operator of communication satellites, **Starlink**, has been in intensive deployment mode, **launching 989 new satellites** (now also in Polar orbits) between January and December 2021. The deployment runs in parallel with Starlink's aggressive pursuit of service rollout covering **250,000 users** across **25 countries** as of February 2022, with over 18000 satellites currently in orbit .[365]

Following a secondary sale of existing shares, to existing and new investors in October 2021, SpaceX is **now valued at $100B**, making SpaceX the second-most valuable private company in the world.[366] Nevertheless a leaked email, supposedly written by Musk, warned of "genuine risk of bankruptcy" and the interdependence of Starlink's second generation (V2) and Starship.[367]

SpaceX also made the headlines by signing a merger agreement with **Swarm Technologies** in July 2021. Swarm **launched 76 satellites** in 2021 bringing its total number of satellites in orbit to 121. The details of the deal were not publicly disclosed. Swarm will reportedly operate as a wholly owned subsidiary of SpaceX, while providing the parent company with access to the intellectual property and expertise developed by Swarm.[368]In Europe, **OneWeb** had an extremely eventful year following the November 2020 buyout when the company was saved from bankruptcy by the **UK Government** and **Bharti.**

The year started with a January 2021 strategic announcement targeting to bring down the full constellation size from 48,000 satellites to roughly 7,000, citing "*superior end user throughput and spectral efficiency while reducing funding requirements and fostering OneWeb's responsible space vision*".[369] Perhaps even more importantly, the company saw further capital injections, bringing the **total equity investment up to almost $3B** with no debt issuance.[370] First in January 2021, **Softbank** and **Hughes Network Systems**, through its parent company Echostar,



Mockup of a OneWeb satellite in orbit (Credit: OneWeb)

[365] Starlink services now have 250,000 users across 25 countries: Elon Musk, Business Standard, 2022.
[366] Elon Musk's SpaceX hits $100 billion valuation after secondary share sale, CNBC, 2021.
[367] Elon Musk says SpaceX could face 'genuine risk of bankruptcy' from Starship engine production, Space Explored, 2021.
[368] SpaceX to acquire Swarm Technologies, SpaceNews, 2021.
[369] OneWeb Adjusts Target Constellation Size Down to 7,000 Satellites, Via Satellite, 2021.
[370] OneWeb Announces Significant New Equity Partner, OneWeb, 2021.

invested approximately $400M into OneWeb.[371] Then in April 2021, **Eutelsat** invested **$550M** into OneWeb for a significant equity stake.[372] In June, **Bharti** further invested $500M to raise its stake in the company, making it the biggest shareholder in the company.[373] In August 2021 another major player, the South-Korean **Hanwha Systems**, joined through a $300M investment for an 8.8% share of the company. Finally in October 2021, **Eutelsat** invested a further sum of $165M, bringing it's total equity to almost 23% and affirming itself as the second largest equity partner.

With the change of fortune, OneWeb saw a strong year in terms of constellation deployment, **launching 284 satellites** and enabling an initial roll out a commercial service in parts of the northern hemisphere.[374] Moreover, in September 2021, OneWeb and **AT&T** agreed to partner on extending AT&T's high-speed broadband services to areas outside its fiber footprint in the United States.[375] A similar partnership followed in November 2021 with **BT Group**, integrating satellite capacity with BT's existing terrestrial capabilities both in the UK and globally.[376] In November 2021 **OneWeb** and **Intelsat** also demonstrated integrated GEO and LEO broadband in an effort to showcase the benefits of managed satcom as a service.[377]

Legacy operators prove their resilience

Beyond its investment in OneWeb, where it is currently the second largest shareholder, **Eutelsat** has developed additional plans in LEO, focused on IoT connectivity through its planned **ELO constellation,** while also planning to launch KONNECT VHTS, Hotbird 13F & 13G and Eutelsat 10B in 2022.[378] In January 2022 the company announced a partnership with Cloud software provider Senet, TrakAssure, and Wyld Networks to offer interoperable terrestrial and satellite **IoT services**, by forming the Multimodal IoT Infrastructure Consortium (MMIIC), that will target the supply chain industry including container logistics and asset tracking.[379]

In July 2021 **Inmarsat** announced its own ambition, manifested through **ORCHESTRA**, a communications network comprised of terrestrial, **LEO (150-175 satellites)** and GEO assets that hopes to unlock ground-breaking new services, in new places, for global mobility customers (e.g. Urban Air Mobility, Industrial IoT, Smart Cruise Ships, Tactical Private Networks).[380] The bold ambition set by Inmarsat, was further raised when **Viasat**, with its own ambition in the LEO constellation landscape, announced to have entered into a definitive agreement under which it will acquire Inmarsat in a transaction valued at **$7.3B**.[381] Viasat is also expecting the launch of ViaSat-3 in the first half of 2022, comprising it's new generation 3-satellite constellation in GEO, hoping to deliver users speeds at 100+ Mbps.

O3b mPower (Credit: SES)

SES continues to be focusing its efforts on MEO with the scheduled launch of the first two batches (totalling 6 out of 11 planned) of **O3b mPOWER** satellites in 2022. SES announced they have signed on Microsoft is as a customer for O3b mPOWER, following their earlier announcement of a

[371] SoftBank Re-Invests in OneWeb, Via Satellite, 2021.
[372] OneWeb receives major investment from Eutelsat, BBC, 2021.
[373] India's Bharti invests $500m in UK space start-up OneWeb, BBC, 2021.
[374] OneWeb lays path to commercial broadband services, BBC, 2021.
[375] OneWeb and AT&T partner to extend fiberlike coverage across United States, SpaceNews, 2021.
[376] BT secures industry first Global Partnership with OneWeb, OneWeb, 2021.
[377] Intelsat and OneWeb demonstrate integrated GEO and LEO broadband service, SpaceNews, 2021.
[378] ELO Fleet, Eutelsat, 2021; Future Eutelsat satellite launches, Eutelsat, 2021.
[379] Eutelsat and Senet Partner on Terrestrial and Satellite LoRaWAN IoT Connectivity, Via Satellite, 2021.
[380] ORCHESTRA - The communications network of the future that will enable ground-breaking new services, in new places, for global mobility customers, Inmarsat, 2021.
[381] Viasat and Inmarsat to Combine, Creating a New Leading Global Communications Innovator, PR Newswire, 2021.

partnership on the Azure cloud business.[382] With the promises of mPOWER, SES signed a number of agreements and MoU's in 2021 to leverage the upcoming capacity, including: (i) expanding its partnership with Orange to Enhance Maritime Services, (ii) bolstering the partnership with Marlink for its customers with data-intensive requirements, (iii) accelerating digital transformation in Colombia with affordable, high-speed and reliable connectivity services through a partnership with Integra Multisolutions, (iv) supporting the deployment of high-performance 4G services in rural and remote areas of Africa through a partnership with iSAT Africa, (v) exploring service agreements for satellite-enabled, high-speed connectivity services in Kazakhstan to accelerate the Digital Kazakhstan project.[383]

Legacy manufacturers are gathering the spoils

European operators are not the only actors benefitting from the trend of mega-constellations, the European manufacturing industry is well positioned to benefit from this trend as well. In February 2021, **Thales Alenia Space** announced it signed a **$3B** agreement with **Telesat** to be the prime contractor on the construction of Lightspeed, Telsat's advanced LEO network, initially comprised of a fleet of **298 satellites**.[384] A large part of the manufacturing process will be conducted in Québec, Canada following an investment of $400M by the **government of Québec**.[385] Later, in August 2021, a major backing through the **Government of Canada** (comprising of loans and equity) Telesat raised further CAD 1.44B.[386] In order to finance its constellation, Telesat also raised $500M through bond issuance due 2026, as part of a debt package that will fund 60% of the project's cost.[387] In November 2021, Telesat announced delays on the manufacturing front, due to component shortages reported by Thales Alenia Space, due to global supply-chain bottlenecks.[388]

Thales Alenia Space will also drive engineering activities and the definition of the mission and end-user needs for **Sateliot's** envisaged IoT services with 5G coverage from 2022 while **Telespazio** will advise and provide insights to Sateliot on promoting the development of the IoT market and on market penetration.[389] This was followed by a successful launch of Sateliot's first satellite for the Spanish startup (a 3U CubeSat manufactured by **Open Cosmos** based in the UK) in March 2021, with plans to launch the rest of the constellation by the end of 2022.[390] To support the ambition, the company organized Series A investment round and **raised €6.5M** in December 2021 and **€3.5M** in February 2022.[391] Among the investors are Indra, Cellnex, Seraphim Capital and GateHouse, with Indra now owning 10.5% of the company. In December 2021, Sateliot announced it will partner with MNOs to connect unmodified user 5G devices to the satellites, similar to the business models of AST, Omnispace and Lynk (adressed below in this section).[392]

In Germany, **OHB** was selected for a contract with an anticipated value of more than $300M to manufacture four satellites for **SpaceLink's** (US) commercial space data relay constellation planned

[382] O3b mPOWER get first cloud customer, on track for launch even as COVID-19 issues loom, SpaceNews, 2021.
[383] SES Press Releases, SES, 2021.
[384] Telesat Picks Thales for Lightspeed LEO Constellation, Via Satellite, 2021.
[385] Telesat to Build Lightspeed Constellation in Québec After Receiving $400 Million Investment, Via Satellite, 2021.
[386] Telesat to receive $1.44 billion through Government of Canada investment, a major milestone towards completing the financing of Telesat Lightspeed, Telesat, 2021.
[387] Telesat raising $500 million in debt for Lightspeed broadband network, SpaceNews, 2021.
[388] https://www.spaceintelreport.com/telesat-supply-chain-issues-hit-lightspeed-constellation-delay-bpifrance-canadas-edc-funding-thales-alenia-space-contract/ Telesat: Supply-chain issues hit Lightspeed constellation, delay Bpifrance, Canada's EDC funding & Thales Alenia Space contract, Space Intel Report, 2021.
[389] Sateliot will rely on the know-how of Thales Alenia Space and Telespazio for the deployment of its constellation of nanosatellites and for the development of the Internet of Things market, Thales Alenia Space, 2021.
[390] Successful launch of the first satellite of the Sateliot constellation, Alen, 2021.
[391] Sateliot raises 10 million euros in Series A round, SpaceNews, 2022.
[392] IoT constellation startup Sateliot: We'll partner with MNOs to connect unmodified user 5G devices to our satellites, Space Intel Report, 2022.

to be launched in MEO, while OHB also invested $25M into Spacelink, which is also strongly backed by the Australian Electro Optic Systems Holdings Ltd. (EOS).[393]

Keeping the focus on European manufacturers, **Airbus** is also benefiting from it's development of the **Arrow satellite platform**, designed and successfully relied upon for the OneWeb constellation. It signed an agreement with **Loft Orbital** in January 2022, for more than fifteen of these platforms to be used for future missions.[394]

Other private and new space actors are also in the mix

Other large constellations are at further stages of development but not yet deployed, namely **Amazon's Project Kuiper** stands out as the constellation lagging behind in terms of development and deployment compared to Starlink and OneWeb, considering its strong backing and ambitious plans, as it only foresees its first launch in Q4 2022.[395] The two test / demonstration satellites, KuiperSat-1 and KuiperSat-2, will reportedly launch with ABL Space on its RS1 vehicle, following up on Amazon's earlier-communicated strategy to be launch agnostic, and rely on multiple launch vehicles and launch partners.[396] Earlier in 2021, Amazon also signed a contract for nine launches of Project Kuiper satellites on United Launch Alliance's Atlas V.[397] In October 2021 **Verizon** and **Amazon** announced they started developing commercial models and technical specifications for Verizon's terrestrial network integration with Kuiper satellites with the aim to extend connectivity services to rural and remote communities across the US.[398]

Another US-based operator receiving increased attention in the satellite communications market is **Lynk,** the self-defined "*world's only independently verified cell-tower-in-space network connectivity provider*".[399]In July 2021 the company announced its 5th satellite began operation and that the company foresees to start offering commercial cellular service, from space, worldwide in 2022.[400] In September and November 2021 respectively, Lynk announced it signed its first commercial partnership agreements with mobile operators, namely Aliv in the Bahamas, and Telecel Centrafrique in the Central African Republic as well as with Unitel, Mongolia's largest mobile operator.[401] Moreover, in September 2021 Lynk announced it has registered hundreds of unmodified mobile phones to its satellite across three different countries (UK, US and Bahamas), providing further proof of the company's technology enabling **Direct Two-way Satellite-to-Mobile-Phone** connections.[402]

Clean room where final testing on BlueWalker 3 is conducted (Credit: AST)

After announcing a SPAC deal in late 2020, Lynk's competitor, **AST SpaceMobile** is also progressing on its plans and deployment. The company started trading on NASDAQ on 7 April 2021. In August 2021 the company noted that it signed MoU's with Smart Communications, Africell, MUNI, UT Mobile, LIBTELCO and others and touted to have agreements and understandings with

[393] SpaceLink hires OHB to build data relay satellites, SpaceNews, 2021.
[394] Industry first: Loft Orbital signs agreement with Airbus to procure more than fifteen Arrow satellite platforms, Airbus, 2022.
[395] Project Kuiper announces plans and launch provider for prototype satellites, About Amazon, 2021.
[396] Amazon to launch 1st prototype internet satellites for Kuiper constellation in 2022, Space.com, 2021.
[397] Amazon signs with ULA for rockets to launch Jeff Bezos' Kuiper internet satellites, CNBC, 2021.
[398] Verizon announces intent to use Amazon's planned Project Kuiper constellation, SpaceNews, 2021.
[399] Lynk Press Releases, Lynk, 2021.
[400] Lynk Begins Operation of Next Generation Fifth "Cell Tower in Space" Satellite, Businesswire, 2021.
[401] Lynk Signs Contracts with First Two Mobile Operators, Lynk, 2021; Lynk Signs Contract with Mongolia's Largest Mobile Network Operator, Lynk, 2021.
[402] Lynk Proves Direct Two-way Satellite-to-Mobile-Phone Connectivity, Lynk, 2021.

operators representing approximately 1.5B users worldwide.[403] In July 2021 the company opened its UK Office at Space Park Leicester, which will house business development, engineering and regulatory functions. Deployment plans were however delayed by December 2021, as AST announced it is pushing back its foreseen BlueWalker 3 Satellite Launch scheduled to launch in March or April 2022 and now considers summer 2022 as the likely launch window.[404] In February 2022, AST announced a new partnership with Vodafone to plan a satellite strategy so that customers in remote locations can use their existing mobile devices to access voice and data services.[405]

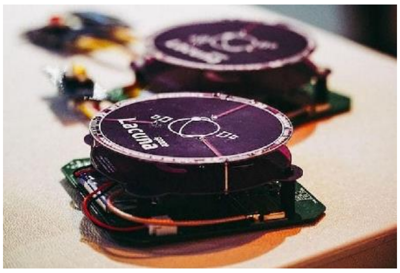
US-based **Omnispace**, another company with sights on combining a satellite constellation with the mobile telecom networks into a single network, has announced a strategic partnership with Lockheed Martin to explore jointly developing 5G capability from space.[406] Earlier in the year Omnispace secured $60M in equity financing to help fund it's constellation.[407] The company hopes to target enterprise market segments, notably agriculture, mining and energy, shipping and logistics. In September 2021 the company announced it successfully demonstrated voice and data communication between the company's on-orbit satellite and existing military communications radios. The company hopes to launch its first two new satellites, being manufactured by Thales Alenia Space, in 2022.[408]

The San Diego-based IoT connectivity company **Ingenu already** leveraging terrestrial IoT/M2M networks, has announced it plans to launch a **72-satellite LEO constellation (AFNIO)** and contracted Phantom Space Corporation from Arizona, for manufacturing and launch services.[409] The constellation aims to enhance Ingenu's existing services and will initially focus on end-to-end solutions for Smart Grid, Smart Factory, Smart Agriculture, Smart Cities, Oil & Gas, Mining, Asset Tracking and Logistics.[410]

In Europe

In France, **Kinéis**, spun off in 2018 from French maritime and environmental monitoring company CLS and raising €100M in 2020, is developing and plans to deploy a **25-satellite IoT constellation** and contracted Rocket Lab for five launches starting in 2023.[411] In November 2021 the company received FCC approval to connect IoT devices in the United States to its upcoming constellation.[412] In early 2022, Kinéis signed a partnership with IoT provider UnaBiz to deliver satellite IoT connectivity to companies in the Asia Pacific, with the initial target being the transportation and logistics sector.

The UK-based **Lacuna space**, focusing on the IoT market, is planning to deploy a 240-satellite LEO constellation. It started the year with the operations of its third satellite in orbit and the launch of its fifth satellite in March 2021.[413] In early 2022, the company announced a partnership with Semtech to extend the coverage of LoRaWAN by adding it to Lacuna's IoT-to-Satellite connectivity, with Lacuna now expecting to begin commercial



Lacuna Space receiver Gateway (Credit: Lacuna Space)

[403] AST SpaceMobile Provides Second Quarter 2021 Business Update, AST Spacemobile, 2021.
[404] SpaceMobile Pushes Back BlueWalker 3 Satellite Launch, Via Satellite, 2021.
[405] Vodafone works with AST SpaceMobile to close digital divide, Fierece Wireless, 2022.
[406] Lockheed Martin partners with satellite start-up Omnispace to build a space-based 5G network, CNBC, 2021.
[407] Omnispace raises $60 million to fund hybrid network, SpaceNews, 2021.
[408] Omnispace Demonstrates Connectivity with NGSO Satellite and Military Radios, Via Satellite, 2021.
[409] Phantom Space Announces Agreement to Build and Launch 72 Satellite Constellation for Ingenu, PR Newswire, 2021.
[410] UnaBiz teams up with Kinéis to deliver satellite IoT connectivity, FutureIoT, 2022.
[411] Rocket Lab Lands Deal to Launch Entire IoT Satellite Constellation for Kinéis, Kinéis, 2021.
[412] French satellite startup Kinéis gets regulatory nod for U.S. expansion, SpaceNews, 2021.
[413] First successful LacunaSat launch in 2021, Lacuna Space, 2021.

services within the first half of 2022.[414]

KLEO Connect, the Germany-based company, with its regulatory domicile in Lichtenstein, and reported Chinese financial backing, unexpectedly launched two test satellites in August 2021 aboard a Long March 6 launch vehicle.[415] The two satellites were built by the Shanghai Institute for Microsatellite Innovation of the Chinese Academy of Sciences. The company has two filings through Lichtenstein, each for 300 satellites at the altitude of approximately 1,500 km and hopes to build a IoT enterprise network in the sky.[416]

Keeping the focus in Europe, June 2021 saw an announcement of an industrial consortium led by satcom startup **Rovial** along with **Mynaric, Reflex Aerospace** and **Isar Aerospace** to develop, build and operate "an independent European satellite-based communications network", aiming to serve a range of applications, including IoT, autonomous vehicles, video/rich-data communications, and defence and humanitarian missions. The consortium's plans, emboldened by the EU Secure Connectivity initiative, hope to launch demonstration satellites in 2022 and roll out commercial service in 2023 or 2024.[417] However some commercial ventures are shifting towards different business models.

The Dutch IoT-focused company, **Hiber**, has decided for a different, perhaps unexpected, strategic approach following its successful funding round in March 2021, securing €26M through the European Innovation Council Fund to expand its IoT satellite network.[418] In October 2021, the company communicated that it dropped plans to operate its own constellation, stating "Hiber will not be further developing its authorized satellite system and is currently in the process of surrendering its space system license to the Administration of the Netherlands".[419] Hiber now aims to rely on other satellite networks to provide IoT services, admittedly due to technical issues with its initial batch of launched satellites, with two of the four satellites launched to date no longer in operation and the other two suffering technical problems.[420] Hiber now plans to use Inmarsat's ELERA network to bring its IoT solutions and services to market.[421]

In a similar fashion, **Myriota**, who rolled out commercial services in North America and Canada in March 2021, then opted to expand its service reach and capacity through **Spire's** Space-as-a-Service capabilities rather than further deploying its own assets.[422] This will enable the Australian company to quickly ramp up its existing coverage in North America, Australia and New Zealand and expand to other markets including Europe. Soon after announcing the deal with Spire, Myriota won a public contract through the Defence Innovation Hub's Next Generation Technologies Fund to expand its satellite communications network for use by the Department of Defence.[423]

---

[414] Semtech and Lacuna Space add IoT-to-Satellite connectivity to LoRaWAN, Electronics Weekly, 2021.
[415] Surprise Chinese launch sends two communications satellites into orbit for Chinese/German venture, Seradata, 2021.
[416] Germany-based, Liechtenstein-registered, Chinese-financed Kleo Connect nears ITU milestone for 300-satellite constellation, Space Intel Report, 2021.
[417] Paris-based Satcom Operator ROVIAL SAS to form consortium with key partners Mynaric, Reflex Aerospace, and Isar Aerospace to develop, build, and operate an independent European satellite-based communications network, Rovial, 2021.
[418] IoT satellite network startup Hiber secures €26M in funding round led by EU's innovation agency, TechCrunch, 2021.
[419] Hiber abandons plans for IoT satellite constellation, SpaceNews, 2021.
[420] Ibid.
[421] Hiber and Inmarsat announce strategic relationship to develop connectivity backbone for global IoT-as-a-service ecosystem, Inmarsat, 2021.
[422] Spire Global and Myriota partner to re-imagine Internet of Things connectivity, Myriota, 2021.
[423] Myriota signs $5.48m Defence satellite contract, InnovationAus, 2021.

Further institutional and private ambitions saw light in 2021

In the USA:

In addition to the development of constellation a host of new filings has been submitted and approved in 2021, with companies in North America at the forefront of these proposals. In November 2021 news emerged that **Boeing** receiving an approval by the FCC for its proposed **147-satellite constellation** with plans to "*provide broadband and communications services for residential, commercial, institutional, governmental, and professional users in the United States and globally*".[424]

FCC - Increasingly swarmed by applications for large constellations

Only a day after, with the deadline looming for the FCC's latest processing round of proposals to use V-band a host of companies submitted constellation proposals to the agency, among those:

- **Astra Space** filed a request proposing a constellation of more than **13,600 satellites** in LEO enabling communications, natural resource applications, and national security missions.[425]
- **Telesat**, with a proposed 1,373-satellite LEO constellation, aiming to provide overlay to its Lightspeed constellation currently under development.[426]
- **Hughes Network Systems** filed a request to the FCC to build a LEO broadband constellation with 1,440 satellites in 36 LEO planes.[427]

In addition, **OneWeb**, **Spinlaunch**, **Inmarsat**, **Intelsat**, **Boeing** and **Amazon** all filed proposals to expand their planned constellations or be granted additional access to V-band, bringing the total number of satellites only in these newly proposed and expanded constellations to **almost 38,000**.[428]

In terms of other developments in investments and acquisition, **ORBCOMM**, a provider of Internet of Things (IoT) solutions operating over 30 LEO satellites, announced that it has entered into a definitive agreement to be acquired by **GI Partners**, in an all-cash transaction valuing ORBCOMM at approximately **$1.1 billion**.[429] In January 2022 Phoenix-based **Mangata Networks**, has closed a **$33M** investment round for an innovative HEO and MEO 791-satellite constellation for connectivity and edge computing.[430] The initial launch of satellites is scheduled for 2024. In early 2022, **E-Space**, founded by former OneWeb executive chairman **Greg Wyler** has closed the "*largest seed funding round in space technology history*" with a $50M investment.[431] The company, with entities in France and the US, is behind the 300,000 satellite filing with the ITU coming out of Rwanda in late 2021.[432] E-Space plans to launch its first test satellites in March 2022.

In China:

Major ambitions have also been further refined and developed in China, with a host of communication-related constellations foreseeing for the coming years. Further plans were revealed with regard to the **GuoWang** constellation, which was first publicly confirmed in March

[424] Boeing gets FCC approval for 147-satellite constellation, Space.com, 2021.
[425] Application for Fixed Satellite Service Mobile Satellite Service by Astra Space Platform Services, LLC., FCC, 2021.
[426] Telesat looks to augment its Lightspeed constellation with an additional 1373 satellites, SpaceQ, 2021.
[427] Telesat, Astra and Hughes request 3 new mega-constellations, Spacewatch.global, 2021.
[428] In race to provide internet from space, companies ask FCC for about 38,000 new broadband satellites, CNBC, 2021.
[429] Orbcomm Enters Into Agreement to Be Acquired by GI Partners, GI Partners, 2021.
[430] Mangata raises $33M for hybrid satellite network with connections to Seattle tech community, GeekWire, 2022.
[431] Greg Wyler's E-Space raises $50 million in funding, Spacewatch.global, 2022.
[432] Wyler behind Rwanda's 300,000 satellite plan, Advanced Television, 2021.

2021 (although previously disclosed in ITU filings). The **China Satellite Network Group** was established in April 2021, a company dedicated to developing, manufacturing and operating the 13,000-satellite broadband constellation. In parallel to the establishment, it was announced that plans by CASC and CASIC, namely the **Hongyan** and **Hongyun** constellations, will undergo major changes, most likely cancellation.[433] In December 2021, the **China Satellite Network Application Company** and **Chongqing Satellite Network System Research Institute** were established in Chongqing, creating a satellite cluster, aimed at further driving the national efforts towards the deployment and operations of GuoWang.[434]

The Chinese private sector is also progressing on parallel satellite constellation plans which are moving fast, with **GalaxySpace**, a Chinese commercial micro-satellites developer from Beijing reporting its first 6 satellites, to be used as test platforms for its planned constellation of approximately 1,000 satellites in LEO, will be launched in early 2022.[435] In parallel, the company is reportedly building a "GalaxySpace is also building a "satellite super factory" in China's Jiangsu Province designed to mass produce low-cost satellites.[436]

The Chinese automotive giant **Geely** (China's largest privately owned car manufacturer) also joined the space game, kickstarting a RNB 4.12B (approx. $600M) satellite project in Qingdao following governmental approval in February 2021.[437] The satellites are be designed to support autonomous vehicles in Vehicle-to-Vehicle and Vehicle-to-Everything communications.[438] The company announced it began manufacturing in October 2021 with a target annual production rate at 500 units.[439]

Geespace mock-up (Credit: Geely)

Moreover, **Spacety** and **Beijing University of Posts and Telecommunications** agreed to launch satellites, forming the **Tiansuan Constellation**, aimed at providing an open-source platform in support of 6G networks, satellite internet and other technologies.[440] The first six satellites are planned to be launched in May 2022 while the constellation is hoped to be completed by the end of 2023.

In Russia:

Russia is reportedly moving ahead with its **Sfera constellation**, revealed in 2018 by the Russian president and initially designed with 288 satellites in a 870km obit.[441] The constellation has now slightly decreased in size reportedly envisaged with 264-satellites (with some outlets however mentioning over 600 satellites), boasting both broadband and Earth observation capabilities.[442] Now scheduled to begin launching in 2023 or 2024, Rogozin, Roscosmos CEO, promising "100% coverage of Russia with space communications and broadband internet by 2024" during an interview in April

[433] China establishes company to build satellite broadband megaconstellation, SpaceNews, 2021.
[434] China's megaconstellation project establishes satellite cluster in Chongqing, SpaceNews, 2022.
[435] China's satellite producer delivers 6 communication satellites, Xinhua English, 2022.
[436] GalaxySpace to Build East China Super Factory to Mass Produce Low-Cost Satellites, YiCai, 2020.
[437] Geely officially launches a 4.12b yuan internet satellite project in Qingdao, Global Times, 2021.
[438] China's Geely begins production of satellites for its self-driving vehicles, TechWire Asia, 2021.
[439] China's Geely builds satellites to guide autonomous vehicles, Nikkei Asia, 2021.
[440] l Chinese firm to build Tiansuan satellite constellation to support 6G development, Global Times, 2021.
[441] Roscosmos plans 20 launches of Soyuz rocket in 2020, TASS, 2019.
[442] Russia's Sphere Satellite Constellation Moves Toward Implementation, Parabolic Arc, 2022.

2021.[443] According to the news outlet, the Arctic zone is a priority area for Roscosmos in view of the development of the Northern

Sea Route. In January 2022, further details of different elements under the Sfera constellation were revealed: "In 2021, agreements were concluded to work on the **Marafon Multisatellite Internet of Things System** with a demonstrator satellite launch in late 2023 or early 2024, and the **Skif Broadband Internet Access System** with a demonstrator launch in late 2022". The federal budget provides funding for Sfera in the amount of RUB 21B for the years 2022-2024".[444]

In Europe:

Another mega-filing came out of Germany in November 2021, with Kepler Communications (of Canada) through the German government proposing **Aether; a 114,582-satellite constellations**; which Kepler reportedly made on behalf of future customers using the Aether terminal, not only for its own satellites.[445]

In a more future-oriented perspective, beyond Earth orbits, the **ESA Moonlight Initiative** must be given attention, as it aims to shape service provision and infrastructure to provide sustainable commercial Lunar data-relay services for communication and navigation.[446] In May 2021, **Surrey Satellite Technology** Ltd (SSTL) has been selected by ESA to lead a Phase A/B1 Study to define the service infrastructure and clearly lay out the development path for a constellation of Lunar communication and navigation satellites.[447]

Finally, **the EU Secure Connectivity** initiative (see section on Policy & Programmes) based on a multi-orbit constellation of satellites is not only important from the perspective of public policy objectives related to security, technological leadership, digital sovereignty, and resilience but also offers a multitude of opportunities for the European space industry, beyond the mere provision of launch services often referred when discussing the initiative. The constellation can provide a **much**-needed avenue for Europe to sustain and develop its competitiveness in the realm of satellite manufacturing and operations.

Efficiently building large constellations requires manufacturing techniques and process, differing from those used in traditional satellite manufacturing. The same is true for operations of large constellations as opposed to single satellites, requiring more automation through AI algorithms and machine learning for collision avoidance, as well as robust end-of-life capabilities to ensure a sustainable orbital environment.

The European industry, in order to keep up with global technological developments, needs initiatives enabling the building-up of capabilities and expertise in rapidly evolving and highly relevant domains.

[443] Roscosmos plans to provide space communications across entire Russia by 2024, TASS, 2021.
[444] Dmitry Rogozin on the results of 2021 and plans for 2022, Roscosmos, 2022.
[445] Kepler Communications, through Germany, registers 114,852-satellite S-band LEO constellation at ITU, Space Intel Report, 2021.
[446] Lunar Satellites, ESA, 2021.
[447] SSTL Lunar to Lead Consortium for ESA Moonlight, SSTL, 2021.

2.1.4 Notable developments in quantum encryption for protecting communications

In light of the development of quantum computing, which is posing a major cyber threat as it will likely be able to decrypt today's encryption keys, emerging technologies such as Quantum Key Distribution (QKD) are being developed.

QKD is particularly relevant for space as it could prove to be more efficient in the space environment than in terrestrial infrastructures due to the physical limitations of quantum communication networks on Earth, thereby providing opportunities for the space sector to play a bigger role in protecting space digital systems. QKD uses encryption keys encoded in entangled photons to secure communications and better detect interference.[449]

According to NSR, **satellite-based quantum communications are expected to generate $2.6 billion in revenues by 2030**. The field of banking, energy, government, and military are expected to be the primary markets to adopt these technologies. In the past few years, $20 billion have been invested globally in quantum related technologies.[450]

Quantum technologies have become a priority for governments, looking to reach quantum supremacy (the time by which a quantum computer can perform a task that would be impossible or would take years to solve for a conventional computer) or to protect themselves from it.

China is currently the most advanced country in the field of space-based quantum encryption following the launch of the world's first quantum satellite Mozi (also referred to as Micius or QUESS) in 2016. It demonstrated the technological feasibility of distributing quantum keys in space. In 2020, China's Mozi satellite successfully connected to the first mobile quantum satellite station.[451] Along with additional research and funding allocated to quantum computing, these developments prompted other actors to react, in particular the European Union, the United States, the United Kingdom, and India.

Quantum Computing and Quantum Encryption

Quantum computing and Quantum encryption should not be misunderstood. Quantum computing does not exist yet and will be fundamentally different than traditional computers. Traditional computers are based on "bits" (successions of 0 and 1), which process the information step by step. Quantum computers will be based on the superposition of bits, whereby quantum bits will be able to be 0 and 1 at the same time. This superposition and the intrication of quantum bits will enable incomparably fast data processing and computing power as well as the decryption of today's encryption keys. QKD is a method to protect a system against the emergence of quantum computing but can be implemented on a traditional computer.[448]

European developments in space quantum and secured connectivity initiatives

In Europe, the European Commission, the European Space Agency, and their respective Member States have taken stock of the problem and decided to work towards **the development of a secure quantum communication infrastructure called EuroQCI**. All EU Member States are now part of the EuroQCI initiative since July 2021, when Ireland signed the EuroQCI declaration.[452] This infrastructure will integrate quantum technologies, in particular QKD, into terrestrial networks,

[448] L'informatique Quantique: la 5e revolution, PWC, 2019.
[449] Quantum and Space: The ultimate solution to secured communications? ESPI, 2021.
[450] Emerging Quantum Communications Via Satellite Revenue Opportunity Of $2.6 Billion By 2030, NSR, 2021.
[451] China's quantum satellite links with world's first mobile ground station, State Council Information Office, 2020.
[452] Ireland joins other 26 Member States in developing secure communication networks across EU, Agence Europe, 2021.

building on new and existing fibre communication networks, which will be complemented by a space-based segment, building on the GOVSATCOM initiative. The objectives for the EuroQCI is to be operational by 2027.[453]

In January 2021, at the 13th European Space Conference, Commissioner Breton revealed the willingness of the EU to develop a multi-orbit secured connectivity system which would build on the GOVSATCOM component of the EU Space Programme and would be integrated into the EuroQCI initiative. Among other objectives, this European constellation aims to "project Europe into the quantum era, ensuring quantum encrypted communication".[454]

In 2021, the European Commission has awarded **several study contracts** for both the EuroQCI and the secure connectivity initiative, which will define the design and technical features of these systems:

<table>
<tr><td rowspan="2">Secured connectivity initiative</td><td>The European Commission selected a consortium of companies including Airbus, Arianespace, Eutelsat, Hispasat, OHB, Orange, SES, Telespazio, and Thales Alenia Space to conduct a year-long study on the design, development and launch of the secured connectivity initiative[455] taking into account the integration of quantum technologies (e.g., payload, encryption).

The study had to analyse two design and implementation options:
• quantum payloads embarked on-board the communication satellites (also analysing how such solution would cope with evolving technologies and QKD-based functionalities that the EuroQCI will offer),
• the space segment of EuroQCI is implemented separately from the connectivity space segment as an overlay service but fully interconnected and interoperable with the connectivity satellites.[456]</td></tr>
<tr><td>Other studies were awarded by the Commission to start-ups (e.g, New Symphonie, UN:IO) on the secured connectivity initiative but did not seem to contain strong aspects related to quantum encryption.</td></tr>
<tr><td rowspan="3">EuroQCI</td><td>In May 2021, the European Commission selected two consortia of companies and research institutes to study the terrestrial design of the EuroQCI for a period of 15 months as part of a coordinated call with ESA, which will launch a similar study for the space component of EuroQCI. The two consortia will have to work hand in hand with the consortia chosen by ESA to design the space segment of EuroQCI.</td></tr>
<tr><td>The first consortium is led by Airbus and includes Leonardo, Orange, PwC France and Maghreb, Telespazio, the Consiglio Nazionale delle Ricerche (CNR) and the Istituto Nazionale di Ricerca Metrologica (INRiM). The study will lay out the details of the end-to-end system and design the terrestrial segment supporting the QKD service. [457]</td></tr>
<tr><td>The second consortium is led by Deutsche Telekom and includes the Austrian Institute of Technology, Thales, and Thales Alenia Space, and Telefonica</td></tr>
</table>

[453] The European Quantum Communication Infrastructure (EuroQCI) Initiative, European Commission, 2021
[454] Speech by Commissioner Thierry Breton at the 13th European Space Conference, European Commission, 2021
[455] European space and digital players to study build of EU's satellite-based connectivity system, Airbus, 2020
[456] GOVSATCOM and EuroQCI: building blocks towards a secure space connectivity system Open procedure, eTendering, 2020
[457] Europe picks EuroQCI satellite quantum communications consortium, SpaceNews, 2021

Investigacion y Desarrollo. Thales Alenia Space covers all aspects related to space based QKD.[458]

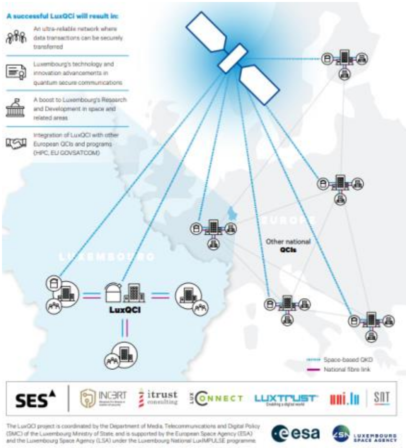
In November 2021, the EU opened three **calls for tenders** to fund quantum encryption projects through the **Digital Europe Programme** in order to further develop the terrestrial and space components of the EuroQCI:

- One project aims at creating a European industrial ecosystem for secure QCI technologies and systems.
- One project aims at deploying advanced national quantum systems and networks for testing quantum communication technologies and for integrating them with existing communication networks as well as use these quantum systems and networks for developing and testing use cases in support of national QCI initiatives for EuroQCI. This project will include the test of the interface between the future QCI space and terrestrial system.
- One project aims to conduct the first deployment of national EuroQCI projects and prepare the large-scale QKD testing and certification infrastructure.[459]

Finally, in 2022 and 2023, the EU Connecting Europe Facility is expected to provide funding to projects supporting cross-border links between national quantum communication networks, along with links between the EuroQCI's earth and space components.

Member States are also developing their national quantum communications infrastructure projects in partnership with satellite operators:

In June 2021, the Department of Media, Telecommunications and Digital Policy of the Luxembourg Ministry of State announced the development of the Luxembourg's Quantum Communications Infrastructure project (LuxQCI) under the Luxembourg National LuxIMPULSE program. The project will be supported by ESA and the Luxembourg Space Agency and is part of the EuroQCI. A consortium led by SES, and including InCert, itrust consulting, LuxConnect, LuxTrust and the University of Luxembourg, will design the LuxQCI.[460] The LuxQCI will integrate both a terrestrial and space-based QKD in a hybrid Key Management System. The QKD technology of the LuxQCI will rely on SES's Quantum Cryptography Telecommunication System (QUARTZ), which is a commercial system support by ESA's ARTES ScyLight programme.[461]



LuxQCI (Credit: SES)

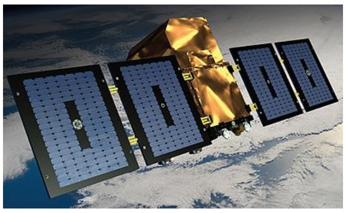
The United-Kingdom is already one step ahead

The British company Arqit developed a satellite-based QKD as well as a QuantumCloud software, which is a Platform-as-a-service that generates encryption keys. Arqit provides quantum encryption through a Platform-as-a-service, which enable any connected device to use quantum encryption. Its software called QuantumCloud can be downloaded by customers to generate encryption keys. The company received funding from ESA to build and launch two small quantum satellite QKDSat 1 and QKDSat 2 by 2023.

[458] AIT And Deutsche Telekom Industry Consortium Design The European Quantum Communication Infrastructure, AIT, 2021
[459] Deploying advanced national QCI systems and networks, European Commission, 2021
[460] SES-led European Quantum Project Progresses to the Next Stage, Via Satellite, 2021
[461] SES-led Consortium to Define Luxembourg's Quantum Communication Infrastructure for Europe, BusinessWire, 2021

In 2021, the British company reached key milestones:

- In May 2021, Arqit raised $400 million through a SPAC to launch quantum encryption satellites in 2023. This led to the creation of Arqit Quantum Inc, and now trades on the Nasdaq. The CEO outlined that the transaction would enable Arqit to establish itself as a leader in the encryption space to face threats from quantum computing. [462]
- In June 2021, during the G7 summit, the United States, the United Kingdom, Japan, Canada, Italy, Belgium, and Austria announced that they will develop a satellite-based quantum technology encryption network, the Federated Quantum System (FQS), which will be based on Arqit's technology and QuantumCloud service, but in a closed platform. It will enable governmental and military communications among allied countries.[463]
- In September 2021, Arqit Quantum Inc. and the company Juniper Networks, specializing in AI-driven networks, signed a 'Technology Alliance Partner Connect' agreement to explore network security technology that will protect against quantum security threats. Arqit's QuantumCloud will be tested on network systems.[464]
- In October 2021, Arqit and the defence company Blue Bear Systems signed a collaboration agreement to jointly demonstrate the use of Arqit's quantum encryption technology on Blue Bear's unmanned systems in the land, maritime, and aerospace domains. Most Blue Bear systems are designed for multi-domain operations, in which all systems of the battlefield are interconnected, relying on communication satellites, terrestrial datalinks, and 5G for connectivity, bringing complex cybersecurity risks.[465]
- In December 2021, Virgin Orbit signed a QuantumCloud software license enable Virgin Orbit to use Arqit's quantum encryption technology to secure its launch infrastructure.[466]



QKDSat (Credit: Arqit)

However, it should be noted that while Arqit received funding from ESA to develop its quantum encryption technology and the UK is still a member of ESA, Arqit and other British companies will likely not be authorised to take part in the EU EuroQCI initiative because of Brexit.

Space quantum developments in the rest of the world

In May 2021, researchers from the UK and Canada announced that they were developing a **QKD payload that will be tested on the Quantum EncrYption and Science Satellite (QEYSSat) mission**, funded by the Canadian Space Agency and expected to be launched by 2023. The goal of the project is to send encryption keys to ground stations on both sides of the Atlantic. British researchers will develop a quantum transmitter and Canadian researchers will develop secure communication protocols for the transmitter as well as the modelling of the quantum system. It is expected to provide extended capabilities to QEYSSat and contribute to the general development of space-based quantum technologies.[467]

QKD developments in the Indo-Pacific region:

- In March 2021, the **Indian Space Research Organisation (ISRO)** demonstrated quantum communication over 300 m. It validated the Navic QKD receiver, which enabled time synchronization between the transmitter and receiver modules, and gimbal mechanism systems for optical alignment. Similarly, to the first Chinese test (2016), ISRO demonstrated its QKD capability through online video-conferencing.[468]

[462] Arqit raising $400 million with a SPAC to launch quantum encryption satellites in 2023, SpaceNews, 2021
[463] Governments ally for federated quantum encryption satellite network, SpaceNews, 2021
[464] Arqit and Juniper Networks Sign Technology Alliance Partner Connect Agreement, Arqit, 2021
[465] Arqit and autonomous systems provider Blue Bear sign collaboration agreement, CSN, 2021
[466] Virgin Orbit licenses QuantumCloud™ from Arqit, Bloomberg, 2021
[467] Testing quantum-secure communication in space, University of Waterloo, 2021
[468] ISRO achieves breakthrough in quantum communication, precursor for quantum satellite, Economic Times, 2021

- In August 2021, **Singapore-based company SpeQtral** signed an agreement with Toshiba to provide QKD solutions to governments and companies. Toshiba has been developing terrestrial QKD products that operate over fibre-optic cables. SpeQtral space-based QKD will complement Toshiba's terrestrial systems.[469] In November, SpeQtral raised $8.3 million in a funding round led by Xora Innovation to further develop its satellite-based systems.[470]

[469] SpeQtral and Toshiba Collaborate to Power Quantum-Secure Communication Solutions in Southeast Asia, Toshiba, 2021
[470] SpeQtral closes US$8.3m funding round, Speqtral, 2021

2.1.5 Increasing development of in-orbit operation technologies

Following the successful demonstrations of Northrop Grumman's Mission Extension Vehicle (MEV) 1 in 2019 and MEV-2 in 2021 for life extension, which proved the possibility and business case of life extension missions, in-orbit operations technologies have further developed. Companies are now conducting in-orbit demonstrations and signing contracts for the development of technologies and missions with commercial satellite operators as well as space agencies. According to NSR, in-orbit services are expected to generate $6.2 billion of revenues by 2030, in particular in the field of life extension.[471]

In-orbit operations comprise in-orbit servicing, which refers to the provision of support services by a spacecraft (servicer) to another space object (serviced) while in orbit; in-orbit manufacturing, which is defined as the use of innovative techniques, such as space resources or 3D printers, to build items and components directly in outer space; in-orbit assembly, which is characterised as the assembly or combination of modular platforms to form a new object as well as the integration of upgrade payloads in orbit.[472]

American start-up Orbit Fab reached important milestones in 2021:

- In June, Orbit Fab successfully launched the Tanker-001 Tenzing, a microsatellite that can be considered as the world's first in-orbit fuel depot. The Tanker-001 Tenzing stores High-Test Peroxide (HTP), which is a green propellant, in a sun-synchronous orbit in order to refuel other spacecrafts while in-orbit.[473]

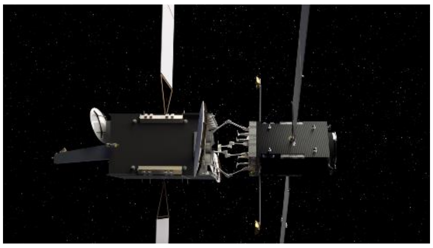
Tanker 001 Tenzing (Credit: Orbit Fab)

- In September, Orbit Fab announced that it will launch a propellant tanker (Tanker-002) to GEO on a Falcon 9 rocket lunar lander mission in late 2022 or early 2023. The tanker will be launched as a secondary payload on the Intuitive Machine' IM-2 lunar lander mission. Tanker-002 will be able to store propellant for a period of 15 years and will store around 90 kg hydrazine. Tanker-002 is expected to provide in-orbit refuelling in GEO and park hundred kilometres away from the GEO belt when it is not operating in order to avoid collisions. Orbit Fab's goal is to launch both tanker and fuel shuttles in space to provide refuelling services.[474]
- In October, Orbit Fab announced the release of the Rapidly Attachable Fluid Transfer Interface (RAFTI), which is its satellite refuelling interface design, as well the RAFTI Open Licence, which specifies the mechanical, electrical, and functional requirements of RAFTI.[475] The RAFTI system comprises two components: the Service Valve (SV), which serves as a fill/drain valve for in-orbit refuelling, a docking adapter, and a secondary servicing connection to facilitate missions that use robotic arms; and the Space Coupling Half (SCH), which The SCH is a double-action latch mechanism that enables both primary docking or secondary attachment of two spacecraft.[476]
- Orbit Fab announced it will offer an Open License for RAFTI and will share its intellectual property with other commercial space companies in order to foster the development of in-orbit operations.

[471] NSR Report: In-Orbit Satellite Servicing and Space Situational Awareness Represent a $6.2 Billion Opportunity, NSR, 2021
[472] In-Orit Services, ESPI, December 2020
[473] Rapidly Attachable Fluid Transfer Interface (RAFTI™), OrbitFab, 2021
[474] Orbit Fab to launch propellant tanker to fuel satellites in geostationary orbit, SpaceNews, 2021
[475] Orbit Fab to Publish Satellite Refueling Interface Designs, OrbitFab, 2021
[476] Rapidly Attachable Fluid Transfer Interface (RAFTI™), OrbitFab, 2021

- Orbit Fab also signed a Cooperative Research and Development Agreement (CRADA) with the U.S. Air Force Research Laboratory (AFRL), Space Vehicle Directorate, and the Spacecraft Technology Division on in-orbit refuelling. Under the agreement, Orbit Fab will share technical details and its RAFTI system and docking guidance solution with the Air Force. The Air Force will provide Orbit Fab with access to its facilities and will review their refuelling technologies, advise on requirements and designs. It will facilitate Orbit Fab's delivery of services to defence customers.[477]

Other developments took place in the field of life extension in 2021



Demonstration vehicle

(Credit: Kurs Orbital)

The Ukrainian start-up **Kurs Orbital** plans to develop and launch a demonstration vehicle in 2023 that will conduct a rendezvous with a non-cooperative satellite in LEO. The company is looking to provide life extension services in GEO as well as de-orbiting services. The company is using docking technologies developed in the 1980s by the Soviet Union and is also developing a new rendezvous acquisition module with machine vision, radar, and robotics for docking non-cooperative satellites autonomously. The company plans to develop four vehicles and start providing in-orbit services by 2025.[478] In February 2021, Kurs Orbital upgraded its bench, which is used to manufacture and benchmark the mutual measurement systems for spacecraft rendezvous system module testing, enabling the start-up to conduct more precise tests.[479] The same month, Kurs Orbital announced that the Kurs One machine vision system bench testing was successfully conducted. It aimed at detecting images of a non-cooperative satellite and detecting the edges of the satellite as well as area of interest on the satellite for further analysis. The test also aimed at detecting the non-cooperative satellite mock-up position and orientation relative to the camera in order to identify docking surface corner points.[480] Additionally, Kurs Orbital joined CONFERS in May to collaborate on developing standards for IOS and facilitate the development of Kurs' system.[481]

Northrop Grumman announced that the Mission Extension Vehicle 2 (MEV-2) satellite successfully docked to Intelsat 10-02 satellite in April and will provide life extension services to the satellite for the next five years. After five years, MEV-2 will undock from IS-10-02 and dock another satellite.[482]

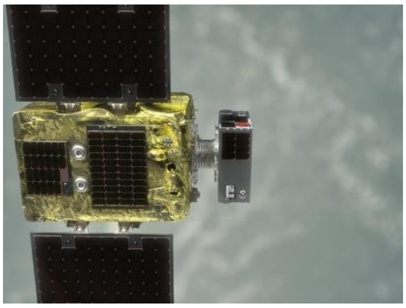
The Shanghai Academy of Spaceflight Technology unveiled its Supplemental Service Vehicle at the Zhuhai Airshow in September. The system was presented as a commercial service spacecraft that can provide life extension services in GEO. The Vehicle, equipped with AI, can carry 1.3 ton of fuel and dock satellites to refuel them.[483]

[477] Orbit Fab, U.S Air Force sign CRADA for On-Orbit Refueling Technology, OrbitFab, 2021
[478] Kurs Orbital will focus on servicing commercial geostationary satellites, KursOrbital, 2021
[479] The Kurs Orbital bench has been modernized, KursOrbital, 2021
[480] Kurs One machine vision system bench testing was successfully conducted, KursOrbital, 2021
[481] Kurs Orbital joins CONFERS, KursOrbital, 2021
[482] A Northrop Grumman robot successfully docked to a satellite to extend its life, Space.com, 2021
[483] 'Space oil tank truck' makes debut at Airshow China, provides energy for satellites' long-term operation, GlobalTimes, 2021

In the field Active Debris Removal (ADR), significant developments took place in 2021

The Japanese company Astroscale reached a number of milestones:

- In July, Astroscale signed a Memorandum of Understanding with Mitsubishi Heavy Industries to cooperate on ADR technologies, in particular for rocket upper stages. Under the MoU, the two companies will share data and technologies for project that can advance in-orbit services.[484]
- The same month, Astroscale and the Ministry of Economy, Trade, and Industry of Japan signed a three-year contract worth around $2.5 million. Under the agreement, the Ministry will support Astroscale in conducting research and development of robotic arm and robotic hands technologies that can be attached to a spacecraft to conduct ADR missions and other in-orbit services as well as autonomous control technologies and interfaces to replace robotic hands. In addition, Astroscale will conduct research regarding the servicing market and provide recommendations regarding the standardization of IOS technologies.[485]
- In August, Astroscale successfully conducted an active debris removal demonstration using its The End-of-Life Services by Astroscale-demonstration (ELSA-d) spacecraft. It consisted in the capture and release of a client's satellite. The demonstration aimed at proving the feasibility and ability of ELSA-d to dock another spacecraft. Astroscale will conduct additional demonstrations in the future using ELSA-d to capture, release, and re-capture a client's satellite; to capture, release, re-capture a non-cooperative and tumbling satellite; and to conduct proximity manoeuvre for an in-orbit inspection and capture a client's satellite.[486] The company also outlined that is was developing an updated version of the ELSA-d spacecraft, called ELSA-m, which will be able to capture several debris at once, which will be used on a mission on a OneWeb satellite under an ESA contract.[487]



Elsa-d (Credit: Astroscale)

- In September, Astroscale announced it signed a contract with Rocket Lab to launch the Active Debris Removal by Astroscale-Japan (ADRAS-J) satellite, which will conduct in-orbit inspection on an old Japanese upper stage in order to deorbit it under a contract with JAXA for the Phase I of their Commercial Removal of Debris Demonstration Project (CRD2), a technology demonstration project to conduct ADR on large orbital debris. ADRAS-J aims at demonstrating proximity operations and in-orbit inspection.[488]
- In October, the UK Space Agency awarded Astroscale a contract to conduct a feasibility study of a future UKSA ADR mission called Cleaning Outer Space Mission through Innovative Capture (COSMIC) that will consist in the removal of two old British satellite, which is expected to be carried out in 2025. UKSA will develop a spacecraft called COSMIC Mission Concept of Operations (CONOPS), which will integrate Astroscale's technology to capture the satellites.[489]
- In November, Astroscale announced it raised $109 million from European and Japanese investors in a Series F funding round led by the Japanese FUND Limited Partnership, which included investors such as Seraphim Space Investment Trust and DNCA Invest Beyond Global

[484] Space Clean-up Company Astroscale Signs Partnerships with MHI and Japanese Government, ViaSatellite, 2021
[485] Astroscale Advances On-Orbit Servicing Technologies with Mitsubishi Heavy Industries and the Government of Japan, Astroscale, 2021
[486] Astroscale successfully demos in-space capture-and-release system to clear orbital debris, TechCrunch, 2021
[487] Astroscale complete first test of satellite capture technology, SpaceNews, 2021
[488] Rocket Lab Wins Contract to Launch Orbital Debris Removal Demonstration Mission for Astroscale, RocketLab, 2021
[489] Astroscale to Lead UK Study of Active Debris Removal Mission, ViaSatellite, 2021

Leaders. The funding will enable Astroscale to accelerate its plans for ADR and other IOS missions.[490]

- The same month, Astroscale unveiled a docking device that could be universally adopted by the space sector in order for all spacecraft to be serviced and facilitate ADR missions. Astroscale presented its "Docking Plate" as a two hook that would facilitate both magnetic and robotic capture. It is expected to come in three different sizes to be installed on most satellites.[491]

Other start-ups are also developing ADR technologies and signing contracts with both public and private actors:

ESA awarded **D-Orbit UK** a contract worth €2.19M to develop ADR technologies. The contract is part of the phase 1 of the development and in-orbit demonstration of a "Deorbit Kit" as part of ESA'S Space Safety Programme. D-Orbit will conduct an in-orbit demonstration of its "Deorbit Kit", which is an equipment that can enable satellites to conduct a propulsive decommissioning manoeuvre at the end of their life or after a failure. In order to develop this Kit, D-Orbit will lead a consortium, which includes Airbus Defence and Space, ArianeGroup, GMV Innovating Solutions, and Optimal Structural Solutions.[492]

Eco Space Tug (Credit: Exolaunch)

The German start-up **Exolaunch** unveiled its Eco Space Tug Program in April. It announced it was developing a line of space tugs called Reliant that will be able to conduct ADR, de-orbiting, and relocation missions. Reliant will be powered by green propulsion system and contains 3D-printed components and carbon fibre composites. Exolaunch will develop two versions of Reliant. The first version is "the Standard", which will be able to conduct orbit correction and relocation missions. It is expected to lift the orbit of a satellite from 250-300 km to 550 km in one hour. The second version is the "Pro", which will be equipped with a hybrid propulsion system and will enable serviced spacecraft to change their altitude and inclination, conduct orbital phasing, and de-orbit. Additionally, Reliant is expected to conduct ADR missions by collecting authorized debris. Flight tests are expected in 2022.[493]

The American company **Starfish Space** closed $7 million in funding to accelerate the development of a space tug that will provide life extension and active debris removal services. The company outlined that the space tug could also be used for mining, in-orbit manufacturing, and recycling. In addition, Starfish develops a software system dedicated to docking and rendezvous proximity operations. In August, Starfish Space was awarded a $1.7 million Phase II Small Business Innovation Research (SBIR) contract by the U.S. Space Force for the development of this software. The software is currently being tested on Orbit Fab's Tanker-001 satellite.[494]

The **Swedish Space Corporation (SSC)** and **Bradford Space** also signed a Memorandum of Understanding at the IAC in October 2021 to provide commercial ADR services from the Esrange Space Centre. The objective is to use Bradford Space's satellite buses and launch them into orbit from Esrange to conduct rendezvous operations and deorbit client's satellites, including in Sun Synchronous Orbit (SSO).[495]

[490] Astroscale raises $109 million Series F round, SpaceNews, 2021
[491] Like a Tow-hook for Satellites: Astroscale Launches Docking Plate to Capture Defunct Satellites, Astroscale, 2021
[492] ESA Awards D-Orbit UK Contract for Debris Removal Demonstration, ViaSatellite, 2021
[493] Exolaunch Introduces Eco Space Tug Program, ExoLaunch, 2021
[494] Starfish Space raises $7M for in-orbit servicing space tug, TechCrunch, 2021
[495] SSC and Bradford ECAPS sign MoU regarding commercial orbital debris removal services, SSC, 2021

Besides, **China** launched the Shijian-21 satellite on board of a Long March 3B rocket in October. Shijan-21 aims at testing space debris mitigation technologies. However, no details regarding the tests or the features of the technologies and instruments on board were made public initially.[496] In January 2022 it was noted that Shijian-21 attached to a defunct Chinese satellite to drastically alter its position and towed it into a high graveyard orbit.[497]

In the field of in-orbit assembly and in-orbit manufacturing, significant developments took place in 2021

- In March, **Airbus Defence and Space** was selected by the European Commission to conduct Horizon 2020's PERIOD (PERASPERA In-Orbit Demonstration) project, which aims to study and test in-orbit satellite assembly and manufacturing. This A/B1 phase study contract accounts for €3 million and will last two years. The PERIOD project also includes DFKI, EASN-TIS, GMV, GMV-SKY, ISIS, SENER and SpaceApps. The project is expected to pioneer the in-orbit assembly of antenna reflectors, spacecraft components and enable in orbit reconfiguration (replacement of payloads).[498]
- The Japanese start-up **Gitai** Japan successfully conducted a technology demonstration to test its S1 robotic arm for operating cables and switches, and assembling structures and panels, raising the S1 robot to Technological Readiness Level (TRL) 7. Gitai also raised $17.1 million in a Series B funding round in order to accelerate the development of a separate satellite servicing demonstration, which is expected to be launched in 2023.[499]
- In August, **Varda Space Industries** signed a contract with Rocket Lab to produce three Photon spacecraft to integrate them into Varda's zero-gravity manufacturing platform. Varda Space Industries plans to use Photon to place the platform in orbit for in-orbit manufacturing missions such as building fibre optic cables, semiconductors, or pharmaceuticals, which have higher performance if produced in a zero-gravity environment. The first Photon spacecraft is expected to be delivered by Rocket Lab in 2023, and the other two in 2024.[500]

Finally, in the field of in-orbit repair and logistics, Lockheed Martin announced it was redesigning the bus LM2100 used for GPS satellites so they can be upgraded with new hardware while in orbit. The updated bus will be able to dock satellites, which will be enable in-orbit hardware upgrades such as new processors and sensors.[501]

[496] China launches classified space debris mitigation technology satellite, SpaceNews, 2021
[497] China's Shijian-21 towed dead satellite to a high graveyard orbit, SpaceNews, 2022.
[498] Airbus pioneers first satellite factory in space, Airbus, 2021
[499] Gitai successfully demos autonomous robot inside the International Space Station, TechCrunch, 2021
[500] Rocket Lab Inks Deal with Varda Space Industries to Supply Multiple Photon Spacecraft for Space Manufacturing Missions, PrabolicArc, 2021
[501] Lockheed Martin to upgrade GPS satellites for in-orbit servicing, SpaceNews, 2021

2.1.6 Developments and demonstrations of new and improved propulsion technologies

A range of new developments in spacecraft propulsion technologies and associated R&D efforts has taken place in recent years, with promises of various improvements compared to existing propulsion options and technologies, notably related to **size**, **power output**, **efficiency**, **reliability** and **sustainability** both in the realm of **launch vehicles and in-space transportation** as well as related to **satellite-propulsion**. Throughout 2021, a host of demonstration missions, R&D breakthroughs and new concepts substantiate hopes of enabling faster, more efficient or longer missions both in Earth orbits as well as in deep space.

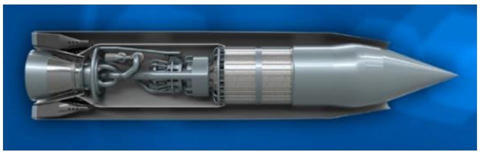
European developments in propulsion technologies

Developments in propulsion solutions for launch vehicles:

Prometheus Engine (Credit: ArianeGroup)

In Europe notable developments have taken place in the field of propulsion for space transportation with the signature of the contracts in May 2021 to advance **Prometheus** and **Phoebus** projects.[502] **Prometheus** is an ultra-low cost, highly versatile reusable rocket engine demonstrator fuelled by liquid methane, suitable for core, booster and upper stages enabling variable thrust and multiple ignitions. Designed for additive layer manufacturing it only uses a limited number of parts, while increasing production speed and reducing waste. In December 2021, ArianeGroup (the project's prime contractor) reached the first technological milestone by successfully performing six tests to validate the fluidic and electrical processes and sequences for the correct operation of two test propellant tanks.[503] **Phoebus** is a highly optimised upper stage that can be used on future launch vehicles, increasing launch capacity and further reducing cost.

Moreover, in October 2021, the new **SPTF (Space Propulsion Test Facility)** centre of excellence was inaugurated in Sardegna, Italy by **Avio,** co-financed by the **Ministry of Defense**, the **Ministry of Economic Development** and the **Region of Sardegna**.[504] The initial role of the centre is to support the testing of a new cryogenic liquid oxygen-methane upper stage (M10) to be used on Vega E. Earlier in 2021, **UK's new National Space Propulsion Facility** was declared open. The project saw significant investment by **ESA's** General Support Technology Programme (GSTP) with approximately €4,500 000 for the design, development and building of the facility, in collaboration with the **UK Space Agency** and UK industrial partners including rocket manufacturer and facility contractor **Nammo UK**. The facility's thruster test cell can sustain tests of the largest class of satellite engines, delivering up to 1300 Newtons of thrust[505]



SABRE (Credit: Reaction Engines)

In July 2021 the **UK Space Agency** awarded a GBP 3.9M grant to support the development of **Reaction Engines'** SABRE (Synergetic Air Breathing Rocket Engine) technology.[506] SABRE is designed as an air-breathing rocket engine that can propel an aircraft from zero to five times the speed of sound in the atmosphere and 25 times

[502] New ESA contracts to advance Prometheus and Phoebus projects, European Space Agency, 2021
[503] Test tanks fuelled for ESA's Themis reusable first stage, Phys.org, 2021
[504] Inaugurated the SPTF, new pole of technological excellence intended for space activities and financed by Avio in collaboration with MiSE and the Sardinia Region, Avio, 2021
[505] ESA-led space propulsion test facility passed to UK owner, European Space Agency, 2021
[506] Reaction Engines secures new UK Government funding for Space Access Programme, GOV.UK, 2021

the speed of sound for space access.[507] This latest grant is devoted to near-term technology demonstration in hydrogen combustion, thermal management and engine control technologies, and follows GBP 50M of earlier funding awarded by the UK Space Agency to Reaction Engines since 2015.

Often overlooked in the development of propulsion systems, 2021 saw the first commercial agreement for the Norwegian startup **Orbital Machines**, developing high-performance electric propellant pumps for small launch vehicles. The turbopumps will reportedly be used by the French startup Venture Orbital Systems on its Zephyr launch vehicle, planned to launch in 2023.[508] Orbital Machines is reportedly in further discussions for its technologies to also be used for in-space applications (e.g. Moon landers). The company with its headquarters in Trondheim (Norway) and a subsidiary in Berlin (Germany) also opened an online equity crowdfunding campaign in 2021, aiming to raise €300,000, which was eventually oversubscribed, receiving €544,890 from 687 investors.[509]

Reusable and eco-friendly propulsion developments:

In the field of green propulsion, the German startup **HyImpulse Technologies** (a DLR spin-off) has successfully carried out a series of engine tests at the **Shetland Space Centre** in Unst, Scotland, testing their hybrid engine using an easy to handle, extremely cheap and safe solid fuel (paraffin wax) and liquid oxygen and announced plans to launch a sounding rocket using the technology in late 2021 or early 2022 following further testing.[510]

The **DLR institute for Space Propulsion** reported further efforts in the area of green fuels, successfully testing two advanced green fuels to replace hydrazine, namely the "Hypergolic Ionic Propellant" consisting of hydrogen peroxide (H_2O_2) as an oxidizer and an ionic liquid (liquid salt) as fuel and "Hydrocarbons mixed with Nitrous Oxide" a mixture of nitrous oxide (N_2O) as an oxidizer and ethane (C_2H_6) or ethene (C_2H_4)) as fuel.[511]

In-orbit and satellite propulsion technologies:

With revisited interest in human spaceflight and exploration in Europe, the **ASPIRE (Advanced Space Propulsion for Innovative Realization of Space Exploration)** project was selected by the European Commission within a Horizon 2020 call. A collaborative effort of 8 industrial actors and institutions the consortium is headed by **SITAEL**.[512] ASPIRE aims is to further advance the development of very high-power electric propulsion system based on Sitael's HT20k, a 20 kilowatt thruster. The propulsion system is designed to support large platforms for Exploration and Space Transportation, potentially enabling crewed missions to the Moon and Mars, as well as On Orbit Operation services.

Equally relevant and **promising** are the developments in the realm of **satellite propulsion**, enabling more flexibility, longer mission lifetimes, lower weight, smaller size and safer operations.

In Europe, the **UK-based URA Thrusters** is developing new **water** (WETHET, AQUAHET, AQUAMET, ICE and HYDRA.) and **ammonia** (NMET) thruster propulsion, reported on tests achieving overall thruster efficiencies of over 35% with their Microwave Electrothermal Thruster (MET) technology, while hoping to increase overall efficiency to 40-50% using alternative propellant technologies.[513]

[507] Sabre - The engine that changes everything, Reaction Engines, 2021
[508] «Liftoff» for rakett-selskapet Orbital Machines: Første millionavtale i boks, Shifter, 2021
[509] Orbital Machines Crowdfunding Campaign, Seedrs, 2021
[510] Ursa Major Raises $85 Million in Series C Funding, PR Newswire, 2021
[511] DLR Creates the Rocket Fuel of the Future, Parabolic Arc, 2021
[512] Sitael is leading the consortium selected by the European Commission to develop very high power electric propulsion for space exploration to the Moon and beyond, Sitael, 2021
[513] URA Thrusters, Linkedin, 2021

Iodine-based electric propulsion (Credit: ThrustMe)

In January 2021, **ThrustMe**'s **iodine-fuelled propulsion system** was successfully tested for the first time in orbit. Iodine represents an alternative to widely used xenon-based systems, whereby xenon is difficult to store, expensive and rare.[514] According to **ThrustMe** this will enable "*small satellites with new manoeuvring and space exploration pote2ntial, and critical new collision avoidance and deorbiting capabilities that will prove vital for the long-term sustainability of the space industry*".[515] In April 2021 the French startup announced that they have completed trial integration of their NPT30-I2 propulsion system into the **Norwegian Space Agency's NorSat- TD** while in July 2021 ThrustMe signed a research agreement with the **Research School of Physics at the Australian National University** (ANU) to study new electrothermal plasma systems and alternative propellants for space applications.

Moreover, in August 2021 saw the signature of Memorandum of Understanding to set the framework for several intended collaborations on Electric Propulsion between **T4i - Technology for Propulsion and Innovation** (Italy) and **Spacety Luxembourg**, with the latter offering flight opportunities for extensive experience of technology IOD/IOV missions namely in the field of iodine-based plasma thrusters.

Dutch by origin, but US-incorporated **Bradford Space** announced updating its Comet electrothermal water-based propulsion technology (already used in active satellites) and transferring production of small satellite thrusters from **the United States to Luxembourg** where the company won the support of the Luxembourg Space Agency and funding through LuxImpulse.[516] Furthermore, in August 2021, **Bradford Space** announced a cooperation agreement with **Neutron Star Systems** for enhanced orbital transport and manoeuvre technology for cis-lunar logistics, leveraging Bradford's excellence in non-toxic propellant systems and the wide propellant flexibility of Nutron's SUPREMETM electric thruster.

The German startup **Morpheus Space** had a busy year following its first venture capital round in 2020. Starting off by **opening an office in the United States** (Los Angeles) in early 2021, and later unveiling a suite of products, named the **Sphere ecosystem**. Sphere includes a new nontoxic propellant, but also indicates Morpheus is moving beyond their initial success in propulsion systems components towards hardware-as-a-service and mission design software-as-a-service solutions.

The Austrian **Enpulsion**, after developing and releasing the ENPULSION MICRO family of thrusters, to cover propulsion needs of heavier satellites (in comparison to their NANO range) had another busy year, marked by a milestone in **July 2021**, when 11 satellites launched on a single rideshare mission had a total of 25 Enpulsion thrusters on board.[517]

In Finland, **Aurora Propulsion Technologies**, offering a portfolio of small satellite propulsion devices, including Resistojet thrusters, plasma brakes and the upcoming E-sail for deep space missions, reported on an expanded partnership with Momentus.[518] In August 2021 the startup then switched its plans and announced it will fly its inaugural AuroraSat-1 with RocketLab in 2022.[519] The 1.5U CubeSat, built in collaboration with SatRevolution and Momentus Space, aims to demonstrate

[514] New Electric Propulsion Engine For Spacecraft Test-Fired in Orbit For First Time, Science Alert, 2021
[515] World's first demonstration of an iodine electric propulsion system in space, ThrustMe, 2021
[516] Bradford's Comet production moves to Luxembourg, SpaceNews, 2021
[517] A new record for ENPULSION with 25 thrusters on board of the SpaceX Transporter-2 rideshare mission, ENPULSION, 2021
[518] Aurora Propulsion Technologies Expands Relationship with Momentus, Aurora Propulsion Technologies, 2021
[519] Rocket Lab Snags AuroraSat-1 Launch After Operator Switches Providers, Via Satellite, 2021

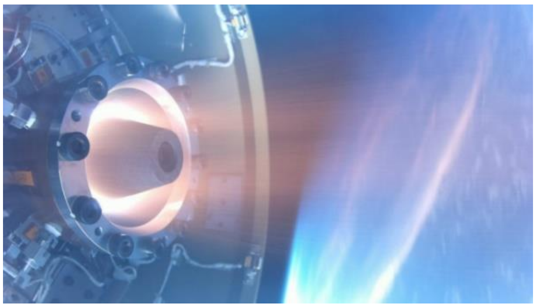
the Aurora Resistojet Module (ARM-A) for propulsion-based mobility control and Aurora Plasma Brake (a deorbiting device, not using any propellant, but utilising the interaction of ionospheric plasma and a charged microtether to generate Coulomb drag).

Developments in the rest of the world

While Europe saw considerable developments in 2021, the USA, China and Japan also pursued significant R&D in the field of propulsion technologies.

Detonation engines:

July 2021, **JAXA** announced it successfully demonstrated the operation of a **rotating detonation engine in space** in July 2021.[520] The engine, despite its compact size offers high thrust while being extremely fuel efficient. It uses detonation waves to combust the fuel and oxidizer mixture, eventually generating high-frequency shock and compression waves generating further detonations in a self-sustaining pattern, while only using a minimal amount of fuel.[521] The engine was developed through collaborative efforts between JAXA, Nagoya University, Keio University and the Muroran Institute of Technology. According to reports, JAXA expects to be regularly using rotating detonation engines as early as 2026.[522]



Rotating Detonation Engine (Source: JAXA)

Earlier in 2021, researchers at the **University of Central Florida in the United States** have developed another type of a detonation-based rocket engine, namely the Oblique Wave Detonation Engine, supported with funding from the U.S. Air Force Office of Scientific Research and an Air Force Research Laboratory Contract.[523]

Beyond conventional Electric & Chemical propulsion:

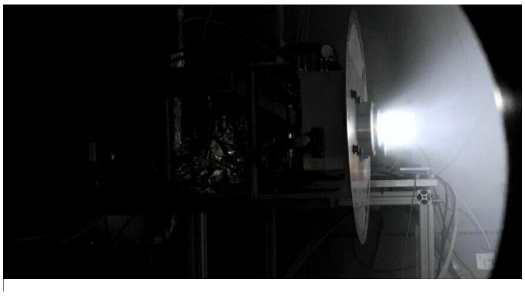
Outside the developments related to detonation-based engines, In July 2021, **Ad Astra Rocket Company's VASIMR** (Variable Specific Impulse Magnetoplasma Rocket), VX-200SS completed 88 hours of continuous operation at 80 kW in a laboratory environment, setting a new high-power world endurance record in electric propulsion and announced further tests at 100 kW in the coming months, promising a future option for high-power in-space electric propulsion with **either solar or nuclear electric power.**[524]

Keeping focus on the United States, in June 2021 **NASA** awarded **ExoTerra Resource** a Phase II Small Business Innovation Research (SBIR) award for the firm's **solar electric propulsion upper stage**, under development in partnership with Virgin Orbit, which will be able to deliver 150 kg of payload to cis-lunar orbit and 180 kg to Geostationary Earth Orbit (GEO), as well as enable exciting interplanetary missions.

Earlier in 2021, in January, **NASA launched its PTD-1** CubeSat and successfully demonstrated a new type of propulsion system. The satellite uses the **Hydros hardware unit** (developed by Tethers Unlimited, Inc), a **water-based propulsion system** using electricity to produce gas propellants –

[520] Japan Tests Rotating Detonation Engine in Space for the First Time, interesting Engineering, 2021
[521] Japan's New Rocket Engine Uses Shock Waves As Propellant, Interesting Engineering, 2021
[522] Ibid
[523] UCF Researchers Develop Ground-breaking New Rocket-Propulsion System, UCF Today, 2020
[524] VASIMR® VX-200SS Plasma Rocket completes record 88-hour high power endurance test, Ad Astra Rocket Company, 2021

hydrogen and oxygen – from liquid water and burning them in a nozzle to generate thrust.[525] As water represents a safe, low-cost and environmentally friendly propellant, studies are underway to determine whether the technology could be further relied upon even in deep-space missions and on larger platforms.[526]



Maxwell Engine (Credit: Phase Four)

Further exploring the possibilities unlocked by the **ASCENT** (Advanced Spacecraft Energetic Non-Toxic) propellant that also contains a significant percentage of water, initially developed by the U.S. Air Force Research Laboratory, **Phase Four** was awarded a contract during the first **Space Force SpaceWERX Pitch Day**.[527] Using ASCENT for its Maxwell thrusters, Phase Four seeks to produce an engine that offers both "*the high thrust capabilities of chemical propulsion and the high efficiency capabilities of electric propulsion*".[528] The company (Phase Four) previously raised $26M during a Series B investment round in June 202. The company is also testing its radio-frequency thrusters (currently using xenon) with water and solid iodine propellants, winning a $750,000 SBIR award in April 2021 to test the latter.[529]

Another US company focusing on in-orbit propulsion, **Orbion Space Technology** announced it was awarded a contract to develop and demonstrate high-thrust propulsion by the U.S. Air Force in August 2021.[530] The project will support the company's El Matador programme which helps small satellites avoid collision. Earlier in the year Orbion announced it **raised $20M** in an oversubscribed Series B funding round.[531]

Moreover, **Accion Systems**, founded in 2014, raised $42M in a Series C funding round in July 2021, to develop the next generation **TILE (Tiled Ionic Liquid Electrospray)** propulsion system and strengthen the supply chain and at-scale manufacturing.[532] in August 2021 the company announced a strategic partnership, whereby Accion and Xplore Inc. agreed for the latter to provide spacecraft hosting services for next-generation TILE thrusters, notably validating the resiliency of TILE's fault tolerant design, and prove its performance as an efficient electric propulsion system in space.[533]

China:

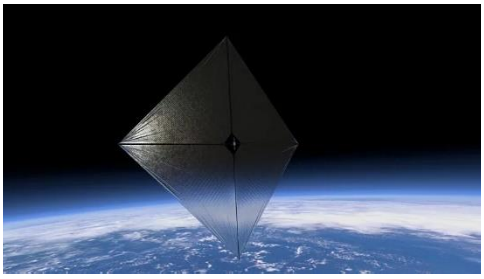
In China, the 2021-deployed **Tianhe core module of the Chinese space station** is using a ion propulsion system which will reportedly greatly improve energy efficiency. Despite these Hall-effect thrusters not representing a novelty *per se*, it is a **first for crewed spacecraft**, which so far relied on conventional chemical propulsion (ISS).[534] Generally ion thrusters used on satellites generate 1kW of thrust, Chinese scientists and engineers are however reportedly pursuing plans to exceed 5MW and even develop systems capable of output up to 500MW for crewed deep space exploration.[535]

[525] NASA CubeSat to Demonstrate Water-Fueled Moves in Space, NASA, 2021
[526] Water-Powered Engines Offer Satellite Mobility, NASA, 2020
[527] Phase Four Wins U.S. Space Force Contract at SpaceWERX Pitch Day, PR Newswire, 2021
[528] Ibid
[529] Phase Four Maxwell to test green propellant, SpaceNews, 2021
[530] Orbion wins contract to demonstrate high-thrust propulsion, SpaceNews, 2021
[531] Orbion Secures $20M in Series B Funding to Scale up Production of Plasma Thrusters for Satellite Constellations, Parabolic Arc, 2021
[532] Accion Systems Raises $42 Million in Series C Led by Tracker Capital, PR Web, 2021
[533] Accion Systems to Fly TILE Thrusters on Xplore XLEO In-Space Tests, Via Satellite, 2021
[534] China's New Space Station Will Be Powered by Ion Propulsion System, Interesting Engineering, 2021
[535] How China's space station could help power astronauts to Mars, South China Morning Post, 2021

Keeping the focus on China, it was reported in **October 2021** the **Academy of Aerospace Solid Propulsion Technology** (AASPT) part of the China Aerospace Science and Technology Corporation (CASC) – tested "*the most powerful solid rocket motor with the largest thrust in the world so far*" planned to be used in China's next generation heavy lift rockets.[536]

Solar sails:

Finally, in the area of solar sails, 2021 saw the final confirmation that **NASA's NEA Scout** (Near-Earth Asteroid Scout) mission, the agency's first deep space mission using a solar sail, will be launched as part of the Artemis I launch in 2022. NEA Scout will visit the 2020 GE Asteroid, the smallest asteroid ever to be visited by a spacecraft. This will pave the way for **Solar Cruiser**, a mission which NASA announced in December 2020 as a solar sail spaceflight test mission, designated to share a ride in 2025 with the agency's Interstellar Mapping and Acceleration Probe.



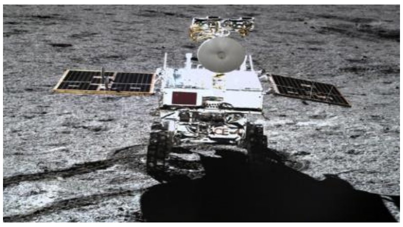
ACS3 Solar Sail Mock-up (Credit: NASA)

Moreover, the **NASA-developed ACS3 (Advanced Composite Solar Sail System)** project progressed to the final pre-launch stages, resulting in an announcement that the ACS3 demonstration will be launched in mid-2022.[537] The mission hopes to guide the design of future larger-scale composite solar sail systems with various possible applications (space weather early warning satellites, near-Earth asteroid reconnaissance missions, communications relays for crewed exploration missions). Once in orbit the spacecraft will attempt a series of orbital changes to demonstrate the capabilities of the solar sail.

[536] China's Space Mining Industry Is Prepping For Launch – But What About The US?, Forbes, 2021
[537] https://www.nasa.gov/directorates/spacetech/small_spacecraft/ACS3

2.2 Other Outstanding Developments

2.2.1 Nuclear power sources enabling faster & longer missions deeper into the universe



Yutu-2, a Chinese lunar rover utilising a RPS (Credit: CNSA)

Nuclear power sources have been used since the early days of the space age, offering unique opportunities compared to photovoltaics and batteries, and enabling some of the most inspiring missions in the history of exploration. In recent decades most activities utilizing nuclear power sources were passive RTG's and RHU's (Radioisotope Power Sources or RPS). However, the past two years saw increased interest for nuclear reactors used for propulsion, namely nuclear thermal propulsion systems.

2021 saw some significant developments in the field of Space Nuclear Power and Propulsion (SNPP) highlighting the increasing support from governments to use these technologies for future space missions.

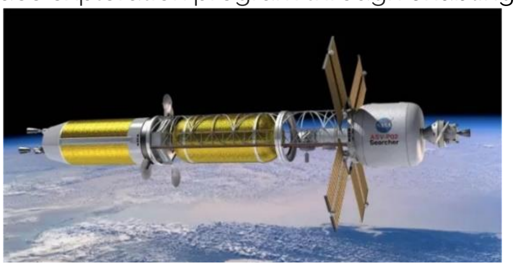
US policy and industrial developments on SNPP

We can consider the **Space Policy Directive 6 (SPD-6),** defining the National Strategy for Space Nuclear Power and Propulsion (SNPP), published on December 21, 2020, as the first milestone in this development from the perspective of pubic innovation policy in the United States. It pursues the following goals:[538]

- Develop **uranium fuel processing capabilities** that enable production of fuel that is suitable to lunar and planetary surface and in-space power, nuclear electric propulsion (NEP), and nuclear thermal propulsion (NTP)
- Demonstrate **a fission power system on the surface of the Moon** that is scalable to a power range of 40 kilowatt-electric (kWe) and higher to support a sustained lunar presence and exploration of Mars.
- Establish the technical foundations and capabilities … that will enable options for NTP to meet future DoD and NASA mission requirements**.**
- Develop **advanced RPS capabilities** that provide higher fuel efficiency, higher specific energy, and longer operational lifetime than existing RPS capabilities.

The direction for innovation in the field of SNPP was continued by the **Executive Order on Promoting Small Modular Reactors for National Defense and Space Exploration** issued in January 2021 which (i.a.) aims to reinvigorate America's space exploration program through enabling private-sector innovation of advanced reactor technologies, with the goal to support:[539]

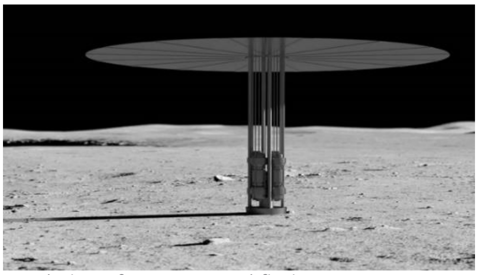
- Demonstration of In-situ Resource Utilization (ISRU) and robotic exploration of permanently shadowed craters on the Moon that contain frozen water (1 kW range).



Concept of a thermal nuclear propulsion spacecraft (Credit: NASA)

[538] Space Policy Directive–6: National Strategy for Space Nuclear Power and Propulsion, Federal Register, 2020
[539] Executive Order on Promoting Small Modular Reactors for National Defense and Space Exploration, archives.gov, 2021

- Support of sustained human habitats, ISRU, other facilities, and rovers on both the Moon and Mars (100 kW range).
- Efficient, long duration deep space propulsion (MW range).
- These public innovation policy goals and ambitions were soon translated into industrial contracts awarded by both NASA, the DoE, and the DoD.
- In July 2021, NASA and the DoE have awarded three 12-month contracts worth up to $5 million exploring nuclear thermal space propulsion concepts to:[540]
- BWX Technologies, Inc., partnering with Lockheed Martin;
- General Atomics Electromagnetic Systems partnering with X-energy LLC and Aerojet Rocketdyne; and
- Ultra Safe Nuclear Technologies, partnering with Ultra Safe Nuclear Corporation, Blue Origin, General Electric Hitachi Nuclear Energy, General Electric Research, Framatome and Materion.
- Moreover, alongside the awards announcement, NASA mentioned it "intends to partner with the DOE and INL to release a request for proposals that asks industry for preliminary designs of a 10-kilowatt class system that NASA could demonstrate on the lunar surface." building on top of previous experience gained within NASA's Kilopower project.



Rendering of a conceptual fission power system on the Moon (Credit: NASA)

- In November 2021, NASA published a request for proposals to develop innovative technologies for a **fission surface power system for lunar power applications** with hopes to deploy such a system by 2030.[541] The request hopes to receive proposals for a flight-ready small fission reactor powered by low-enriched uranium, providing 40 kWe of continuous power for at least 10 years.
- Parallel to the activities led by NASA, in April 2021, DARPA selected Industry teams to develop propulsion design, spacecraft concepts for **demonstrating on-orbit Nuclear Thermal Propulsion** (NTP) system as part of the first phase of the Demonstration Rocket for Agile Cislunar Operations (DRACO) program. The 18-month Phase 1 consists of two tracks:
- Track A, focusing on the preliminary design of an NTP reactor and propulsion subsystem concept will be performed by General Atomics;
- Track B producing an Operational System spacecraft concept to meet mission objectives and design a Demonstration System spacecraft concept, independently performed by Blue Origin and Lockheed Martin.
- In November 2021 the Defense Innovation Unit, as support to other existing government projects issued a solicitation seeking "*mature commercial technologies that can provide power and propulsion in the near term*" aimed at small nuclear-powered engines for space missions beyond Earth orbit.
- As noted by experts during a **government hearing in October 2021** "the United States needs to move at a fast pace to stay competitive" when it comes to R&D nuclear propulsion related R&D. Indeed, other countries, namely Russia and China are considering nuclear technologies as key enablers for future exploration of our solar system.[542]

[540] NASA Announces Nuclear Thermal Propulsion Reactor Concept Awards, NASA, 2021
[541] NASA seeks proposals for lunar reactor, World Nuclear News, 2021
[542] NASA thinks US needs nuclear-powered spacecraft to stay ahead of China, space.com, 2021

SNPP developments in the rest of the World

Russia:

- In May 2021 Roscosmos revealed more information on the **TEM space tug**, a nuclear-powered spacecraft that will be able to transport heavy cargo in deep space, the development of which has long been in the making but publicly available information were scarce.[543] Roscosmos announced that an interplanetary mission is scheduled for 2030, and will likely perform flybys of the Moon, Venus and Jupiter. In parallel, Roscosmos revealed further plans to use the same nuclear reactor as part of a future orbital station.
- In August 2021, Director General of Roscosmos Dmitry Rogozin noted that "*Only a nuclear-powered space tug can become a transportation space system to propel large research stations or habitable orbital modules in the solar system and outside it*" and revealed plans to test a drip-type radiant cooler on board the ISS Nauka module.[544]

China:

- Further towards the East, China is reportedly also betting big on nuclear propulsion to support its ambition in outer space. In November 2021, reports surfaced of China developing a nuclear reactor to help its missions to the Moon and Mars.[545] For the time being, one of the major challenges reportedly faced by the Chinese research community is cooling technology for the massive reactor. The project, directed by the central government, started in 2019, but no schedules have been publicly communicated to date.

Europe:

- Research related to nuclear technologies for space exploration has been limited compared to other major space powers. Europe never developed native capabilities for RPS or nuclear reactors to be used in space. Interest has however grown in recent years with some RPS-related R&D activities (Am-241, Pu-238) taking place throughout the last decade and (to a large extent) pursued through an ESA funded programme led by the University of Leicester.[546]
- Europe, despite its mastery of nuclear technologies for terrestrial applications, and leadership in areas of nuclear R&D and nuclear safety, seems unable to leverage existing expertise and transfer it to the realm of space exploration - likely due to political unwillingness rather than lack of engineering ambition. Nevertheless, certain developments in 2021 suggest nuclear technologies are also increasingly considered within some European space programmes.
- In early 2021, **Rolls-Royce** and the **UK Space Agency** launched a first study into future nuclear power options for space exploration, building on top of the expertise developed by Rolls-Royce in the area of nuclear submarines, and a strong UK-based nuclear research network and supply chain.[547] Moreover, in September 2021, further steps towards developing native RPS capabilities have been taken with ESA awarding **Tractebel** (Belgium) in partnership with ORANO and SCK CEN, a contract to evaluate the possibility of producing plutonium 238 (Pu-238), on the Moon.

These global developments, despite perhaps not yielding immediate short-term implications can have a **profound effect on the space exploration landscape beyond 2030** and the developments need to be closely monitored especially with the prospects of long-term crewed missions in deep space.

---

[543] First mission of Russia's nuclear-powered space tug to take 50 months, TASS, 2021
[544] Russia expects groundbreaking results from testing nuclear space tug elements in orbit, TASS, 2021
[545] China's space programme will go nuclear to power future missions to the moon and Mars, South China Morning Post, 2021
[546] European Radioisotope Thermoelectric Generators (RTGs) and Radioisotope Heater Units (RHUs) for Space Science and Exploration, Springer, 2019
[547] Rolls-Royce & UK Space Agency launches first study into nuclear power for space exploration, Rolls-Royce, 2021

2.2.2 Industrial and innovative developments for a responsible space sector

Recent years have seen an increased push towards a **responsible and sustainable space sector.** In light of developments in space tourism and other new technologies, the space sector is under increased scrutiny in regard to environmental impact. Many companies in the space sector are attempting to transition to more sustainable practices within their activities, and many new, innovative, and sustainable initiatives and projects have been developed throughout the year with the goal of creating not only a more responsible space sector, but also one that strives towards sustainable solutions.

Actors in the space sector, including industrial actors, have created **concrete initiatives for achieving the goal of a responsible and sustainable space sector.** In 2021, the **Space Sustainability Rating** (SSR) was launched to house reduce space debris and ensure that space missions are managed sustainability. The idea was developed by the ESA, THE World Economic Forum Global Future Council on Space, MIT Media Lab and other international partners, with. Several companies, including Airbus, Astroscale, AXA XL, elesco, Lockheed Martin, Planet, SpaceX, and Voyager Space Holdings were actively involved in the conceptualisation of the SSR and have expressed interest in continuing to participate in the initiative.[548] The EPFL Space Center (eSpace) has been chosen to lead the Sustainable Space Rating (SSR) in June 2021.[549]

Space Debris

In November 2021, at the fourth edition of the Paris Peace Forum, actors from all over the world launched the **"Net Zero Space" initiative**. The initiative aims to take concrete steps to reduce space debris and achieve the sustainable use of outer space by 2030. Many industrial actors have supported the initiative and outlined concrete steps for their contributions: Selected examples include: [550]

Paris Peace Forum (Credit: Paris Peace Forum)

- Astroscale has pledged to develop solutions for on-orbit servicing, as well as to build the economics and government/commercial collaboration to develop norms, regulations, and incentives for the responsible use of space.
- Arianespace pledged to reduce its orbital footprint with the Vinci restartable engine to deorbit Ariane 6 upper stages at the end of the launch sequence.
- Eutelsat pledged to implement an updated Space Degree Mitigation Plan, to ensure its continued success in deorbiting its spacecraft, as well as working closely with French authorities to update France's national space law and consider space debris as a new challenge.
- ISISpace has pledged to develop and use disruptive space technologies for debris removal and mitigation and comply with the strictest norms about sustainable space operations.
- SpaceAble aimed to provide the space community with the commercialisation of ISSAN, a SSA software solution dedicated to the aggregation and processing of space data, and to test an Orbiter in 2023, designed as an orbit inspection satellite, among other measures.

[548] World's first space sustainability rating launched. World Economic Forum. July 2021.
[549] eSpace to operate the Sustainable Space Rating by 2022, EPFL, 2021
[550] Net Zero Space. Paris Peace Forum. November 2021.

Green satellite propulsion

2021 also saw a focus on **green propulsion in space, as well as green propellants for launch vehicles**, with both public and private actors investing in new technologies to replace traditional environmentally harmful and carcinogenic propellants. **Notable developments for green propulsion in space include:**

- In February 2021, the Hiber four satellite was launched on a SpaceX rocket equipped with a new green propulsion system developed by Dawn Aerospace and Hyperion Technologies. The green propulsion system will allow the Hiber four satellite to move from its sun synchronous orbit (500 km) to its intended final 600 km orbit three months faster than with electric alternatives. The green fuel is made of nitrous oxide and propene is more efficient than hydrazine-based alternatives. Additionally, the fuel also allows the operators to have increased control over the satellite, as compared to many operators who choose to forgo propulsion technologies all together due to the high toxicity and costs.[551]
- Dawn Aerospace's Smallsat Green Propellant Thruster was effectively utilised in space onboard D-Orbit's ION Satellite Carrier. The thruster uses a green propellant combination of nitrous oxide and propelene. In addition to being environmentally friendly alternative to hydrazine, the green propellant can also save satellite operators about $500,000M due to the safety precautions required to handle traditional propellants.[552]
- UK-based company Astrotech and ESA have completed an eight-month test for a number of green propellants. Two of the green propellants tested were shown to be compatible with up to ten welded materials.[553]
- From 2019-2020, NASA conducted its Green Propellant Infusion Mission (GPIM) test. In June 2019, the GPIM was launched as a payload on the Space Test Program 2 mission that launched on a SpaceX Falcon Heavy. In a January 2021, at a panel at the SciTech Forum, it was announced that the spacecraft had met its performance goals. The propellant, deemed Advanced Spacecraft Energetic Non-Toxic, or ASCENT, is now being considered for a variety of projects by different actors.[554]

GPIM (Credit: NASA)

Environmentally responsible propellants

- UK-based company Orbex has developed a new more environmentally friendly rocket called Orbex Prime. The rocket is not only reusable but also runs on biofuel as opposed to traditional rocket fuel, resulting in 86% less emissions when compared to other rockets of similar size, and 96% less emissions when compared to a horizontal carrier aircraft launch.[555] The Orbex Prime is planned to be launched in late 2022 from Space Hub Sutherland in Scotland.[556]
- In March 2021, DLR announced the successful test of two its advanced green fuels, which can act as substitutes for hydrazine. The green fuel "Hypergolic Ionic Propellant" has been successfully tested in a combustion chamber. The fuel would be particularly interesting for human spaceflight missions as it does not require complex ignition devices and is also not toxic

[551] Hiber Four Satellite in Space with Green CubeSat Propulsion Launched on SpaceX Rocket. Dawn Aerospace. February 2021.
[552] Dawn Aerospace's Smallsat Green Propellant Thruster Proves Itself On D-Orbit's ION Space Tug. Satnews. May 2021.
[553] How green is my satellite propellant? Asks ESA. Electronics Weekly. February 2021.
[554] Green propellant successfully demonstrated on NASA mission. SpaceNews. January 2021.
[555] This Environmentally Friendly Rocket Uses Biofuel and Produces 96% Less Emissions. India Times. October 2021.
[556] The Orbex Environmentally Friendly Prime Rocket to be Launched from Scotland. SatNews. November 2021.

and carcinogenic like hydrazine. Additionally, DLR research have successfully tested a 3D-printed combustion chamber in conjunction with its second green rocket propellant, "Hydrocarbons mixed with Nitrous Oxide".[557]

- According to its Chairman, ISRO has been working towards the development of non-hazardous fuels for its rockets and satellites. ISRO is looking to develop green propulsion through hydrogen peroxide for its rockets to take humans to space as part of the Gaganyaan mission. [558]
- US-based aerospace firm, Blueshift has launched the world's first commercial biofuel powered rocket. The rocket, Stardust, is intended to launch small satellites and research projects. The company tested the prototype in February 2021 and is also set to develop another version of the rocket called the Red Dwarf. The components of the rocket's biofuel remain a closely guarded secret.[559]

Reusability and alternative launch methods

- The California-based company, Relativity Space, has unveiled its 3D-printed launch vehicle, Terran R. In addition to being entirely 3D-printed within 60 days, the rocket, all seven engines, the first and second stages, as well as the fairing to protect payloads, are designed with reusability in mind. The development builds on the company's smaller Terran 1, which is also entirely 3D printed. The Terran R will launch for the first time from Cape Canaveral Launch Complex in 2024 and Relativity Space has already secured a contract for the vehicle.[560] Relativity Space has raised nearly $1.35B in capital since its founding and currently has a $4.2B valuation. To keep up with its growth, the company secured a former Boeing aircraft manufacturing facility in Long Beach, California, USA which will be transformed into the company's second factory.[561]
- The start-up Stoke Space Technologies has invested in a new test facility for the construction of its fully reusable rockets. The goal of the company is to create a low-cost, fully reusable rocket which could be launched repeatedly without detailed inspection or the replacement of parts following every launch. The company is targeting the satellite launch market with its strategy focusing on quick turnaround.[562]
- In October 2021, California-based start-up, SpinLaunch successfully completed a test flight of its prototype suborbital accelerator. The system launches by attaching a rocket to a rotating arm in a centrifuge and spinning at several times the speed of sound. The launch is powered by kinetic energy by catapulting objects into orbit and is a potential alternative to fuel-based rockets. The company plans to conduct 30 suborbital test flights from its launch site as Spaceport America in New Mexico over the next six to eight months.[563]

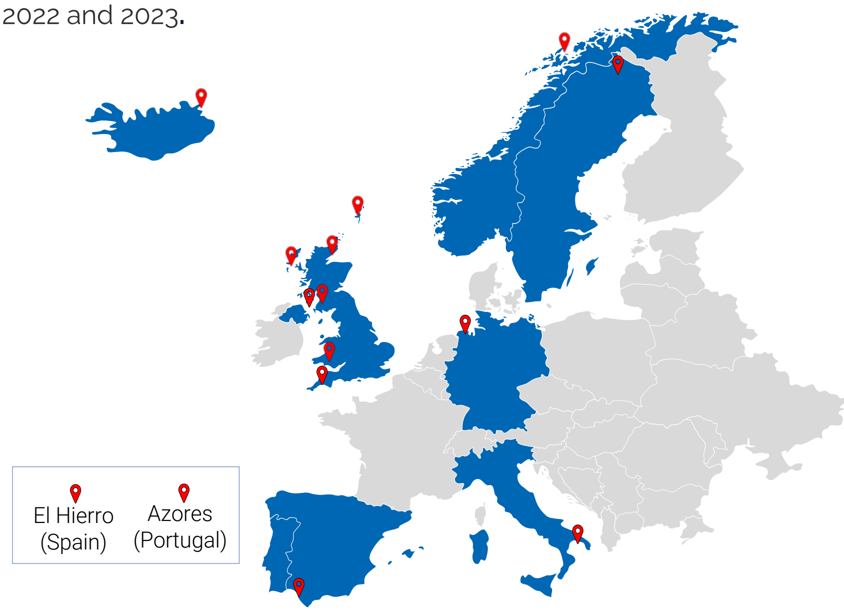
In addition to developing environmentally friendly and innovative technologies for space systems and launches, **industrial actors have increasingly emphasized the sustainability of their own operations**. Following the announcement of its new solar carports at its Toulouse facility in October 2020, Thales Alenia Space installed sustainable parking installations at other European company sites in 2021. The carports produce clean, carbon-free energy and provide green energy for the facilities. Overall, the initiative should help Thales in achieving its goal of lowering greenhouse gas

[557] From chemical synthesis to utilisation- DLR is creating the rocket fuels of the future. DLR. March 2021.
[558] ISRO working on green fuels like hydrogen peroxide for rockets. Economic Times. December 2020.
[559] This rocket uses carbon neutral biofuel, and its creators want it to become the Uber of space. Euronews. February 2021.
[560] First Fully Reusable Rocket That Can Be Entirely 3D-Printed In 60 Days. Intelligent Living. July 2021.
[561] 3D printer Relativity Space is expanding, with giant new facility to build reusable rockets. CNBC. June 2021.
[562] Stoke Space stakes its claim in the launch industry's rush to fully reusable rockets. GeekWire. September 2021.
[563] SpinLaunch conducts first test flight. Aerospace Testing International. November 2021.

emissions by 40% by 2030.[564] Additionally, Eutelsat has reaffirmed its commitment to the UN SDGs in its corporate social responsibility challenges.[565]

2.2.3 The interwoven development of micro launchers and spaceports in Europe

2021 saw significant evolution in the planning and development of new spaceports across Europe. In conjunction with these new developments, many companies are eager to secure access to the developed launch sites. The next few years will again prove significant for the development of Europe's launch capacities as spaceports in **Germany, Norway, Sweden, and the UK** anticipate first launch dates in 2022 and 2023**.**



A number of operational, planned, and considered spaceports in Europe

Germany

In Germany, an industrial consortium of offshore specialists and engineering firms known as the German Offshore Spaceport Alliance (GOSA), have been developing plans for the construction of the **North Sea Spaceport** using a carrying vessel and facilities at the port of Bremerhaven, on the North Sea.[566] The spaceport aims to enable the launch small satellites into polar and sun-synchronous orbits

- Building on regional expertise in heavy-lift cargo and offshore wind farm components, GOSA seeks to conduct its first launch from the North Sea in 2023.[567]
- As of September 2021, the German Offshore Spaceport Alliance's plans for the North Sea floating launch site have been officially endorsed by the outgoing German government, with Economy Minister Peter Altmaier saying that the German government would act as an "anchor customer" for the launch site off Germany's northern coast.[568]

---

[564] Thales Alenia Space's Site in Toulouse Generates Green Energy. Thales Alenia Space. October 2020.
[565] Preserving a sustainable space environment: Eutelsat. MyITU. June 2021.
[566] Launches Planned from Combi Dock I Vessel. BreakBulk, 2021.
[567] Launches Planned from Combi Dock I Vessel. BreakBulk., 2021
[568] German government, industry back North Sea spaceport plan, Phys Org., 2021.

- The German Offshore Spaceport Alliance also signed MoUs with four European launch vehicle manufacturers who are eager to gain access to the launch site.[569] These include German companies HyImpulse and Rocket Factory Augsburg, as well as Dutch company T-Minus and UK-based Skyrora.[570]
- While plans are in place for the spaceport, the German government has not yet committed to the 25 to 30€ million in start-up financing required for the project. The decision on funding is expected during the next legislative period.[571]

Norway

Andøya Space has been providing launch services for sounding rockets since 1962, the site is expanding to also offer launches from polar and sun-synchronous orbits, at its new facility being constructed 35 kilometres from the current launch facility.

Andøya Spaceport (Credit: Norsk Romsenter)

- In October 2021, Andøya Space officially received $42.9 million from the Norwegian government for the construction of the small satellite launch base.[572]
- The first launchpad will be ready by the end of 2021, with the second to follow in 2022, and the site reaching full operational capacity in 2023.
- In April 2021, German start-up Rocket Factory Augsburg signed a contract with Norway's Andøya Space Facility. The company plans to launch its first RFA One small satellite launch vehicle in 2022. The contract between Rocket Factory Augsburg and Andøya Spaceport will secure launch capacity for the company's first years of operation.[573]
- Additionally, in April 2021, Isar Aerospace signed an agreement with Andøya to launch its Spectrum rocket, securing exclusive access to one of its launch pads for up to 20 years.[574] Isar Aerospace will carry out its first test launch from the site in 2022.[575] The partnership represents a major milestone for both Andøya Space and Isar Aerospace.

Sweden

In October 2021, the **Esrange Space Center in Kiruna**, Sweden signed a loan agreement with the Nordic Investment Bank to create a satellite launch site through extensive modernization of the centre.

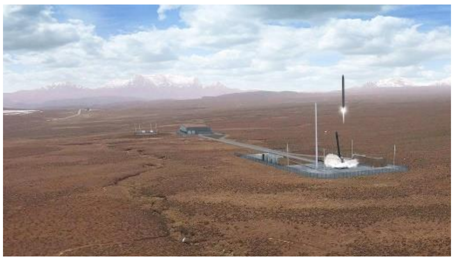
- Modernization efforts have been underway since 2015, with the first satellite launch expected in 2022.[576] The 12€ million loan will finance the enablement of reusable rockets and launch abilities, bringing the total investment in the centre since 2015 to 50€ million.[577]
- In October 2021, Bradford Space signed an MoU for its Square Rocket satellite bus to be launched from Esrange Space Center to rendez-vous with and de-orbit debris. The orbital debris service will be available from 2024 and will launch from the new launch facility currently under construction at Esrange.[578]

---

569 Germany backs floating North Sea spaceport plan, The National News, September 2021.
570 "Viele haben das damals belächelt"- Weltraumbahnhof in Nordsee gewinnt erste Kunden, Handelsblatt, 2021.
571 Start-ups plan rocket airport in the North Sea, Startbase. 2021.
572 Satellite launch base at Andøya secures funding, SpaceWatch Global, 2021.
573 Rocket Factory Augsburg Secures Launch Site in Andøya. High North News, 2021.
574 Isar Aerospace signs up for Andøya launchpad in Norway, SpaceWatch Global, 2021.
575 Isar Aerospace & Andøya Space Sign 20-Year Satellite Launch Agreement, Orbital Today, 2021.
576 Sweden to host Europe's first satellite launch station, The Mayor, 2021.
577 SSC Invests into Esrange Space Center for 2022 Launch, Via Satellite, 2021.
578 Orbital Debris Removal Services MoU Signed by Swedish Space + Bradford Space/ECAPS, Satnews, 2021.

- Additionally, the centre is already being used for engine testing by both Rocket Factory Augsburg and Isar Aerospace.[579]

United-Kingdom



Space Hub Sutherland (Credit: HIE)

The United Kingdom has multiple spaceports currently under development, with additional spaceports expected. In September 2021, the UK published its National Space Strategy. In addition to the Space Hub Sutherland, SaxaVord Spaceport, and Spaceport Cornwall, three additional spaceports were proposed: Argyll, Prestwick, and Snowdonia.[580]

Launches from the UK spaceport, **Space Hub Sutherland**, are poised to begin in 2022 following a series of legal challenges regarding planning permissions for the spaceport's construction.[581]

- The site is set to include a launch pad, a control centre, and the associated infrastructure for up to 12 small satellite launches a year.
- The responsible entity, Highlands and Islands Enterprise aims to make Space Hub Sutherland the world's greenest spaceport.
- The Scottish aerospace company Orbex and its Prime rocket will be the site's main user following its completion. Orbex focuses on the small satellite market and provides launch services for nanosatellites and CubeSats. Orbex has secured six launch contracts for its launches from Sutherland.[582]

The proposed **SaxaVord Spaceport** (formerly Shetland Spaceport) is to be built on the island of Unst, off the northern coast of Scotland.

- The site will have three launch pads and associated ground equipment, control centres, integration facilities, and a ground station.
- SaxaVord has not yet received planning permissions for construction, but this is expected to be granted. Lockheed Martin has shown considerable interest in the launch site and has selected ABL Space Systems for its first orbital launch there, which is planned for 2022.[583]
- In October 2021, Scottish aerospace company, Skyrora, announced its intentions to use Saxaford for its orbital launch services starting in 2022. Saxaford Spaceport and Skyrora signed a ten-year agreement for the use of the facilities to launch Skyrora's XL rocket. The company focuses on small satellites and plans to launch from Saxaford 16 times annually by 2030.[584]

In addition to the UK's vertical launch capabilities, the UK is also seeking to establish horizontal launch options. The **Newquay Airport in Cornwall** has been selected as the site for a horizontal launch site, with Virgin Orbit having announced in 2021 that it is set to launch its Launcher One rocket in June 2022.[585]

[579] In Sweden's Far North, a Space Complex Takes Shape, The New York Times, 2021.
[580] UK spaceports and launchers gearing up for first flights, NASA Spaceflight, 2021.
[581] Space Hub Sutherland - September 2021 Newsletter, Highlands and Islands Enterprise, 2021.
[582] UK spaceports and launchers gearing up for first flights, NASA Spaceflight, 2021.
[583] UK's first vertical satellite launch: rocket ordered for Pathfinder project due to take off from Shetland next year, The Scotsman. 2021.
[584] UK spaceports and launchers gearing up for first flights, NASA Spaceflight, 2021.
[585] UK spaceports and launchers gearing up for first flights, NASA Spaceflight, 2021.

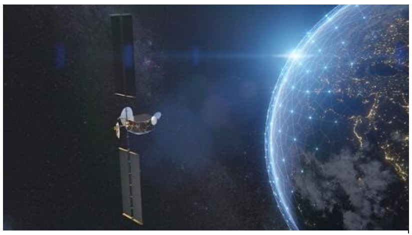
2.2.4 Promises of fully reprogrammable satellites

In light of the increasing digitalisation of space systems as well as rapidly changing market dynamics, the satellite communication industry sees increasing value in software-defined satellites, especially in GEO.

Software-defined satellites are fully reprogrammable satellites with digital payloads, enabling operators to remotely repurpose the satellite's mission while in orbit. Software-defined satellites can typically redirect and adjust beams, change frequency bands, coverage areas, power distribution, and mission architecture on demand through software updates sent from the ground station. Fully reprogrammable satellites provide operators with the flexibility to adapt to changing demand and new market dynamics while reducing costs.[586] **While most satellites currently in orbit have some degree of software-defined capabilities, fully reprogrammable satellites are only emerging.**

According to Northern Sky Research (NSR), software-defined satellites could generate $86.9 billion of cumulative revenues by 2030.[587] At the moment, traditional space companies such as Airbus (One Sat satellites) and Boeing (702X satellites) seem to lead this emerging market. Other companies such as Lockheed Martin (SmartSat platform) or Thales Alenia Space (Space Inspire) are also developing software-defined solutions.

In 2021, Airbus reached several key milestones in the development of its fully flexible satellite product line:



Airbus' One Sat (Credit: Airbus)

- On January 8th, 2021, Instelsat announced it has selected Airbus to build two OneSat telecommunication satellites for Intelsat's next-generation software-defined network.[588] The two software-defined satellites are expected to be delivered in 2023 and will provide connectivity to in-flight broadband users as well as mobility applications. Intelsat, which filed for Chapter 11 bankruptcy in May 2020, sees software-defined satellites as an essential part of its restructuration and future business plan to adapt to new market dynamics. In July 2021, Intelsat issued a request for proposals (RFP) for 10 software-defined satellites.[589]
- On March 25th, 2021, the Japanese SKY Perfect JSAT Corporation selected Airbus to build Superbird-9, a fully digital in-orbit reconfigurable telecommunications satellite. The satellite will be based on Airbus' OneSat product line. Airbus will design and manufacture the Superbird-9 spacecraft and will also provide services for reprogrammable in-orbit operations and ground segment, as well as an advanced digital suite to manage the digital payload. The investment as well as the contract between SKY Perfect JSAT and Airbus accounts for around ¥30 billion. The satellite is expected to be launched in 2024.[590]
- On April 21st, 2021, Airbus announced it has successfully achieved the Final Design Review of its OneSat product line with customers and space agencies, namely ESA, CNES, and UKSA. Airbus is currently manufacturing seven OneSat satellites for Inmarsat, Intelsat, Optus, and SKY Perfect JSAT, which will be launched in 2023 and 2024.[591]

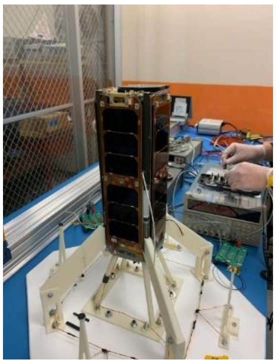
[586] Software-Defined Satellites Meet Software-Defined Ground, Kratos, 2021 ; How Software-Defined Satellites Will Shape Communications, ViaSatellite, 2021
[587] Software-Defined Satellite Trend Triggers $86.9 Billion Revenue Opportunity, NSR, 2021
[588] Airbus signs multi-satellite contract with Intelsat for OneSat flexible satellites, Airbus, 2021
[589] Betting on flexibility: Intelsat's post-bankruptcy growth strategy, SpaceNews, 2021
[590] SKY Perfect JSAT signs contract with Airbus to build Superbird-9 telecommunications satellite, Airbus, 2021
[591] OneSat Final Design Review successfully achieved, Airbus, 2021

- **On July 30th, 2021, Eutelsat Quantum, the first commercial fully software-defined satellite, was launched from the Guiana Space Centre in Kourou on an Ariane 5 rocket.** Eutelsat Quantum is an ESA Public-Private Partnership Project with Airbus as the prime contractor responsible for manufacturing the satellite's payload and Surry Satellite Technology Ltd responsible for manufacturing the new platform. Eutelsat Quantum will provide communications services to both commercial and governments users. In terms of capabilities, Eutelsat Quantum allow users to define downlink and uplink service areas per beam, allocate radiofrequency power per channelizer, and allocate bandwidth within assigned spectrum bands to each channelizer and define frequency plan. Eutelsat Quantum's remote-control system enables users to become Virtual Satellite Operators (VSO) and issue reconfiguration orders.[592]


Eutelsat's Quantum satellite (Credit: Airbus)

Thales Alenia Space also signed contracts for software-defined satellites:

- On November 18th, 2021, Thales Alenia Space announced that it signed a contract with SES to deliver ASTRA 1P and ASTRA 1Q, two Ku-band GEO satellites. ASTRA 1Q will be based on Thales' Spacebus NEO product line and the Space Inspire (INstant SPace In-orbit REconfiguration) software-defined solution. ASTRA 1Q will allow mission and services reconfiguration, instant in-orbit adjustment to the demand, flexibility for video broadcasting and broadband connectivity services. The two satellites are expected to be launched in 2024.[593]
- In January 2022, it was announced that Thales Alenia Space signed a contract with Intelsat for another pair of software-defined satellites, namely Intelsat 41 (IS-41) and Intelsat 44 (IS-44), based on Space Inspire platform. Intelsat's objective is to use software-defined satellites to build the world's first global 5G software-defined network.[594]
- **Finally, Lockheed Martin also made progressed in the development of its software-defined platform SmartSat:**
- In April 2021, Lockheed Martin unveiled a new line of Intelligence, Surveillance, and Reconnaissance (ISR) satellites for tactical warfare. This new line will be based on Lockheed Martin's LM 400 bus and will be able to reconfigure its mission in orbit through software-defined capabilities based on the SmartSat platform.[595]
- In January 2022, Lockheed Martin and the University of Southern California (USC) launched the La Jument AI nanosatellite on a SpaceX's Falcon 9 rocket as part of a rideshare mission. The mission aims at demonstrating artificial intelligence and machine learning technologies using Lockheed Martin's SmartSat software-defined satellite architecture.[596]


La Jument (Credit: USC)

592 How software-defined satellites put you in control of your satcoms, Eutelsat, 2021
593 Thales Alenia Space To Build State-Of-The-Art Astra 1p And Astra 1q Satellites For SES, Thales, 2021
594 Thales Alenia Space to build state-of-the-art Intelsat 41 and Intelsat 44, Thales Group, 2022.
595 Lockheed Martin Releases New Line of Mid-Size ISR Satellites, ViaSatellite, 2021
596 Lockheed Martin, USC Launch La Jument AI Satellite Payload with Ability to Enhance Images in Orbit, Lockheed Martin, 2022

2.2.5 Rising interest in commercial SIGINT solutions

Signal Intelligence (SIGINT) is the interception of radio frequency signals for intelligence purposes. SIGINT satellites are designed to detect, intercept, and distribute transmissions from radios, radars, satellites, or any other electronic system. SIGINT comprises Communications Intelligence (COMINT), which is the analysis of intercepted communications between people (text, voice, etc.), and Electronic Intelligence (ELINT), which is the analysis of intercepted electronic signals derived from non-communication electronic systems such as missiles or radars.

Historically, activities and technologies enabling SIGINT had always been the sole domain of governments. SIGINT missions used to be only conducted in the frame of military activities. However, SIGINT technologies and solutions are now available to public and private actors, providing commercial services for maritime domain awareness, RF spectrum mapping, RF interference detection, RF for Space Situational Awareness, etc. In the past few years, there has been a rising interest in commercial SIGINT solutions from both industrial and government customers. The RAND Corporation distinguished three types of commercial markets for SIGINT capabilities:

- **The government-only market:** capabilities are built and operated by a commercial provider but only accessible to the government,
- **The commercialized market:** capabilities are available in legal commercial markets,
- **The democratized market:** capabilities are available in both legal and illegal markets or available for free (e.g., satellite eavesdropping, hijacking, or hacking solutions available online).[597]

In 2020, the SIGINT market was estimated at $4 billion in the United States. The global SIGINT market is expected to reach $23.42 billion by 2029.[598] There is also a rising interest in SIGINT solutions in China with a market forecast estimated at $3.2 billion per year by 2027.[599]

Several developments took place in 2021:

The U.S. based company **HawkEye 360** Inc. is the world's first commercial company providing SIGINT solutions such as RF mapping, maritime domain awareness, and interference detection. It was founded in 2015 and achieved a few milestones in 2021:

HawkEye's Cluster 3 (Credit: HawkEye 360)

- In July, HawkEye360 expanded its satellite-based radio frequency (RF) data collection and analytics operations with the launch of 3 satellites (Cluster 3).[600]
- In September, HawkEye 360 Inc., announced that it signed a contract with the National Geospatial-Intelligence Agency (NGA) for $10 million per year, which can be renewed for four years. It will help NGA to detect and map RF in order to track military and criminal activities.[601]
- In November, HawkEye 360 Inc. raised $145 million in a Series D funding round led by Insight Partners and Seraphim Space Investment Trust.[602]

[597] SIGINT for Anyone, Rand, 2017
[598] Signals Intelligence (SIGINT) - Market and Technology Forecast to 2029, Research and Markets, 2021
[599] Signals Intelligence (SIGINT) - Global Market Trajectory & Analytics, Research and Markets, 2021
[600] HawkEye 360 expands satellite-based RF data collection, Janes, 2021
[601] National Geospatial-Intelligence Agency Awards HawkEye 360 RF Mapping Contract, PRNewswire, 2021
[602] HawkEye 360 Closes $145M Funding Round, ViaSatellite, 2021

Kleos Space is a Luxembourgish company providing SIGINT services for maritime security, emergency response, and interference detection.

- In September, Kleos Space, which is publicly traded in Germany and Australia, announced it had raised AUD 12.6M to develop its constellation.[603]
- In October 2021, Kleos presented a paper regarding the performance of the radio frequency mapping capabilities of its radio frequency reconnaissance satellites at the GEOINT Symposium. Kleos plans to launch up to 20 clusters of RF-reconnaissance satellites.[604]
- In October, Kleos ordered four additional RF reconnaissance satellites, which are planned to be launched in 2022.[605]

Spire Global is an American company providing space-based weather data solutions, which is now looking to provide commercial SIGINT solutions:

- In 2021, Spire discovered that its weather forecasting antennas were accidentally picking up signals, which were used to jam the GPS. T Spire's reflectometry satellites, which are used to monitor sea levels, can measure GPS signals as they bounce off the surface of the Earth. As a result, Spire Global is looking to add a new RF interference detection service to its portfolio.[606]
- In August, Spire Global was awarded £800 000 by the UK Defence and Security Accelerator (DASA) as part of the "Space to Innovate Campaign". The funding will help supporting the demonstration of radio frequency (RF) signals detection and geolocation from Spire's LEO nanosatellite constellation.[607]
- In December, Spire Global acquired exactEarth, a Canadian company providing satellite-AIS data services for maritime surveillance awareness, for $161.2 million.[608] The transaction confirms Spire's pivot to SIGINT solutions.

Unseenlabs is a French company providing commercial maritime surveillance solutions, including the monitoring of illegal fishing and shipping activities of vessels that do not emit AIS signals.

- On April 27th, it raised a €20 million for its radio-frequency geolocation constellation in a Series B funding round conducted by 360 Capital fund, Omnes fund, Blue Oceans Partners, Definvest fund, and Breizh Up.[609] Unseenlabs, which aims at launching up to 25 nanosatellites by 2025 outlined that the funding will enable it to complete its constellation.[610]
- On August 17th, Unseenlabs launched BRO-4, its fourth maritime surveillance satellite, on a Vega rocket from Kourou, French Guiana.[611]

[603] Kleos Space orders reconnaissance satellites for 2022 launch, SpaceNews, 2021
[604] Unseenlabs raises €20 million for its geolocation nano fleet, SpaceWatchGlobal, 2021
[605] Kleos Space orders reconnaissance satellites for 2022 launch, SpaceNews, 2021
[606] Spire Pivots Weather CubeSats To SIGINT Missions, Breakingefence, 2021
[607] Spire Global Receives DASA Next-Gen Space Tech Funding for RF Signals Detection and Geolocation Project, Spire, 2021
[608] Spire Global Adds 150 Customers With ExactEarth Acquisition, ViaSatellite, 2021
[609] Rennes-based UNSEENLABS snaps up €20 million for its satellite geolocation tech, EU-Startups, 2021
[610] Satellite maritime RF geolocation startup Unseenlabs raises $24M Series B round to field full constellation by 2025, Space Intel Report, 2021
[611] Successful Launch Of Unseenlabs' Fourth Satellite, Unseenlabs, 2021

- **Aurora Insight** is an American company, which provides commercial SIGINT solutions by merging ground-based spectrum analytics with aerial solutions. In 2018, it added space-based SIGINT solutions to its portfolio by launching the THEA 3U CubeSat, which carries an AIS receiver and demonstrated that a VHF radio receiver could function on a CubeSat.[612]

Aurora's Charlie (Credit:Aurora)

- On January 24th, Aurora Insights successfully launched its second satellite (CHARLIE) on a SpaceX's Transporter-1 rideshare mission.[613]
- In April, Aurora Insights announced that the CHARLIE satellite successfully completed preliminary testing and started conducting RF mapping. CHARLIE is collecting 15 times as much data as the THEA satellite.[614]
- On April 28th, Aurora Insight successfully launched its third satellite on a rideshare mission on board ArianeSpace's Vega rocket from French Guiana.[615]
- These developments and the rising interest in commercial SIGINT solutions brings us to a seemingly paradoxical situation, where commercial providers are increasingly relevant for national security, and operate critical elements for military operations and security missions, while on the other hand no clear governance defining and coordinating the use of space for security applications at the European level exists. Such an evolution could further foster and consolidate European R&D and support commercial providers in the development of novel products and services, while also ensuring national security objectives are also considered alongside commercial perspectives.

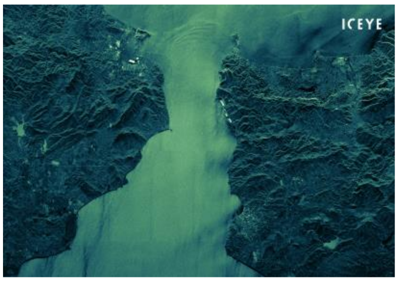
[612] THEA (All-Alpha), Gunter's Space Page, 2021
[613] Satellite Charlie Was Successfully Launched With Spacex's Transporter-1 Mission, Aurora, 2021
[614] Aurora Insight Commissions Second Satellite, "CHARLIE," and Prepares For Third Satellite Launch, PRNeuwswire, 2021
[615] Aurora Insight Launches Third Satellite "BRAVO" to Measure 5G, Aurora, 2021

2.2.6 Increased relevance of SAR technologies and services

In the past few years, there has been an increasing interest in Synthetic Aperture Radar (SAR) images as well as significant developments in Europe. SAR satellites enable to remotely map the reflectivity of objects or environments with high spatial resolution, through the emission and reception of electromagnetic signals.[616]

According to Research and Markets, the global SAR market is currently valued at $3320.2 million and is expected to be valued $6474.0 million by 2026. In addition, Research and Market notes that COVID-19 has created an increasing demand for SAR satellite images, enabling economic actors to better monitor the consequences of the pandemic on the economy.[617] The U.S. National Geospatial-Intelligence Agency's Commercial and Business Operations Group also conducted an assessment of the commercial satellite imagery sector, which showed that European countries are leading in the field of SAR, in particular the Finish company ICEYE, which has the world's best revisit rate.[618]

ICEYE's SAR constellation currently counts 14 satellites, and the company is planning to further expand it by launching at least four additional spacecrafts by mid-2022 aiming to achieve an average access time of three hours anywhere in the world.



SAR image (Credit: ICEYE)

ICEYE reached key milestones in 2021 and significantly expanded its activities:

- In May, ICEYE's SAR constellation reached a 10,000 km^2 coverage through new "Scan mode" imaging capabilities, turning ICEYE into the only New Space SAR company to achieve such coverage. The Scan mode improved ICEYE's existing SAR capabilities allowing the company to provide the most comprehensive persistent land and sea monitoring.[619]
- In June, ICEYE became the first SAR satellite company whose satellite imagery has been fully integrated into ESA's Earthnet Program Third Party Missions (TPMs) data portfolio, after being under evaluation since 2019.[620] The integration enables interested parties to have free access to ICEYE's SAR data and imaging modes.
- In June, ICEYE launched a next-generation spacecraft demonstration mission equipped with its latest SAR satellite technology, which will allow new and innovative capabilities in SAR imaging, including improvements in ground resolution, simultaneous imaging, and almost immediate data downlink and delivery. The launch also included three SAR satellites that have been added to ICEYE's SAR constellation.[621]
- In October, ICEYE became the first European New Space company to be named as a Contributing Mission to the Copernicus Programme. Copernicus services will have access to ICEYE's SAR imagery, which is expected to be used to improve awareness in public safety, border control, security, and maritime domains, and will enhance Copernicus services' assessment and planning capacities.[622]

---

[616] Microwave Remote Sensing of Land Surfaces, ScienceDirect, 2017
[617] Synthetic Aperture Radar Market - Growth, Trends, COVID-19 Impact, and Forecasts (2021 - 2026), Research and Markets, 2021
[618] NGA plans annual survey of international Earth imagery leaders. SpaceNews. October 2021.
[619] ICEYE Introduces the World's First Wide Area Imaging for Persistent Monitoring with New Space SAR Satellites. ICEYE. May 2021.
[620] ESA adds Iceye data to Third Party Mission portfolio. SpaceNews. June 2021.
[621] ICEYE Launches Four New Radar Imaging Satellites, Taking a Further Leap Forward in Persistent Monitoring Capabilities. ICEYE. July 2021.
[622] ICEYE Named as a Contributing Mission to Europe's Copernicus Satellite Imaging Programme. ICEYE. October 2021.

In 2021, in response to rising interest and demand for its SAR imagery and data**, ICEYE consolidated and established new partnerships**. **In November, the Finland-based company signed agreements with:**

- The National Oceanic and Atmospheric Administration (NOAA) to continue contributing to the near-real time evaluation of the impact environmental hazards with SAR satellite imagery. NOAA is also seeking to use ICEYE's data to identify burned areas within active fires to assist firefighters.[623]
- The UK-based McKenzie Intelligence Services (MIS) to provide flood hazard data throughout active flood events. MIS aims to combine ICEYE's observation analysis with its Global Events Observer (GEO) platform to enhance its services and support the delivery of property loss estimates to the Lloyd's market.[624]
- The Abu Dhabi-based company G42 to collaborate on the development of advanced SAR products. The two companies aim to jointly develop advanced algorithms and analytics to serve customers in several domains, and to deploy ICEYE's cloud based Near Real Time (NRT) SAR processing capabilities on G42 Cloud to improve G42's geospatial analytics platform.[625]
- The Japanese company Aon for a satellite solution combining ICEYE's SAR data with Aon's digital building datasets. The goal is to provide insurers with data on flood hazards, reduce volatility and improve understanding of the impact these events have on their portfolios.[626] In June, ICEYE expressed its intention to open an office in Tokyo within a year.[627]
- ICEYE U.S., the company's subsidiary, signed a cooperative research and development agreement with the U.S. Army Space and Missile Defense Technical Center (SMDTC). ICEYE and SMDTC will investigate how the Army can benefit from access to SAR imagery and data and explore SAR-related concepts to meet the Army and Defense Department requirements.[628]

Additionally, ICEYE partnered with the Canada-based company MDA to supply an X-band SAR spacecraft for MDA's next-generation commercial EO mission CHORUS. MDA's objective is to deliver the most extensive radar imaging capacities and unlock new services, such as dedicated vessel detection imaging modes and satellite monitoring of North Atlantic's icebergs with new level of precision and in all weather conditions. Furthermore, the two companies signed a separate agreement to distribute ICEYE's data to MDA's RADARSAT-2 customers and to develop products based on their SAR data integration and analytics.[629]

Outside Europe, companies and public institutions also show significant interest in developing and using SAR images

- In February, Synspective released the first image of its striX-α SAR satellite, making it the first commercial SAR image from a Japanese company. Synspective is aiming to build a SAR satellite constellation in LEO able to observe the location of a disaster occurring anywhere in the world within 2 hours. The Japanese company will launch its second SAR satellite "StriX-β" on a Rocket

[623] ICEYE Announces Contract with NOAA to Tackle Environmental Hazards Often Linked to Climate Change. ICEYE. November 2021.
[624] ICEYE Announces Flood Hazard Analysis Agreement With McKenzie Intelligence Services. ICEYE. November 2021.
[625] G42 and ICEYE Sign a Memorandum of Understanding to Collaborate and Develop Advanced SAR Products. ICEYE. November 2021.
[626] Aon and ICEYE Launch Solution to Better Manage Climate Risks in Japan. ICEYE. November 2021.
[627] Iceye establishes office to serve Japanese market. SpaceNews. June 2021.
[628] Iceye and U.S. Army forge collaborative research pact. SpaceNews. November 2021.
[629] MDA and ICEYE Sign Agreement to Integrate X-band SAR Satellite Into MDA's CHORUS™ Constellation. ICEYE. December 2021.

Lab's Electron rocket in early 2022, aiming to in-orbit demonstrate Interferometric SAR (InSAR), and its third SAR satellite "StriX-1" with Exolaunch in mid-2022.[630] [631]

- Between June and September, Capella Space released two new data types, launched its fourth SAR satellite equipped with a Phase Four's Maxwell electric thruster, and an Open Data Program aiming to make its SAR data publicly accessible to researchers, non-profits, developers, and disaster response organisations.[632] [633] Capella's new data types are the Geocoded Ellipsoid Corrected (GEC) designed for users who wish to interpret SAR data through imagery and to provide image clarity, spatial resolution, and low noise; and the new product delivery format Sensor Independent Complex Data (SICD) that enables sensor-independent storage and dissemination of SLC SAR image data.[634]
- In July, e-GEOS partnered with the Israel-based ISI (ImageSat International) to launch the world's most capable commercial Electro Optical-SAR EO satellite constellation, which brings together five COSMO-SkyMed first and second-generation dual use SAR satellites and ISI's three EROS Next Generation Electro Optical ultra-high-resolution satellites. The new constellation enables new data and services for customers.[635] In October, the two companies launched an innovative SAR-EO Maritime Surveillance service to detect and track dark ships.[636]
- In October, the National Reconnaissance Office (NRO) launched the Broad Agency Announcement Framework (BAA) for Strategic Commercial Enhancements, a program open to both national and foreign companies to acquire emerging remote sensing phenomenologies from commercial providers. The first procurement involves SAR imagery and data, and the relevant request for bids was published on October 12th.[637] [638]
- In October, China Electronics Technology Group (CETC) and Spacety partnered to develop a X and C-band SAR constellation named Tianxian. The SAR constellation will consist of 96 satellites with four imaging modes of imaging functions, and the company's goal is to provide customers timely and accurate imaging observations and monitoring services. The launch of its first spacecraft is planned for February 2022.[639]
- In December, China unveiled plans for another constellation named "36 Tiangang", which comprise SAR satellites. The new constellation will be made of 36 satellites that are planned to be launched between June 2022 and May 2023. 36 Tiangang will be used for disaster prevention, early warning and natural resource monitoring, and its data will be combined with geological survey and monitoring data collected by ground-based sensors in areas prone to disasters. The project is led by Tianjin Satcom Geohe Technologies and involves Satellite (Zhuhai) Aerospace Technology, facilities under the Harbin Institute of Technology, and is supported by the Ministry of Natural Resources.[640]

[630] Interferometric SAR (InSAR) is a SAR analytics technique capable of detecting displacements at the millimetre level on the ground surface through radar images. Synspective Signs Agreement to Launch Second SAR Satellite, "StriX-β" with Rocket Lab. Synspective. December 2021.
[631] Japanese Satellite Company Synspective Signs Launch Agreement with Germany's Exolaunch to Launch the third SAR Satellite "StriX-1" on Soyuz-2. Exolaunch. September 2021.
[632] Capella Space and Phase Four reveal Maxwell Engine performance. SpaceNews. June 2021.
[633] Capella Debuts Open-Access Program for SAR Data. ViaSatellite. September 2021.
[634] Capella Space Releases New SAR Data Types. ViaSatellite. June 2021.
[635] e-GEOS and ISI partner to create the world's most capable commercial SAR-Electro Optical satellite constellation. Telespazio. July 2021.
[636] ISI and e-GEOS Are Detecting And Tracking Dark Ships With New Synergistic SAR-EO Maritime Surveillance Service. e-Geos. October 2021.
[637] NRO to tap commercial industry for space-based radar data. SpaceNews. October 2021.
[638] National Reconnaissance Office releases solicitation for commercial space radar imagery. SpaceNews. October 2021.
[639] Chinese partnership to create Tianxian SAR satellite constellation. SpaceNews. October 2021.
[640] China's SAR satellite surge continues with new constellation plan. SpaceNews. December 2021.

2.2.7 Progress in habitats and life support for exploration

As deep space exploration and space tourism are becoming increasingly relevant, **new technologies must emerge to sustain human life in space** for extended periods of time. 2021 was marked by a series of technological developments in this domain, characterized by public-private partnerships as well as increased interest by NewSpace companies.

Specific efforts have emerged for the establishment of a **long-term lunar presence and the human-presence on a Mars**, relying on in situ and on-site resources:

- In April 2020, NASA's Perseverance Rover successfully extracted oxygen from Mars for the first time. The MOXIE instrument aboard the rover.[641]
- In May 2021, Metalysis and ESA announced team Malt as the winner of the first phase of its Grand Challenge to develop new ideas for future lunar settlements. The winner, team Malt is a Spanish interdisciplinary group focusing on biomedicine and space applications. As part of the first phase of the challenge, the group has been awarded €50,000.[642]
- Belgium-based Space Applications Services has partnered with ESA to create a technology which will perfect the process of creating oxygen from lunar soil. The technologies will be tested on the moon as part of the ISRU mission in 2025.[643]
- In the same framework of the ESA ISRU project, as well, a collaboration between the Polytechnic of Milan and OHB seeks to refine technologies for producing water on the moon.[644]
- Spartan Space, a France-based space start-up has designed its new 'Euro hab', a new semi-permanent inflatable lunar habitat which the company seeks to deploy either as part of NASA's Artemis efforts or ESA's crewed lunar surface missions in the late 2020s.[645]
- In October 2021, ESA formed a partnership with Incus, OHB, and Lithoz for a joint project designed to develop and test 3D printing in moon-like microgravity environments. The goal of the project is to use recycled powders from scrap metals available on the moon to create advanced metal spare parts and reduce the materials that would need to be transported to the moon.[646]
- The Indian Canadian space architecture start-up, AAKA Space Studio has designed "NOAH", a Mars analogue habitat for permanent settlers. The shelter should act as an intermediate step between the temporary and permanent habitats to be constructed. The prototype will be subject to a three-month test in November 2022.[647]
- In August 2021, NASA sent a technological demonstrator 3D printer to the ISS. The printer was developed by Redwire and is intended to use lunar dust to 3D print, with the potential of the technology being integrated in the Artemis mission.[648]

Several other technological developments to **enhance a long-term presence in space** have been developed in 2021:

- The University of Manchester has partnered with Skidmore, Owings, & Merril, to develop a space habitat enhanced using graphene. Graphene can improve the strength of buildings and

[641] NASA's Perseverance Mars Rover Extracts First Oxygen from Red Planet. NASA. April 2021.
[642] Metalysis-ESA Grand Challenge: team Malt wins first phase. ESA. May 2021.
[643] European startup builds oxygen-making machine for 2025 moon mission. Space.com. May 2021.
[644] Producing water on the moon is now a reality – A collaboration between Politechnico de Milano and OHB Italia within the ISRU Project of the European Space Agency. OHB Italia. May 2021.
[645] French Space Startup Builds Ingenious New Inflatable Lunar Habitat Prototype. Forbes. October 2021.
[646] ESA to Test 3D Printing in Space Using Scrap Metals from the Moon. Interesting Engineering. October 2021.
[647] How this Indo-Canadian Startup is Foraying into "Space Architecture", Prototype to be Tested in Leh, India. Analytics India. October 2021.
[648] L'impression 3D s'essaie à la poussière de Lune sur l'ISS. L'usine Nouvelle. August 2021.

machines and could balance out the extreme temperatures that space structures must withstand. Additionally, the strength of graphene will make future space structures more resistant to space debris and micrometeoroids.[649]

AI-powered farming techniques (Credit: DLR)

- DLR and UF Space Plants Lab, who have long since partnered on space agriculture projects, are currently designing a new facility, a semi-inflatable cylindrical space greenhouse. The greenhouse will have advanced remote monitoring and AI-powered robotic arms. The end goal of the project is to create a space greenhouse that is fully autonomous or can be operated from Earth.[650]

[649] Graphene in Space: Wonder Material Strengthens New Space Habitat Prototype. Interesting Engineering. October 2021.
[650] Space agencies are learning how to farm on Mars and the moon. CNBC. June 2021.

3 Global Space Economy

3.1 Overview and Main Indicators

Each year, the Satellite Industry Association (SIA), the trade association of the American satellite industry, and the Space Foundation (SF), an American not-for-profit organisation advocating for the sector, release reports that breaks down the value of the global space economy.

In 2020, SIA estimated the global space economy to be worth $371 billion,[651] **whereas the Space Foundation estimated it in the order of $447 billion.**[652]

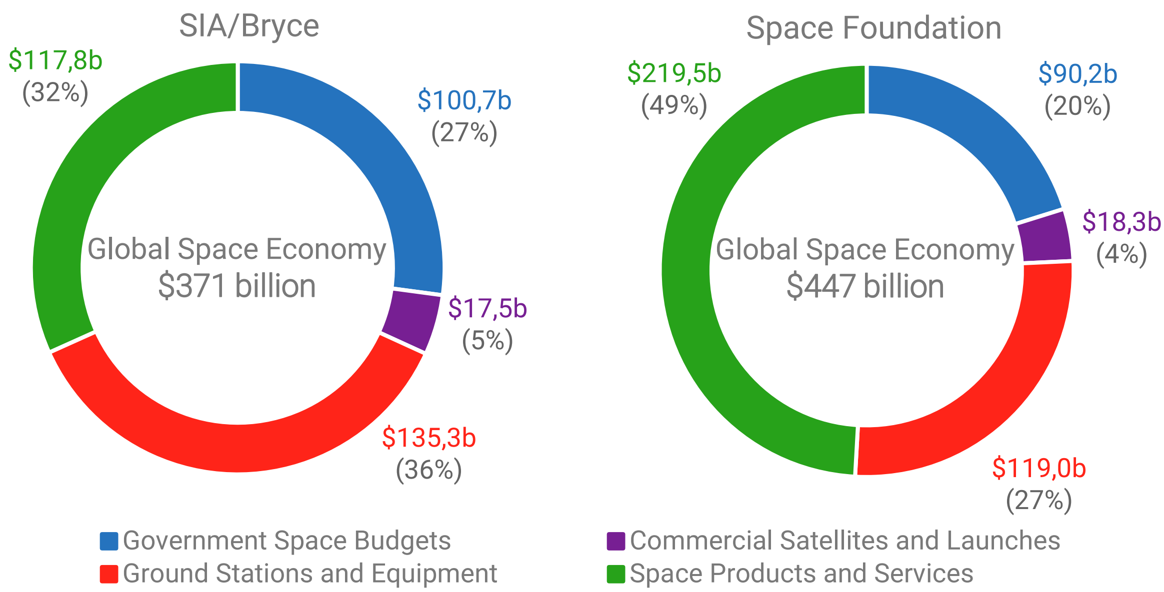


Figure 1: Global space economy estimations by SIA/Bryce (left) and the Space Foundation (right)

These two estimations can be broken down into four major segments:

- **Government space budgets**, which corresponds to the economic activity directly related to government spending. It covers in particular public space programmes and other activities of governmental space organisations (i.e., space agencies, development agencies, military organisations and bodies, etc.).
- **Commercial satellites and launches**, which corresponds to the economic activity of satellite manufacturers and launch service providers outside public markets (i.e. commercial space). It covers in particular the provision of commercial satellites and launch services to private operators.
- **Ground stations and equipment,** which corresponds to the economic activity related to the ground segment of space infrastructures including ground stations, teleports, networks and user equipment.
- **Space products and services**, which correspond, to the economic activity of companies selling space-enabled products and services such as Direct-to-Home services or satellite imagery products. This part of the space economy is usually referred to as downstream and is the most complex to delineate.

[651] 2021 State of the Satellite Industry Report (prepared by Bryce Space and Technology). Summary, Satellite Industry Association, 2021. https://brycetech.com/reports/report-documents/SIA_SSIR_2021.pdf
[652] The Space Report 2021 (Q2 and Q3), Space Foundation, 2021.

The following table provides a more detailed overview of the global space economy estimations made by SIA/Bryce and the Space Foundation for each segment:

Global Space Economy	SIA/Bryce			Space Foundation		
	$371 billion			**$447 billion**		
Government Space Budgets	$100.7	U.S. budget	n.a.	$90.2B	U.S. budget	$51.8B
		Non-U.S. budget	n.a.		Non-U.S. budget	$38.4B
Commercial Satellites and Launches	$17.5B	Satellites	$12.2B	$18.3B	Satellites	$16.2B
		Launches	$5.3B		Launches	$2.1B
Ground Stations and Equipment	$135.3B	GNSS[1]	$103.4B	$118.4B	GNSS	$84.4B
		Others[2]	$31.9B		Others	$34B
Space Products and Services	$117.8	Television	$88.4B	$219.5B	Television	$89.9B
		Communications[3]	$20.5B		Communications	$20.8B
		Remote Sensing	$2.6B		Remote Sensing	$3.7B
		Satellite Radio	$6.3B		Satellite Radio	$8.0B
		PNT[4]	$0.0B		PNT	$97.1B
Others	-	-	-	$0.49B	Insurance Premiums	$0.45B
					SSA	$0.04B

Figure 2: Detailed comparison of space economy estimations by the SIA/Bryce and the Space Foundation

1 Includes GNSS chipsets and navigation devices
2 includes network stations and user equipment such as satellite TV dishes or satellite mobile phones
3 includes Fixed Satellite Services (FSS), Mobile Satellite Services (MSS) and Broadband services
4 Positioning, Navigation and Timing services, enabled by GNSS and augmentation system

The two reports estimate the global space economy by recording government space budgets as well as space-related commercial revenues. However, methodological differences adopted when estimating the value of each segment lead to some significant discrepancies in the estimation of the various segments and of the total space economy value.

Overall, the two reports mostly agree on the size of government space budgets, with SIA reporting a total approximately 10% higher than the SF at $100.7 billion and the Space Foundation reporting a value equal to $90.2 billion. The distribution between U.S. and non-U.S. space budgets was not made available publicly by the SIA in 2021. The Space Foundation estimates that the U.S. government budget reached $51.8 billion in 2020, representing more than 57% of the total public budget Worldwide.

With regards to their assessment of the **size of the commercial satellite and launch markets, this year the two report also find very similar estimates**. This is new since previous editions of the two reports used different methodologies that led to significant differences in estimations for this segment. In their 2019 estimates for instance, the SIA had valued the segment at $19.1 billion whereas the Space Foundation had estimated revenues in the order of $5 billion. The main rationale behind this shift is a change in the Space Foundation's methodological approach in 2021. As such, in 2021 the commercial satellite and launch market was estimated at $17.5 billion by the SIA and at $18.3 billion by the Space Foundation.

In the ground stations and equipment segment, the SIA and Space Foundation estimate that the revenues from network stations and user equipment (included in the "other" category) stand between $31.9 and $34 billion. However, their estimations of the revenue from GNSS chipsets and navigation devices differ substantially, with the SIA estimating $103.4 billion of revenues and the Space Foundation estimating them around $84.4 billion, a difference of $19 billion. The difference in their estimated revenue from GNSS chipsets and navigation devices has thus remained completely stable since 2019, where it was also equal to $19 billion, seemingly confirming the observed reduction from 2018 to 2019 (estimated revenues in this segment were $30 billion apart in 2018). Overall, the SIA and the Space Foundation respectively estimate the total revenues stemming from ground stations and equipment segments to be $135.3 and $118.4 billion, which represents an approx. $5 billion increase in revenues compared to 2019.

The Space Products and Services segment represents the revenues stemming from applications enabled by space systems, also known as **the 'downstream' segment**. This segment **constitutes the largest share of the space economy**, representing respectively 32% and 49% of the total value according to the SIA and the Space Foundation. The largest portion of this economic activity is direct-to-home television, which both reports estimate just under $90 billion (the Space Foundation uses the SIA as its primary source here). The main difference between the two valuations is the inclusion of positioning, navigation and timing (PNT) services enabled by GNSS in the Space Foundation's report. Whereas the Space Foundation lists this as worth $97.1 billion, making it the largest component of this segment, the SIA does not take it into account in its analysis. Other categories in this segment include satellite communications, valued at over $20 billion by both reports, remote sensing, and satellite radio.

Furthermore, the Space Foundation also includes the value of insurance premiums at $0.45 billion, using data from insurance company AXA XL, and a Space Situational Awareness (SSA) segment valued at approx. $400 million using data from Northern Sky Research. For the SIA and Space Foundation, the year-on-year growth of global space economy stood between 1.4% and 5.4% in 2019-2020. The compound annual growth rate (CAGR) for the global space economy since 2013 is estimated to be 2.2% for the SIA and 5.1% for the Space Foundation.

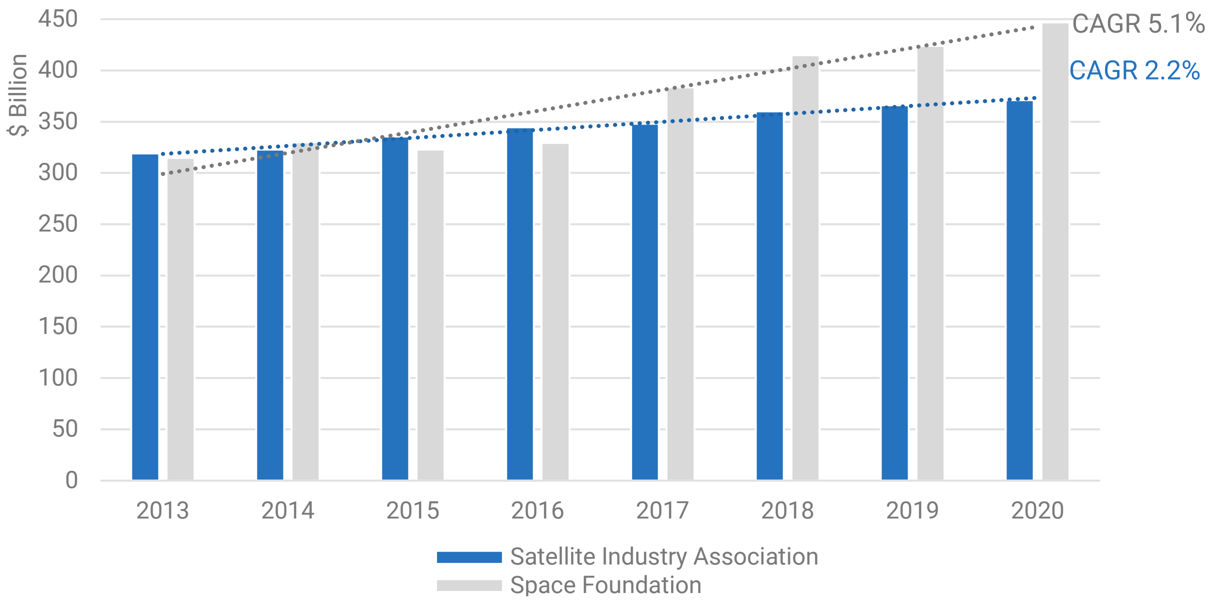


Figure 3: Global Space Economy Evolution (Source: SIA, Space Foundation, ESPI

Whilst the SIA and Space Foundation held broadly similar figures from 2013 to 2016, the inclusion of PNT services by the Space Foundation in 2017 widened the gap with SIA estimation. This also results in a difference in the compound annual growth rate (CAGR) from 2013 to 2020 - with 5.1% for the Space Foundation but only 2.2% for the SIA.

Assessing the space economy: limits and pitfalls

Several organizations have forecasted that the space economy could be worth up to $1 trillion by 2040. While discussions about a trillion-dollar space economy can attract a lot of positive attention on the sector, the spotlight put on space economics raises questions about the methodologies used to estimate the size and growth of the space economy.

Perimeter of the space economy: where does the space economy start, where does it end?

By definition, the value of the space economy corresponds to the value of all final goods and services produced by the space sector. While the inclusion of the value of satellites and launch services in the space economy is straightforward, setting the limits of the space economy becomes increasingly difficult going down the space value chain and reaching "space-related" or "space-enabled" goods and services (e.g. navigation services, data analytics, TV broadcast contents). Definitions of the space economy perimeter vary greatly, and methodologies applied to estimate the economic value of downstream products may be contested. Yet, this peripheral part of the space economy accounts for a large share of the overall value as currently estimated.

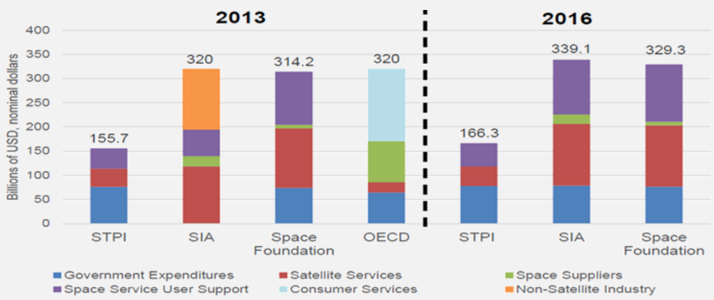
Measuring the space economy: budgets, revenues, gross value added… what is measured and how?

The measurement of the economic value of the goods and services produced by the space sector is another major challenge. Space economy assessments use a mix of data to estimate the value of space goods and services including public budgets and expenditures, company revenues, price estimates and other indicators to assess the value of "space-enabled" goods and services. Methodologies are rarely disclosed which does not allow to verify their soundness and validity. An issue often underlined is the risk of double-counting (i.e. counting both expenditures to buy goods and services and revenues from selling those goods and services) which can lead to an overestimation of the size of the space economy.

Macro-economic conditions: how to consider inflation or exchange rates?

The estimation of the global space economy over time also raises issues to account for macro-economic factors such as inflation or exchange rates fluctuation. Available estimations are provided in current prices (i.e. not corrected for changes in prices) which creates a bias in the perception of the space economy growth. Estimations are provided in US Dollars which also creates a bias related to the fluctuation of currency exchange rates over time. A direct conversion into US Dollars does not allow either to account for the major differences in purchasing power between different countries.

A study by the Science and Technology Policy Institute (STPI) addressed some of these pitfalls and found that existing estimations may be overestimating the size of the economy by twice their measured amount. This significant variation highlights the increasing need to elaborate a consistent estimate for space economy indicators as initiated recently by the U.S. Bureau of Economic Analysis.



STPI Measuring the Space Economy: Estimating the Value of Economic Activities in and for Space

3.1.1 Commercial satellites and launches

The market for commercial satellites and launches was worth $17.5 billion according to the SIA and $18.3 billion according to the Space Foundation which makes the estimate from the Space Foundation higher than that of the SIA for the first time. Furthermore in 2021 the SIA merged commercial human spaceflight into governmental space budgets decreasing the overall commercial satellite and launches envelope. Another point that can be highlighted is that even though the total for both organisations is close, the distribution between commercial launchers and commercial satellite manufacturing is quite different with commercial launches representing 11% of the total for SF and 30% for SIA/Bryce.

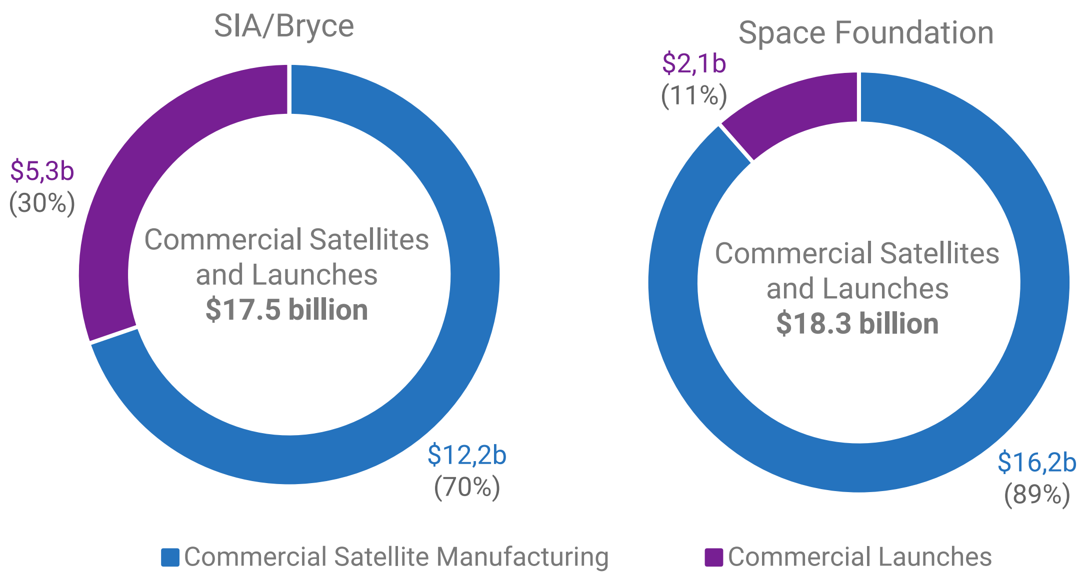


Figure 4: Commercial satellite and launch industry revenues (Source: SIA, Space Foundation)

The revenues from commercial satellite manufacturing and launches estimated by the Space Foundation have seen a considerable increase as a result of a change in methodology, which does not allow for a meaningful comparison of 2020 estimates with previous years. The SIA highlights a small drop in revenues of 8.4% going from $19.1 in 2019 to $17.5 in 2020. This is notably due to the lack of inclusion of commercial human spaceflight for the first time.

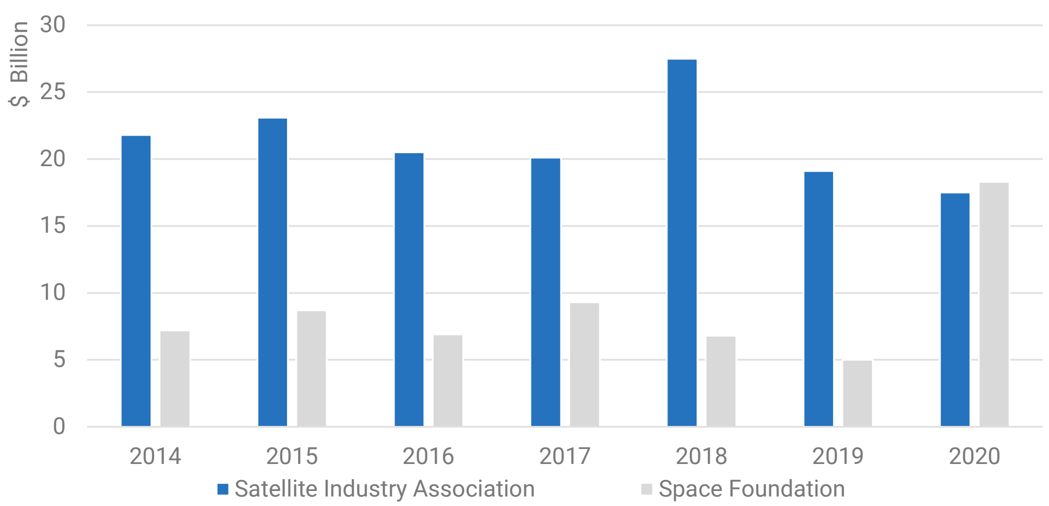


Figure 5: Commercial satellite and launch industry revenue evolution (Source: SIA, Space Foundation)

3.1.2 Commercial launches

To estimate the economic activity related to commercial launches, both SIA and the Space Foundation rely on a market valuation of launches operated during the year that they qualify as "commercial". Both organizations reach the same "tally" of launches in 2020 of 114 launches out of which 104 were successful. ESPI also recorded the same total number of launches, including ten failures.

The SIA and the Space Foundation differ however in their methodology for qualifying and counting commercial launches. The SIA considers that 94 of the 114 launches were "commercial", with an estimation of the total value of these launches at $5.3 billion. On the other hand, the Space Foundation considers that only 43 out of the 114 launches were "commercial", with an estimation of the total value of these launches at $2.1 billion.

The SIA seems to define "commercial launches" as those involving a financial transaction, including for governmental payloads. This corresponds to 82% of 114 launches in 2020. Just over one third (40%) of this revenue was captured by U.S. industry.

On the other hand, the Space Foundation defines commercial launches as launches carried out for non-government customers, representing 37% of successful launches, up 10% since 2019. The economic value of launches for government customers should be covered by the government space budget segment according to Space Foundation's methodology. The Space Foundation estimates the value of governmental launches in the order of $9.25 billion.

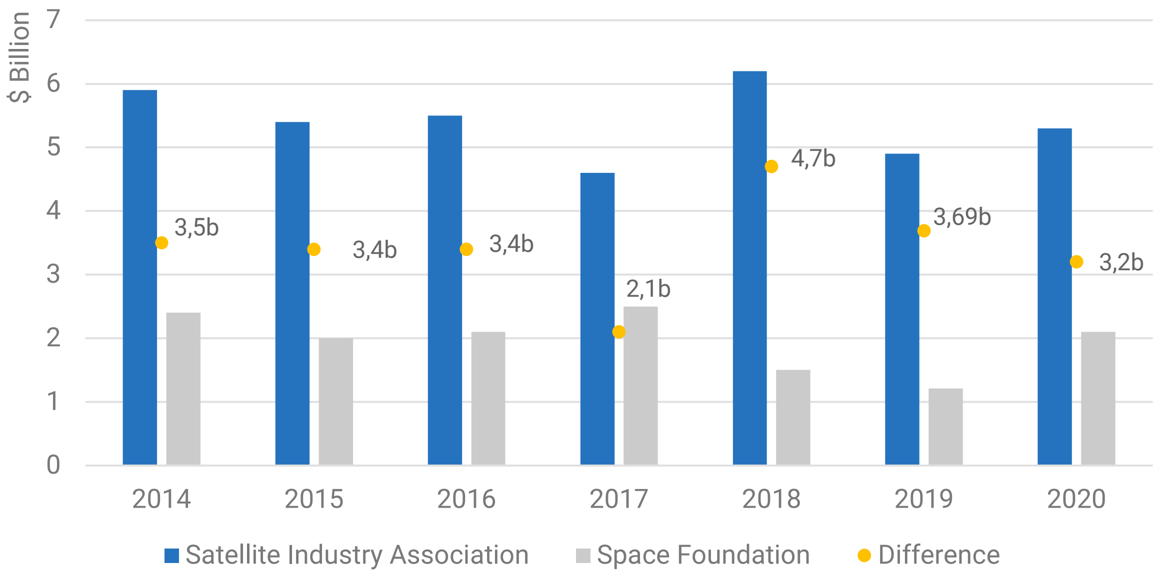


Figure 6: Commercial launch revenues evolution (Source: SIA, Space Foundation)

The difference in estimations between SIA and the Space foundation has been stable in the last few years, with an average variation of approx. $3.4 billion. The largest difference was in 2018 with a divergence in estimation of $4.7 billion, while the lowest difference was measure in 2017 with only $2.1 billion between the two estimates. Overall, both the data collected by the SIA and the Space Foundation remains consistent within the measured period, with a standard deviation of $0.6 billion and $0.5 billion respectively. The highest revenues from commercial launches were measured in 2018 for the SIA at $6.2 billion, with the 2017 having the lowest at $4.6 billion. On the other hand, the Space Foundation estimates that the higher commercial launch revenues were in 2018 at $2.5 billion, with revenues in 2019 being the lowest at $1.2 billion.

3.1.3 Commercial satellite manufacturing

According to SIA, revenues of the commercial spacecraft manufacturing industry were down to $12.2 billion in 2020. This represents a small $300 million decline as compared to 2019, but also a steep decrease of $7.3 billion as compared to 2018. The Space Foundation estimated the commercial spacecraft manufacturing industry to be worth $16.2 billion in 2020 but, here again, the recent change of methodology does not allow a meaningful comparison with previous years.

Both the estimation of the SIA and of the Space Foundation still rely on a valuation of "commercial satellites" launched during the year. In 2020, ESPI recorded a total of 1.266 spacecraft put in orbit, including 1.120 commercial spacecraft (i.e. spacecraft primarily intended to serve a commercial market and to make profit).

The SIA included 1.194 satellites in its estimation in 2020. Out of these satellites, 11% were used for remote sensing and 84% for telecommunication. The Space Foundation, on the other hand, included 1.230 spacecraft in its estimation in 2020, out of which 1098 spacecraft were considered commercial for a staggering 89% of commercial payloads. This is a 330% increase compared to 255 commercial spacecraft put in orbit in 2019.

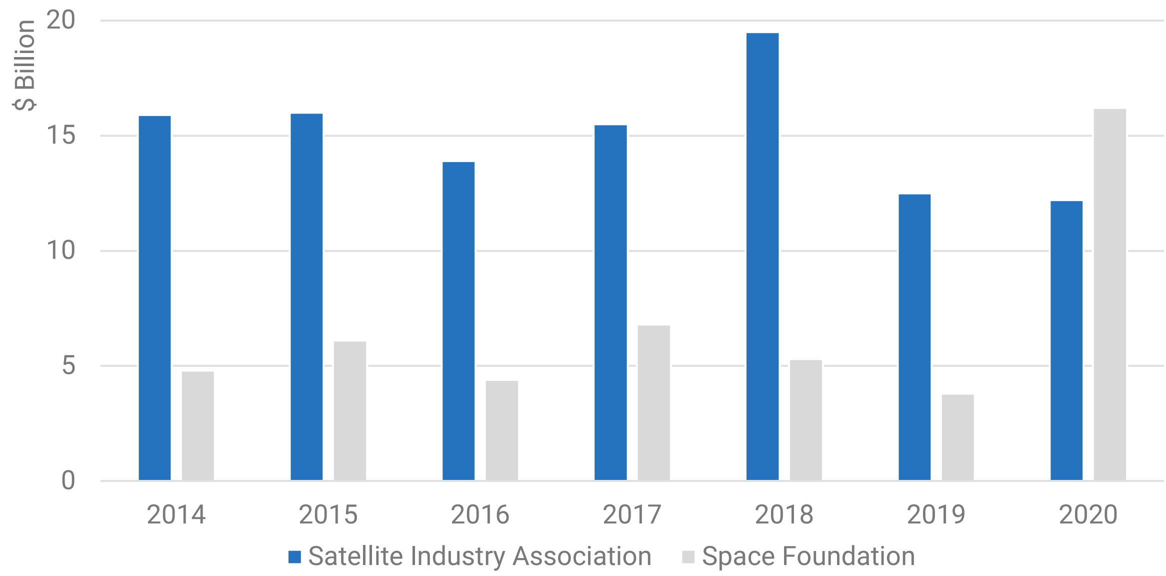


Figure 7: Commercial satellite manufacturing revenues evolution (Source: SIA, Space Foundation)

3.1.4 Ground stations and equipment

The SIA and the Space Foundation estimate the total value of ground stations and equipment revenue in 2020 to be $135.3 billion and $118.4 billion respectively. The main difference between these two estimations is related to the value of GNSS chipsets and software, with a difference of $19 billion.

In this segment, $84.4 billion, or 71.3% of the $118.4 billion reported by the Space Foundation, correspond to revenues from navigation chipsets and software. This is a 7.7% year over year estimated growth by the SF. The SIA reports a similar proportion, at 74% of the $135.3 billion total revenues or a total of $103.4 billion for GNSS equipment. The rest of the segment includes network stations and user equipment such as satellite TV dishes or satellite mobile phones. These are estimated at $32 billion by the SIA and $35 billion by the Space Foundation.

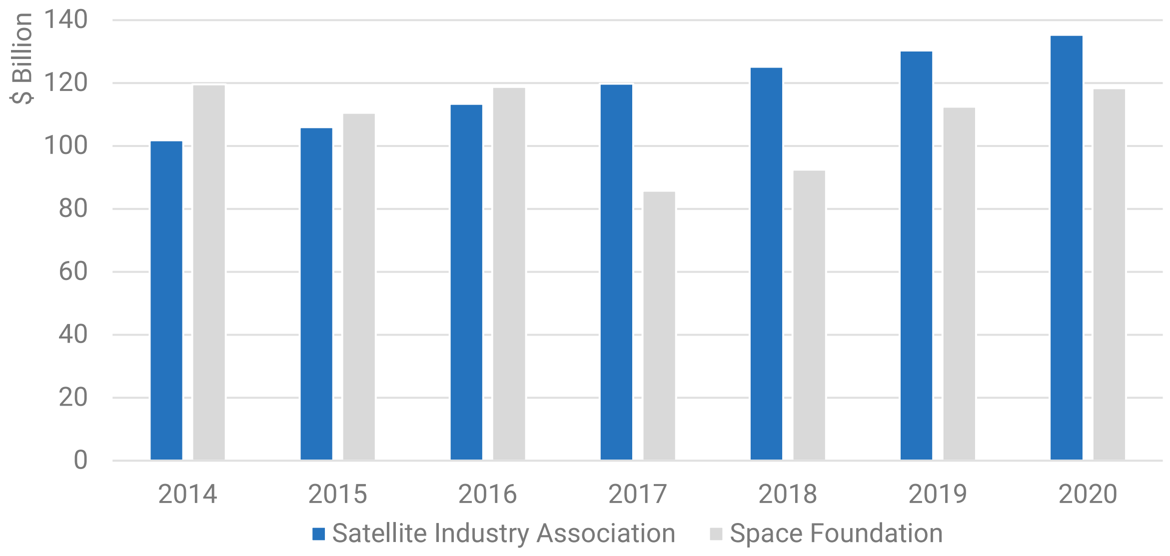


Figure 8: Ground stations and equipment revenues evolution (Source: SIA, Space Foundation)

The SIA data show a continuous growth with a year-on-year increase from 2019 to 2020 of 3.8%. This is very similar to the year-on-year increase between 2018 and 2019 which was of 4%. The Space Foundation data show a large drop between 2016 and 2017. However, after this, the segment continued to grow, with a year-on-year increase of 5.3% between 2019 and 2020.

3.1.5 Space products and services

The segment of space products and services, corresponding roughly to the downstream sector, comprises the sales of a variety of space-based solutions to end-users including governments, businesses and individuals. Categories of space products and services include:

- **Television**: TV broadcast and Direct-to-Home services,
- **Communications**: Services ranging from texting and telephony to broadband internet,
- **Remote Sensing**: Wide variety of solutions enabled by optical and radar satellite imagery, from sales of raw data to turnkey analytics services,
- **Satellite Radio**: Radio services via satellites, usually for personal vehicles (mainly XM Sirius revenues),
- **PNT value-added services**: Wide variety of solutions enabled by GNSS signals (not included by the SIA in their assessment).

The space products and services segment are estimated to be $117.8 billion by the SIA and $219.5 billion by the Space Foundation. This large discrepancy is due to the inclusion of PNT services by the Space Foundation, which account for nearly half of the segment. Estimations for other space products and services are very similar between the two sources with direct-to-home television taking up the largest portion, $88.4 billion for SIA and $89.9 for the Space Foundation.

The PNT value-added services category includes in-vehicle navigation systems, fleet management services, and revenues from smartphone applications that use location-based services. The Space Foundation estimated this economic activity to be worth $97.1 billion in 2020.

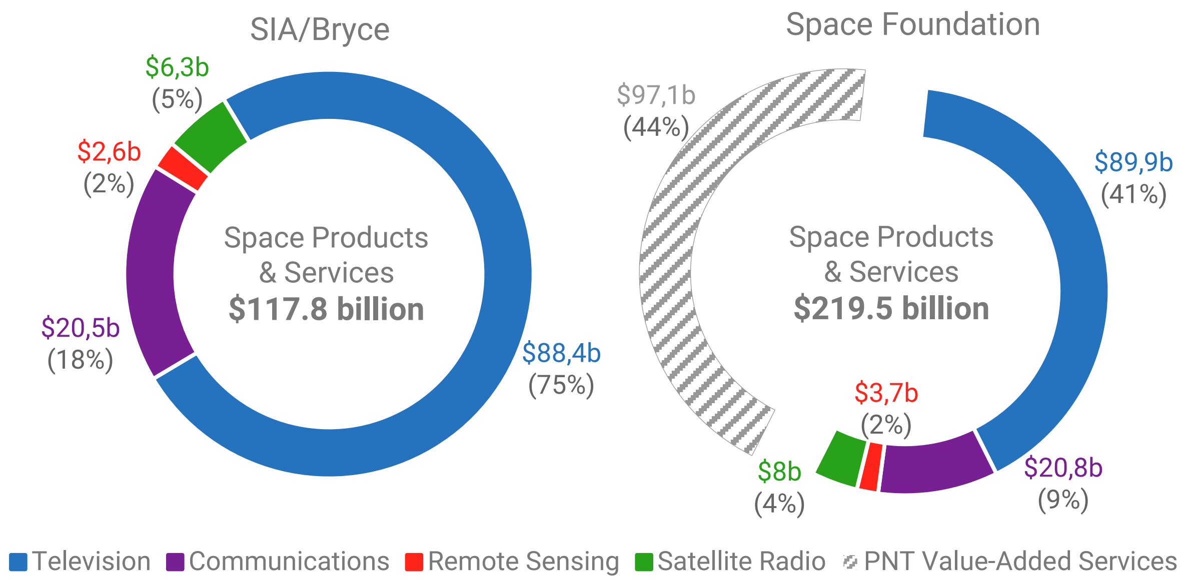


Figure 9: Commercial space products and services revenues (Source: SIA, Space Foundation)

For the SIA, revenues from space products and services segment decreased in 2020 compared to 2019, from $123 billion to $117.8 billion. The Space Foundation's estimate, on the other hand continued its year per year increase (even though small), going from a revenue of $218 billion in 2019 to $219.5 billion in 2020.

The Space Foundation saw an 0.7% increase compared to 2019, while SIA estimated that revenues decreased by approx. 4.2%. A general analysis shows that the estimates for the market size comparison in the period going from 2014 and 2017 were very similar between the SIA and the Space Foundation. However, the decision by the Space Foundation to also include revenues stemming from PNT activities in their perimeter of analysis in 2017 has led to a growing divergence in estimates with the SIA.

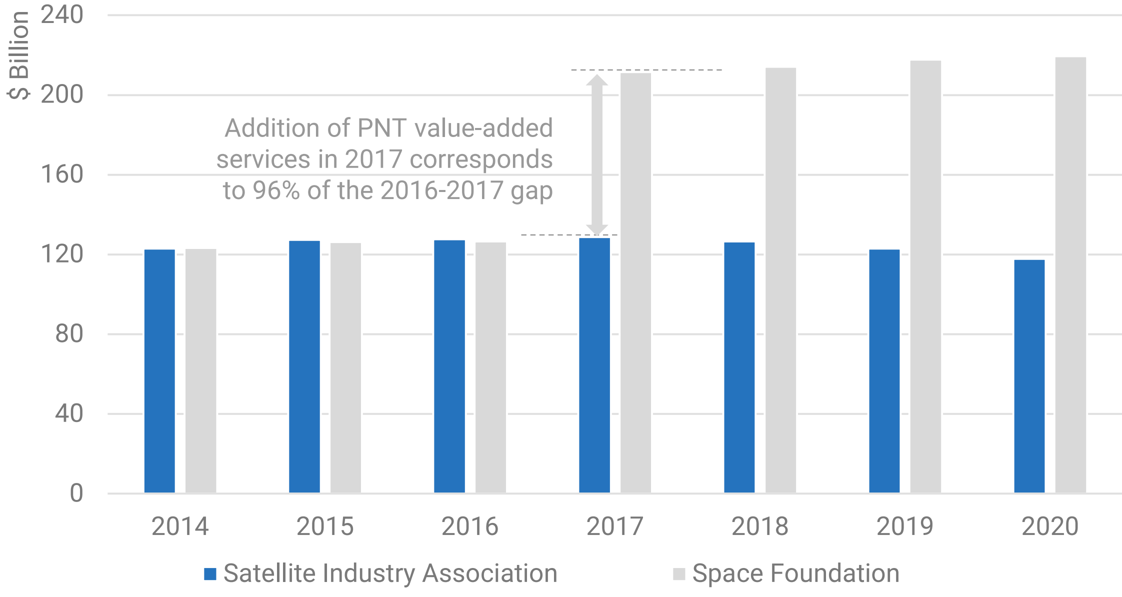


Figure 10: Commercial space products and services evolution (Source: SIA, Space Foundation, ESPI)

The total revenues estimated by the Space Foundation for this sector jumped by almost $85 billion between 2017 and 2018 due to the PNT activities. PNT activities are also the main drivers behind the increase in revenues from 2018 to 2019 according to the Space Foundation, with an increase in revenues stemming from these activities estimated at approx. 5.3%. Based on data form the GSA, the Space Foundation expects the PNT value added services segment to grow significantly over the next 10 years.

3.1.6 Space insurance sector

Space insurance landscape

Space activities involve inherently risky operations, and the insurance sector provides space actors with solutions to help mitigate financial setbacks that can arise from activities undertaken in the phases ranging from pre-launch to in-orbit operations. Insurers usually compete on coverage terms, capacity and most often on premium prices. While they are typically packaged together in most insurance solutions, there is a distinction between property insurance (first party) and liability insurance (third party). While the property insurance insures against the failure of a satellite during launch or operation and will typically cover the cost of the satellite, the liability insurance of a satellite insures against damage caused to a third-party by the launch or satellite operator.

First party liability covers the riskiest phase of the satellite's life cycle, with 34% of GEO satellite losses since 2000 occurring during launch,[653] and usually represents the third-largest expenditure of commercial satellite ventures after launch and manufacturing. The liability insurance, on the other hand, may be mandatory in some countries for the obtention of a license having drafted national legislations to this end.[654]

There are currently approximately between 30 and 35 insurers operating in the space industry across the world.[655] **In 2020, 46.5% satellite launches worldwide had insurance**,[656] with only approx. 7% of satellites insured. Overall, GEO satellites are more often insured, with around half of them holding insurance in 2020. In contrast, the number of LEO satellites having been insured is less than 2%. This is in line with recent trends in the sector, as only approx. 2% of non-geostationary satellites have carried insurance on orbit since 2017.[657]

The decision to ensure a spacecraft is often taken in relation to the overall costs and risks associated with the mission. The price of insurance premiums for a single satellite, launch vehicle or spacecraft may vary depending on its size, cost, and the type of mission it will carry. GEO satellites thus often incur higher premium prices, as they are in many cases the most expensive private commercial satellites to produce, assemble and launch. The high costs associated with these types of satellites throughout their development stage and operational lifespan is typically the main reason driving customers and operators to be more risk-averse than with other types of satellites such as those in LEO and CubeSats.

Therefore, whereas a large telecommunications satellite operator may choose a more comprehensive insurance to cover the risk of loss of their investment, operators of smaller satellites may seek more basic insurance packages to reduce costs.

Operators of satellite constellations such a SpaceX with Starlink therefore tend to be less risk averse and launch and operate their constellations without property insurance, basing their risk reduction strategy on the launch of more satellites than needed. These operators are likely to view the entire constellation as the asset rather than a single satellite.[658]

Still, **space insurance companies are trying to adapt their business practices to New Space companies.**[659] Indeed, for smaller companies such as Kacific, that are backed by venture capital

[653] Space Insurance Update, AXA XL, 2019.
https://iuai.org/IUAI/Study_Groups/Space_Risks/Public/Study_Groups/Space_Risk.aspx.
[654] Third Party Liability and Insurance Innovation in the Smallsat Era, Mathieu Luinaud, Virgile Salmon, December 2020.
[655] Space Insurance and Collision Risk, AXA, March 2021.
[656] The Space Report 2021 (Q3), Space Foundation, October 2021.
[657] Ibid.
[658] Space insurance premiums rose by 2x-3x in late 2019 and the increase is holding — so far, Space Intel Report, March 2020.
[659] Insurers to New Space: Be patient with us as we adapt and learn to price your risk, Space Intel Report, December 2021.

companies or that are public, ensuring their space assets is important to keep the confidence of their investors, and thus their cash flow.[660]

Insurance companies profit in 2020

In recent years several factors have put pressure on the space insurance business. One of these factors is that claims have outsized premiums in the past three years, with major failures causing cutting the revenue for insurance companies. Accordingly, even though in 2020 the industry only saw $24.6 million in profits, it was enough to make it the most lucrative year since 2017.[661]

Moreover, in 2021 insurance companies further increased in their profits, thus cementing their break away from previous consecutive years of losses. With approx. $500 million in premiums and the value of claims only reaching $360 million, the insurance market had a revenue of approx. $140 million. Importantly, there are still some potential claims in dispute, such as damage to the PSN 6's solar array[662] and the MEASAT-3 satellite failure due to fuel depletion, which could claim up to $45 million.[663] The most notable insured failure in 2021 was the SXM-7 satellite, which failed in orbit, amounting to $225 million.

2018	Reported claims	Cause
WorldView-4	$183 million	In-orbit failure
Angosat-1	$121 million	In-orbit failure
Al Yah 3	$115 million	Partial launch failure
Soyuz MS-10	$71 million	Launch failure
Turksat-4b	$25 to $60 million	Partial launch failure
2019		
Falcon Eye-1	$415 million	Launch failure
ChinaSat-18	$250 million	Post-launch anomaly
Eutelsat 5 West B	$192 million	Partial failure
2020		
Thaicom 5	$26 million	On-orbit anomaly
Express AM-6	$39 million	Payload failure
Palapa-N1	$252 million	Launch failure
2021		
SXM-7	$225 million	Payload failure

Table 5: Major insurance claims in the space sector 2018-2021 (ESPI compilation)

However, despite the positive results for the last two years, some trends are worrying the insurance market, namely the increasing congestion and the amount of debris, which increase risks for insurers.[664]

[660] Space insurers just might book 2020 as a gross profit, but with the lowest premium volume, Space Intel Report, May 2021.
[661] The Space Report 2021 (Q3), Space Foundation, October 2021.
[662] "Space Insurance Year 2021 was a winning one on a calendar basis, Seradata, February 2022.
[663] Measat gives up on drifting satellite in a blow for insurers, SpaceNew, August 2021.
[664] The Space Report 2022 (Q1), Space Foundation, April 2022.

Moreover, 2020 was the year with the lowest premium volume in 20 years and even though 2021 saw this number increase, it is still under a trend of a general decrease in premium volumes since 2012, which can be explained in part by the New Space market focus on LEO satellites instead of the traditionally insured GEO satellites.[665] Indeed, even though 99% of new satellites launched in 2021 were placed in LEO (the majority of which by SpaceX and OneWeb), most of the insured spacecraft are traditionally located in GEO.[666]

Accordingly, a few underwriters, such as AIG, already ceased providing their services to the space insurance market, while others exclude collision damage in the contracts.[667] Considering this paradigm, OneWeb's decision in 2021 to insure more than $1 billion in assets during the launch flight phase of its LEO constellation was a positive development for underwriters in their expansion into the LEO market.[668]

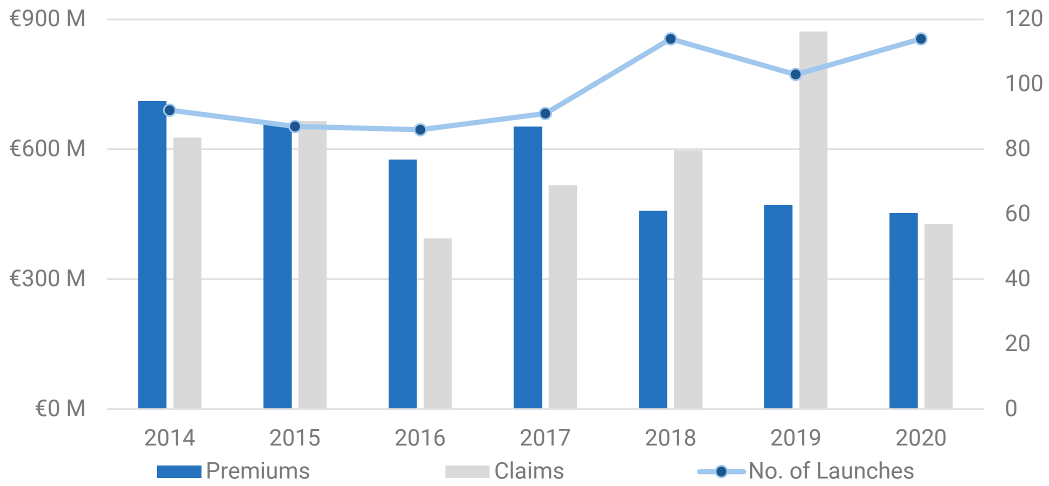


Figure 11: Insurance premiums and claims 2014-2020 (Seradata, AXA XL, ESPI)

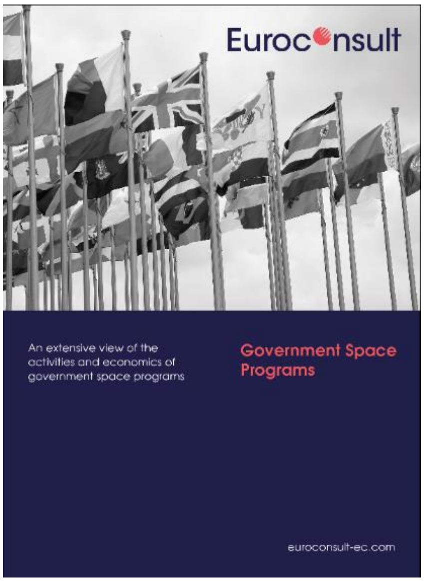
Civilian space tourism is eagerly being monitored by the insurance market sector.[669] Space tourism saw record numbers in 2021 and there are various plans to develop commercial space stations, which will bring more civilian tourists to space. Notwithstanding the risks, which are still being analysed by the market, insurance companies see these developments as opportunities where their services can be provided, especially regarding commercial space stations.[670]

Nevertheless, Blue Origin, one of the companies involved in the future space station Orbital Reef, decided to guarantee its financial responsibility by an agreement with a "parent guarantor" to set up a fund held in escrow, instead of buying insurance. This decision came after the U.S. Federal Aviation Administration updated the company's maximum probable loss (MPL) from $75 million to $150 million, to allow the company to start human spaceflights. The increase in MPL meant that the amount to be insured would also rise.[671]

[665] Space insurers just might book 2020 as a gross profit, but with the lowest premium volume in 20+ years, Space Intel Report, May 2021, and "The Space Report 2022 (Q1), Space Foundation, April 2022.
[666] The Space Report 2022 (Q1), Space Foundation, April 2022.
[667] Launching into space? Not so fast. Insurers balk at new coverage, Reuters, September 2021.
[668] OneWeb signs a mission critical launch insurance agreement through Marsh, OneWeb, October 2021.
[669] Bezos' 2021 Space Odyssey Is a Risk Too Far for Insurers, Insurance Journal, June 2021.
[670] The Space Report 2022 (Q1), Space Foundation, April 2022.
[671] Blue Origin to perform first New Shepard launch under updated license, SpaceNews, August 2021.

3.2 Institutional Space Budgets

The following section makes use of Euroconsult data for national space budgets with their permission.



Data are extracted from the Euroconsult Government Space Programs report which provides a comprehensive assessment of 87 countries with a detailed analysis of their space programs and space budgets. Various sources of information are collected by Euroconsult on government space programs and budgets from government agencies' primary information, public sources, and estimates. This information is harmonized and processed to form a coherent set of data.

The report provides an in-depth profile for each country, including:

Country factsheet: high-level key figures on that country's space program, including top 3 applications, high-profile space missions, total space budget, world ranking, space spending per capita, 5-year CAGR, etc

- Analysis of government space strategy and space policy documents, including key stakeholders
- Assessment of government budgets, split by application, civil/defence, and 10-year historical data and 10-year forecast
- Breakdown and analysis of government space program by application (satcom, satnav, EO, exploration, etc.)
- Roadmap of all satellites and space missions launched by that country (10-year historical and 10-year forecast)

Euroconsult complete report is available here.

3.2.1 Global overview and evolution

The total institutional budget for space programmes in 2020, including intergovernmental organisations, is estimated to be $100.7 billion by the SIA/Bryce, $90.2 billion by the Space Foundation, and $82.5 billion by Euroconsult. The variation between estimates in institutional budgets is notable, mainly due to the difference in the definition and the perimeter selected in the scope of each study. In terms of year-on-year evolution, while the Space Foundation records an increase of only $3.3 billion (3.8%) in 2020, Bryce reported an increase of $7.2 billion (7.7%). Euroconsult reports an increase of $7.7 billion (10%).

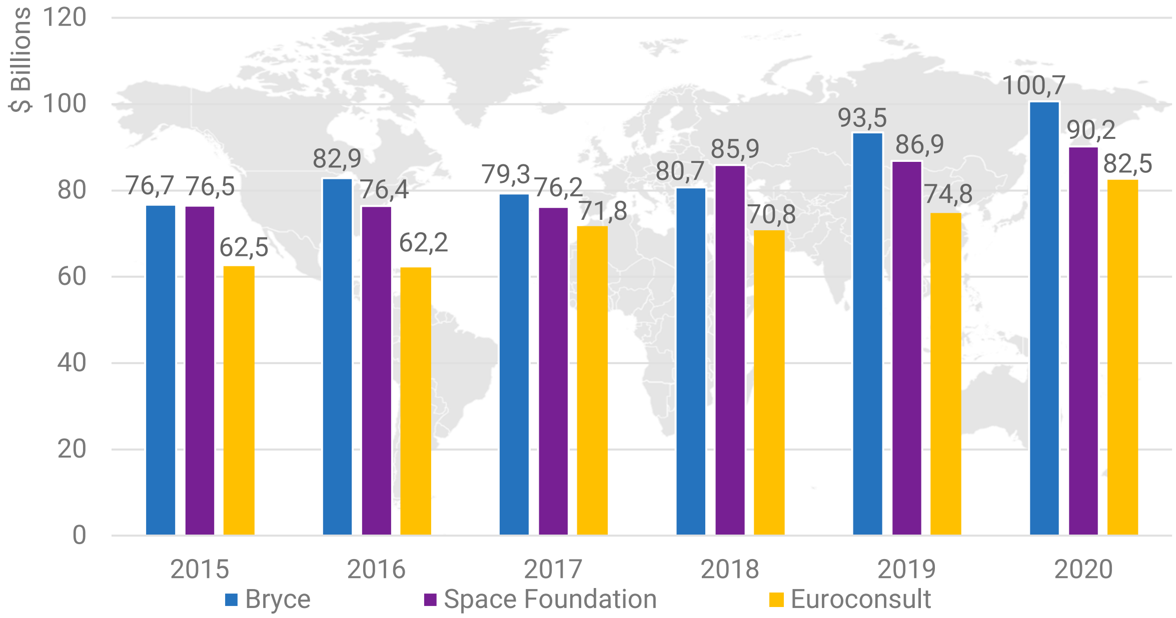


Figure 12: Global institutional space budget evolution (Source: SIA, Space Foundation, Euroconsult)

It is important to note that institutional budgets provide an incomplete perspective on governments' respective investment in the space sector and cannot be directly compared. The influence of currency exchange rates and purchase power differences should not be overlooked. Governments may also invest in the space sector through classified military spending or programmes in adjacent sectors.

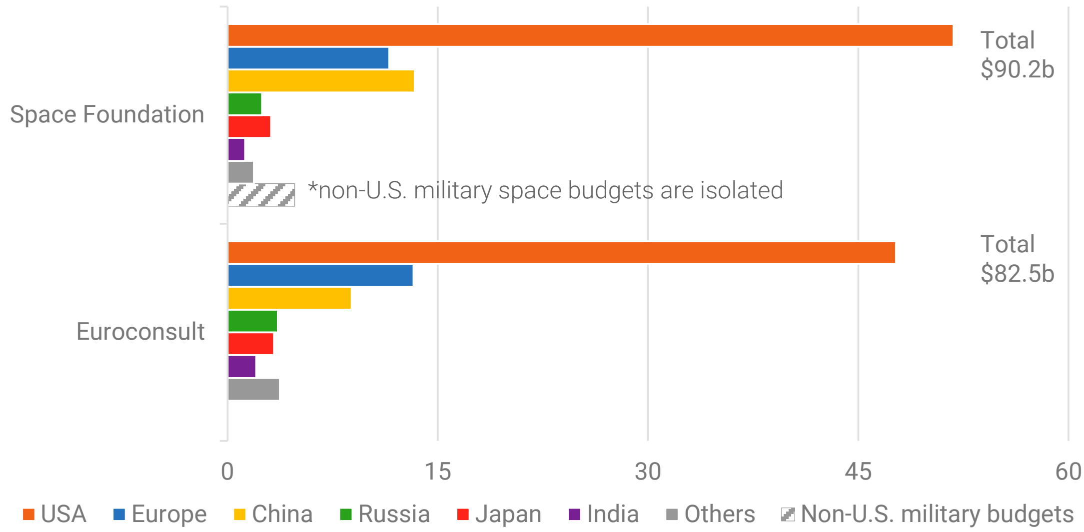


Figure 13 :Institutional space budgets in 2020 (Source: Space Foundation, Euroconsult)

When comparing the specifics of institutional space budgets, Euroconsult diverges from the Space Foundation in its estimation of China's and Europe space budget, considering Europe's budget to be significantly larger than China's by almost 42% or $4.7 billion. This is contrary to the Space Foundation estimate that sees China's budget as larger than Europe's by a total of $1.9 billion or 15% larger. This divergence can be caused my multiple factors and notably by the fact that China's real budget is unknown.

With regards to the world military space budget, the Space Foundation indicates a slight decrease from $32.6 billion to $31.3 billion between 2019 and 2020 or a $1.3 billion decrease originating primarily from a decrease in U.S budgets. At the same time its estimate of the world civil budget increased from $54.4 billion to $60.3 billion between 2019 and 2020. This increase in civil budget is a result of increased civil expenditure in other countries going from $28 billion in 2018 to $30.3 billion in 2019.

Euroconsult have slightly lower figures in total; however, it highlights a slightly larger military budget in 2020 reaching a total of $32.4 billion in comparison of its 2019 world military budget of $28.3 billion. Euroconsult also shows a growth in global civil budget growing from $46.5 billion in 2019 to $50.1 billion in 2020.[672]

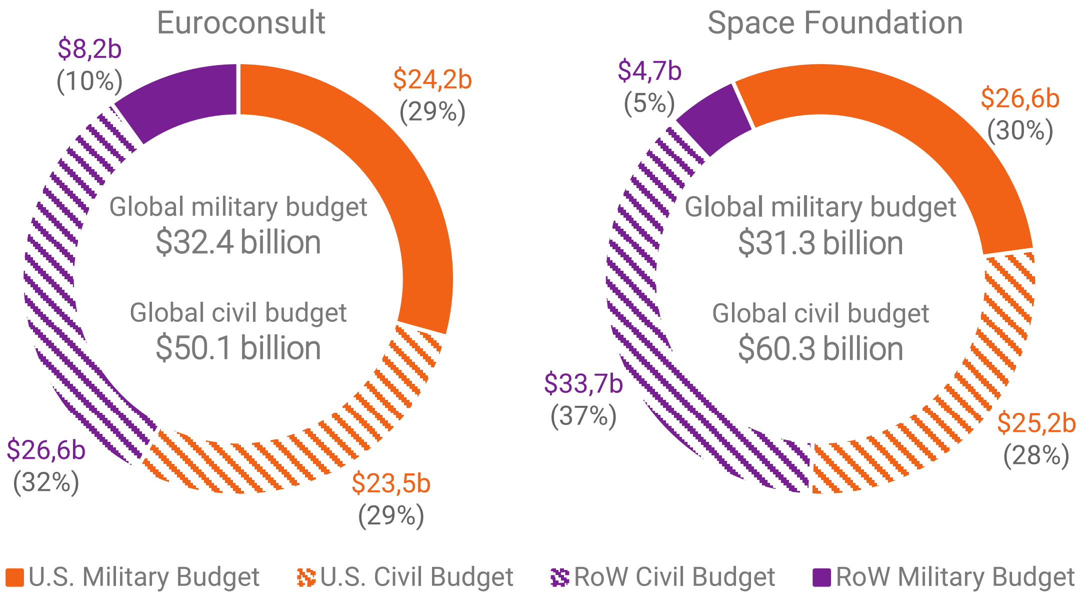


Figure 14: Civil vs Military budgets in the U.S. and Rest of the World in 2020 (Source: Space Foundation and Euroconsult)

In 2020, the United States accounted for approx. 41% to 42% of expenditures on global space programmes, depending on the organisation assessing with a gradual decrease observed in the last few years. The U.S. budget represented roughly 75% of global space budgets in the early 2000s. This can be explained by the growth rate of budgets for other nations, which has increased at a faster rate over the last two decades.

The prominence of the United States in the space sector is boosted by its military budget. The U.S. military budget is estimated by the Space Foundation to be $26.6 billion, just lower than the civil budget of $25.2 billion. This represents a slight increase compared to both budgets in 2019 which were of $23.0 billion for the military budgets and the civil budget of $24.1 billion. More than half (51%) of the U.S. space budget goes to military departments. In contrast, only one fifth (14%) of the space

[672] Government Space Budgets Surge Despite Global Pandemic, ViaSatellite, 2021.

budget for the rest of the world goes to military budgets, at $4.7 billion. This makes the U.S. military budget approx. 6 times larger than that of the rest of the world

Euroconsult reports similar proportions, although the overall budget is reportedly smaller. The U.S. military budget was recorded as $24.2 billion in 2020, with the rest of the world spending $8.2 billion. This means the U.S. spends 2.9 times more than the rest of the world on military space. The U.S. spends $23.5 billion on civil programmes, with the rest of the world spending $26.6 billion.

3.2.2 Space budget per country

Nominal space budgets

In 2020 Euroconsult estimated the total global institutional space budget at $82.5 billion. As in the previous years, in 2020 the United States budget is larger than all the other combined. The second largest spender is China, which budget is estimated at $8.85 billion. Similarly, to 2019, the next places are taken by France, Russia, and Japan. These top five largest space budgets represent over 80% of the global total.

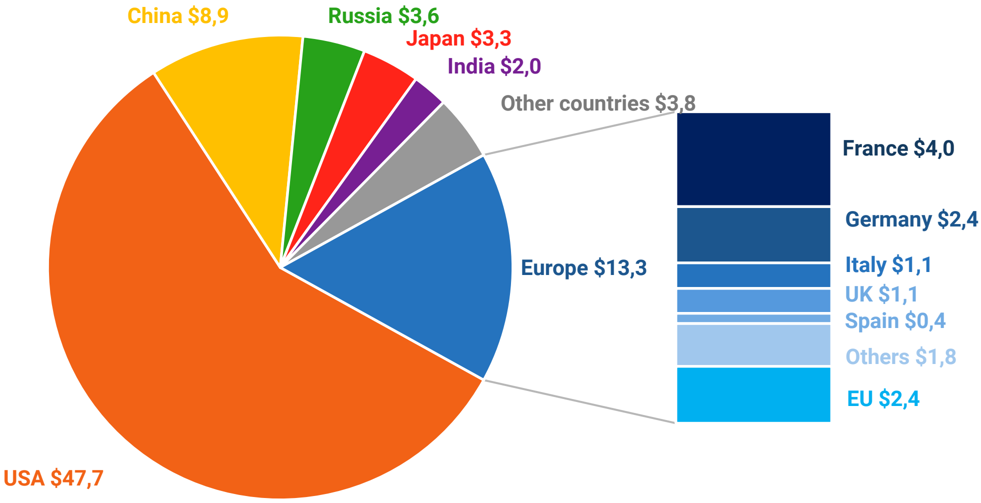


Figure 15: Institutional space budget per country in 2020 in USD (Source: Euroconsult)

In 2020 the United States remained the country with the largest institutional space budget, which reached $47.7 billion. Between 2019 and 2020 the budget grew by $4.7 billion (11%). This increase is twice the $2 billion growth already seen in 2019. In contrast, the Space Foundation reports slightly larger numbers than Euroconsult. The Space Foundation estimates that the U.S. budget reached $51.8 billion in 2020, nearly 10% increase year over year.

There was no change either in terms of the second place, which has been taken by China since several years. Euroconsult estimates the Chinese budget at approx. $8.8 billion, whereas the Space Foundation gives it a much higher valuation of $13.4 billion. Interestingly, even though the Space Foundation estimation is higher than the one provided by Euroconsult, it claims to include only civil budget. Such a large discrepancy may come from the fact that the information on Chinese space budget is not based on official figures and is more speculative due to China's policy of opacity towards its space programme. Another challenge is posed by the Chinese monetary policy, which causes difficulties with valuating the real value of the Yuan. Consequently, Chinese space budget estimations do not necessarily reflect the level and growth of space activity in the country.

The 3rd place is taken by France, which budget is estimated by Euroconsult at $4 billion. The French spending increased by 22.4% year over year. The growth was so significant that the France now ranks before Russia in terms of governmental space budget. The estimated French budget includes French contributions to ESA and EUMETSAT but does not cover the share of the EU space budget provided by France.

Euroconsult reports the Russian budget as $3.6 billion, which makes it the fourth largest in the world in 2020. According to the estimates, the public spending in Russia grew at 6.8% year over year.

The 2020 Japanese spending is estimated at $3.3 billion, which means it is the 5th largest budget worldwide observed by Euroconsult. The valuation remains nearly the same as the one from 2019.

The European space budget, understood here as the sum of EU and ESA member states budget (excluding Canada) reached $13.3 billion according to Euroconsult. The valuation of each country's budget includes contributions to ESA and EUMETSAT (wherever applicable) and the EU space budget is reported separately. French budget estimated at $4 billion is the largest in Europe and stands for over 30% of the total European space budget. The EU spends the second largest sum of $2.43 billion which represents 18.3% of the European total. Third comes Germany with an estimated institutional spending of $2.40 billion, which is only $0.03 smaller than the EU and represents 18.1% of the total. Other European countries with significant space budgets are Italy ($1.1 billion, 8,2% of total), the United Kingdom ($1.1 billion, 8.0%) and Spain ($450 million, 3.4%).

It was previously highlighted which country spends most in nominal values. However, countries across the world vary considerably in terms of their economic and demographic potential. Clearly, what is a large budget for a smaller economy may be a marginal one for one of the global leaders.

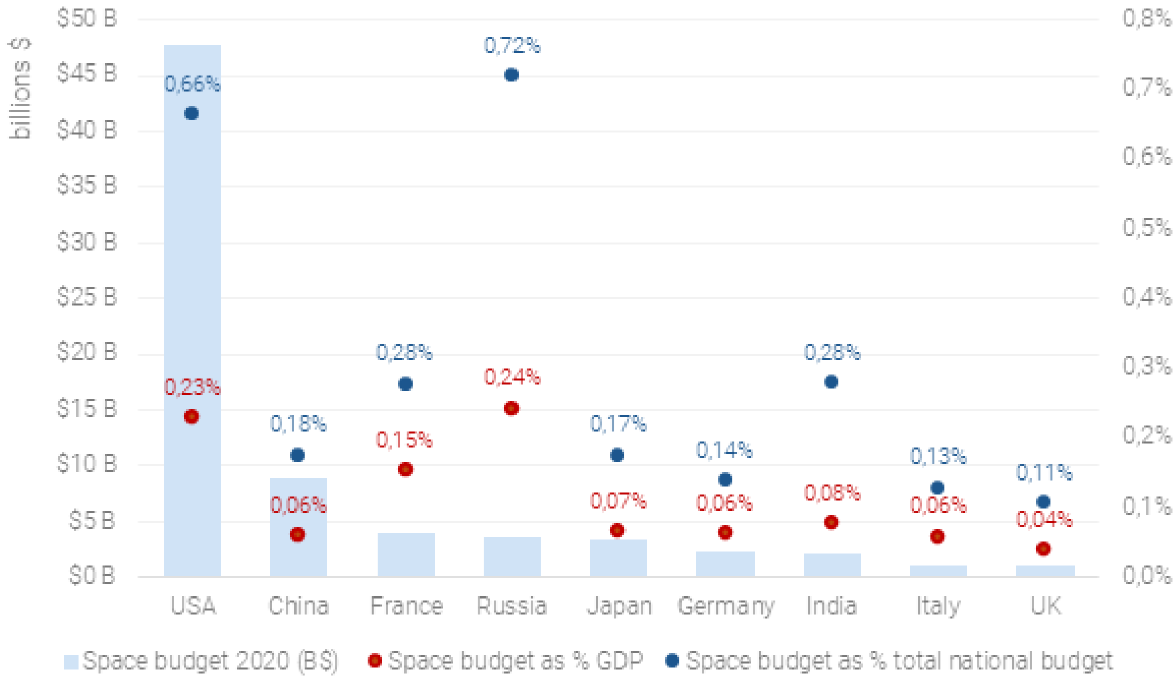


Figure 16: Space budgets as % of GDP and as % of total government expenditure in 2020 (Source: Euroconsult, IMF, ESPI)

The figure above focuses on the relation between national space budgets, total government expenditure and GDP. It presents the national space budgets as a share of the total national budgets and as a share of the GDP. Countries are ranked in a descending order by their nominal space budgets which are represented by the bar chart.

When it comes to presenting the national space budgets as a share of the total national expenditure, Russia comes first spending 0.72% of the national budget on space related initiatives. Second highest result is obtained by the US, which allocates 0.66% of the budget on space programmes. The third place is taken *ex aequo* by France and India, both allocating 0.28% of their budget for space endeavours. Among the nine analysed countries, Italy and the UK space budgets represent the lowest share in the national expenditures, 0,13% and 0.11% respectively.

If the national space budgets are compared with the total GDP, Russia comes first again. Russian space budget represents the 0.24% of the GDP. The US boasts a slightly lower ratio of 0.23%. The third place is taken by France, which space budget value is equal to 0.15% of the French GDP. All the other countries' space budgets represent somewhat between 0.08% of the total GDP (India) and 0.04% (the UK).

Interestingly, the US boasts the largest nominal space budget, but when it comes to the relative values, the US is second both in terms of the share of the space budget in the total budget and in the GDP. Conversely, Russia, which has the fourth largest nominal space budget, comes first in of those metrics. Although the relative measures for Russia are only slightly larger than the US ones, this difference gains much more significance when combined with the fact that the Russian nominal budget is over 13 times smaller than the American. The conclusion can be drawn that the space budget is equally important in both countries, however, the US economy is simply much stronger. Another interesting observation can be made about India. Indian space budget is the seventh largest in nominal values, however, the share of the space budget in the total national expenditure is the third largest in the world, *ex aequo* with France. A conclusion may be drawn that even though China, Japan and Germany boast larger space budgets in nominal values, the priority of space funding in India is higher, which is illustrated by a higher share of the space related spending in the total volume.

PPP-adjusted space budgets

Another perspective can be provided by adjusting the national space budgets for purchasing power parity. Purchasing power parity is an approach which allows to level the price differences between countries. For instance, the cost of labour in nominal prices varies substantially across different countries and purchasing power parity helps to remove this factor so that the adjusted values are easier to compare with each other. Purchasing power parity is often used to study GDPs. However, adjusting the space budgets for purchasing power parity may have stronger limitations than usually, since the prices on the space goods market are less elastic than on consumer goods market. Nevertheless, the purchasing power parity approach enriches the scope of the analysis and emphasises the fact that intermediate and labour costs are significantly lower in some World economies such as China, Russia and India.

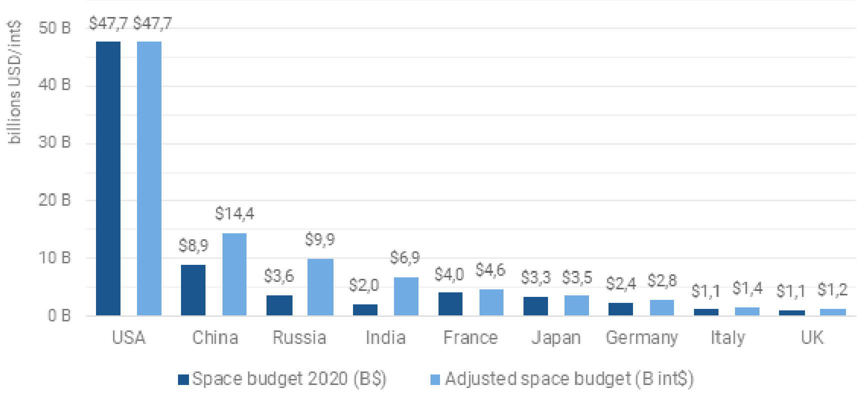


Figure 17: National budgets per capita adjusted for PPP (Source: Euroconsult, IMF, ESPI)

Purchasing power parity approach uses the US Dollars as a reference point; thus, the US budget remains unchanged after the adjustment. Adjusted Chinese budget is over 60% larger than the nominal one. The largest growth after adjustment was observed for Russia and India, which adjusted budgets tripled compared to the nominal ones. Overall, the developed countries adjusted space budgets have seen much less increase than those of the emerging economies. Consequently, the ranking of the largest space budgets is shuffled. Despite a significant raise China remained second, however, the other emerging economies advanced significantly. Russia moved from the 5th position to the 3rd and India from the 7th to the 4th overtaking France, Japan and Germany.

The US government spends $145 per capita which allows the US to come first in this metric. The second largest result of $60 per capita is obtained by France. The third place is taken by Germany which spends $29 per capita. Chinese and Indian budgets per capita are the lowest $6 and $1 respectively.

As far as the PPP adjusted space budgets per capita are concerned, the US results remain unchanged, since, as mentioned before, the US dollars are the reference point for the adjustments. Second come France and Russia *ex aequo* with PPP adjusted space budget per capita of $69. The fourth largest result is obtained by Germany ($34) followed by Japan ($28). China and India take again the last two positions with PPP adjusted space budgets per capita of $10 and $5 respectively.

The United States comes first in both metrics, the same as in the comparison of the total volumes. However, in the per capita approach the US domination is reduced. For instance, the US nominal budget is twelve times larger than the French one, but in per capita approach it is only two and half times larger. An even smaller difference is observed when it comes to PPP adjusted space budgets per capita, which not only reduces the proportion between the US and France to two, but also allows Russia to obtain a result equal with France. It means that Russian PPP adjusted space budget per capita nearly tripled in comparison to the nominal space budget per capita.

The most significant change occurs when it comes to the position taken by China. Although China has the second largest space national budget, per capita they come eighth, spending as much as $6 per capita in nominal values and $10 in the PPP adjusted. By the same token India comes 7th in terms of nominal budget and last in both nominal space budget per capita ($1) and PPP adjusted space budget per capita ($5). It should be underlined though that China and India are also the two largest countries worldwide, which together represent around 1/3 of the world population.

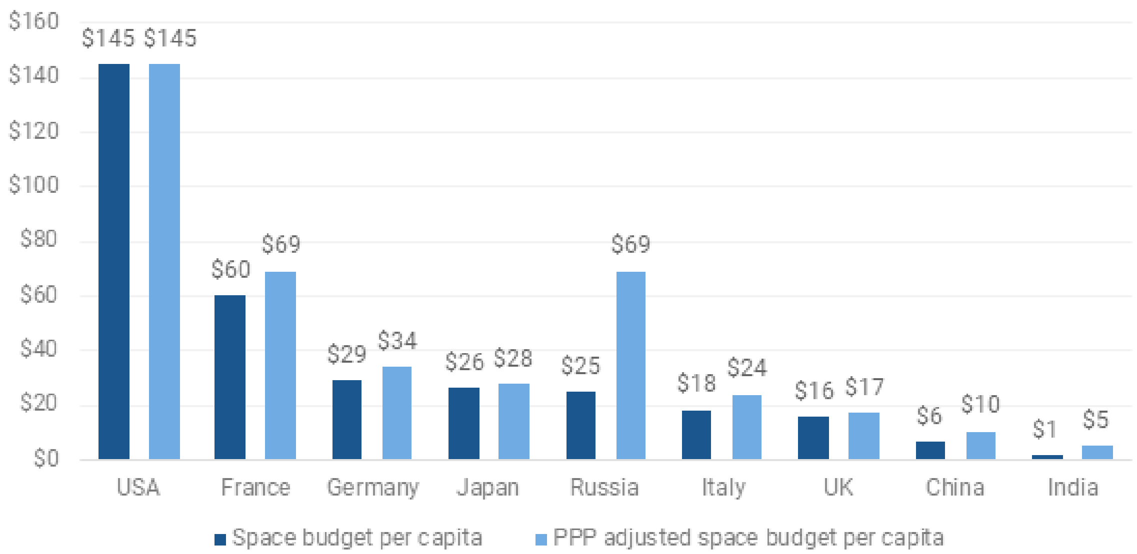


Figure 18: Space budget per capita in 2020 (Source: Euroconsult, World Bank, ESPI)

The differences between countries are not as clear as they might seem if only nominal budgets were taken into consideration. Although the US occur to obtain the highest or second to highest results in every analysed metric, an important conclusion can be drawn from the comparison of the national space budgets with the total national budgets and the GDP. The proportions turn out to be roughly the same for the US and Russia. This can be interpreted that the space budget is equally important for both countries, they just differ in terms of their economic potential. Another important aspect is brought to light when the national space budgets are adjusted for the purchasing power parity. This metric emphasises a perhaps undervalued potential of the emerging economies, which do not spend as much as developed countries in terms of nominal values but may catch up thanks to lower operational and labour costs.

3.3 European Space Budgets

3.3.1 Consolidated European space budget

Space budgets in Europe are intertwined with a variety of budget transfers (delegations, contributions) between different national, intergovernmental and supranational actors. Overall, and after consolidation, ESPI estimates the consolidated European space budget was around €11,648 million in 2020 (Figure 19).

This includes two main sources of public funding:

- National space budgets are the primary source of public funding in Europe. In 2020, the total space budget of European countries (ESA and EU member states) was around €9,518 million.
- This budget includes:
  - Contributions to ESA budget of €4,389 million
  - Contributions to EUMETSAT budget of €465 million
  - Budget remaining with national bodies for the management of national space programmes and other space projects outside ESA and EUMETSAT
- The European Union space budget is the second source of public funding in Europe. This budget is financed through Member States contributions to the budget of the Union but managed as a supranational budget complementing national budgets. In 2020, the EU space budget represented an additional public investment of €2,130 million.

In 2020, the budget of the European Space Agency was €6,676 million, including national contributions EUMETSAT (€134 million).

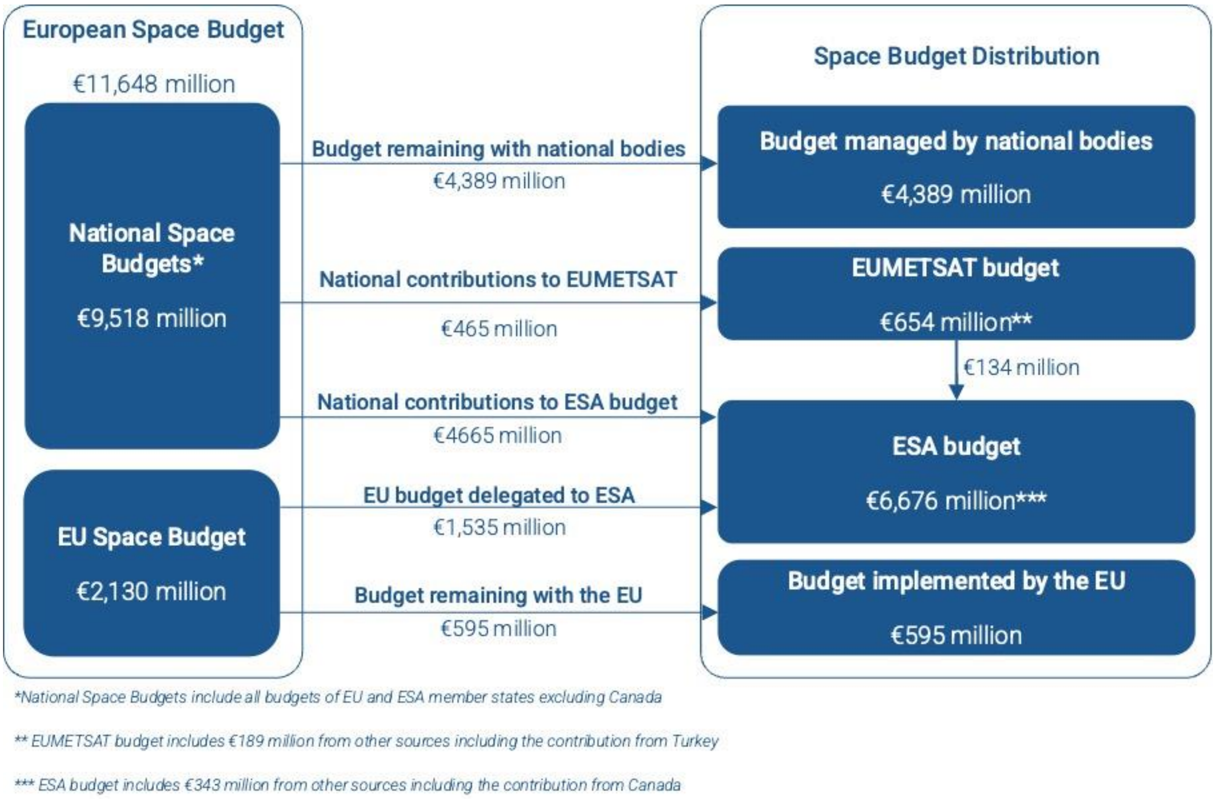


Figure 19. Consolidated European space budget 2020 (ESA, EUMETSAT, Euroconsult, ESPI)

3.3.2 National space budgets

European countries delegate approximately a half of their national space budget to ESA and EUMETSAT and therefore contribute primarily to European space programmes. Most of the countries implement more than half of their national space budget through ESA. The table below shows the estimated national space budget (civil and military) for ESA Member States in 2020.

European countries	National space budgets in 2020	ESA contribution	National activities
Austria	€ 73.9 M	€ 51.2 M	€ 22.7 M
Belgium	€ 256.1 M	€ 210.0 M	€ 46.1 M
Czech Republic	€ 67.1 M	€ 44.7 M	€ 22.4 M
Denmark	€ 49.4 M	€ 33.8 M	€ 15.6 M
Estonia	€ 6.5 M	€ 3.7 M	€ 2.8 M
Finland	€ 61.9 M	€ 27.4 M	€ 34.5 M
France	€ 3,543.1 M	€ 1,311.7 M	€ 2,231.4 M
Germany	€ 2,108.7 M	€ 981.7 M	€ 1,127.0 M
Greece	€ 30.7 M	€ 20.6 M	€ 10.1 M
Hungary	€ 15.7 M	€ 11.7 M	€ 4.0 M
Ireland	€ 33.3 M	€ 24.8 M	€ 8.5 M
Italy	€ 954.6 M	€ 665.8 M	€ 288.8 M
Luxembourg	€ 169.3 M	€ 29.9 M	€ 139.4 M
Netherlands	€ 145.6 M	€ 100.3 M	€ 45.3 M
Norway	€ 143.8 M	€ 86.3 M	€ 57.5 M
Poland	€ 79.7 M	€ 38.4 M	€ 41.3 M
Portugal	€ 39.2 M	€ 21.0 M	€ 18.2 M
Romania	€ 50.9 M	€ 34.3 M	€ 16.6 M
Slovenia	€ 13.8 M	€ 3.2 M	€ 10.6 M
Spain	€ 390.7 M	€ 249.5 M	€ 141.2 M
Sweden	€ 123.5 M	€ 83.2 M	€ 40.3 M
Switzerland	€ 213.9 M	€ 167.0 M	€ 46.9 M
United Kingdom	€ 930.4 M	€ 464.3 M	€ 466.1 M

Table 6: National space budgets of European countries in 2020 (Source: Euroconsult, ESA, ESPI)

3.3.3 European Space Agency

The ESA budget has continuously been growing until 2021 where it saw a slight year over year decrease. In 2021, ESA budget reached €6,489 million which is almost a 3% decrease compared to the 2020 budget of €6,676 million.

In terms of programmes, the Earth Observation budget remains the largest budget allocation at ESA accounting for €1.439 million which represents 22% of the total ESA budget but also shows a 7% decrease as compared to the EO budget in 2020. The second biggest programme in terms of budget allocation is Navigation which is one of the rare programmes at ESA that saw a budget increase in 2021. The Navigation programme saw a 11% increase year over year, going from €1.103 million in 2020 to €1.223 million in 2021. It now upholds 19% of the total ESA budget. Both EO and Nav represented together in 2021 41% of the total ESA budget.

The space transportation programme also saw a budget decrease, going from €1.536 million or 23% of the total budget in 2020 to €1.175 million in 2021 which represents an impressive decrease of 23%. 2021 also saw the share of space transportation decrease in the overall budget of ESA, going from 23% in 2020 to 18% in 2021.

Following Space transportation, the biggest programmes in terms of budget allocation are Human Spaceflight at 10%, Scientific Programmes at 8.6% and finally Telecommunications and Integrated Applications at 6.7%

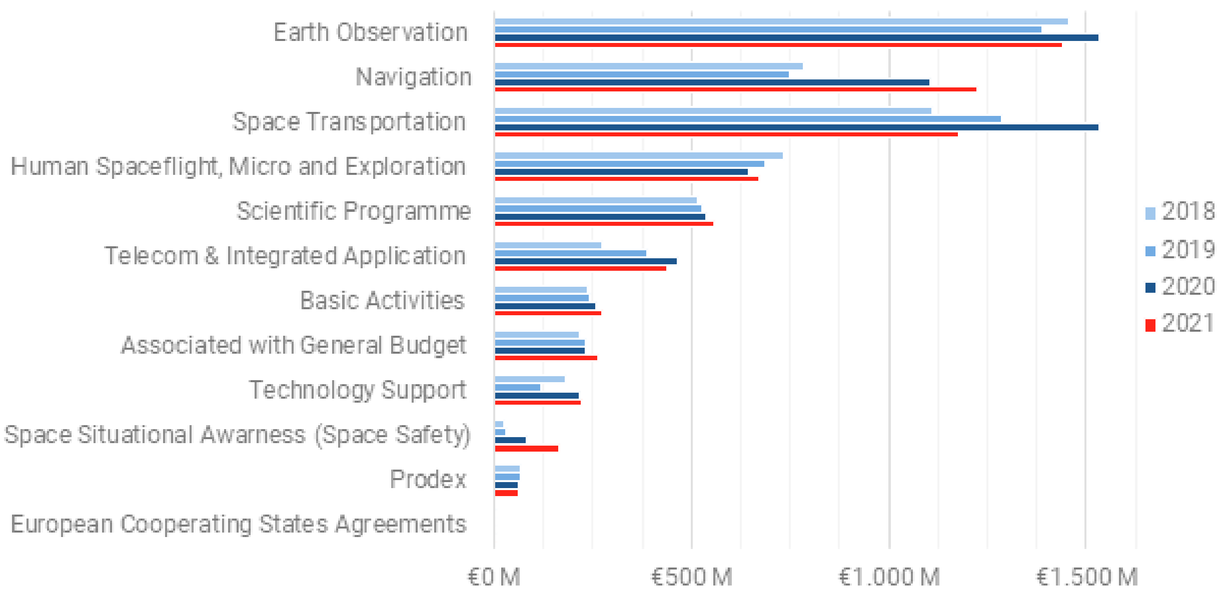


Figure 20: ESA programmatic budget allocations from 2018 to 2021 (Source: ESA)

The reduction of the total budget was a result of the decreased national contributions, which declined from €4692 billion in 2020 to €4348 million in 2021, a change of -7% compared with 2020. Only eight member countries increased their contributions to ESA, however, none of them is among the usual top four major funders. The total increase of these eight countries sums up to 93 million which can barely cover for half of the decrease observed at the largest contributor – France.

Despite the large decrease of nearly 20%, France continues to be the largest contributor to ESA, accounting for €1,066 million or over 23% of the total member states contribution. Also, German contribution decreased year over year, however, much less significantly than French. In 2021 Germany donated €969 million, only 1,3% less than in the previous year. German contribution represents approximately 21% of total member states contributions. The third largest contributor

Italy (€590 million) and the fourth United Kingdom (€419 million) followed the trend and reduced their contributions by 11.4% and 9.8% respectively. Conversely, Belgium (€256 million) substantially raised its share of funding by nearly 22% year over year, which allows it to take over Spain which used to take the fifth position for the last three years. The other countries which increased their donation are Hungary, Portugal, Poland, Switzerland, Austria and Romania. However, it should be underlined that the last two countries had reduced their funding in 2020 so much, that the 2021 raise was not enough to reach their level of funding from 2019.

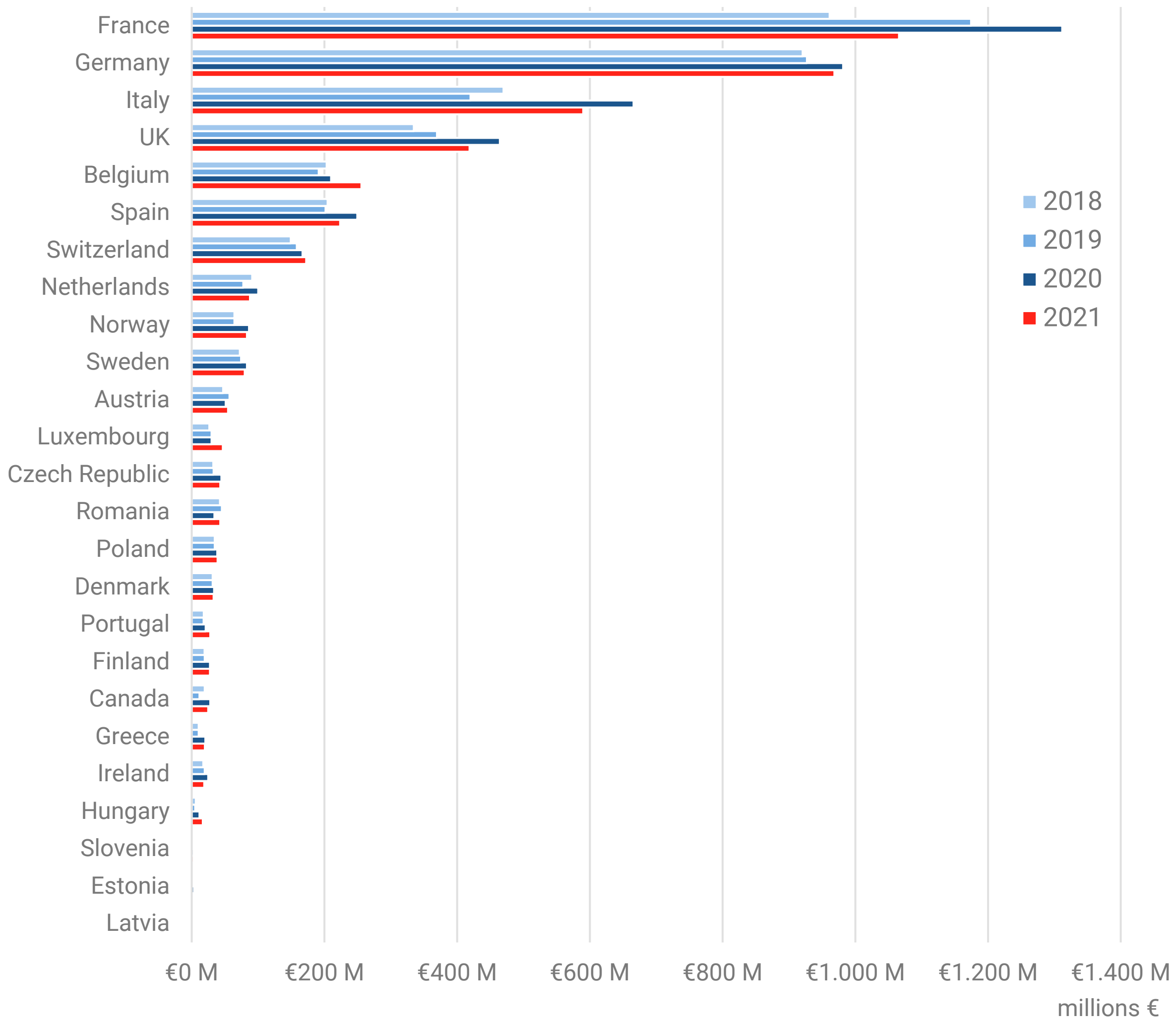


Figure 21: Member states contributions to ESA budget from 2018 to 2021 (Source: ESA)

The figure below illustrates the distribution between national budgets and the national contributions to the ESA budget. Only a few countries keep more than 50% of their national space budget under national management, however, interestingly, the two largest ESA contributors France and Germany are among those. Luxembourg keeps the largest share of their budget nationally (82.3%), whereas Belgium contributes the largest proportion of its space budget to ESA (82.0%).

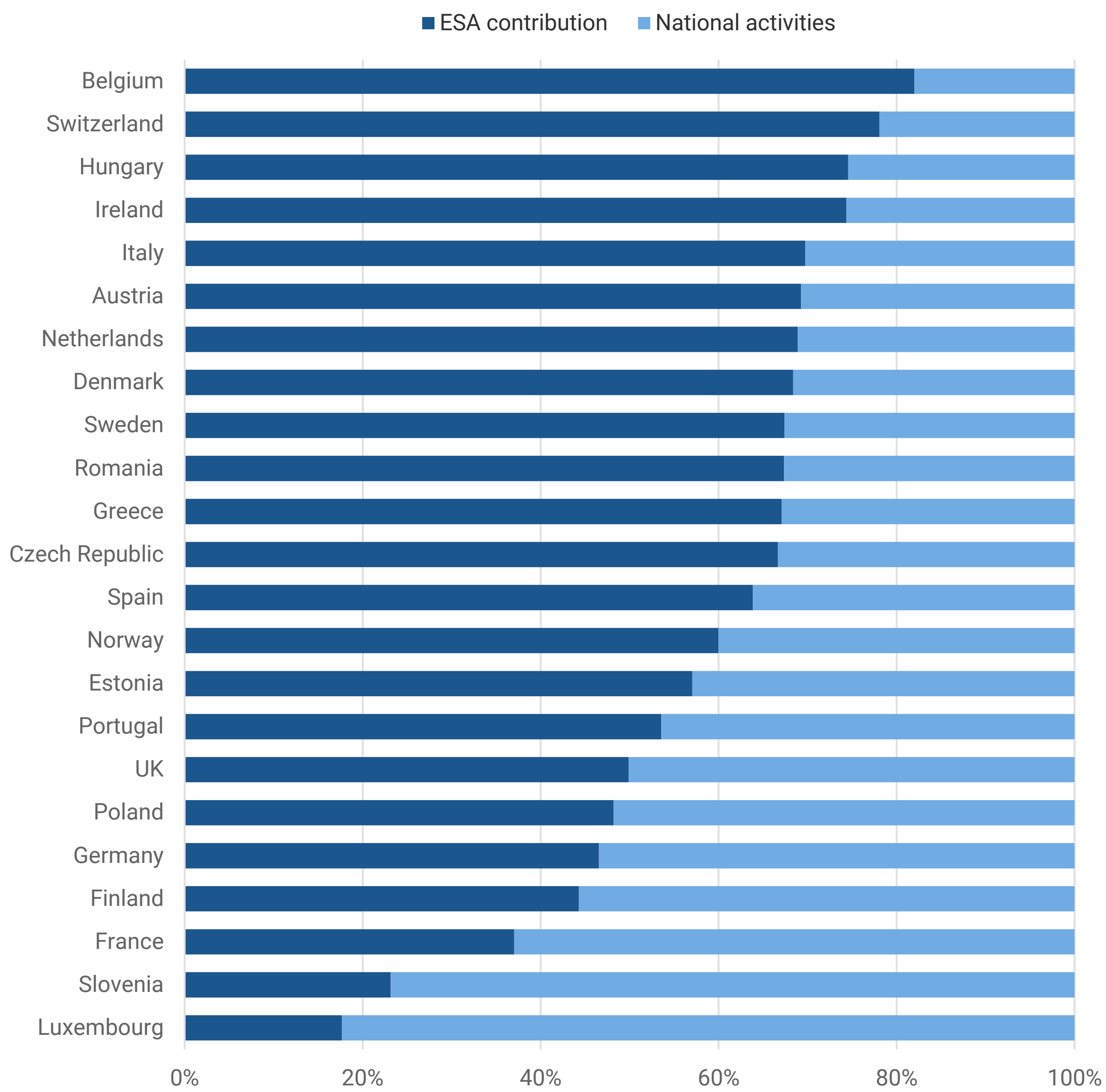


Figure 22: Member states budget allocation comparison in 2021 (Source: ESA, Euroconsult, ESPI)

3.3.4 European Union

The European Union conducts various space activities that are implemented and managed by different executive bodies and agencies including in particular the European Commission, the European Union Agency for the Space Programme (EUSPA) and the European Space Agency.

In 2021, the European Union space budget stood at €2034 million. €1997 million are dedicated to the European Space Programme, which covers several flagship programmes of the EU:

- **Galileo and EGNOS** are Europe's GNSS and SBAS programmes providing improved positioning and timing information.
- **Copernicus** is the European Union Earth Observation flagship programme.
- **GOVSATCOM and SSA**
- **Other space activities** implemented by the European Commission, the European External Action Service, the EU Satellite Centre, the EU Joint Research Centre and other European bodies.

Moreover, the EU also has other budget instruments with allocations for the space sector such as the **Horizon Europe**, **InvestEU**, **European Defence Fund**, and a proposal for the **Secure Connectivity System**.

Galileo and EGNOS

The European Commission Navigation and Positioning flagship programme entered its operational phase on the 15th of December 2016, following the European Commission's Declaration of Initial Service and is on track to enter its full operational capacity in the next few years. Its GNSS constellation Galileo currently has 28 satellites in orbit, with additional satellites presently being manufactured, albeit with delays due to COVID-19. EGNOS is used to improve the performance of GNSS, such as the U.S. GPS and relies on 3 payloads hosted on GEO satellites to provide Safety-of-Life (SoL) services to aviation, maritime and land-based users. In 2021, the European Commission committed about €1245 million to Galileo and EGNOS, a marginal increase of roughly 0,6% compared to the €1239 million committed in 2020.

On 14 April 2021, Galileo officially reached 2 billion smartphones[673], and is currently serving more than 2.5 billion devices and 15 million cars. In 2021, two additional satellites were launched, reaching a total of 28 of the 30 planned satellites for Full Operational Capability.[674] Moreover, in January 2021 the European Commission awarded €1.47 billion in contracts to Thales Alenia Space and Airbus Defence and Space to launch a total of 12 second generation Galileo Satellites.[675]

The EGNOS programme also made several major steps towards the completion of Version 3, awarding a major procurement deal in 2021 and signing a €100 million 15-year contract with Eutelsat Communications, for the development and operation of the next-generation EGNOS GEO-4 service.[676]

The 2021-2027 Multiannual Financial Framework defines the budget of the EU for the next 7 years, including for the EU space programme. In 2020 the European Union approved its space programme

[673] Smartphone users put their trust in Galileo with 2 billion Galileo-enabled devices sold, EUSPA, April 2021.
[674] EU Space Programme – Performance, European Commission. https://ec.europa.eu/info/strategy/eu-budget/performance-and-reporting/programme-performance-overview/eu-space-programme-performance_en
[675] Commission awards €1.47 bn in contracts to launch the 2nd Generation of Galileo Satellites, European Commission, January 2021.
[676] Eutelsat to host EGNOS GEO-4 payload, European GSA, February 2021.

for the MFF 2021-2027, which significantly increased its space budget and navigated more towards security-related activities.

The EU has committed €9.01 billion to Galileo and EGNOS as part of the new MFF, which represents a 31.8% increase compared to the budget committed to the two components in the previous period. With the new budget, the EU mainly projects to provide additional resources for continuity in operations and infrastructure for the components. It also expects to enhance the current capabilities as well as the development of the next generation of Galileo and EGNOS services, and drive for deeper integration of satellite navigation data in other policy areas and economic sectors.

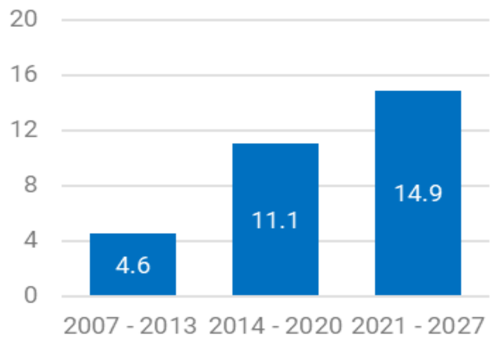


Figure 23: Evolution of Space budget in EU MFF (figures in € billion, current prices)

Copernicus

The Copernicus programme relies on a fleet of EO satellites named Sentinels complemented by third-party missions, which display a variety of capabilities and address various applications from land to sea level monitoring. The Copernicus programme develops a global, continuous and autonomous high accuracy observation of Earth systems offering European countries scientific precision and autonomy in questions related to the global environment. In 2021, the European Union dedicated about €707.3 million to Copernicus, which represents an increase of approx. 10% compared to the €643.9 million committed in 2020.

As part of the MFF 2021-2027, the EU has committed approx. €5.4 billion to the Copernicus Earth Observation programme, an increase of roughly 26% compared to the €4.3 billion commitment under the previous MFF. The increased budget attributed to Copernicus in the new MFF will provide resources for the continuity of operations as well as for the enhancement of capabilities for the programme.

GOVSATCOM / SSA

The EU has also provided for an increase in budget for the development of its Space Situational Awareness and GOVSATCOM initiative as part of the EU Space Programme. As part of the new MFF, the EU has committed €442 million to SSA and GOVSATCOM.

The committed appropriation for the GOVSATCOM and SSA was €37.1 million in 2021. Up until 2021, these programmes were under a preparatory action with a budget of €10 million for the period of 2019-2020.

Although the two components have a relatively smaller budget compared to both Galileo/EGNOS and Copernicus, the increased budget as well as their inclusion in the new MFF underlines the growing importance of the security and defence dimension of EU engagement in space.

The SSA component will build upon the work by several member states in the 2015-established EU Space Surveillance and Tracking (EUSST) Support Framework with the objective of monitoring and preventing space hazards and will also include an early-stage EU engagement in space weather and near-Earth objects. The GOVSATCOM initiative, on the other hand, is addressing the need for a secure, guaranteed and autonomous governmental satellite communications capability for the EU and its Member States. It will primarily rely on existing capacity until 2025, with some of the early programme developments having included major involvement of the European Defence Agency.

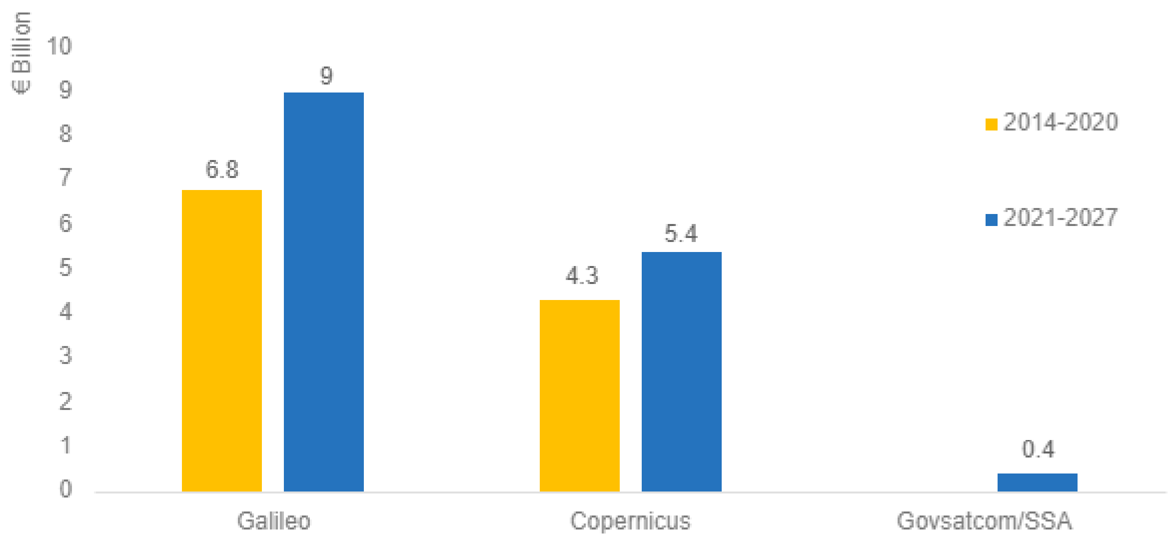


Figure 24: Evolution of budgets Galileo, Copernicus and Govsatcom/SSA between MFF 2014-2020 and MFF 2021-2027

Horizon Europe

The Horizon Europe research and innovation funding programme was established in April 2021, with a budget of €95.5 billion for the period of 2021-2027 (including €5.5 billion from NextGenerationEU). Its support for space technologies and applications will be under Cluster 4 named "Digital, Industry and Space", with a total budget of €13.5 billion for the duration of the Horizon Europe, plus an additional €1.35 billion from NextGenerationEU.

The support provided through Horizon Europe is thematically linked with the development of Copernicus and Galileo services, SSA and GOVSATCOM-related activities, as well as other strategic innovation areas such as reusable launchers, European technology non-dependence and space science. It will thus be used in support of the overlining objectives set by the EU Space Programme.

In addition, the **European Innovation Council** has been established under Horizon Europe with a total budget of €10 billion for the current MFF period. In order to enable the support of selected start-ups and SMEs, the European Commission and the EIB Group have established that approx. €3 billion will be attributed to the **European Innovation Council Equity Fund**. The EIC Fund is an innovative instrument through which the European Commission can make direct and quasi-direct equity investments in funded companies. The EIC will support research and innovation on the continent through three main instruments, which include:

- The **EIC Accelerator**, with a budget of €495.1 million in 2021, to support European companies to scale up and develop their disruptive, high risk and high impact technologies. The Dutch start-up Hiber is the first space company to have benefited from this mechanism since the establishment of the EIC as it closed a €26 million round in 2021.[677]
- The **EIC Pathfinder**, with a budget of €132 million in 2021, to support research in breakthrough and highly disruptive technologies.
- The **EIC Transition**, with a budget of €40.5 million in 2021, to support the transition between research and real innovation opportunities.

[677] European Innovation Council Fund: first equity investments of €178 million in breakthrough innovations, European Commission, January 2021.

InvestEU Programme

The **InvestEU programme** and the **InvestEU Fund** are projected to have a key role in this regard. Within the new MFF, the EU provided the programme with a total EU budget guarantee of €26.2 billion to attract over €372 billion in additional investment over 2021-2027 that will provide support to European start-ups and SMEs including in the space sector with the objective of "underpinning space entrepreneurship".

Accordingly, as a successor to the InnovFin Space Equity Pilot, the **CASSINI** was established in January 2022 and is managed by the Directorate-General for Defence Industry and Space. The space entrepreneurship initiative will run until 2027 and has three main vectors:

- Access to Finance, has approx. €1 billion budget to provide capital to Venture Capital Funds to be invested in European space companies.
- Prizes and Competitions, contains various initiatives to stimulate the development of innovative commercial solutions, get market validation and ideas based on European space data.
- Business Development and Networks, aiming to organise networking events and training for companies.

European Defence Fund

The European Defence Fund, which has been established with a budget of approx. €8 billion for the period 2021-2027, is a grant programme from the European Commission to strengthen defence research and development and promote an innovative and competitive industrial base. The EDF 2021 Work Programme sets a budget of €1.2 billion for the funding of projects undertaken in the scope of its annual call for proposals.

The calls for proposals are distributed among 15 thematic categories, and space is one of these categories, under which a call for projects was placed by the EDF in 2021 with a budget of €50 million to improve "space-based PNT resilience in contested environments through the mapping and analysis of threats". Additionally, the EDF has two non-thematic categories of actions: "Disruptive technologies", with a budget of €60 million and a call in 2021 and "Open calls for innovative and future-oriented defence solutions", with a budget of €63.5 million, to which the space industry was also eligible.

EU Space-based Secure Connectivity System

In February 2022 the European Commission proposed the secure connectivity initiative to establish a secure satellite communication system for the Union and its Member States' governmental entities through a public-private partnership. The proposal will be funded through the existing 2021-2027 MFF, allocating a budget of €1600 million from 2023 to 2027. Considering that the MFF did not foresee this new programme, its budget will be sourced from reductions in other programmes, including €400 million from the EDF and €260 million from the Union Space Programme.

An additional envelope of €800 million will serve as a contribution to the Secure Connectivity System, to be implemented under the Horizon Europe (€430 million), the Union Space Programme (€220 million) and the Neighbourhood, Development, and International Cooperation Instrument (€150 million). This brings the total contribution of the Union to the Secure Connectivity System up to €2400 million until 2027.

3.3.5 EUMETSAT

EUMETSAT is an intergovernmental organisation supplying climate and weather satellite data to European Member States national meteorological services since 1986.

EUMETSAT activities are primarily funded through Member States contributions, which represented 75% of its total revenues in 2020, down from 84% in 2019, 85% in 2018 and 83% in 2017. More specifically, Member States contributions in 2020 were reduced by 12% compared to 2019. They went from €559.5 million in 2019 to €490 million in 2020.[678]

Member States contributions are calculated on the basis of their Gross National Income (GNI).

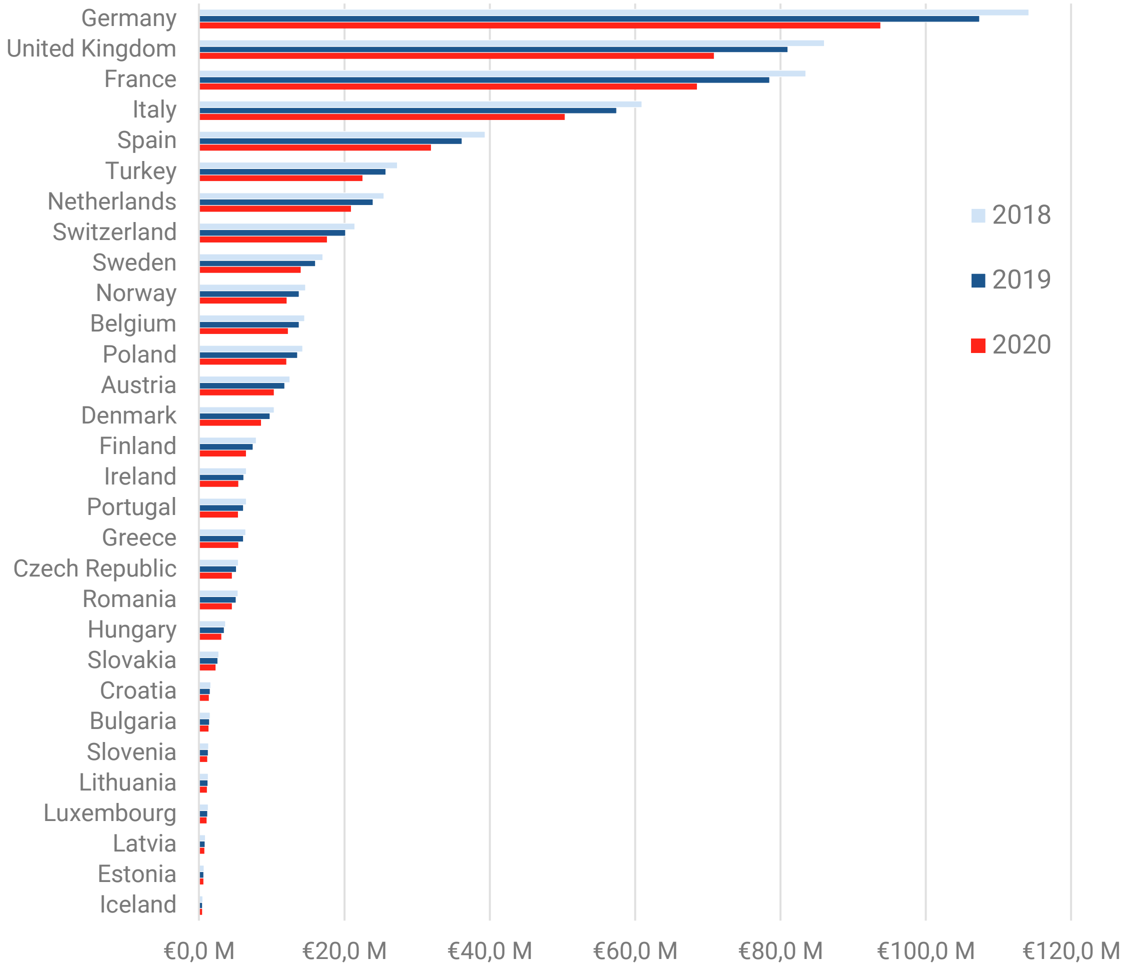


Figure 25: Member states contributions comparison for 2018/2019/2020 (Source: EUMETSAT, ESPI)

Germany remained the largest contributor to the EUMETSAT budget with €93.8 million, which is however a 13% decrease from the €107.7 million it funded in 2019. The United Kingdom remained the second biggest contributor in 2019 after surpassing France in 2018 following a 22.1% increase in its contribution. The UK's total contribution in 2020 amounts to €71 million, a 12% decrease compared to is 2019 contribution. The third and fourth contributors to the EUMETSAT budget are Frances and Italy with an endowment of €68 million and €50 million respectively.

Beyond Member States contributions, other sources of revenues for EUMETSAT originated from products sales and other contributions totalling €67 million of its income or 10% of its total revenue.

[678] Annual Report 2019 & 2020, EUMETSAT, 2021.

Following the contraction in Member States contributions in 2020 compared to 2019, EUMETSAT's overall revenue decreased by 2% going from €664.8 million to 654.2 million.

3.4 European Space Economy Statistics

3.4.1 European space manufacturing industry

Main indicators

ASD-Eurospace, the trade association of the European space industry, provides robust and detailed insights on the state of the industry in its authoritative *Facts & Figures* annual report.[679] This edition highlights the consequences of the pandemic in the European space industry, which overall had negative effects across all costumer and product segments alike.

Accordingly, despite a slight upturn in industry activity of 2.8% in 2019, particularly in satellite applications systems sales, the Covid-19 pandemic reversed this trend in 2020. The final sales of the European space manufacturing industry decreased by 12.3% to around €7,707 million, representing approx. less €1 billion in sales in comparison to 2019. ASD-Eurospace underlined that such a downturn was unprecedented since the first edition of the report in 1991.

Space industry employment, on the other hand, grew to reach 50121 permanent staff (in Full-Time Equivalent - FTE), an increase of 2.8%. When including other personnel, not directly employed by space industry companies, the number of total staff increases by over 2000 to 52523.

Key figures employment (FTE) and sales (M€)	2018	2019	2020	Variation
Direct industry employment (FTE)	45772	48766	50121	+2.8%
Other personnel working on site (FTE)	2940	2356	2402	+2.0%
Total space industry employment (FTE)	48712	51122	52523	+2.7%
Final sales (M€ current e.c.)	8552	8788	7707	-12.3%

Table 7: Main industry facts

Industry sales by customer segments

The distribution of industry sales by customer segment shows that the European space industry addresses primarily domestic markets: in 2020, public and private European customers accounted for 82% of industry sales, decreasing 1% in relation to the previous year. The European public sector (ESA, EUMETSAT, European Commission, national space agencies and other civil and military institutions) remains the principal source of revenues for the European space manufacturing industry, corresponding to 64% of final sales in 2020.

European public programmes have become increasingly important over the past decade in terms of share of industry revenues, with sales to European public entities growing from approx. $3 billion in 2010 to roughly €5 billion in 2020. Still, the pandemic particularly affected sales in this customer segment, representing less 11.8% in comparison to 2019.

Specifically, ESA's programmes had loss above €500 million, representing less 14% sales to the Agency. Nevertheless, the report notes a caveat in the data, stating that the ESA's cash continuity measures to keep inflow of capital to the companies are not represented, as they are not sales and thus are not counted as revenues.

[679] Facts & figures – The European space industry in 2020, ASD-Eurospace, July 2021.

Following a 4.8% growth in sales to commercial and export markets in 2019, 2020 saw a contraction in this figure, placing it at a similar level as in 2009 (approx. €2.7 billion). Nevertheless, in 2020, even though sales to European commercial entities decreased by 19.9% to €1.3 billion, commercial exports to the rest of the world increased by 22.8%, to €933 million.

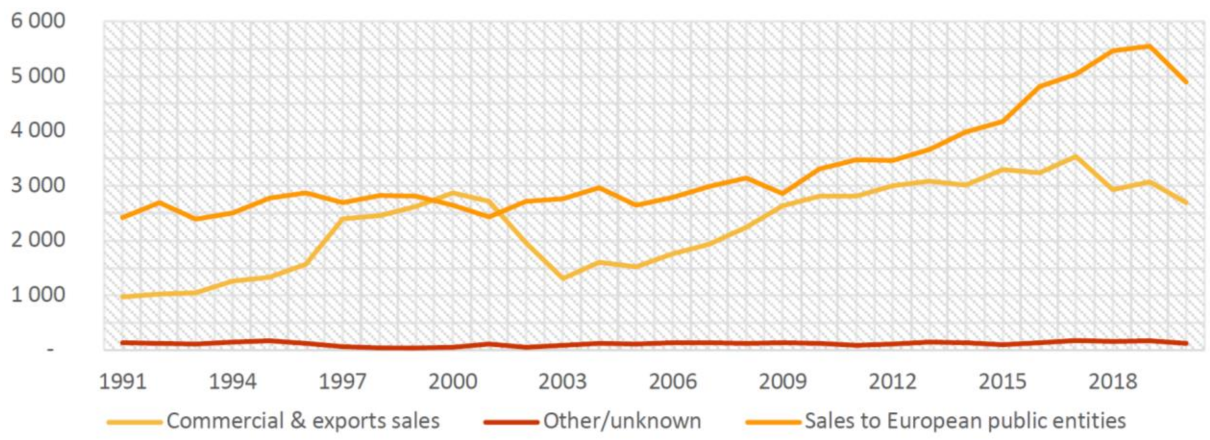


Figure 26: Sales by main market segment - type of system (M€)

Final sales by main customer segment (M€)	2018	2019	2020	Variation
European public customers	5465	5549	4896	-11.8%
European private customers	1524	1618	1296	-19.9%
Other European customers	105	115	99	-13.9%
Public customers RoW	593	696	457	-34.3%
Private customers RoW	808	760	933	+22.8%
Other customers RoW	57	50	25	-49.4%

Table 8: Final sales by main customer segment (M€)

Industry sales by product segments

The distribution of industry sales by product segment shows that satellite application systems, including the development and production of telecommunication, Earth observation and navigation systems, is the main market of the European space industry, representing 46% of sales. This segment grew steadily peaking in 2017 at €4.3 billion, then it fluctuated until 2019, almost equalizing the previous peak. In 2020, the pandemic led to a significant fall of 16.7% to €3.5 billion, contracting to numbers similar to those of 2015.

Ground systems and services, including electric and mechanical ground segment equipment (EGSE & MGSE) as well as engineering and other specialized services is the second source of revenue, representing 20.3% of the total sales by macro segment.

Traditionally the second product segment with most sales, launcher systems was downgraded to third in 2020. The COVID pandemic caused the segment to contract by 23.2%, now representing 17%

of the sales. Eurospace also reports that a small share of revenues is associated to the export of launcher sub-systems and equipment for foreign launchers, representing 7% of the total.

Lastly, scientific systems, including human spaceflight, exploration, Earth and space science programmes is the fourth industry market, account for 14.7% of the total sales.

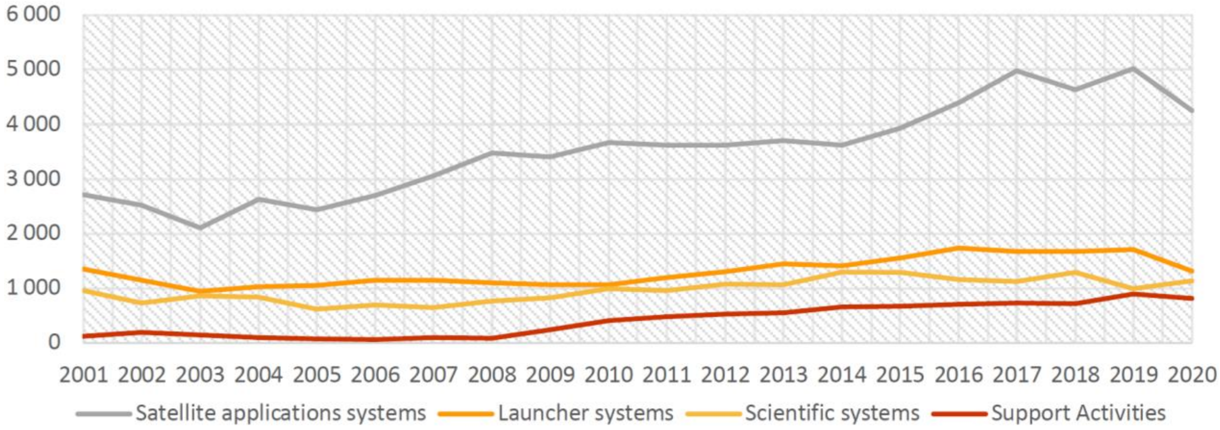


Figure 27: Sales by main market segment - type of system (M€)

Final sales by main product segment (M€)	2018	2019	2020	Variation
Launcher systems	1679	1714	1316	-23.2%
Satellite applications systems	3841	4213	3511	-16.7%
Scientific systems	1297	996	1132	13.7%
Ground systems and services	1521	1705	1566	-8.1%
Other & Unknown	215	161	183	14.0%

Table 9: Final sales by main product segment (M€)

Industry employment

Employment in the European space industry has been steadily growing since 2005. A total of 1401 jobs (FTE) were created in 2020 (+2.7%). The sector now employs a total of 52,523 workers (FTE). The space sector is a male-dominated industry where women count for only 22% of employment, a proportion that has not changed since 2019. The mean average age is 44 with a most common age (mode average) of 37. The industrial space workforce is also highly qualified with 73% of employees having attained a tertiary (university) level of education.

The geographic distribution of industry employment within the European space sector is highly concentrated and generally proportional to national space budgets, with some exceptions in countries with smaller budgets and workforce. Comparably to public budgets, 90% of the direct space industry employment is located in 6 countries: France, Germany, Italy, the United Kingdom, Spain and Belgium.

Industry employment (FTE)	2018	2019	2020	Confidence level
Austria	445	416	456	71%
Belgium	1584	1576	1549	54%
Bulgaria	na	76	102	0%
Cyprus	na	25	25	0%
Czech Republic	187	292	324	11%
Denmark	257	257	285	52%
Estonia	39	39	51	24%
Finland	168	227	280	35%
France	16830	17848	17644	74%
Germany	8929	9634	10293	81%
Hungary	97	130	130	0%
Ireland	82	64	66	30%
Italy	5120	5334	5509	75%
Latvia	na	41	41	0%
Lithuania	na	99	99	0%

	Luxembourg	36	36	41	32%
	Netherlands	1166	1240	1272	33%
	Norway	499	555	592	89%
	Poland	266	290	374	51%
	Portugal	165	239	254	49%
	Romania	na	41	83	70%
	Slovakia	na	31	31	0%
	Spain	3930	3815	4293	79%
	Sweden	1057	996	985	37%
	Switzerland	881	917	911	73%
	United Kingdom	4033	4483	4425	53%

Table 10: European space industry employment by country,

(Copyright by Eurospace - all rights reserved, used with permission, reproduction forbidden)

3.4.2 European remote sensing industry insights

Every two years, the European Association of Remote Sensing Companies (EARSC) surveys the remote sensing industry to gain insights into the state of the industry. In 2020, EARSC began conducting the survey annually. The 6th survey occurred in 2021, with data from 2020.[680]

713 companies participated in the 2021 survey, from 32 countries. 65% had 10 or fewer employees, and 92% had 50 or fewer. The number of companies founded each year has grown between 2009 (8 new companies) and 2016 (above 60). However, since then, there was a downward trend with an abrupt decline from 2018 onwards, reaching the lowest value since 2012 of approx. 22 companies.

[680] EARSC Survey 2021, EARSC Secretariat, 2021. https://earsc.org/wp-content/uploads/2021/10/EARSC-Industry-survey-2021.pdf

The UK has the most remote sensing companies, at over 100, followed by Germany and France. Despite having the most companies, the UK does not employ the most people in the remote sensing sector. France holds this title, at 1794 employees, followed by Germany (1434) and the UK (1049). This is partially explained by Airbus, which has many employees in France and Germany.

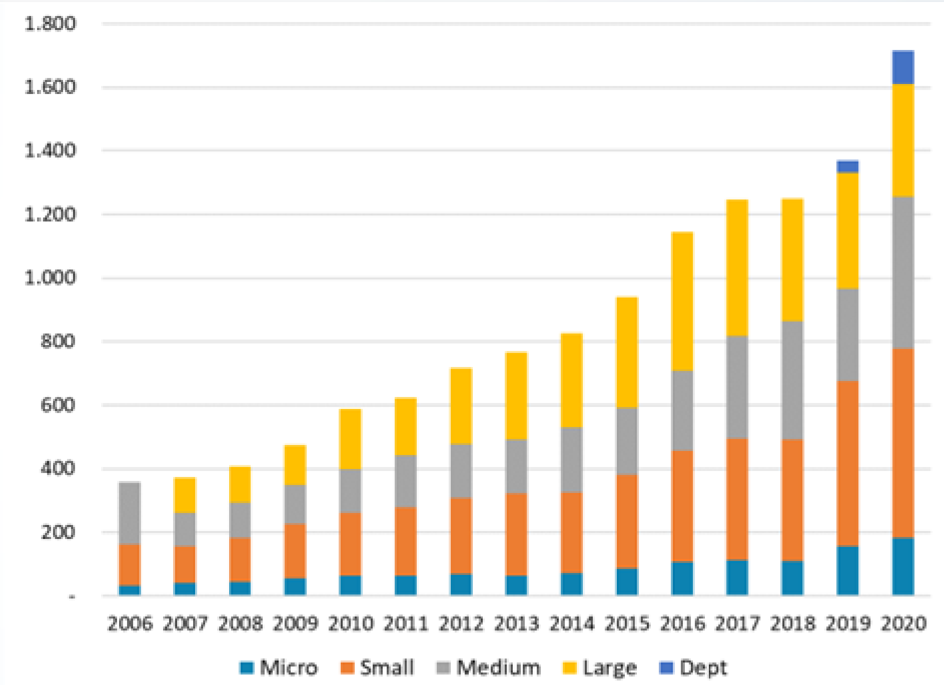


Figure 28: EARSC Survey 2020 evolution of revenues per company's class (Source: EARSC)

In total in 2020, 11.597 people were employed in the remote sensing industry in Europe. This is a large increase of over 17% since 2019. The employment figures have increased with a 5-year CAGR of 10%. 61% of job creation in the sector comes from companies formed 4 and 5 years ago, meaning they have secured revenue and investment and can expand. However, 75% of companies reported that it was not easy to fill open positions.

Total sector revenues in 2020 were €1.71 billion, growing by 25% since 2019. As the revenue growth rate between years is affected by single large contracts, CAGR is a more helpful measure. For the 5 years leading up to 2020, the CAGR was between 10% and 12%.

About the effects of COVID-19, roughly half of the surveyed businesses reported a decrease in their revenues in 2020, 37% stated no changes and only 14% had increased profits. Still, the effects of the pandemic may be lagging, as some contracts deadlines are scheduled later than the EARSC report. Therefore, the next report will provide more consolidated data regarding this issue. Some of the other prevalent impacts of Covid-19 were the necessity to adapt their products or services (24%), the reduction of contractors and subcontractors (20%) and the loss of investment (15%).

3.4.3 European GNSS and EO sector

The European Union Agency for the Space Programme (EUSPA) released the first issue of the EO & GNSS Market Report in January 2021 (previously called GNSS Market report and published by the GSA). The report emphasizes the growth of the EO and GNSS markets and how these industries contribute to innovations.

Earth Observation (EO)

According to the report, the EO global market turnover will grow from €2.8 billion in 2021 to €5.5 billion in 2031. The sales of this market mainly come from EO value-added services, amounting to €2.2 billion in 2021 and €4.7 billion in 2031.

Currently, 55% of the global revenues come from five market segments: Urban development (€339 million), Agriculture (€337 million), Climate Services (€318 million), Energy and Raw Materials (€313 million), and Infrastructure (€209 million). Nevertheless, Insurance and Finance, which in comparison only amounts to €145 million in 2021, will grow substantially to achieve the largest revenue in the market at €994 million, representing 18.2% of the global revenues in 2031.

Distributing the revenues of the EO market according to the companies' headquarters, in 2019 most of it was concentrated in the U.S. and European industries, which hold over 83% of the global market, with 42% and 41%, respectively. On the other hand, China had 6%, Canada 4%, and Japan 3%.

Among the categories comprising the industry's value chain, Europe is particularly prevalent in the global Analysis, Insights, and Decision market, with 50% of the global market share. Moreover, Europe's leadership in the Analysis market translates into its segments: the market share of the European industry is above 80% in Maritime and Inland Waterways, Fisheries and Aquaculture, and Aviation and Drones.

	2021		2031	
	EU27	Share of World	EU27	Share of World
Data revenues (€)	82 million	15.4%	117 million	14.6%
Value-added service revenues (€)	342 million	15.3%	664 million	14.2%

Table 11: EU27 EO market demand in 2021 and forecast in 2031 (Source: EUSPA)

Global Navigation Satellite Systems (GNSS)

According to the report, the global GNSS market was worth €199 billion in 2021, with an installed base of GNSS devices of 6.5 billion units worldwide. It is projected that this value will more than double over the next decade with annual revenues reaching €492 billion by 2031 for an installed base of 10.6 billion units.

The growing installed base is driven mainly by the Consumer Solutions, Tourism and Health segments, as between 2021 and 2031 approx. 92% of the GNSS receivers will be bought as smartphones and other devices.

In terms of revenues, the majority of the GNSS downstream market proceeds stem from services, which are comprised of added-value services and augmentation services. Accordingly, in 2021, its revenues reached €150.5 billion, representing 76% of the market, and are projected to increase to €405,2 billion in 2031, representing more than 82% of the market.

Particularly regarding added-value services, it constitutes the largest portion of the revenues. Accordingly, this industry is the main driver of the growth of the global GNSS market revenues. In 2021, these services accounted for €126 billion in revenues (63% of the global market sales) and are projected to reach just over €354 billion in 2031 (72% of the global sales).

From a geographical standpoint, the global market is concentrated mainly in companies with headquarters in the U.S. and Europe. In 2019, they represented 29% and 25% of the revenues, respectively. Still, the share of the European industry in the global market shrunk by 2%, from 27% in 2017 to 25% in 2019. On the other hand, the U.S. continues to lead the global GNSS market, having increased its share of the revenues from 28% in 2017 to 29% in 2019.

This reverses a trend highlighted in the previous 2019 GNSS market report, which stated that the European industry was “closing the gap” with its American counterpart. Moreover, Japanese, Chinese and South Korean companies accounted for 36% of the global market in 2019.

Regarding market segments, the ones where the European industry holds a larger share are Space (65%), Road and Automotive (53%) and Maritime (47%). In contrast, the European industry had a smaller market share in Rail (14%), Drones (10%) and Consumer Solutions (7%).

	2021		2031	
	EU27	Share of World	EU27	Share of World
Devices revenues (€)	12.1 billion	25.0%	21.6 billion	24.8%
Services Revenues (€)	27.4 billion	18.2%	53.7 billion	13.3%

Table 12: EU27 GNSS market demand in 2021 and forecast in 2031 (Source: EUSPA)

Many other key statistics are publicly available in the EO & GNSS Market Report.

3.5 Global Private Space Investment

3.5.1 European private space investment

Over the period 2014-2021, 370 private investment deals involving European space start-ups were recorded, amounting to a total of €1.901 million. In 2021, private investments in European space start-ups reached a new high of **€611.5 million spread over a record 86 deals.**

The figure represents a conservative estimate of the total volume of investments as the value of 15 recorded transactions were not disclosed this year. In line with ESPI's definition of what constitutes a start-up the estimate also does not include investments in space ventures after they have successfully reached maturity. In line this definition, OneWeb is not included within the perimeter of companies considered to fall under what is defined as a start-up, in particular as it is a company having more than 250 employees (400 in 2021).

Following a plateauing of investments at around €200 million per year in 2017-2019, 2021 confirms the new upside trend that started in 2020 with a new record high and a 14% year-on-year increase in investment volume. In addition, the sheer number of deals recorded in 2021 breaks away from the flat number of deals that had characterised the European space investment landscape since 2017, which oscillated between 50 and 60 deals per year.

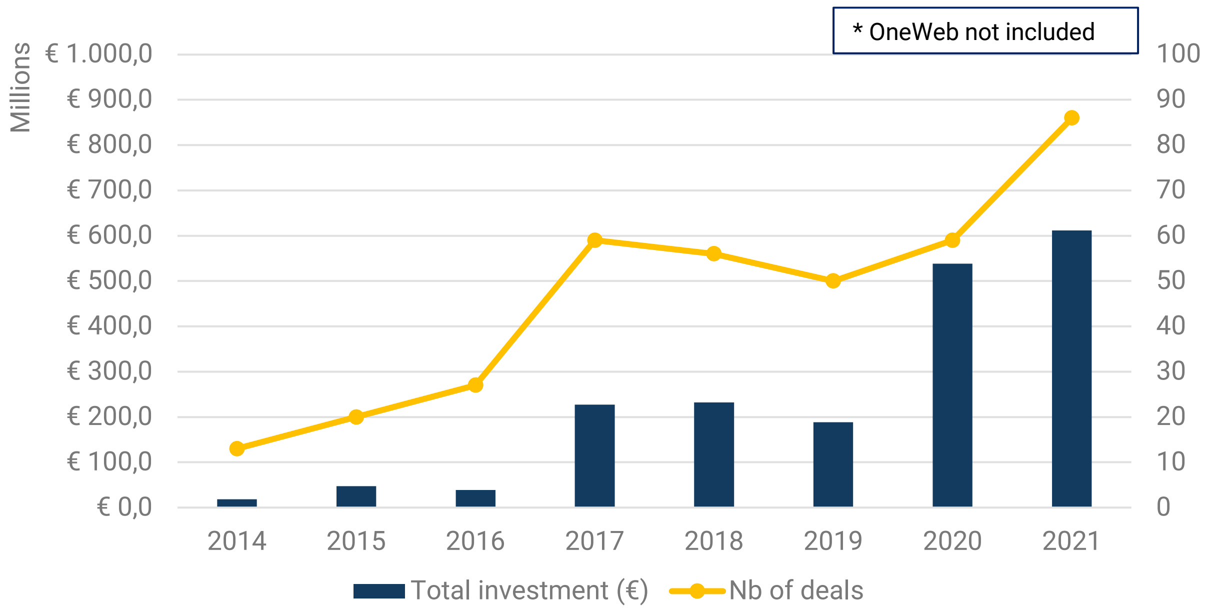


Figure 29: Investment value and number of deals per year 2014-2021

In 2021, the top five deals constituted 44% of the total volume invested. Consequently, the remaining 81 deals accounted for approximately 56% of the total volume. These figures are in contrast with observations made in 2017, 2018 and 2020, where the value of the top five deals made up 65%, 60%, and 65% of the total respectively.

As such, the figures indicate a significantly higher degree of distribution across companies with regards to the value of the deals in 2021, relative to previous years. Notably, it also shows that the record volume invested in 2021 is mostly a result of the comparatively higher number of deals recorded, as opposed to previous years which were dominated by a few stand-out deals.

Venture Capital has accounted for a vast majority of the investments in European space start-ups in the 2014-2021 timeframe, constituting 63% of the total invested. In 2021 again, Venture Capital deals again made up a majority of the transactions in number (67) and accounted for 78% of the total volume invested.

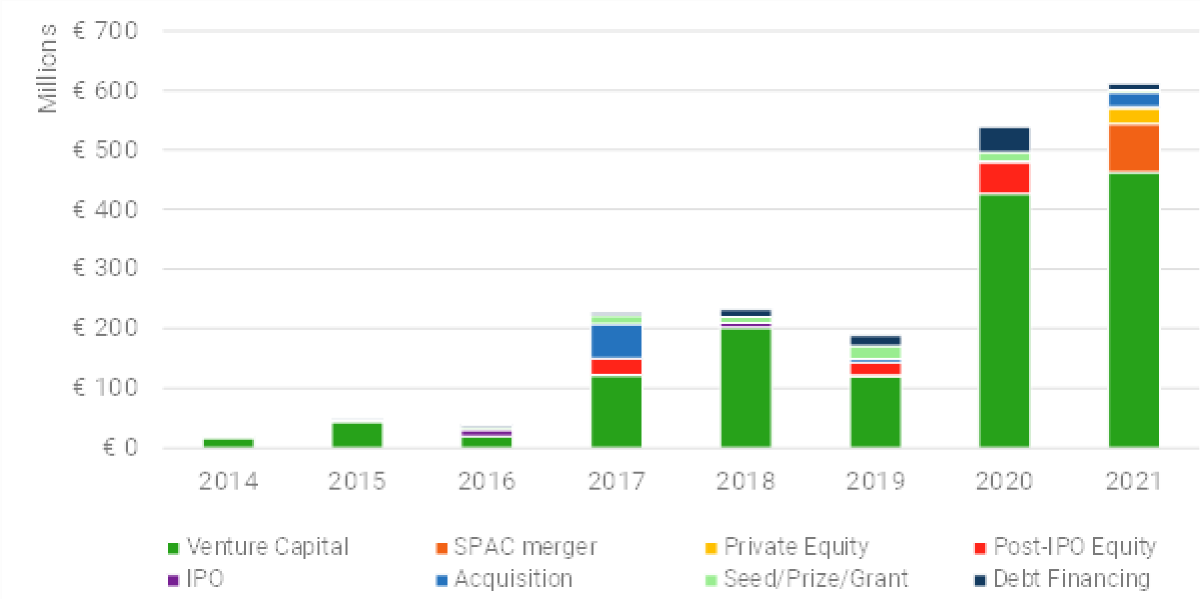


Figure 30: Investment type 2014-2021

Whereas the actual value of Venture Capital investments remained constant from 2020 to 2021 (around €420 million), the number of VC deals more than doubled year-over-year. This figure indicates a continued increase in the use of this type of funding to finance space start-ups in Europe. In terms of investor type, while around 26% of these deals included some form of participation from public funds, the vast majority of Venture Capital investments in 2021 came from private investment companies.

Following Venture Capital, the deal category constituting the largest type of investments in terms of volume are SPAC mergers. Although the category only includes one deal, Arqit's successful SPAC merger in September was valued at €80.6 million when considering net proceeds. Net proceeds account for what the company effectively receives from the transaction when summing trust proceeds from the merger with the SPAC (following the redemption of original investors) and the associated PIPE proceeds, net of eventual transaction fees and other expenses. Arqit's exit represents the first time a European space company goes public through a SPAC merger.

3.5.2 European investment in a global context

This year, the ESPI Investment Database was expanded to cover global investment in space start-ups since 2019. Comparably to European deals, information on foreign deals is sourced from a combination of online public resources, financial databases such as Crunchbase and Pitchbook and private information sources. All deals are reported in euros using World Bank exchange rates averaged on monthly basis.

Just like the European segment of this report, a space company is defined as a company providing analytics originating primarily from space-based systems, manufacturing ground and or upstream equipment and provides services that rely on such systems.

To provide comparable metrics with already established sources such as BryceTech and Seraphim capital, ESPI uses a broader "New Space" perimeter in this chapter that features a less stringent definition of "start-ups" and includes companies such as SpaceX or OneWeb.

Global investment into space ventures has been continuously growing from €5.2 billion in 2019 to €12.2 in 2021. Number of deals have seen similar growth going from 166 deals in 2019 to 268 deals in 2021.

An interesting index to look at is the percentage of the total global volume of investment that is taken by the top 5 deals. In 2019, the top 5 deals accounted for €1.1 billion or 21% of the total in 2019, in 2020 the top 5 deals accounted for a total of €2.2 billion or 33% of the total finally, in 2021, the top 5 deals accounted for a total of €3.8 billion or 31% of the total investment in 2021.

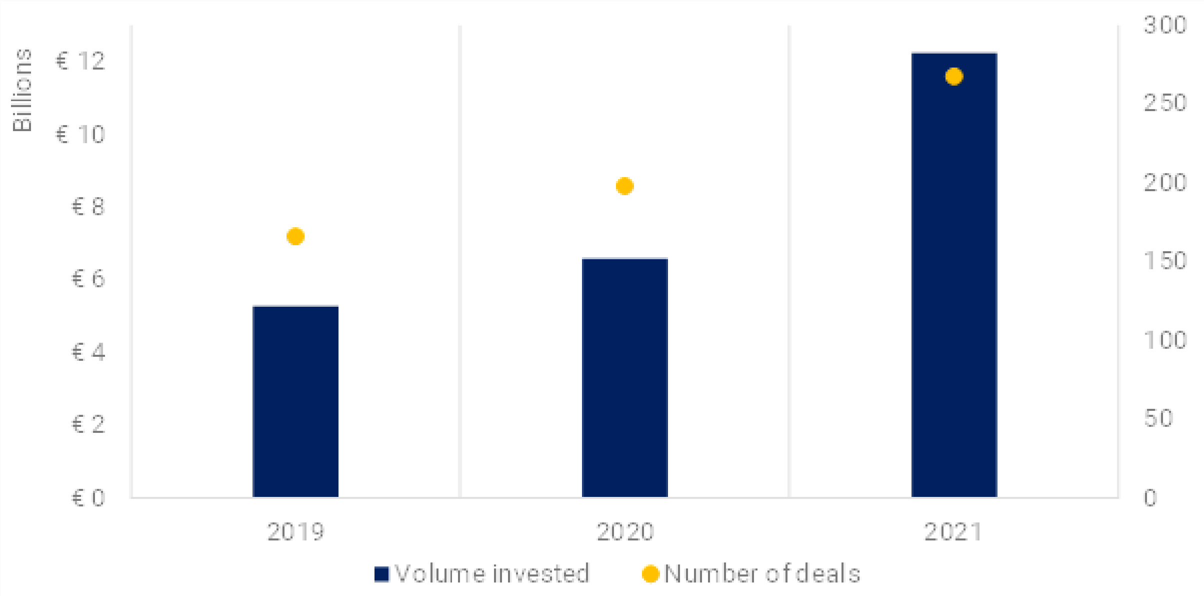


Figure 31: Global investment & deals

Venture Capital accounts for the largest share of financing globally. In 2019 this share was of 68%, slightly decreasing in 2020 to 64%. In 2021 this share remained very similar attaining €7.5 billion or 61% of the total.

The big development in 2021 were SPAC mergers with 10 SPAC's recorded for a total of almost €3 billion. The standout mergers in 2021 were Rocket lab, Planet and Astra totalling €1.6B between all three SPAC's. ESPI also accounts the self-capitalization into Blue Origin from Jeff Bezos, which is approximately $1 billion per year and is included as "Angel" investment.

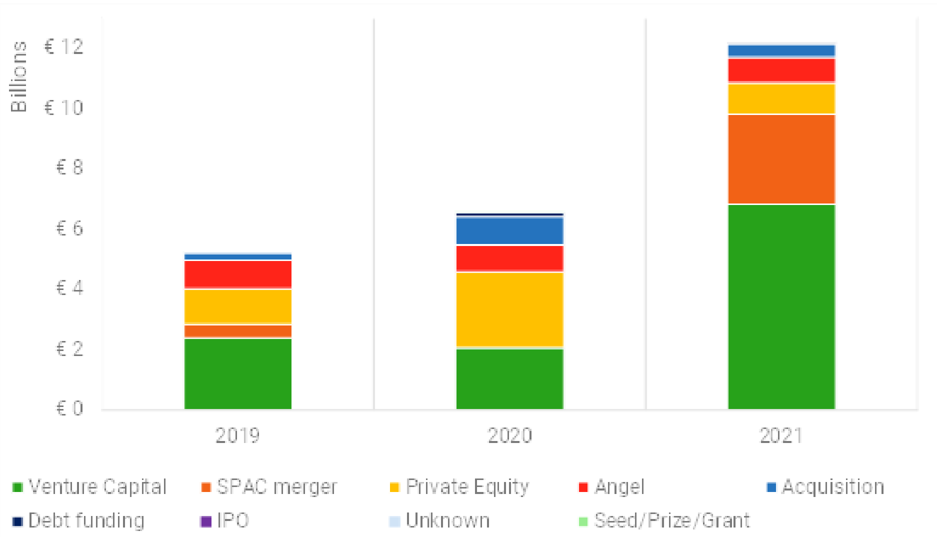


Figure 32: Investment type

3.5.3 Regional differences in investment

The USA have historically been the most attractive location for New Space investment and ventures. The United-States have also seen a significant growth over the past three years, going from €3.2 billion in 2019 to €9 billion in 2021. This represents a 72% growth over 3 years.

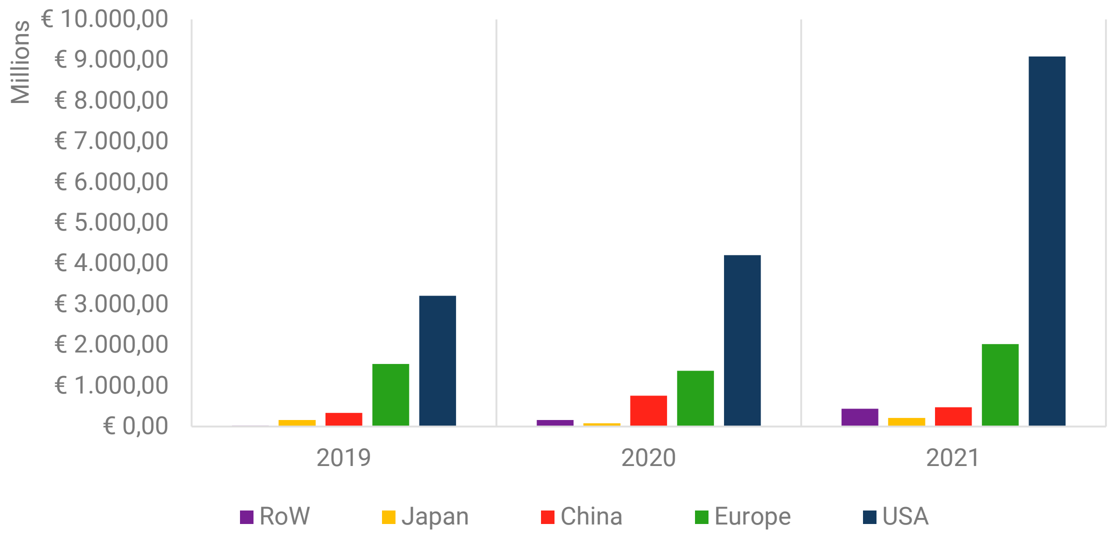


Figure 33: Investment volume per region

Europe remains the second region attracting the most investment into New Space ventures. Over the past three years total investment has increased by 33% going from €1.5 billion in in 2019 to €2 billion in 2021.

China and Japan have also seen a healthy growth in terms of investment into New Space ventures. Japan has seen a 33% growth with investments going from €161 million in 2019 to €214 million in 2021 and China seeing 41% increase over three years with investment growing from €337 million in 2019 to €476 million in 2021.

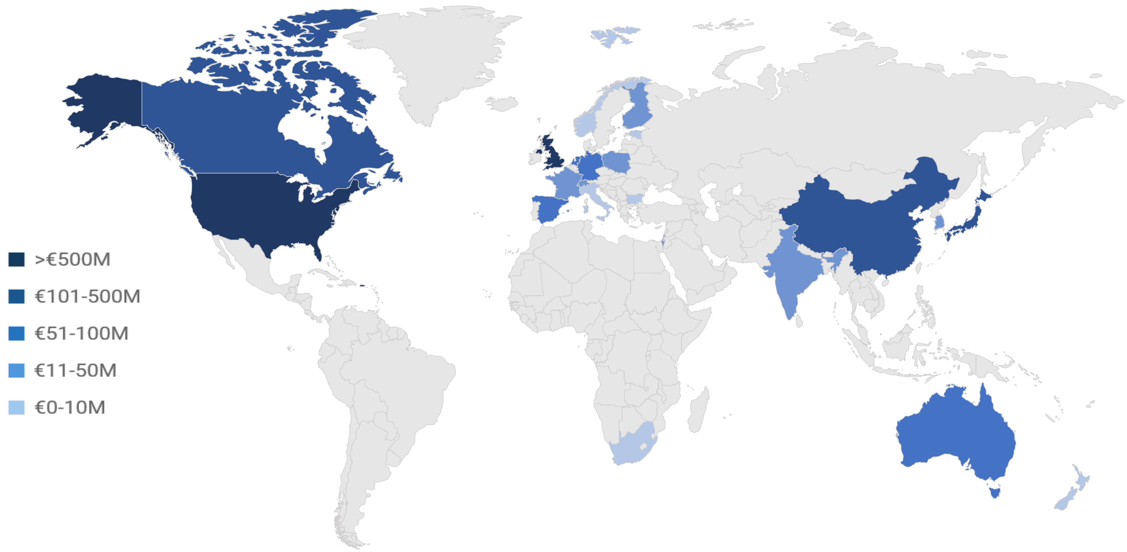


Figure 34: Investment volume map

Perhaps most incredibly, the biggest growth in investment has been seen throughout the rest of the world. With worldwide countries (outside of the US, Europe, China, and Japan) seeing their total investment increase from €24 million in 2019 to €434 million in 2021. This represents an incredible **1700%** growth over three years. Notably in 2021, countries like Canada, Australia, Israel, India, South-Korea and Singapore reached records in terms of investment.

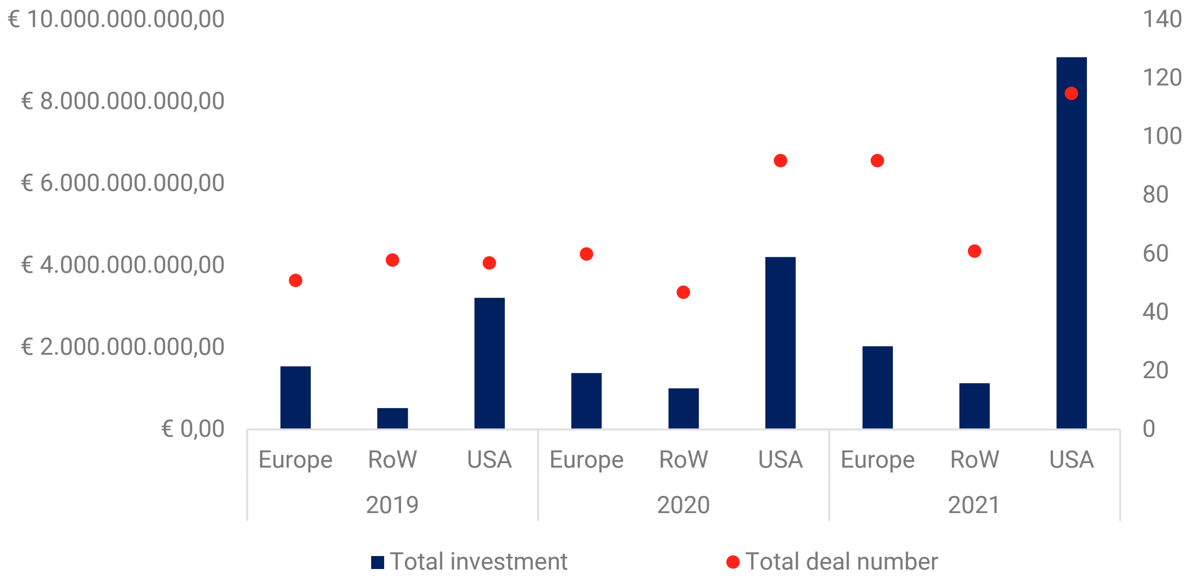


Figure 35: Number of deals per region

Europe has averaged 68 deals over the past 3 years compared to 88 for the USA. As such, while there is only a 25% difference in deal number between the EU and the US, there is 108% difference in investment volume between both regions (Europe has averaged €1.6 billion over 3 years as compared to €5.5 billion for the USA). The US saw 115 deals in 2021 for a total of €9 billion. This makes an average deal size of €78 million. In comparison, Europe saw a total of 92 deals totalling approx. €2 billion, this makes an average deal size of €22 million. This extremely large difference is deal size (112%) is caused by a range of factors linked to the dynamics of the European and US investment ecosystems.

4 LAUNCHES & SATELLITES

4.1 Global Space Activity Evolution 2000-2021

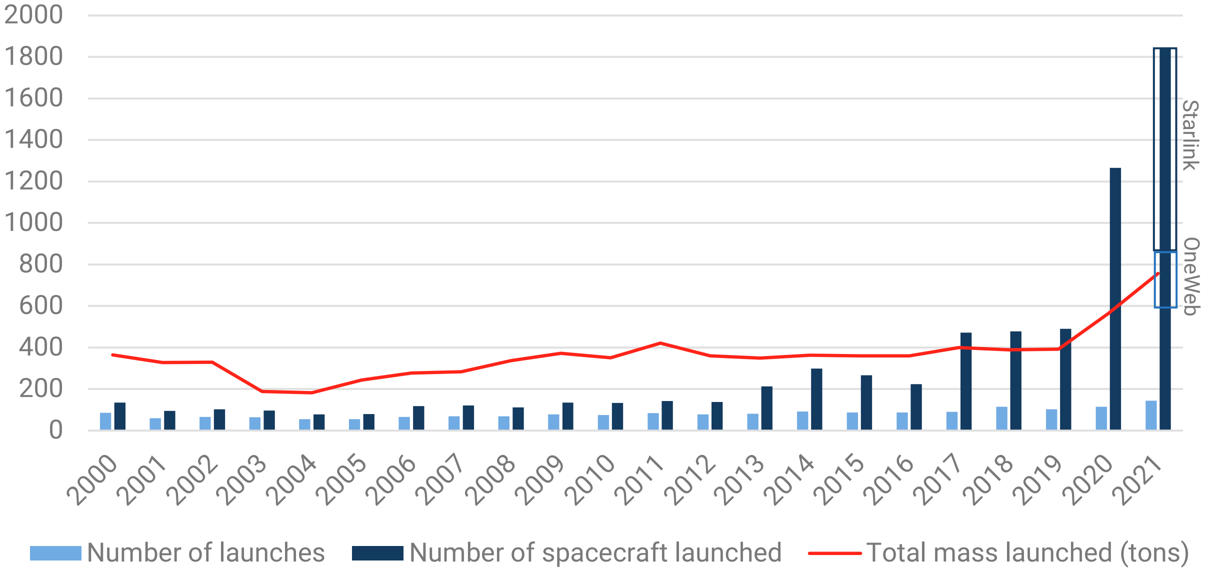


Figure 36: Evolution of launch activity over time (2000-2021)

The global space activity broke all records in 2021 and reached a whole new level. With 144 launches being carried out in the world, 2021 sets a new record, 26% higher than the previous one set in 2020 with 114 launches. Confirming the skyrocketing trend started in 2020, a new record high of 1843 satellites were launched in a single year (45% more than in 2020), largely due to the launch of mega-constellations including Starlink, OneWeb, Planet and Swarm spacecraft. As a result, the total mass launched also increased drastically, although not in the same proportion, reaching 756 tons (34% more than in 2020).

As mentioned above, the most important change concerns the number of spacecraft launched to orbit. While the period 2017-2019 already marked a major step compared to previous years, the period 2020-2021 brought the launch sector to an entirely new level: in these two years, as many satellites were launched as in the timeframe 2008-2019. This stark increase is in large part due to the 1822 Starlink satellites and, to a lesser extent, to the 388 satellites deployed for OneWeb, representing together 71% of all satellites launched worldwide in 2020-2021. In this regard, the routine deployment of mega-constellations is expected to contribute to a large majority of the global space activity in upcoming years (e.g. on top of Starlink and One Web, 3000+ satellites are planned for Project Kuiper, 5000 for Lynk Global…). Involving heavier satellites than CubeSat constellations, these projects will also lead to an increase of both the mass launched and number of launches every year, as already demonstrated in 2020 and 2021.

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Number of launches	77	81	92	87	86	91	114	103	114	144
Spacecraft launched	138	213	298	266	223	471	477	490	1266	1843
Mass launched (tons)	360	348	363	360	359	401	389	385	564	756

Table 13: Key space activity statistics (2012-2021)

4.1.1 Launch activity evolution by country

The evolution of the activity of top space launch countries (United States, Russia, Europe, China) shows very different profiles. Furthermore, despite a strong domestic space sector, other countries such as India and Japan still have a comparatively limited launch activity (they respectively conducted two and three launches in 2021, launching 20 and 11 spacecraft to orbit).

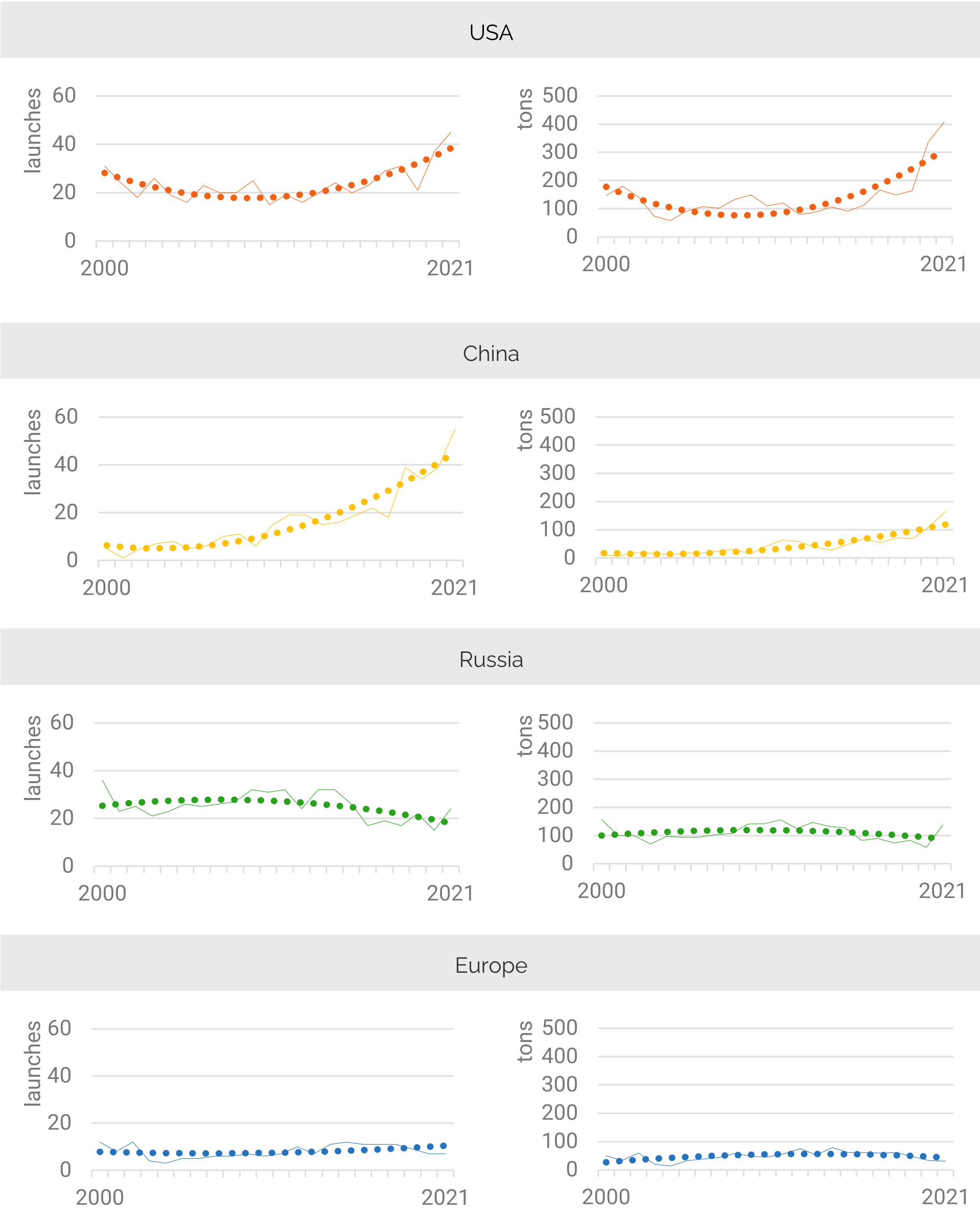


Figure 37: Evolution of the number of launches (left) and total mass launched (in tons, right) per country (2000-2021), with trendline

- **United States:** after a decrease related to the retirement of the space shuttle and other factors, the U.S. activity is now experiencing a new steep growth, largely driven by new launch service providers, such as SpaceX, and by the recovery of the capacity to service the ISS, for both cargo and crew missions. The role of SpaceX in the striking increase of 2020-2021 is predominant (68% of the U.S. launches and 22% of the total number of launches over the two years), due to the rollout of the Starlink constellation as well as the launch of several crewed spacecraft to the ISS, on top of the cargo Dragons that the company usually delivers.
- **China:** the Chinese launch activity has skyrocketed since 2000 and China has now become the most active country in terms of number of launches, ahead of the United States (55 launches in 2021, a record). China carried out more launches in 2020 and 2021 than in 2019, although several of them failed. However, the country is not yet a leader in terms of mass launched. The strong growth in institutional demand from Chinese authorities remains the main driver, as almost all payloads launched by China are domestic and more than 80% of the mass is launched for governmental actors (civil and military).
- **Russia:** along the rest of its space sector, the launch activity of the historical leader has experienced a sharp decrease over time, both in number of launches and mass launched. This decreasing trend accelerated in 2020 with only 15 launches but bounced back in 2021 to the level of 2019 (24 launches). In terms of mass, while the country has been on a decreasing trend over the past year, 2021 marks a record since 2014 with 138 tons put in orbit. This increase is due to the launch of two modules for the International Space Station, in line with the trend making ISS-related activities a significant share of the Russian launch activity in terms of number of launches (one third of Russian launches in 2021) and of mass launched (52% of the total mass put in orbit in 2021).
- **Europe:** the launch activity has remained rather stable around 10 launches and 50 tons put in orbit per year. The introduction of the new launchers Vega and Soyuz contributed to diversifying and expanding European launch capabilities. Nevertheless, a significant drop is visible in 2020 and 2021 (the average mass launched over the two years represented only 68% of the mass launched in 2019), partly explained by the Guiana Space Centre's closure because of the COVID-19 pandemic and by the decreasing number of launches. On the contrary, other major space powers were not impacted by the sanitary crisis (with the exception of Russia in 2020) and launched more in 2020 and 2021 than in pre-pandemic times.

4.1.2 Spacecraft orbit and mass

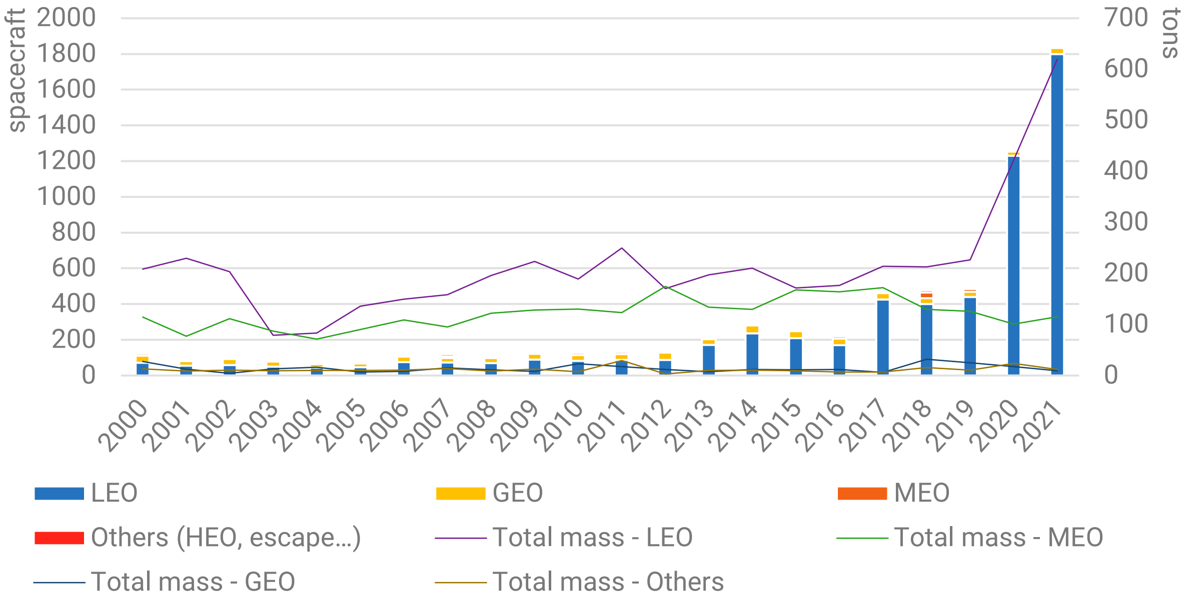


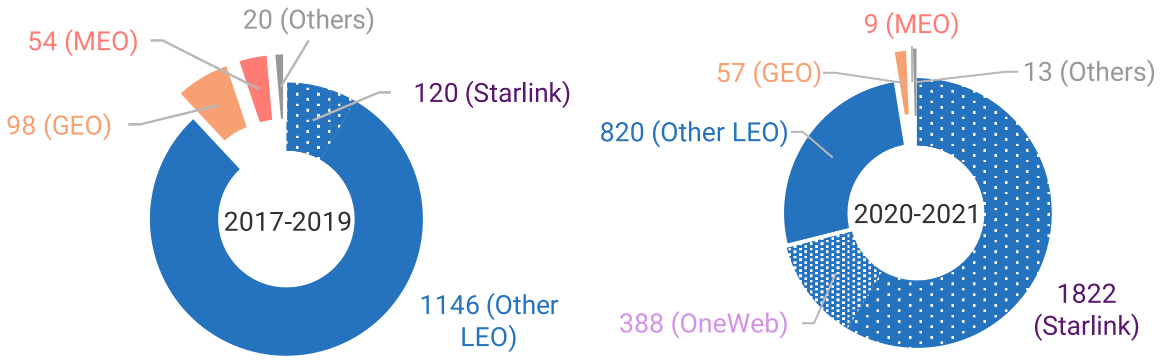
Figure 38: Evolution of the number and mass of spacecraft launched per orbit (2000-2021)

Over the past ten years, the number of satellites launched to GEO has remained rather stable, with a maximum of 45 in 2014 and a minimum of 24 in 2020. In line with this trend, 33 satellites were launched to geostationary orbit in 2021. An overwhelming majority of satellites is deployed in LEO, mainly due to the launch of small spacecraft and CubeSats in the context of (mega)constellations (for Earth observation or telecommunications) and technology/demonstration missions. During the period 2017-2019, LEO was the destination of 88% of all satellites launched but, in 2020-2021, this rate reached 98%. This remarkable increase is mostly due to the launch of Starlink and OneWeb satellites; yet, even when excluding them, still 91% of all spacecraft launched in 2020-2021 were destined to LEO.

The number of launches to MEO also increased over time but to a much lesser extent (5 in 2009, 16 in 2019, with a peak at 31 in 2018), due to the deployment of several GNSS systems (China's Beidou, Europe's Galileo), as well as the development of satcom systems in MEO (e.g. the O3b constellation and its 20 satellites that were launched between 2013 and 2019). Therefore, the (quasi-)completion of GNSS constellations (e.g. Galileo, Beidou) and the development of LEO satcom mega-constellations may explain the low number of satellites that were launched to MEO in 2020 (5) and 2021 (4, the lowest number since 2002).

Interestingly, from 2020 onwards, most of the mass was launched to LEO even when excluding human spaceflight activities. This is new, as this orbit used to dominate "only" in terms of number of spacecraft. However, the predominance of LEO spacecraft in terms of number is not fully mirrored when we focus on the mass launched. While spacecraft launched to LEO accounted for 98% of all spacecraft in 2020-2021, they represented 72% of the total mass sent to orbit (excluding human spaceflight activities). In comparison, spacecraft launched to GEO (mostly telecommunication satellites) accounted for only 1.8% of all spacecraft launched but 21.7% of the total mass (when excluding human spaceflight activities).

Number of satellites launched



Total mass launched (in tons), excluding human spaceflight activities

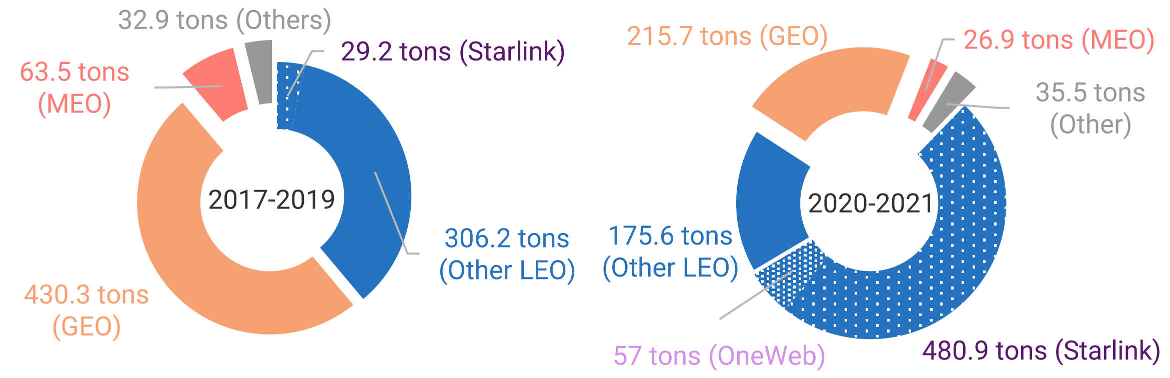


Figure 39: Comparison of the number of satellites and total mass launched by orbit between the period 2017-2019 (left) and the period 2020-2021 (right)

The total mass launched to GEO has increased over time (+34% between 2009 and 2017), but this trend is starting to reverse. In the last three years, the mass drastically decreased due to difficulties in the satcom market (governmental satellites being included, 23 and 21 GEO satcoms were launched in 2018 and 2019, and only 15 in 2020 and 16 in 2021, as compared to 30 in 2017). The average mass of GEO satcoms increased to reach 5 tons in 2019 (it was around 3 tons in the 2000s). The total mass launched to LEO (including human spaceflight) was around 200 tons per year over the past years, comparable to the years 2000s when the ISS was under construction. However, in the period 2020-2021, this amount reached around 520.9 tons in average (422 tons in 2020 and 619.7 tons in 2021). The launch of mega-constellations for telecommunication purposes (in particular Starlink) as well as the increased number of human spaceflight activities by U.S. and Chinese agencies are the main drivers of this stark increase.

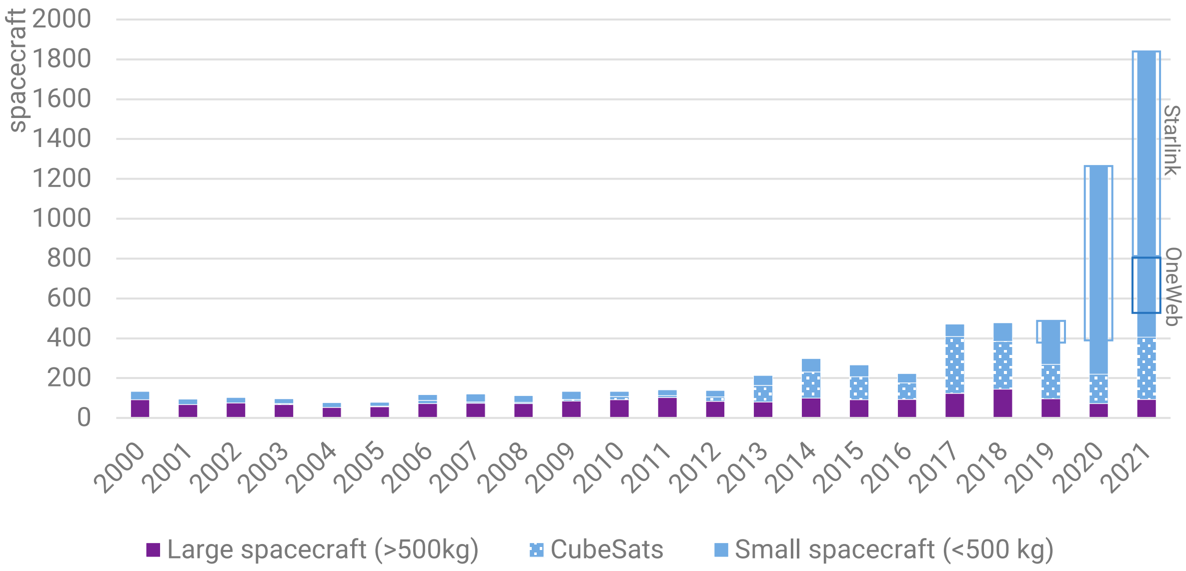


Figure 40: Evolution of the number of spacecraft launched per mass category (2000-2021)

CubeSats became the dominant category of payloads launched to orbit from 2013, but this pre-eminence decreased with time, in particular in the past three years (when other types of small spacecraft below 500 kg became the overwhelming category). Over the past years, the number of small spacecraft launched (including CubeSats) reached an all-time high: in 2019, they were four times more numerous than large spacecraft (80% of all spacecraft launched); and in 2020-2021, small spacecraft represented 18 times the number of large spacecraft sent to orbit. Here again, this very high number is mostly linked to the 1822 Starlink and 388 OneWeb satellites launched in only 3 years. Yet, even excluding these constellations, the number of small spacecraft launched in 2020-2021 represented more than four times the quantity of large spacecraft launched in this period, thus demonstrating a real trend towards the miniaturisation of satellites and their greater use for a wide variety of missions.

Despite the very high share of small spacecraft launched, large spacecraft still account for the majority of the mass put in orbit every year, even though this dominance is fading. While large spacecraft accounted for 94% of the total mass launched in the period 2017-2019, they represented only 59% of the mass launched to orbit in 2020-2021. Since 2000, the number and total mass of large spacecraft have been highly variable ranging between 53 and 145 spacecraft for approximately 180 to 430 tons. Since 2012, the total mass of large spacecraft had stabilised around 360 tons per year but had been following a slightly decreasing trend since the peak reached in 2017 (389 tons). Therefore, 2021 is an exceptional year as it reverses this trend and sets a record for the mass of large spacecraft launched to orbit (427 tons), in part due to the launch of multiple heavy military satellites and to the multiplication of human spaceflight missions after the entry into operations of the Chinese space station.

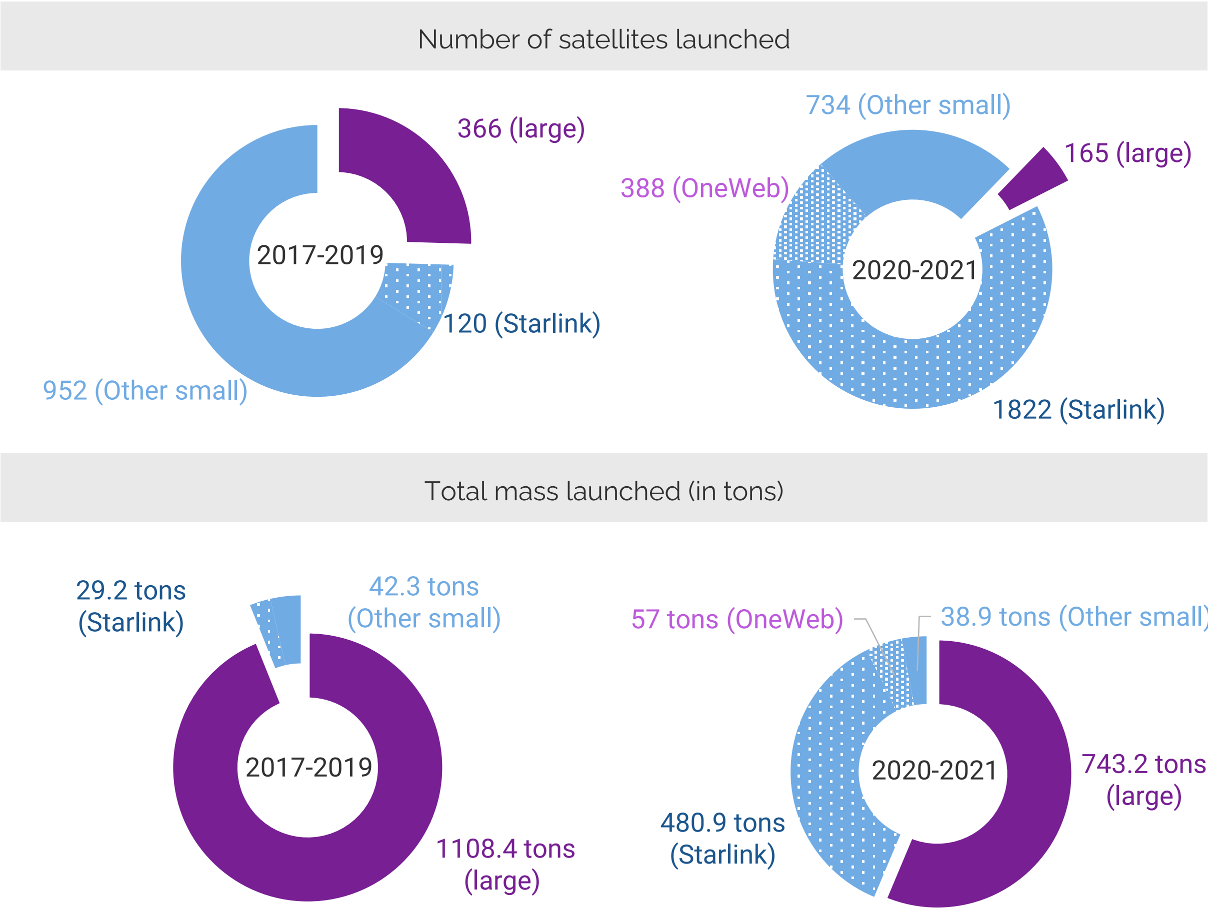


Figure 41: Comparison of the number of satellites and total mass launched per mass category between the period 2017-2019 (left) and the period 2020-2021 (right)

4.1.3 Space missions and markets

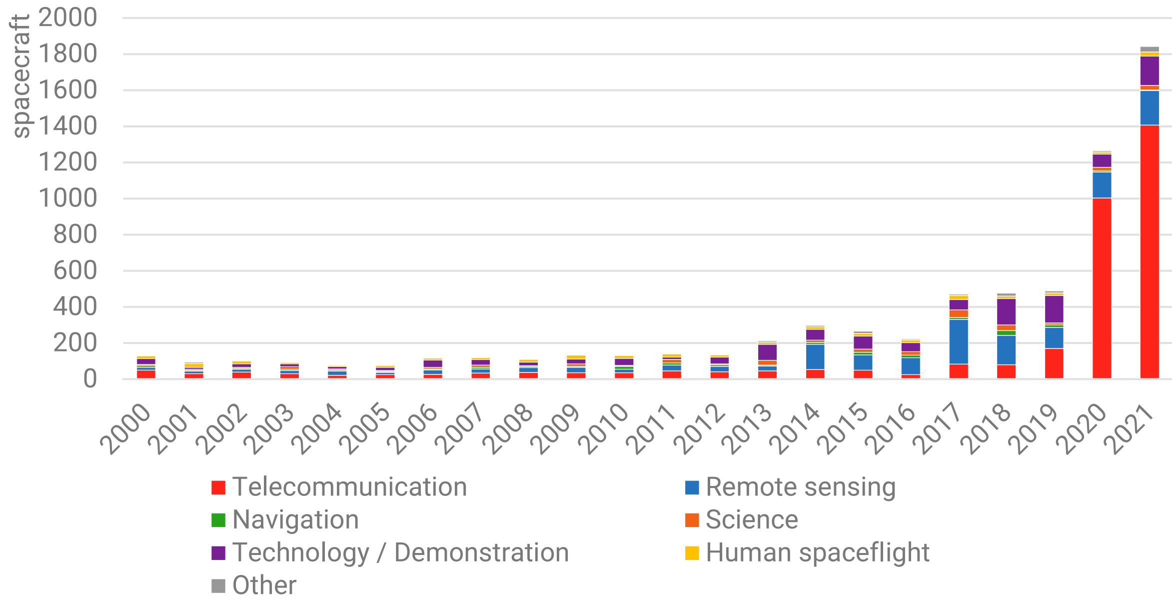


Figure 42: Evolution of the number of spacecraft launched, per mission (2000-2021)

A majority of spacecraft is now launched for telecommunication, remote sensing and technology/demonstration missions. Small satellites represent 82% of the mass launched for telecommunication missions in 2021, a significant change compared to the previous paradigm in which heavy GEO satcom accounted for the bulk of this mass. Despite their limited individual size, telecommunication spacecraft still account for 49.7% of the total mass launched in 2021 (less than in 2020), compared to 29.6% for human spaceflight and 4.5% for technology/demonstration (a sharp decrease compared to the previous year, when it stood at 12%). The share of remote sensing spacecraft represents 13.1% of the total mass launched in 2021 (an improvement compared to 2020, when it accounted only for 8.4%).

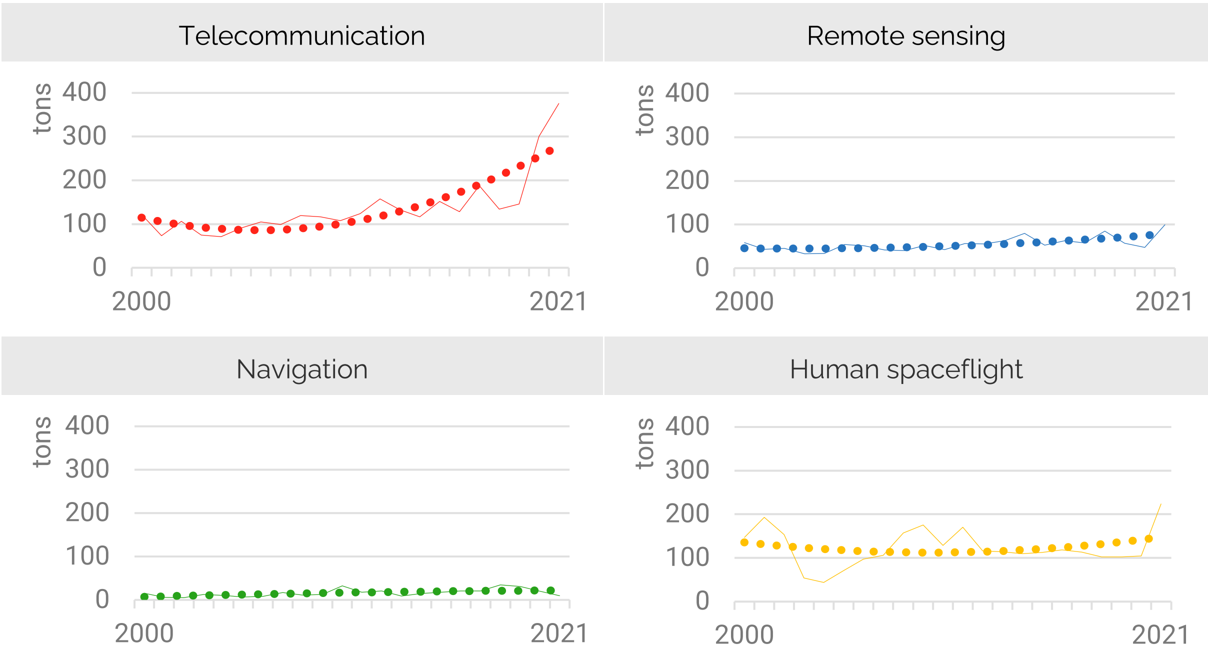


Figure 43: Evolution of the total mass launched (in tons) per mission (2000-2021) with trendline

The high number of telecommunication and, to a lesser extent remote sensing satellites, launched during recent years is mostly due to the launch of constellations, in particular Starlink and OneWeb, but also the CubeSat constellations of Planet and Spire. While the number of technology/demonstration satellites increased substantially in 2018 and 2019 to reach a third of all spacecraft (mostly CubeSats), it decreased in 2020, but came back to its previous level in 2021, with 162 satellites launched. However, the share that they represent dropped in the past two years: in average, they represented 7.5% of all spacecraft launched in the period (26% without Starlink and OneWeb). Their mass, even though it remains low, tends to increase. For instance, in 2018, the average mass of the 144 satellites launched for this category of missions was of 67 kg. It grew to 263 kg in 2019 and 950 kg in 2020 but fell back to 209 kg in 2021. The major increase in 2020 can be explained by a few heavy Chinese and American satellites aimed at testing/demonstrating technologies for these countries' military and civil space programmes. Finally, the number of human spaceflight missions, mostly comprising the servicing of the ISS, remained rather steady with 12 to 20 missions per year (with the exception of the period following the Columbia disaster in 2003).

Telecommunication and human spaceflight spacecraft are the two main types of missions contributing to the total mass launched. Even though the mass related to human spaceflight missions has decreased slightly between 2010 and 2019, more than 100 tons were still launched every year to service the ISS. However, 2021 marks a record year for human spaceflight, as more than 200 tons were launched for this kind of activity: this can be explained by the launch of two modules by Russia and by the entry into operations of the Chinese Space Station.

From 2010 onwards, the total mass launched for telecommunication missions has increased and 130 to 150 tons in average were launched every year until 2019. A new record high of 300 tons was achieved in 2020 (+60% compared to the previous record), a record that was beaten again in 2021 with 375 tons launched.

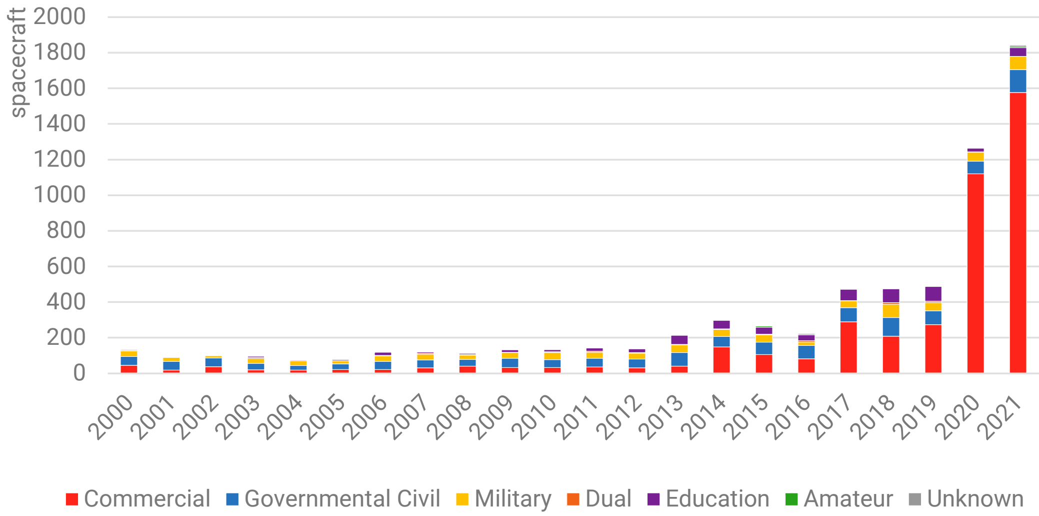


Figure 44: Evolution of the number of spacecraft launched per market (2000-2021)

Data show a steep increase of the number of commercial satellites over the period 2017-2019, but the year 2020 marks a change of scale, continued in 2021. While more than 200 spacecraft were launched each year to provide commercial services between 2017 and 2019, representing between 40% and 60% of the total number of satellites launched, 1120 commercial satellites were launched in 2020 alone and 1576 in 2021 (that is, in average over the two years, 86.7% of all spacecraft). Even with Starlink and OneWeb satellites excluded from the calculation, commercial satellites still account for 54% of the spacecraft launched in 2020-2021. The total mass of commercial satellites also grew over time, although to a lesser extent, as many of these satellites belong to the category of small spacecraft. These figures illustrate the growing momentum in commercial space activities and the emergence of new entrants, services, and markets.

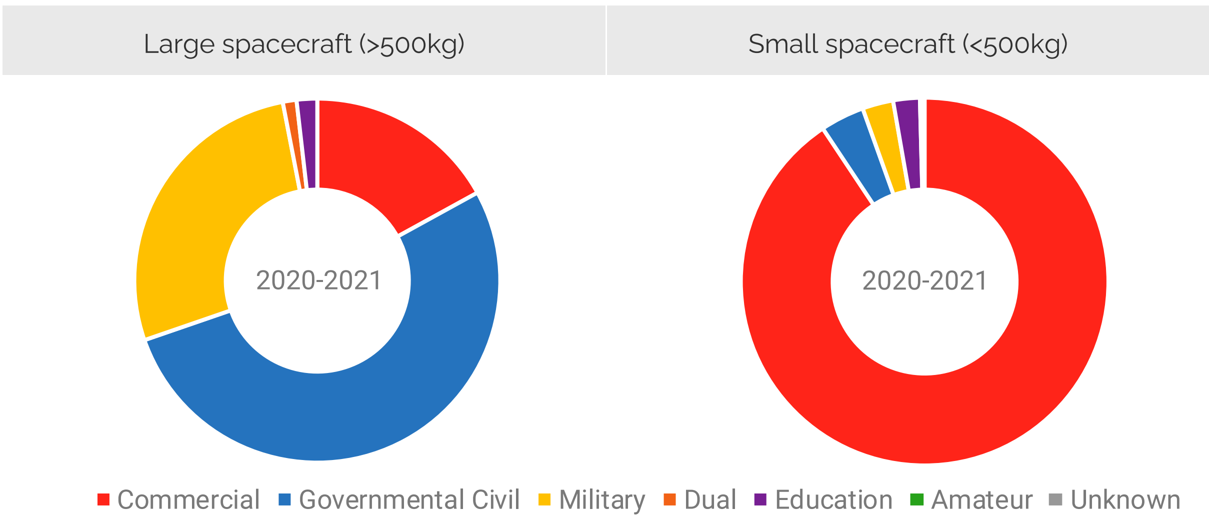


Figure 45: Number of spacecraft launched per market and mass category (2020-2021)

While being less numerous than commercial satellites, spacecraft used for institutional purposes (governmental civil, military and dual) have continued to make up a great share of the total mass launched over the past years, representing between two thirds and three quarters of the total mass between 2015 and 2019. While this share significantly decreased in 2020-2021, institutional spacecraft still account for 48.3% of the total mass launched over the two years. With regard to the military market, the number and mass of these satellites have grown, slightly but steadily, since 2000. Since 2015, several dozens of military satellites have been launched per year, for an average mass of 78 tons. Two peaks can be identified: one in 2018, with 73 military spacecraft launched, and one in 2021, with 75. Various factors contribute to this growth, which concerns a variety of missions, both operational and experimental. It is also noteworthy that, while governmental civil missions have represented the largest share in terms of mass launched since 2000, primarily due to human spaceflight, this position is eroding in 2020 and 2021 in front of the commercial activity. Commercial missions indeed account for slightly more than half of the total mass launched these years, strongly driven by Starlink spacecraft.

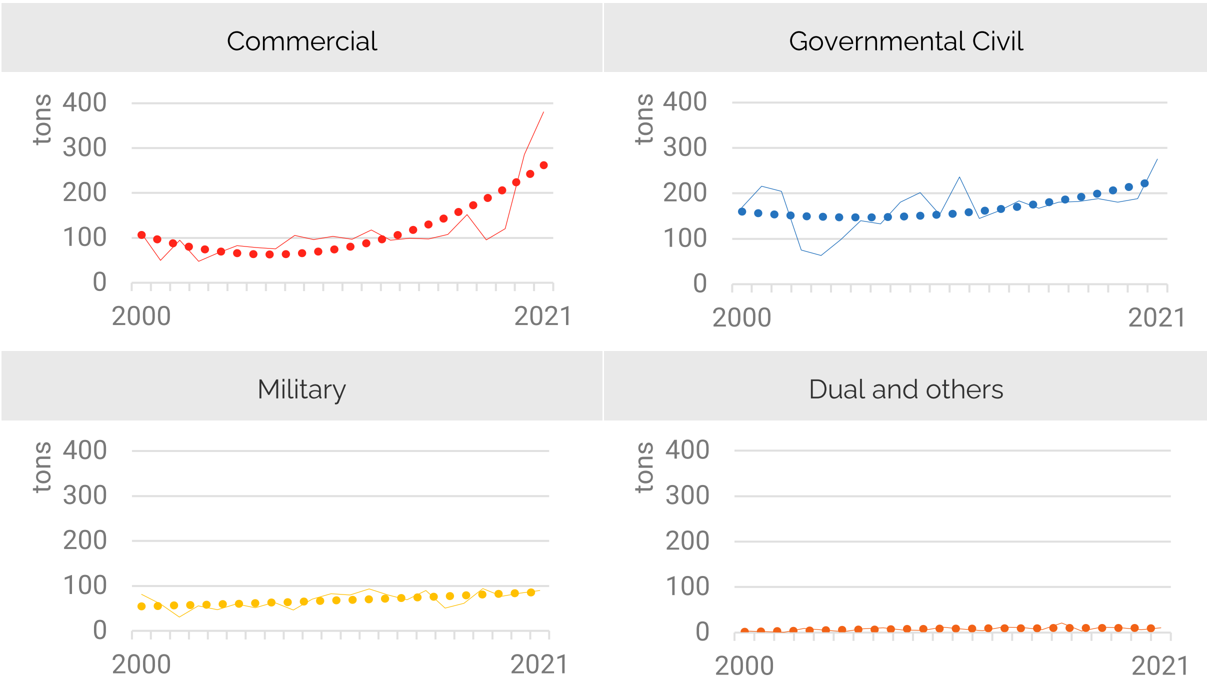


Figure 46: Evolution of total mass launched (in tons) per market (2000-2021) with trendline

4.1.4 Spacecraft manufacturing and procurement by country

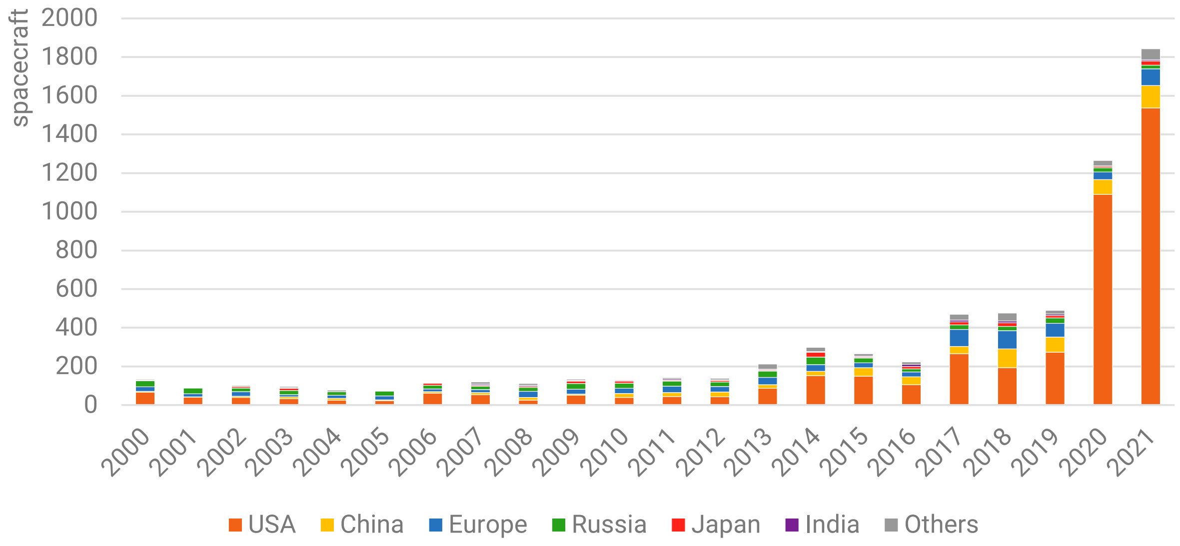


Figure 47: Evolution of the number of spacecraft per manufacturing country (2000-2021)

The manufacturing activity of the United States skyrocketed over the last decade. Between 2017 and 2019, 51% of all spacecraft launched worldwide were integrated in this country, corresponding to 38% of the total mass. In 2020-2021, these shares respectively reached 84.5% and 61.4%, again largely boosted by Starlink (and OneWeb[681]). Spacecraft manufacturing in China also experienced a massive growth, in parallel with the increase of the country's launch activity. Between 2017 and 2019, China produced 15% of spacecraft that were launched (17% of the total mass). While the strong increase of the U.S. activity decreased China's share of the number of spacecraft launched in 2020-2021 (only 6.2%), the share of Chinese-made spacecraft in the total mass launched increased to 20.8% over the period, confirming that the U.S. spike is mostly due to smaller satellites. The activity of Russia remained stable with a vast majority of its output concerning human spaceflight vehicles (Soyuz, Progress) and satellites for various domestic public programmes. The output of Europe has been irregular and does not allow to draw a clear trend, although it has been somewhat declining in the recent years. In the period 2017-2019, Europe manufactured 18% of all spacecraft put in orbit for about 17% of the mass launched. In 2020-2021, these figures dropped to 4% of satellites launched and of the total mass launched.

[681] OneWeb spacecraft are produced by OneWeb Satellites, a joint venture between OneWeb and Airbus. Although these two companies are European, the main production line is located in Florida, hence ESPI considers the satellites as a U.S. output. It is expected that the production is repatriated to the United Kingdom by 2024-2025.

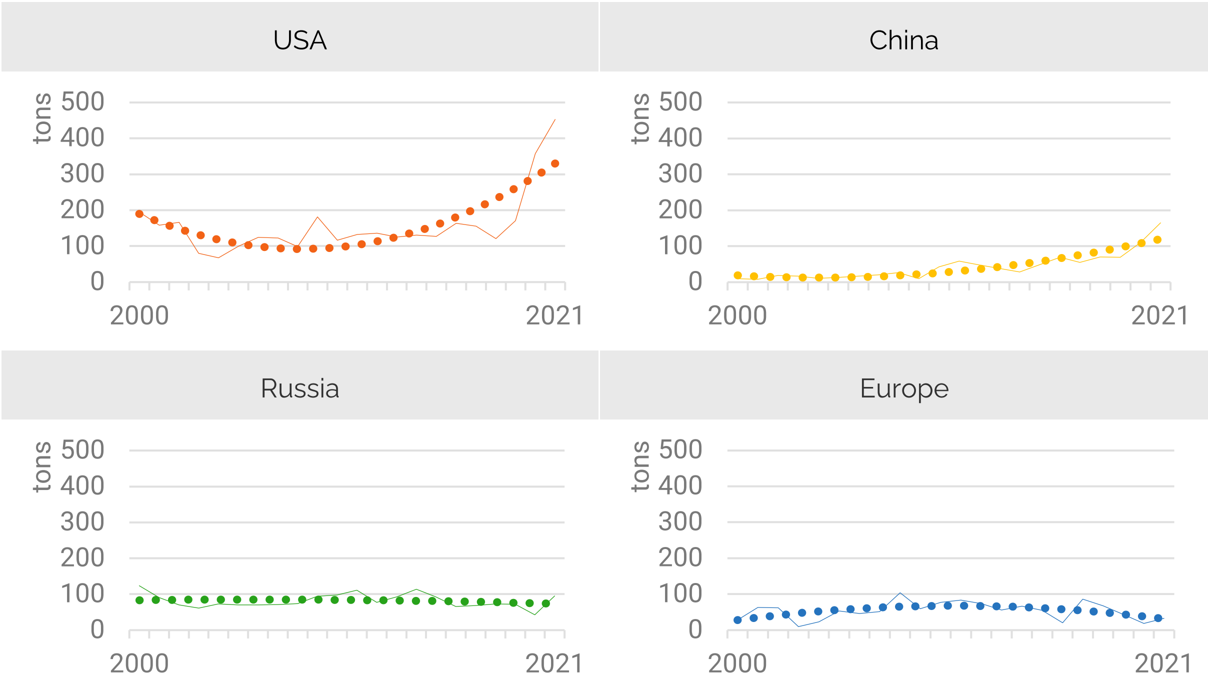


Figure 48: Evolution of spacecraft mass (in tons) per manufacturing country (2000-2021) with trendline

With the popularisation of the CubeSat standard, a growing number of countries and organisations have already developed a spacecraft, even though very basic. Since 2017, more than 400 organisations have produced a satellite, including agencies, governmental bodies, universities, research institutes and others. Nevertheless, the spacecraft manufacturing activity is still highly concentrated in a few countries but also a few companies. Over the last 5 years, the top 10 companies produced 78% of the total mass put in orbit.

This concentration is even more visible in the commercial market (mostly telecom). A few companies and organisations compete on the international commercial satellite market and capture most of the related activity. The top 10 manufacturers produced 95% of commercial satellite mass during the period 2015-2019, and 98% in 2020-2021. U.S. companies, including Boeing, Lockheed Martin, Orbital ATK (now Northrop Grumman), Space Systems Loral (now Maxar Technologies) and SpaceX, are the main actors on the market. SpaceX put into orbit 120 operational Starlink satellites in 2019, and 1822 more in 2020-2021, giving way to one of the first large-scale fully vertically integrated activities: SpaceX is the manufacturer, operator and launch service provider of its constellation. In parallel, the deployment of OneWeb's constellation allowed this company to quickly become one of the leading actors in terms of mass launched.

Position	Top 10 (2015-2019)	Share of the total commercial satellites mass	Top 10 (2020-2021)	Share of the total commercial satellites mass
1	SSL/Maxar	26.1%	**SpaceX**	**74%**
2	TAS	19.9%	OneWeb Satellites	8.6%
3	Boeing	15.1%	CAST	4.2%
4	Airbus	12.8%	Maxar	3.7%
5	CASC	6.8%	Airbus	2.8%
6	**SpaceX**	**5.5%**	TAS	1.5%
7	Orbital ATK/NG	3.4%	ISS Reshetnev	1.3%
8	Lockheed Martin	2.7%	Northrop Grumman	0.9%
9	Mitsubishi Electric	1.8%	Lockheed Martin	0.9%
10	NEC	0.9%	Chang Guang	0.6%
	Total	95%	Total	98%

Table 14: Share of the mass launched (in tons) for the commercial market by the top 10 manufacturers

The leading position of European companies Airbus and Thales Alenia Space, which used to be prominent, starts to be increasingly challenged, in particular due to difficulties on the GEO satcom market. In the period 2017-2019, the two European companies delivered 150 tons of commercial satellites, corresponding to 40% of the total mass. However, in 2020-2021, they delivered only 29 tons (excluding the satellites produced by OneWeb Satellites), accounting for 4.3% of the mass launched.

The commercial activity of the China Aerospace Science and Technology Corporation (through its subsidiaries), remains rather limited because of difficulties to enter large segments of the market, for example due to ITAR restrictions.

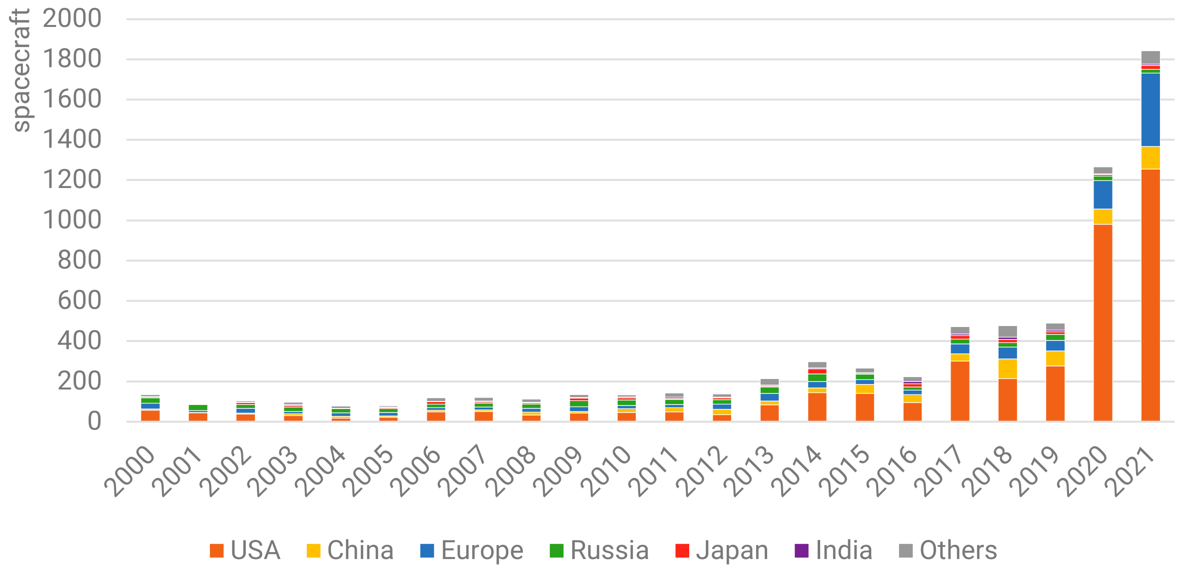


Figure 49: Evolution of the number of spacecraft per procuring country (2000-2021)

A large majority of spacecraft is procured domestically, mostly because of procurement rules and market constraints. For this reason, the distribution of spacecraft per manufacturing and procuring country is almost identical, with a slight variation related to import/export of commercial satellites. This is the case both for the number of spacecraft and the corresponding mass. As a result, it is not surprising that most of the spacecraft are also procured by U.S. organisations and companies. During the period 2017-2019, 55% of spacecraft launched worldwide were procured by the United States, corresponding to 36% of the total mass. This share reached 71.9% of spacecraft and 55.9% of the total mass launched in 2020-2021. In China, a significant share of the space activity serves a domestic need. Therefore, China's growth comes first and foremost from an increase of national investment in the space sector. The number and mass of satellites ordered by Chinese organisations and operators has multiplied by more than 10 since 2000, for the first time exceeding 100 tons in 2020; the increase accelerated in 2021, with an augmentation of 57% (164 tons) compared to the year before.

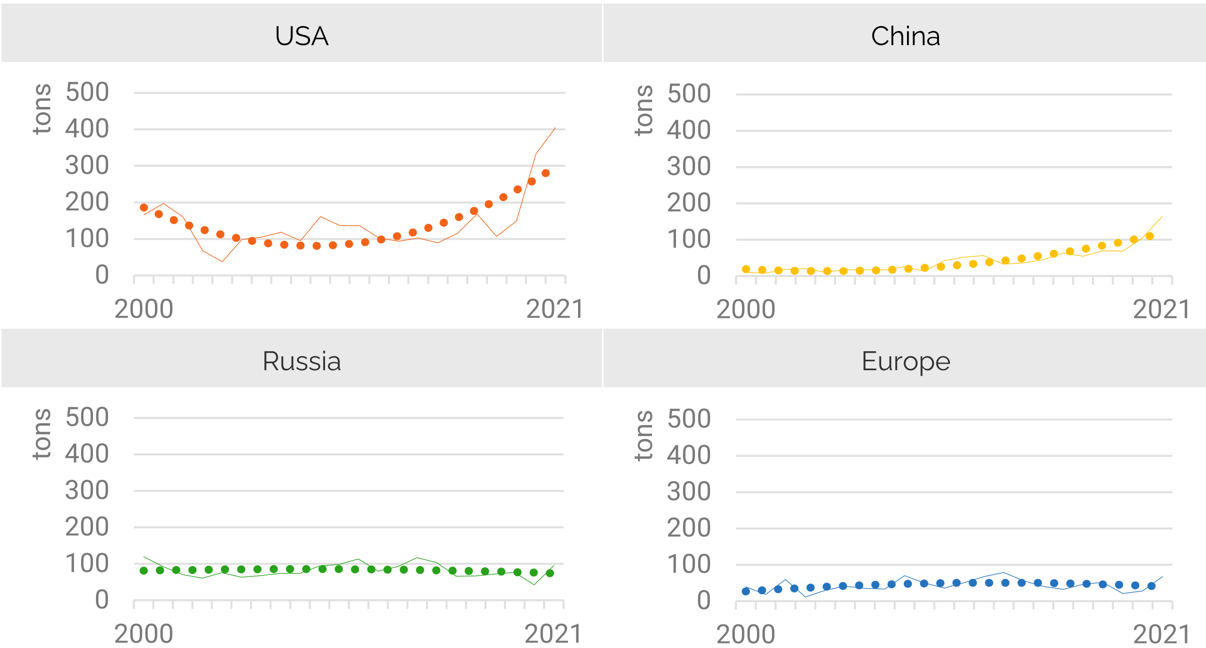


Figure 50: Evolution of total mass launched (in tons) per customer country (2000-2021) with trendline

Interestingly, Europe is the only region where the manufacturing output is much higher than the domestic demand, underlining the importance of export markets for European companies. The demand of European organisations is usually below 50 tons per year (with the exception of 2021, in large part due to OneWeb spacecraft) while the industry output is regularly well above this threshold. Procurement statistics in Russia are somewhat biased by the human spaceflight activity, as Progress and Soyuz capsules are attributed to Russia although they may be paid for, at least partially, by other countries.

On the commercial market, leading satellite operators and customers are more diverse and include European, American, Russian, Chinese, Japanese, Canadian and Arabic companies. Over the period 2015-2019, shares of top operators were relatively well spread and represented slightly more than half of the mass launched for the commercial market. However, in 2020-2021, the top 10 operators represented more than 90% of this mass. This remarkable increase is strongly driven by SpaceX and its Starlink constellation, which accounts for three quarters of the total mass launched for the commercial market during these two years. In the future, the distribution of mass could become more balanced again, as several operators are contemplating constellations of smaller satellites in LEO, either for their traditional activities (e.g. Telesat) or to address new markets (e.g. Eutelsat LEO for Objects, aimed at providing Internet of Things).

Position	Top 10 (2015-2019)	Share of the total commercial satellites mass	Top 10 (2020-2021)	Share of the total commercial satellites mass
1	Iridium	11.7%	**SpaceX**	**73.5%**
2	Intelsat	10.2%	OneWeb	8.7%
3	SES	5.8%	China Satcom	2.5%
4	Eutelsat	5.5%	SiriusXM	2.1%
5	**SpaceX**	**5.5%**	RSCC	1.3%
6	Inmarsat	4.9%	Turksat	1.2%
7	SKY Perfect JSAT	4.4%	Eutelsat	1.1%
8	Telesat	3.4%	SES	1%
9	Arabsat	3.3%	Embratel	0.9%
10	DirecTV	2.7%	SKY Perfect JSAT	0.9%
	Total	57.4%	Total	93.2%

Table 15: Share of the mass launched (in tons) for the top 10 operators on the commercial market

Finally, several of these companies contributed to the bounce of the market of GEO satellites in 2020 (21 commercial satellites ordered compared to 10 in 2019 and 12 in 2018). But this exceptional situation was the result of the replacement of satellites stemming from the C-band spectrum reallocation taking place in the United States. In 2021, only 9 GEO satellites were ordered for commercial customers, even lower than previous numbers. Half of these spacecraft will be provided by European manufacturers, but the customers are mostly non-European. Moreover, two of them will be micro-GEO satellites, therefore cheaper, and not the usual heavy systems sent to this orbit.

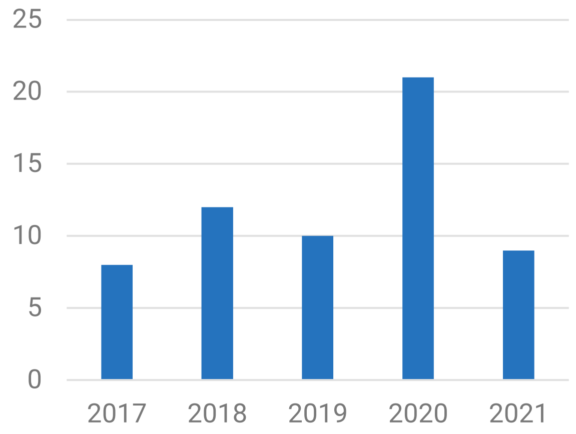


Figure 51: Evolution of the number of commercial GEO satellites' orders (2017-2021)

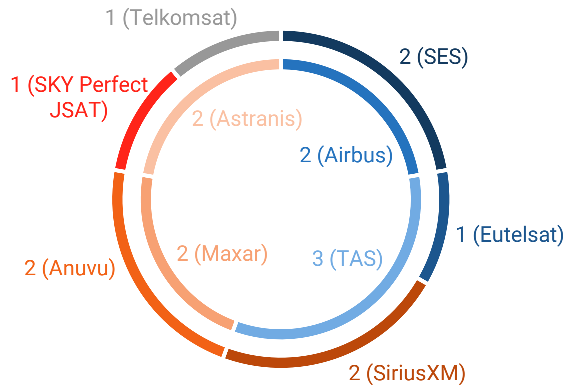


Figure 52: Number and share of commercial GEO satellites' orders by manufacturer (inner circle) and operator (outer circle) in 2021

4.2 Global Space Activity in 2021

4.2.1 Launch activity in 2021

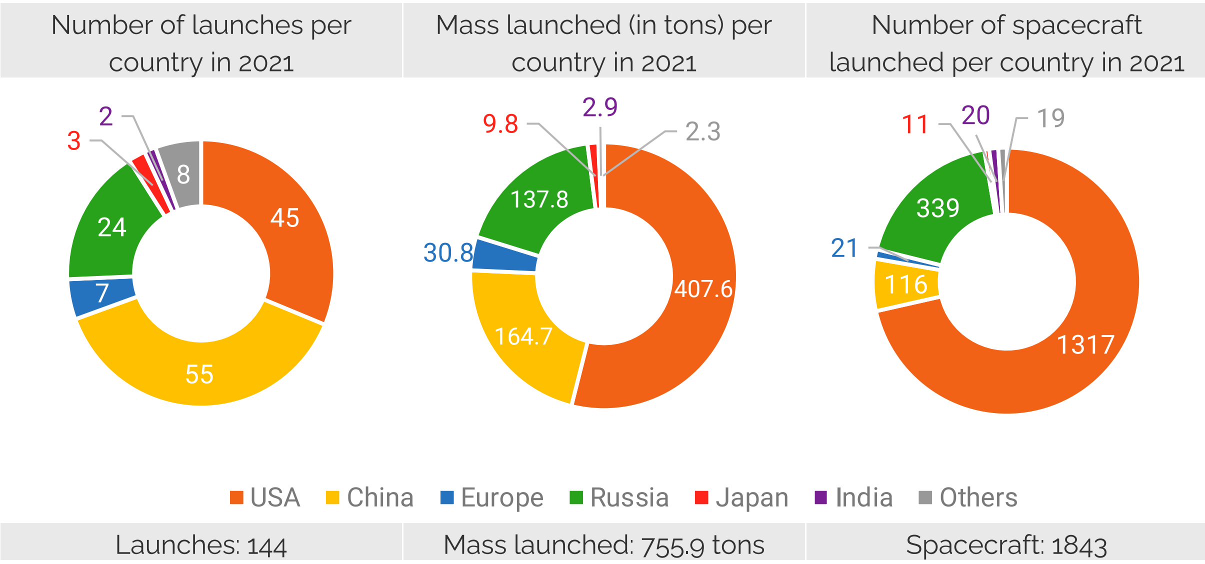


Figure 53: Number of launches, spacecraft and mass launched in 2021 per launch country

In 2021, nine countries (United States, China, France (for Europe), Russia, Japan, India, New Zealand, South Korea and Iran) launched 1843 spacecraft belonging to 48 nations. Among these nations, Kuwait, Moldova, Myanmar, Paraguay and Tunisia had their first satellite launched, joining the more than 90 countries involved in outer space activities. These figures and the numbers given below also include failed launch attempts, which represent 6.9% of all launches carried out this year (10 failures for 144 launches). For the fourth consecutive year, China conducted most of the launches (55, accounting for 38.2% of all launches), which is a new record for the country. The number of launches from the United States (45) has also increased compared to 2020 (37) but remains quite far from Chinese launch activity. The third traditional main launch country, Russia, lags behind with only 24 launches (16.7% of the total), which is nonetheless the highest number since 2015. The number of satellites that it put into orbit remains almost three times superior to China, in major part due to the launch of OneWeb satellites from Baikonur and Vostochny (83.8% of the satellites launched from Russia, the launch service is provided by Arianespace).

In terms of mass launched, the United States holds the first place, primarily due to the launch of Starlink satellites (64.8% of the total mass launched by the United States) and its human spaceflight activities. As in 2020, China is ahead of Russia, despite the role of the latter in bringing crew and cargo to the ISS (accounting for 52% of the total mass launched by Russia). This breakthrough is caused by the launch of numerous remote sensing satellites and of heavy demonstration spacecraft, as well as by the deployment of the new Chinese space station and the related human spaceflight activities. With 7 launches, European activity equalled 2020's. Only 30.8 tons were launched from Kourou, the lowest level since 2004, which can partly be explained by delays in the first launches of Vega C and Ariane 6. In terms of number of launches, the most active spaceport for the year 2021 is for the first time a Chinese site, the Jiuquan Satellite Launch Center, with 21 launches conducted from there, followed by Cape Canaveral (19 launches) and the Xichang Space Centre (16 launches). However, in terms of mass, Cape Canaveral remains by far the major spaceport, with 190 tons, that is, 27% more than the second (Kennedy Space Launch Center, with 150 tons).

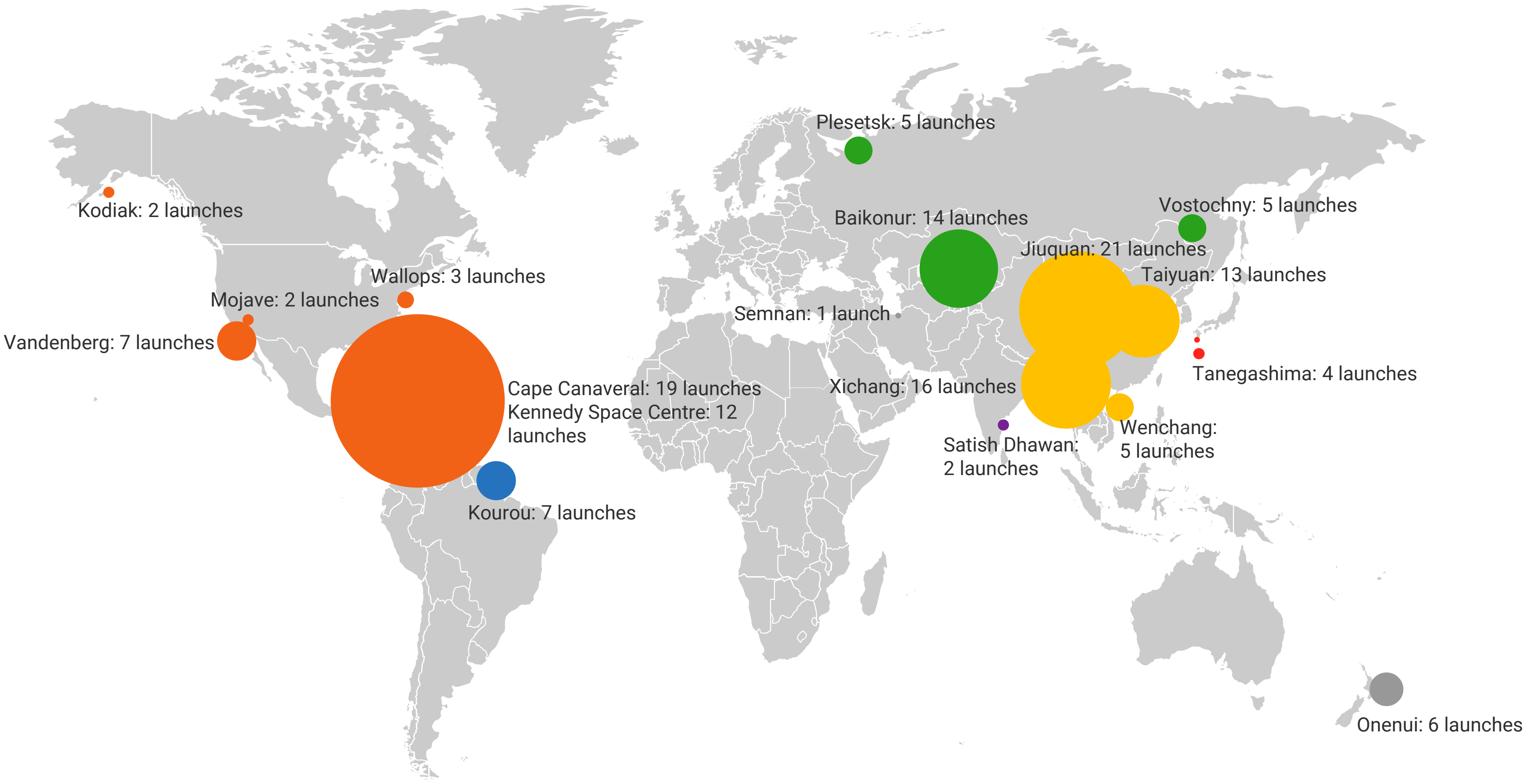


Figure 54: Number of launches per spaceport in 2021

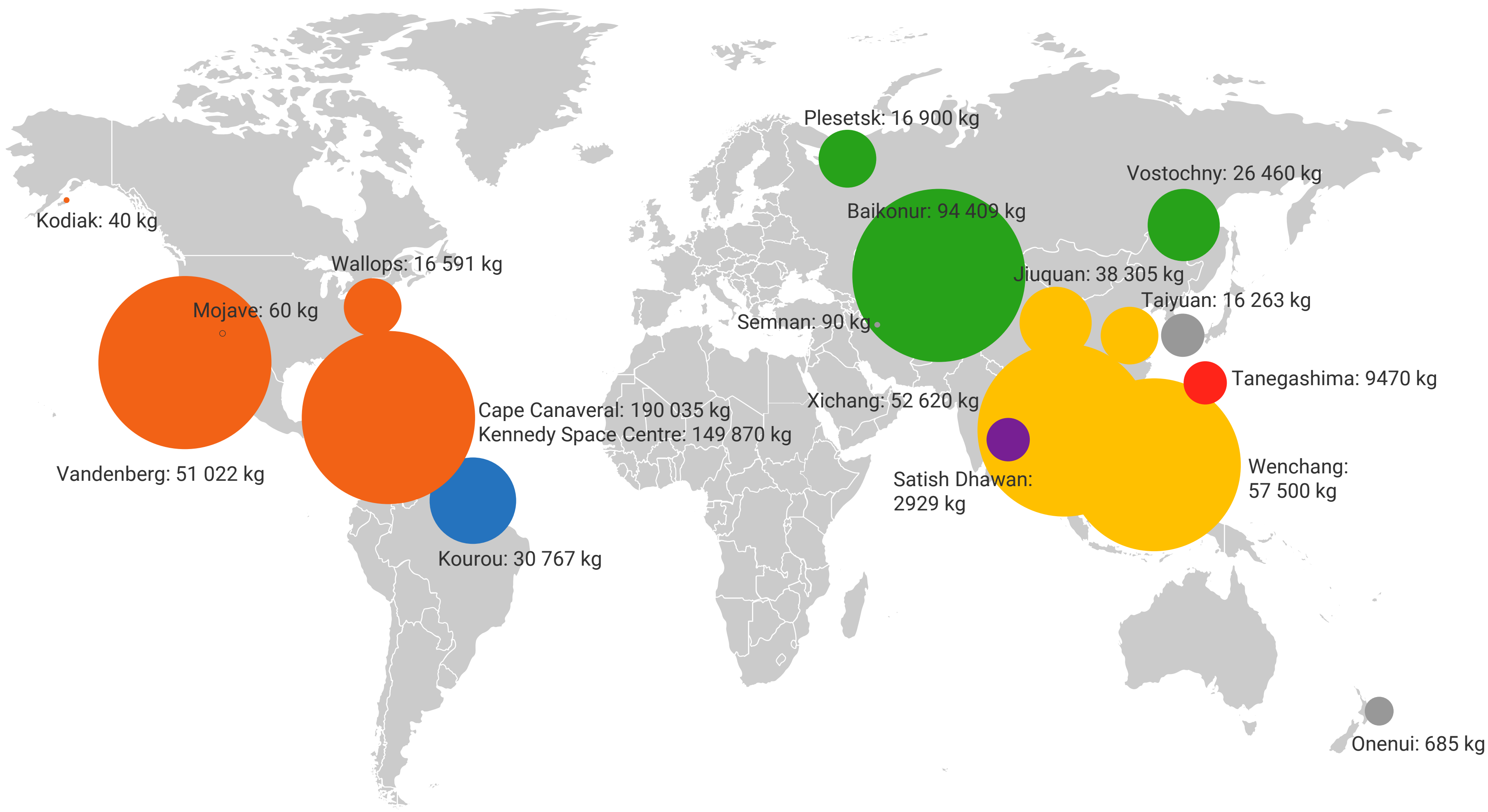


Figure 55: Total mass launched per spaceport in 2021

4.2.2 Spacecraft launched in 2021: customers and manufacturers

Spacecraft per procuring country in 2021	Mass (in tons) per procuring country in 2021

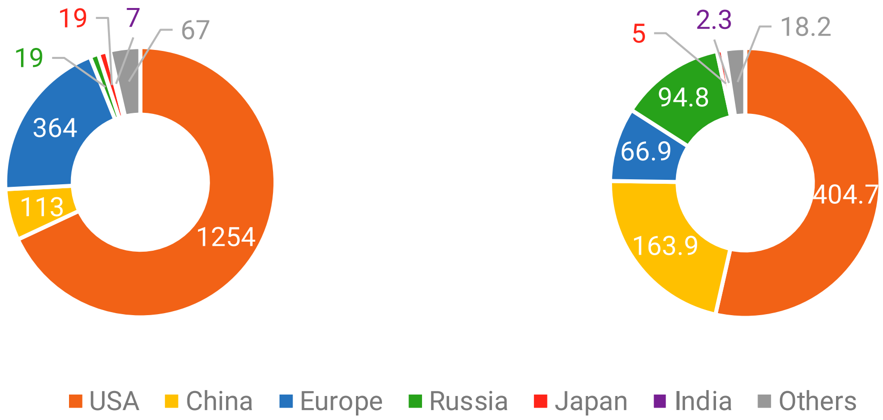


Figure 56: Number and mass of spacecraft per procuring country in 2021

The United States was the top customer country in 2021 with 1254 satellites launched for U.S. operators, accounting for over 400 tons. 68% of the spacecraft launched in 2021 were American. In terms of mass, satellites operated by U.S. organisations account for 53.5% of the mass launched, and those for China for 21.7%, while the number of satellites it procured is 11 times lower than the American one. The average weight of spacecraft launched for Chinese organisations is thus much higher than it is for their American counterparts (1451 kg vs. 323 kg).

From a manufacturing perspective, the United States has an even more prominent position, in particular in terms of number of spacecraft produced (83.4%) and, to a lesser extent, in terms of satellite mass (59.9%). It shows that, even though most of the spacecraft built by U.S. companies are for U.S. customers, several satellites launched in 2021 were also the result of U.S. exports. Of course, these high figures are primarily due to SpaceX's spacecraft (Starlink and Dragons), as the company builds the spacecraft that it operates, following its vertical integration model. Following the trend started in 2020, the company played a pivotal role in 2021 launch activity, as it alone represented 74.1% and 44.4% of the mass manufactured respectively in the United States and globally, which was put in orbit that year (in diminution compared to 2020, though).

Europe was the third biggest space systems manufacturer in 2021, but the mass of European-built satellites launched in orbit that year represents not even half of the mass launched for European operators. This is once again due to OneWeb satellites which, although being procured by a UK company, are currently manufactured by a company established in the United States. Other countries procure five times more satellites than they produced. This underlines that, despite efforts to develop their domestic industry, the growing demand from new spacefaring nations is still mainly filled by the more capable industry of leading spacefaring nations, in particular for heavy advanced systems.

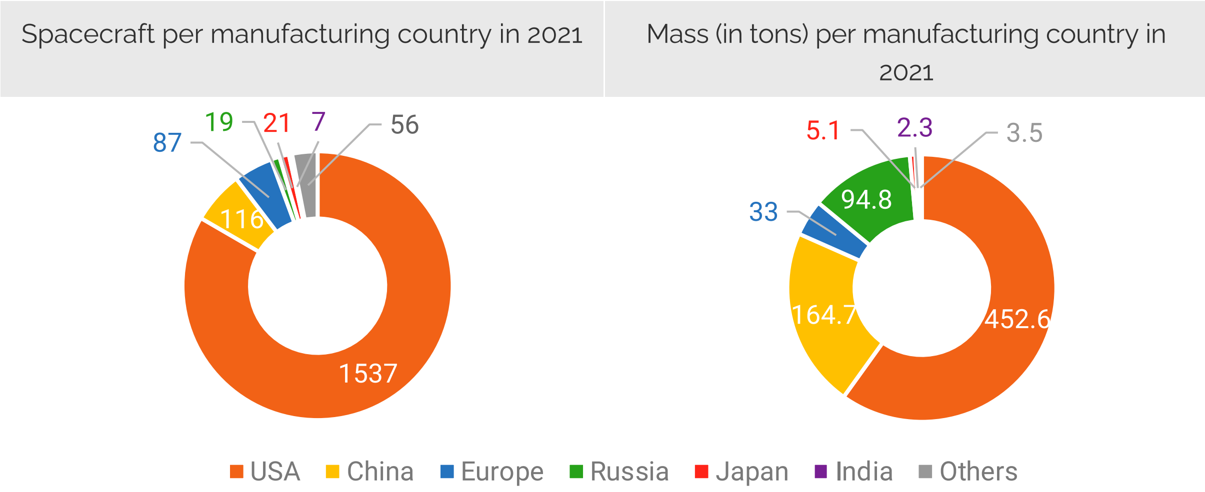


Figure 57: Number and mass of spacecraft per manufacturing country in 2021

4.2.3 Spacecraft launched in 2021: missions and markets

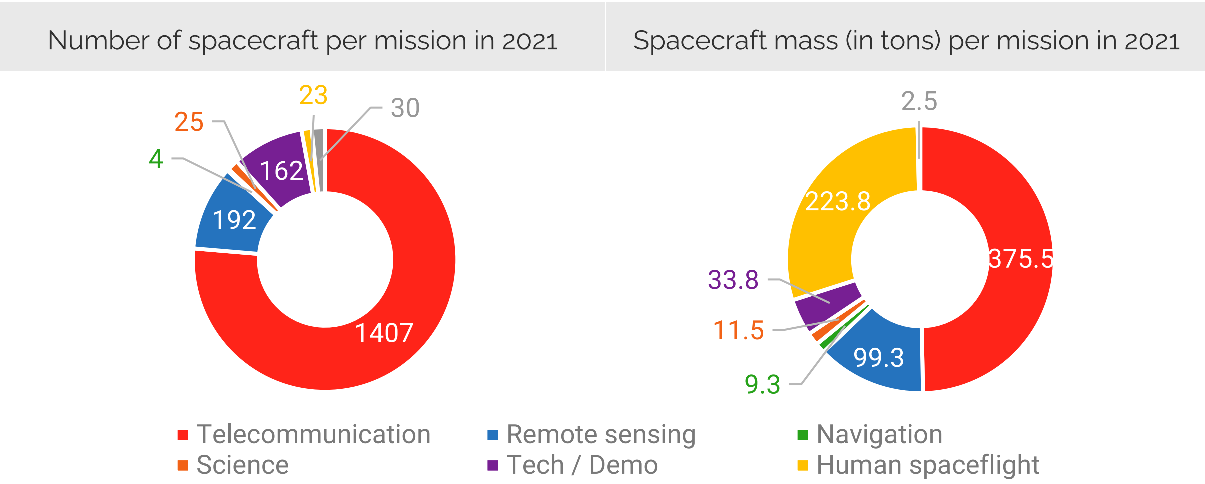


Figure 58: Number and mass of spacecraft per mission in 2021

Mainly as a result of the Starlink and OneWeb constellations, an overwhelming majority (76.3%) of the satellites launched in 2021 serve telecommunication purposes, followed to a much lesser extent by remote sensing (10.4%) and technology/demonstration spacecraft (8.8%). Telecommunication satellites represent roughly half of the total mass launched, followed by human spaceflight systems, which remain the second main category of mission in terms of mass launched (29.6%) after a noticeable increase in 2021. Interestingly, while almost as many spacecraft were launched for remote sensing missions as for technology/demonstration purposes, the mass launched for the former is almost three times higher than for the latter, showing that the average remote sensing satellite is much heavier.

Commercial satellites account for 85.5% of the satellites launched in 2021, and this is the second consecutive year that the majority of the mass launched is dedicated to the commercial market (51%), which now integrates activities previously exclusively conducted for public organisations (e.g. the crewed spaceflight launched in the "Inspiration4" mission). Slightly more than one third of the mass (37%) was launched for governmental civil purposes (77% of which for human spaceflight) and 12% for military purposes, both numbers being in line with the figures of 2020. As usual, other markets remain negligible in terms of mass launched.

Number of spacecraft per market in 2021	Spacecraft mass (in tons) per market in 2021

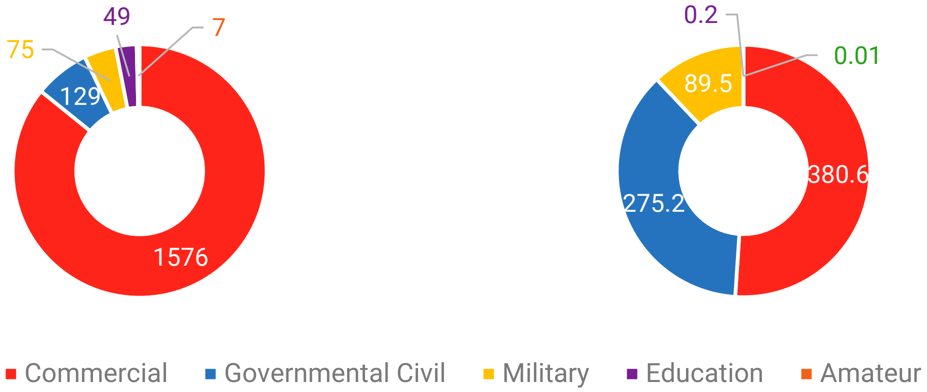


Figure 59: Number and mass of spacecraft per market in 2021 (excluding Other and Unknown missions)

4.3 Launch Log and Activity Highlights

4.3.1 ESPI launch log 2021

Launch date	Launch country	Launcher	Outcome	Spacecraft name	Customer country	Manufacturer country	Mass at launch (kg)	Orbit	Mission	Market
08/01/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Türksat 5A	Turkey	France	3500	GEO	Telecommunication	Commercial
17/01/2021	USA	LauncherOne	Success	CACTUS 1	USA	USA	2,8	LEO	Tech/Demo	Gov. Civil
				CAPE 03	USA	USA	1,3	LEO	Tech/Demo	Education
				ExoCube 2	USA	USA	3,2	LEO	Earth Science	Gov. Civil
				Fox-1E	USA	USA	1,3	LEO	Radio Amateur	Amateur
				MiTEE 1	USA	USA	3,4	LEO	Tech/Demo	Gov. Civil
				PICS (1 & 2)	USA	USA	1,35 (each)	LEO	Tech/Demo	Gov. Civil
				PolarCube	USA	USA	3,9	LEO	Tech/Demo	Gov. Civil
				Q-PACE	USA	USA	2,76	LEO	Space Science	Gov. Civil
				TechEdSat 7	USA	USA	2,5	LEO	Tech/Demo	Gov. Civil
19/01/2021	China	CZ-3B/G3	Success	Tiantong-1 03	China	China	5400	GEO	Telecommunication	Commercial
20/01/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
20/01/2021	New Zealand	Electron KS	Success	GMS-T	France	Germany	50	LEO	Tech/Demo	Commercial
24/01/2021	USA	Falcon-9 v1.2 (Block 5)	Success	ARCE-1 (A, B & C)	USA	USA	1 (each)	LEO	Tech/Demo	Gov. Civil
				ASELSAT	Turkey	Turkey	5	LEO	Tech/Demo	Military
				Astrocast 1 (5 satellites)	Switzerland	Switzerland	5 (each)	LEO	Telecommunication	Commercial
				Capella (3 & 4)	USA	USA	100 (each)	LEO	Earth Observation	Commercial
				Charlie	USA	Lithuania	8	LEO	Tech/Demo	Commercial
				Flock-4s (48 satellites)	USA	USA	5 (each)	LEO	Earth Observation	Commercial
				GHGSat-C2	Canada	Canada	15	LEO	Earth Observation	Commercial
				Hawk (2A, 2B & 2C)	USA	Canada	25 (each)	LEO	Signal Intelligence	Commercial
				Hiber 4	Netherlands	Netherlands	4	LEO	Telecommunication	Commercial
				ICEYE (X8, X9 & X10)	Finland	Finland	85 (each)	LEO	Earth Observation	Commercial
				IDEASSat	Taiwan	Taiwan	4	LEO	Earth Science	Gov. Civil
				ION-SCV 2	Italy	Italy	100	LEO	Other	Commercial
				Kepler (8 satellites)	Canada	Canada	16 (each)	LEO	Telecommunication	Commercial

				Lemur-2 (8 satellites)	USA	USA	4 (each)	LEO	Earth Observation	Commercial
				PIXL 1	Germany	Denmark	4	LEO	Tech/Demo	Gov. Civil
				Prometheus-2 10	USA	USA	2	LEO	Tech/Demo	Gov. Civil
				PTD-1	USA	USA	11	LEO	Tech/Demo	Gov. Civil
				QPS-SAR 2	Japan	Japan	100	LEO	Earth Observation	Commercial
				Sherpa-FX	USA	USA	150	LEO	Other	Commercial
				SOMP 2b	Germany	Germany	2	LEO	Tech/Demo	Education
				SpaceBEE (36 satellites)	USA	USA	0,4 (each)	LEO	Telecommunication	Commercial
				Starlink (10 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
				UVSQ-SAT	France	Netherlands	1	LEO	Tech/Demo	Gov. Civil
				V-R3x (1, 2 & 3)	USA	USA	1 (each)	LEO	Tech/Demo	Gov. Civil
				YUSAT 1	Taiwan	Taiwan	2	LEO	AIS	Gov. Civil
29/01/2021	China	CZ-4C	Success	Yaogan 31-02 (A, B & C)	China	China	500 (each)	LEO	Signal Intelligence	Military
01/02/2021	*China*	*Hyperbola-1*	*Failure*	*Unknown (3 satellites)*	*China*	*China*	*20 (each)*	*LEO*	*Unknown*	*Unknown*
02/02/2021	Russia	Soyuz-2-1b	Success	Lotos-S1 4	Russia	Russia	6000	LEO	Signal Intelligence	Military
04/02/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
04/02/2021	China	CZ-3B/G2(2)	Success	TJS 6	China	China	3000	GEO	Early Warning	Military
15/02/2021	Russia	Soyuz-2-1a	Success	Progress-MS 16	Russia	Russia	7280	LEO	Cargo Transfer	Gov. Civil
16/02/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
20/02/2021	USA	Antares-230+	Success	Cygnus CRS-15	USA	USA	8000	LEO	Cargo Transfer	Gov. Civil
				Dhabisat	UAE	UAE	1	LEO	Tech/Demo	Education
				Guaranisat-1	Paraguay	Japan	1	LEO	Earth Observation	Education
				Gunsmoke-J 2	USA	USA	5	LEO	Tech/Demo	Military
				Hirogari	Japan	Japan	2,4	LEO	Tech/Demo	Gov. Civil
				IT-SPINS	USA	USA	4	LEO	Earth Science	Gov. Civil
				Lawkanat 1	Myanmar	Japan	50	LEO	Earth Observation	Gov. Civil
				Maya-2	Philippines	Japan	1	LEO	Tech/Demo	Education
				RSP-01	Japan	Japan	1,3	LEO	Other	Amateur
				TAU-SAT 1	Israel	Israel	2	LEO	Space Science	Education
				ThinSat 2 (9 satellites)	USA	USA	1,5 (each)	LEO	Tech/Demo	Education
				Tsuru	Japan	Japan	1	LEO	Tech/Demo	Education
				TUMnanoSAT	Moldova	Moldova	1	LEO	Tech/Demo	Education
				Unknown (2 satellites)	USA	USA	5 (each)	LEO	Unknown	Military

24/02/2021	China	CZ-4C	Success	Yaogan 31-03 (A, B & C)	China	China	500 (each)	LEO	Signal Intelligence	Military
28/02/2021	Russia	Soyuz-2-1b Fregat	Success	Arktika-M 1	Russia	Russia	2100	HEO	Meteorology	Gov. Civil
28/02/2021	India	PSLV-DL	Success	Amazônia 1	Brazil	Brazil	637	LEO	Earth Observation	Gov. Civil
				SAI-1 NanoConnect-2	India	India	2	LEO	Tech/Demo	Education
				SDSAT	India	India	4	LEO	Tech/Demo	Education
				Sindhu Netra	India	India	10	LEO	AIS	Military
				SpaceBEE (12 satellites)	USA	USA	0,4 (each)	LEO	Telecommunication	Commercial
				UNITYsat 1 / JITsat	India	India	1	LEO	Telecommunication	Education
				UNITYsat 2 / GHRCEsat	India	India	1	LEO	Telecommunication	Education
				UNITYsat 3 / Sri Shakthi Sat	India	India	1	LEO	Telecommunication	Education
04/03/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
11/03/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
11/03/2021	China	CZ-7A	Success	Shiyan 9	China	China	4000	GEO	Tech/Demo	Gov. Civil
13/03/2021	China	CZ-4C	Success	Yaogan 31-04 (A, B & C)	China	China	500 (each)	LEO	Signal Intelligence	Military
14/03/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
22/03/2021	Russia	Soyuz-2-1a Fregat	Success	3B5GSAT	Spain	UK	3	LEO	Telecommunication	Commercial
				BCCSAT-1	Thailand	Thailand	1	LEO	Tech/Demo	Education
				BeeSat (4 satellites)	Germany	Germany	0,33 (each)	LEO	Tech/Demo	Education
				CANYVAL-C 1 / Pumbaa	South Korea	South Korea	3	LEO	Astronomy	Gov. Civil
				CANYVAL-C 2 / Timon	South Korea	South Korea	1	LEO	Astronomy	Gov. Civil
				CAS500-1	South Korea	South Korea	500	LEO	Earth Observation	Gov. Civil
				ChallengeOne	Tunisia	Tunisia	3	LEO	Tech/Demo	Commercial
				CubeSX-HSE / NIU VShE-DZZ	Russia	Russia	3	LEO	Tech/Demo	Education
				CubeSX-Sirius-HSE	Russia	Russia	3	LEO	Tech/Demo	Education
				DIY-1 / Arduiqube	Argentina	Argentina	0,25	LEO	Radio Amateur	Education
				DMSat 1	UAE	Canada	15	LEO	Earth Observation	Gov. Civil
				ELSA-d Chaser	Japan	Japan	175	LEO	Tech/Demo	Commercial
				ELSA-d Target	Japan	UK	17	LEO	Tech/Demo	Commercial

				FEES	Italy	Italy	0,3	LEO	Tech/Demo	Commercial
				GRBAlpha	Slovakia	Slovakia	1	LEO	Tech/Demo	Gov. Civil
				GRUS 1 (4 satellites)	Japan	Japan	100 (each)	LEO	Earth Observation	Commercial
				Hiber 3	Netherlands	Netherlands	4	LEO	Telecommunication	Commercial
				Kepler (6 & 7)	Canada	Canada	16 (each)	LEO	Telecommunication	Commercial
				KMSL	South Korea	South Korea	3	LEO	Biology	Gov. Civil
				KSU-Cubesat	Saudi Arabia	Saudi Arabia	1	LEO	Earth Observation	Education
				LacunaSat 2b	UK	UK	3	LEO	Telecommunication	Commercial
				NAJM-1	Saudi Arabia	USA	50	LEO	Tech/Demo	Education
				NanoSatC-Br 2	Brazil	Netherlands	2	LEO	Earth Science	Gov. Civil
				Orbikraft-Zorky	Russia	Russia	8	LEO	Tech/Demo	Commercial
				SAMSON (1, 2 & 3)	Israel	Israel	8	LEO	Tech/Demo	Gov. Civil
				SMOG-1	Hungary	Hungary	0,25	LEO	Tech/Demo	Education
				STECCO	Italy	Italy	0,25	LEO	Radio Amateur	Education
				Unicorn-1	UK	UK	0,5	LEO	Tech/Demo	Commercial
				UniSat 7	Italy	Italy	25	LEO	Tech/Demo	Commercial
				WildTrackCube-SIMBA	Kenya	Italy	1	LEO	Tech/Demo	Education
22/03/2021	New Zealand	Electron Photon-LEO	Success	BlackSky 7	USA	USA	56	LEO	Earth Observation	Commercial
				Centauri 3	Australia	USA	10	LEO	Telecommunication	Commercial
				Gunsmoke-J 1	USA	USA	5	LEO	Tech/Demo	Military
				Myriota 7	Australia	USA	5	LEO	Telecommunication	Commercial
				Photon Pathstone	New Zealand	New Zealand	200	LEO	Tech/Demo	Commercial
				RAAF-M2	Australia	Australia	12	LEO	Tech/Demo	Military
				Veery Hatchling	USA	USA	1	LEO	Tech/Demo	Commercial
24/03/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
25/03/2021	Russia	Soyuz-2-1b Fregat	Success	OneWeb (36 satellites)	UK	USA	147 (each)	LEO	Telecommunication	Commercial
30/03/2021	China	CZ-4C	Success	Gaofen 12-02	China	China	2400	LEO	Earth Observation	Gov. Civil
07/04/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
08/04/2021	China	CZ-4B	Success	Shiyan 6-03	China	China	1500	LEO	Tech/Demo	Military
09/04/2021	Russia	Soyuz-2-1a	Success	Soyuz-MS 18	Russia	Russia	7080	LEO	Crew Transfer	Gov. Civil
23/04/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Crew Dragon USCV-2	USA	USA	12055	LEO	Crew Transfer	Gov. Civil
25/04/2021	Russia	Soyuz-2-1b Fregat	Success	OneWeb (36 satellites)	UK	USA	147 (each)	LEO	Telecommunication	Commercial
26/04/2021	USA	Delta-4H (upg.)	Success	KH-11 18	USA	USA	17000	LEO	Earth Observation	Military

27/04/2021	China	CZ-6	Success	Foshan 1 Jinzijing 1 (-01 & -02) NEO-1 Qilu (1 & 4) Taijing-2 01 Tianqi 9 Zhongan Guotong 1 / Hangsheng 1	China China China China China China China	China China China China China China China	100 50 (each) 30 150 (each) 60 50 37	LEO LEO LEO LEO LEO LEO LEO	Tech/Demo Earth Observation Tech/Demo Earth Observation Earth Observation Telecommunication Earth Observation	Gov. Civil Commercial Commercial Gov. Civil Commercial Commercial Gov. Civil
29/04/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
29/04/2021	France	Vega	Success	BRAVO ELO Alpha Lemur-2 (2 satellites) NorSat-3 Pléiades Neo 3	USA France USA Norway France	Lithuania USA USA Canada France	6 6 4 (each) 15 920	LEO LEO LEO LEO LEO	Tech/Demo Tech/Demo Earth Observation AIS Earth Observation	Commercial Commercial Commercial Gov. Civil Commercial
29/04/2021	China	CZ-5B	Success	Tianhe	China	China	22500	LEO	Space Station Infrastructure	Gov. Civil
30/04/2021	China	CZ-4C	Success	Yaogan 34	China	China	2300	LEO	Earth Observation	Military
04/05/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
06/05/2021	China	CZ-2C(3)	Success	Tianqi 12 Yaogan 30-08 (-01, -02 & 03)	China China	China China	50 300 (each)	LEO LEO	Telecommunication Signal Intelligence	Commercial Military
09/05/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
15/05/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Capella 6 Starlink (52 satellites) Tyvak 0130	USA USA USA	USA USA USA	112 260 (each) 11	LEO LEO LEO	Earth Observation Telecommunication Tech/Demo	Commercial Commercial Commercial
15/05/2021	*New Zealand*	*Electron KS*	*Failure*	*BlackSky (8 & 9)*	*USA*	*USA*	*56 (each)*	*LEO*	*Earth Observation*	*Commercial*
18/05/2021	USA	Atlas-5(421)	Success	SBIRS-GEO 5 TDO (3 & 4)	USA USA	USA USA	4850 20 (each)	GEO GEO	Early Warning Tech/Demo	Military Military
19/05/2021	China	CZ-4B	Success	HaiYang 2D	China	China	1575	LEO	Earth Science	Gov. Civil
26/05/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (60 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
28/05/2021	Russia	Soyuz-2-1b Fregat	Success	OneWeb (36 satellites)	UK	USA	147 (each)	LEO	Telecommunication	Commercial
29/05/2021	China	CZ-7	Success	Tianzhou 2	China	China	13000	LEO	Cargo Transfer	Gov. Civil
02/06/2021	China	CZ-3B/G3	Success	FY 4B	China	China	5300	GEO	Meteorology	Gov. Civil

03/06/2021	USA	Falcon-9 v1.2 (Block 5)	Success Success Success Success Success	Dragon CRS-22 iROSA (2B & 4B) MIR-SAT 1 RamSat SOAR	USA USA Mauritius USA UK	USA USA Mauritius USA Denmark	12000 690 (each) 1 2 2	LEO LEO LEO LEO LEO	Cargo Transfer Space Station Infrastructure Earth Observation Tech/Demo Tech/Demo	Gov. Civil Gov. Civil Gov. Civil Education Gov. Civil
06/06/2021	USA	Falcon-9 v1.2 (Block 5)	Success	SXM 8	USA	USA	7000	GEO	Telecommunication	Commercial
11/06/2021	China	CZ-2D(2)	Success	Beijing 3 Haisi 2 Taikong Shiyan 1 / TKSY01-TJ Yangwang 1	Singapore China China China	China China China China	500 185 20 42	LEO LEO LEO LEO	Earth Observation Earth Observation Tech/Demo Astronomy	Commercial Gov. Civil Education Commercial
13/06/2021	USA	Pegasus-XL	Success	Odyssey / TacRL-2	USA	USA	200	LEO	Space Situational Awareness	Military
15/06/2021	USA	Minotaur-1	Success	USA (316, 317 & 318)	USA	USA	150 (each)	LEO	Unknown	Military
17/06/2021	USA	Falcon-9 v1.2 (Block 5)	Success	GPS-3 5	USA	USA	3880	MEO	Navigation	Military
17/06/2021	China	CZ-2F/G	Success	Shenzhou 12	China	China	8082	LEO	Crew Transfer	Gov. Civil
18/06/2021	China	CZ-2C(3)	Success	Tianqi 14 Yaogan 30-09 (-01, -02 & -03)	China China	China China	50 300 (each)	LEO LEO	Telecommunication Signal Intelligence	Commercial Military
25/06/2021	Russia	Soyuz-2-1b	Success	Kosmos 2550 / Pion-NKS 1	Russia	Russia	6500	LEO	Earth Observation	Military
29/06/2021	Russia	Soyuz-2-1a	Success	Progress-MS 17	Russia	Russia	7280	LEO	Cargo Transfer	Gov. Civil
30/06/2021	USA	Falcon-9 v1.2 (Block 5)	Success	ARTHUR 1 Astrocast (5 satellites) Capella 5 Centauri 4 D2 / AtlaCom-1 EG 3 Faraday Phoenix Ghalib GNOMES 2 Hawk (3A, 3B & 3C) ICEYE (4 satellites) ION-SCV 3	Belgium Switzerland USA Australia International Australia UK UAE USA USA Finland Italy	Belgium Switzerland USA USA Lithuania USA Denmark Netherlands USA Canada Finland Italy	20 4 (each) 112 8 8 8 10 3 30 25 (each) 85 (each) 100	LEO LEO LEO LEO LEO LEO LEO LEO LEO LEO LEO LEO	Tech/Demo Telecommunication Earth Observation Telecommunication Tech/Demo Telecommunication Tech/Demo Tech/Demo Meteorology Signal Intelligence Earth Observation Other	Commercial Commercial Commercial Commercial Commercial Commercial Commercial Commercial Commercial Commercial Commercial Commercial

				KSF 1 (4 satellites)	Luxembourg	Netherlands	8 (each)	LEO	Signal Intelligence	Commercial
				Lemur-2 (6 satellites)	USA	USA	4 (each)	LEO	Earth Observation	Commercial
				LINCS (A & B)	USA	USA	15 (each)	LEO	Tech/Demo	Military
				Lynk 06	USA	USA	60	LEO	Tech/Demo	Commercial
				Mandrake (2A & 2B)	USA	USA	50 (each)	LEO	Tech/Demo	Military
				NAPA 2	Thailand	Netherlands	10	LEO	Earth Observation	Military
				Neptuno	Spain	Spain	4	LEO	Tech/Demo	Gov. Civil
				ÑuSat (4 satellites)	Argentina	Argentina	40 (each)	LEO	Earth Observation	Commercial
				PACE-1	USA	USA	8	LEO	Tech/Demo	Gov. Civil
				Painani-II	Mexico	Mexico	3	LEO	Tech/Demo	Gov. Civil
				QMR-KWT	Kuwait	UAE	1	LEO	Radio Amateur	Education
				Shasta	USA	USA	22,5	LEO	Tech/Demo	Commercial
				Sherpa-FX 2	USA	USA	120	LEO	Other	Commercial
				Sherpa-LTE 1	USA	USA	203	LEO	Other	Commercial
				SpaceBEE (28 satellites)	USA	USA	0,4 (each)	LEO	Telecommunication	Commercial
				Spartan	Bulgaria	Bulgaria	6	LEO	Other	Commercial
				Starlink (3 satellites)	USA	USA	260 (each)	LEO	Telecommunication	Commercial
				Tenzing	USA	USA	35	LEO	Tech/Demo	Commercial
				Tiger-2	Luxembourg	Lithuania	6	LEO	Telecommunication	Commercial
				TROPICS Pathfinder	USA	USA	4	LEO	Tech/Demo	Gov. Civil
				TUBIN	Germany	Germany	17	LEO	Tech/Demo	Gov. Civil
				Umbra-SAR 2001	USA	USA	50	LEO	Earth Observation	Commercial
				W-Cube	Finland	Finland	4	LEO	Tech/Demo	Gov. Civil
				YAM 2	USA	USA	80	LEO	Other	Commercial
				YAM 3	USA	USA	83	LEO	Other	Commercial
30/06/2021	USA	LauncherOne	Success	Brik-2	Netherlands	Netherlands	6	LEO	Tech/Demo	Military
				Gunsmoke-J 3	USA	USA	6	LEO	Tech/Demo	Military
				STORK (4 & 5)	Poland	Poland	3 (each)	LEO	Earth Observation	Commercial
				STP-27VPA (2, 3 & 4)	USA	USA	6 (each)	LEO	Tech/Demo	Military
01/07/2021	Russia	Soyuz-2-1b Fregat	Success	OneWeb (36 satellites)	UK	USA	147 (each)	LEO	Telecommunication	Commercial
03/07/2021	China	CZ-2D(2)	Success	Jilin-1 Gaofen-03D (-01, -02 & -03)	China	China	40 (each)	LEO	Earth Observation	Commercial
				Jilin-1 Kuanfu-01B	China	China	1300	LEO	Earth Observation	Commercial
				Xingshidai 10	China	China	10	LEO	Earth Observation	Commercial
04/07/2021	China	CZ-4C	Success	FY 3E	China	China	2300	LEO	Meteorology	Gov. Civil

06/07/2021	China	CZ-3C/G2	Success	TL 1E	China	China	2400	GEO	Satellite Data Relay	Gov. Civil
09/07/2021	China	CZ-6	Success	Ningxia-1 (5 satellites)	China	China	120 (each)	LEO	Signal Intelligence	Commercial
19/07/2021	China	CZ-2C(3)	Success	Tianqi 15 Yaogan 30-10 (-01, -02 & -03)	China China	China China	50 300 (each)	LEO LEO	Telecommunication Signal Intelligence	Commercial Military
21/07/2021	Russia	Proton-M	Success	MLM-U / Nauka	Russia	Russia	20350	LEO	Space Station Infrastructure	Gov. Civil
29/07/2021	China	CZ-2D(2)	Success	Tianhui 1-04	China	China	700	LEO	Earth Observation	Military
29/07/2021	New Zealand	Electron KS	Success	Monolith	USA	USA	10	LEO	Tech/Demo	Military
30/07/2021	France	Ariane-5ECA+	Success	Eutelsat Quantum Star One D2	France Brazil	France USA	3461 6190	GEO GEO	Telecommunication Telecommunication	Commercial Commercial
03/08/2021	*China*	*Hyperbola-1*	*Failure*	*Jilin-1 Mofang-01A*	*China*	*China*	*18*	*LEO*	*Tech/Demo*	*Commercial*
05/08/2021	China	CZ-6	Success	KL-Beta (A & B)	Germany	China	120 (each)	LEO	Tech/Demo	Commercial
05/08/2021	China	CZ-3B/G3	Success	ZhongXing 02E / ShenTong 2E	China	China	5000	GEO	Telecommunication	Military
10/08/2021	USA	Antares-230+	Success	Cygnus CRS-16 PIRPL	USA USA	USA USA	8000 48	LEO LEO	Cargo Transfer Tech/Demo	Gov. Civil Military
11/08/2021	*India*	*GSLV Mk.2(4)*	*Failure*	*GISAT 1 / EOS 3*	*India*	*India*	*2268*	*GEO*	*Earth Observation*	*Gov. Civil*
17/08/2021	France	Vega	Success	BRO 4 LEDSAT Pléiades Neo 4 RADCUBE Sunstorm	France Italy France Europe Europe	Denmark Italy France Hungary Finland	6 1 920 3 2	LEO LEO LEO LEO LEO	Signal Intelligence Tech/Demo Earth Observation Tech/Demo Tech/Demo	Commercial Gov. Civil Commercial Gov. Civil Gov. Civil
18/08/2021	China	CZ-4B	Success	Tianhui 2-02 (A & B)	China	China	1500 (each)	LEO	Earth Observation	Gov. Civil
21/08/2021	Russia	Soyuz-2-1b Fregat	Success	OneWeb (34 satellites)	UK	USA	147 (each)	LEO	Telecommunication	Commercial
24/08/2021	China	CZ-2C(3)/YZ-1S	Success	RSW (1 & 2) Unknown (China)	China China	China China	350 (each) 50	LEO LEO	Tech/Demo Tech/Demo	Gov. Civil Gov. Civil
24/08/2021	China	CZ-3B/G3	Success	TJS 7	China	China	3000	GEO	Early Warning	Military
28/08/2021	*USA*	*Astra Rocket-3*	*Failure*	*STP-27AD1*	*USA*	*USA*	*20*	*LEO*	*Other*	*Military*
29/08/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Binar-1 CAPSat CUAVA 1	Australia USA Australia	Australia USA Australia	1 4 3	LEO LEO LEO	Tech/Demo Tech/Demo Tech/Demo	Gov. Civil Gov. Civil Education

				Dragon-CRS 23 IOD-AMBER Maya (3 & 4) PR-CuNaR2 SPACE-HAUC	USA UK Philippines Puerto Rico USA	USA Sweden Philippines Puerto Rico USA	12000 6 1 (each) 3 4	LEO LEO LEO LEO LEO	Cargo Transfer Tech/Demo Tech/Demo Space Science Tech/Demo	Gov. Civil Commercial Education Gov. Civil Education
02/09/2021	*USA*	*Firefly Alpha*	*Failure*	*BSS 1* *FossaSat 1b* *FossaSat 2* *GENESIS (-L & -N)* *Hiapo* *Qubik (1 & 2)* *Serenity* *Spinnaker-3*	*USA* *Spain* *Spain* *Spain* *USA* *Greece* *USA* *USA*	*USA* *Spain* *Spain* *Spain* *USA* *Greece* *USA* *USA*	*3* *0,25* *0,5* *0,4 (each)* *1* *0,2 (each)* *4* *25*	*LEO* *LEO* *LEO* *LEO* *LEO* *LEO* *LEO* *LEO*	*Tech/Demo* *Tech/Demo* *Tech/Demo* *Radio Amateur* *Tech/Demo* *Tech/Demo* *Radio Amateur* *Tech/Demo*	*Commercial* *Commercial* *Commercial* *Amateur* *Education* *Amateur* *Education* *Gov. Civil*
07/09/2021	China	CZ-4C	Success	Gaofen 5-02	China	China	1000	LEO	Earth Observation	Gov. Civil
09/09/2021	Russia	Soyuz-2-1v	Success	Kosmos 2551 / Razbeg	Russia	Russia	500	LEO	Earth Observation	Military
09/09/2021	China	CZ-3B/G2(2)	Success	ZX 9B / ChinaSat 9B	China	China	5500	GEO	Telecommunication	Commercial
14/09/2021	Russia	Soyuz-2-1b Fregat	Success	OneWeb (34 satellites)	UK	USA	147 (each)	LEO	Telecommunication	Commercial
14/09/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (51 satellites)	USA	USA	295 (each)	LEO	Telecommunication	Commercial
15/09/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Inspiration4	USA	USA	12055	LEO	Space Tourism	Commercial
20/09/2021	China	CZ-7	Success	Tianzhou 3	China	China	12000	LEO	Cargo Transfer	Gov. Civil
27/09/2021	China	Kuaizhou-1A	Success	Jilin-1 Gaofen-02D	China	China	230	LEO	Earth Observation	Commercial
27/09/2021	USA	Atlas-5(401)	Success	Landsat 9 Cesium Satellite (1 & 2) CuPID CUTE	USA USA USA USA	USA USA USA USA	2864 6 (each) 6 6	LEO LEO LEO LEO	Earth Observation Tech/Demo Space Science Astronomy	Gov. Civil Commercial Gov. Civil Gov. Civil
27/09/2021	China	CZ-3B/G2(2)	Success	Shiyan 10	China	China	4000	GEO	Tech/Demo	Unknown
05/10/2021	Russia	Soyuz-2-1a	Success	Soyuz MS-19	Russia	Russia	7080	LEO	Crew Transfer	Gov. Civil
14/10/2021	China	CZ-2D(2)	Success	CHASE / Xihe HEAD (2E & 2F) Jinzijing 2 JTSY / MOTS MD 1 QX 1	China China China China China China	China China China China China China	550 45 147 103 25 50	LEO LEO LEO LEO LEO LEO	Space Science AIS Telecommunication Tech/Demo Tech/Demo Tech/Demo	Gov. Civil Commercial Commercial Gov. Civil Commercial Commercial

				SSS 1 SSS 2A Tianshu 1 Tianyuan 1	China China China China	China China China China	30 4 50 6	LEO LEO LEO LEO	Tech/Demo Tech/Demo Tech/Demo Tech/Demo	Education Education Commercial Education
14/10/2021	Russia	Soyuz-2-1b Fregat	Success	OneWeb (36 satellites)	UK	USA	147 (each)	LEO	Telecommunication	Commercial
16/10/2021	USA	Atlas-5(401)	Success	Lucy	USA	USA	1550	Escape	Planetary Science	Gov. Civil
16/10/2021	China	CZ-2F/G	Success	Shenzhou 13	China	China	8082	LEO	Crew Transfer	Gov. Civil
21/10/2021	*South Korea*	*Nuri*	*Failure*	*Unknown (South Korea)*	*South Korea*	*South Korea*	*1500*	*LEO*	*Tech/Demo*	*Gov. Civil*
24/10/2021	France	Ariane-5ECA+	Success	SES 17 Syracuse-4A	Luxembourg France	France France	6411 3852	GEO GEO	Telecommunication Telecommunication	Commercial Military
24/10/2021	China	CZ-3B/G2(2)	Success	ShiJian 21	China	China	5000	GEO	Tech/Demo	Gov. Civil
26/10/2021	Japan	H-2A-202	Success	QZS 1R / Michibiki 1R	Japan	Japan	4000	MEO	Navigation	Gov. Civil
27/10/2021	China	Kuaizhou-1A	Success	Jilin-1 Gaofen-02F	China	China	230	LEO	Earth Observation	Commercial
28/10/2021	Russia	Soyuz-2-1a	Success	Progress-MS 18	Russia	Russia	7280	LEO	Cargo Transfer	Gov. Civil
03/11/2021	China	CZ-2C(3)/YZ-1S	Success	Yaogan 32-02 (-01 & -02)	China	China	1500 (each)	LEO	Signal Intelligence	Military
05/11/2021	China	CZ-6	Success	Guangmu 1 / CASEarth	China	China	753	LEO	Earth Science	Gov. Civil
06/11/2021	China	CZ-2D(2)	Success	Yaogan (35A, 35B & 35C)	China	China	750 (each)	LEO	Earth Observation	Military
09/11/2021	Japan	Epsilon-2 CLPS	Success	ARICA ASTERISC DRUMS Hibari KOSEN 1 NanoDragon RAISE 2 TeikyoSat 4 Z-Sat	Japan Japan Japan Japan Japan Vietnam Japan Japan Japan	Japan Japan Japan Japan Japan Vietnam Japan Japan Japan	1 4 62 55 3 4 110 52 46	LEO LEO LEO LEO LEO LEO LEO LEO LEO	Tech/Demo Space Science Tech/Demo Tech/Demo Astronomy Tech/Demo Tech/Demo Tech/Demo Tech/Demo	Gov. Civil Gov. Civil Commercial Gov. Civil Gov. Civil Gov. Civil Gov. Civil Gov. Civil Commercial
11/11/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Crew Dragon USCV-3	USA	USA	12055	LEO	Crew Transfer	Gov. Civil
13/11/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (53 satellites)	USA	USA	295 (each)	LEO	Telecommunication	Commercial
16/11/2021	France	Vega	Success	CERES (1, 2 & 3)	France	France	446 (each)	LEO	Signal Intelligence	Military

18/11/2021	New Zealand	Electron KS	Success	BlackSky (10 & 11)	USA	USA	56 (each)	LEO	Earth Observation	Commercial
20/11/2021	USA	Astra Rocket-3	Success	STP27-AD2	USA	USA	20	LEO	Other	Military
20/11/2021	China	CZ-4B	Success	Gaofen 11-03	China	China	805	LEO	Earth Observation	Gov. Civil
22/11/2021	China	CZ-4C	Success	Gaofen 3-02	China	China	2950	LEO	Earth Observation	Gov. Civil
24/11/2021	Russia	Soyuz-2-1b	Success	UM / Prichal	Russia	Russia	8180	LEO	Space Station Infrastructure	Gov. Civil
24/11/2021	China	Kuaizhou-1A	Success	Shiyan 11	China	China	250	LEO	Tech/Demo	Unknown
24/11/2021	USA	Falcon-9 v1.2 (Block 5)	Success	DART (Asteroid) LICIACube	USA Italy	USA Italy	500 14	Escape Escape	Planetary Science Planetary Science	Gov. Civil Gov. Civil
25/11/2021	Russia	Soyuz-2-1b Fregat	Success	Kosmos 2552	Russia	Russia	1500	HEO	Early Warning	Military
26/11/2021	China	CZ-3B/G3	Success	ZhongXing 01D/FengHuo 02D	China	China	5320	GEO	Telecommunication	Military
02/12/2021	USA	Falcon-9 v1.2 (Block 5)	Success	BlackSky (12 & 13) Starlink (48 satellites)	USA USA	USA USA	56 (each) 295 (each)	LEO LEO	Earth Observation Telecommunication	Commercial Commercial
05/12/2021	France	Soyuz-ST-B Fregat-MT	Success	Galileo (27 & 28) / Galileo-FOC (FM23 & FM24)	Europe	Germany	733 (each)	MEO	Navigation	Gov. Civil
07/12/2021	USA	Atlas-5(551)	Success	ASCENT LDPE-1 STPSat 6	USA USA USA	USA USA USA	15 850 2572	GEO GEO GEO	Tech/Demo Tech/Demo Tech/Demo	Military Military Military
07/12/2021	China	Ceres-1	Success	Baoyun Jinzijing (1-03 & 5) Lize 1 Tianjin Daxue 1 / Tianjin University-1	China China China China	China China China China	20 50 8 40	LEO LEO LEO LEO	Tech/Demo Earth Observation Tech/Demo Earth Observation	Commercial Commercial Commercial Gov. Civil
08/12/2021	Russia	Soyuz-2-1a	Success	Soyuz-MS 20	Russia	Russia	7080	LEO	Crew Transfer	Gov. Civil
09/12/2021	USA	Falcon-9 v1.2 (Block 5)	Success	IXPE	USA	USA	337	LEO	Astronomy	Gov. Civil
09/12/2021	New Zealand	Electron KS	Success	BlackSky (14 & 15)	USA	USA	56 (each)	LEO	Earth Observation	Commercial
10/12/2021	China	CZ-4B	Success	ShiJian 6-05 (A & B)	China	China	1200 (each)	LEO	Tech/Demo	Military
13/12/2021	Russia	Proton-M Briz-M (Ph.1 mod. 2)	Success	Ekspress-AMU 3 Ekspress-AMU 7	Russia Russia	Russia Russia	2150 1980	GEO GEO	Telecommunication Telecommunication	Commercial Commercial

13/12/2021	China	CZ-3B/G3	Success	TianLian 2B	China	China	600	GEO	Telecommunication	Gov. Civil
15/12/2021	*China*	*Kuaizhou-1A*	*Failure*	*GeeSAT (1A & 1B)*	*China*	*China*	*130 (each)*	*LEO*	*Tech/Demo*	*Commercial*
18/12/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Starlink (52 satellites)	USA	USA	295 (each)	LEO	Telecommunication	Commercial
19/12/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Türksat 5B	Turkey	France	4500	GEO	Telecommunication	Commercial
21/12/2021	USA	Falcon-9 v1.2 (Block 5)	Success	Dragon CRS-24 DAILI FEES 2 GASPACS GT-1 Light 1 PATCOOL STP-H7 STP-H8 TARGIT	USA USA Italy USA USA UAE USA USA USA USA	USA USA Italy USA USA Lithuania USA USA USA USA	11000 6 0,3 1 1 3 3 550 350 3	LEO LEO LEO LEO LEO LEO LEO LEO LEO LEO	Cargo Transfer Earth Science Tech/Demo Tech/Demo Tech/Demo Earth Science Tech/Demo Other Other Tech/Demo	Gov. Civil Gov. Civil Commercial Education Education Gov. Civil Gov. Civil Gov. Civil Gov. Civil Gov. Civil
22/12/2021	Japan	H-2A-204	Success	Inmarsat-6 F1	UK	France	5470	GEO	Telecommunication	Commercial
23/12/2021	China	CZ-7A	Success	Shiyan 12 (-01 & -02)	China	China	3000 (each)	GEO	Tech/Demo	Unknown
25/12/2021	France	Ariane-5ECA+	Success	James Webb Space Telescope	USA	USA	6162	Escape	Astronomy	Gov. Civil
26/12/2021	China	CZ-4C	Success	XW 3 / CAS 9 ZY-1 02E	China China	China China	6 1500	LEO LEO	Radio Amateur Earth Observation	Amateur Gov. Civil
27/12/2021	Russia	Soyuz-2-1b Fregat	Success	OneWeb (36 satellites)	UK	USA	147 (each)	LEO	Telecommunication	Commercial
27/12/2021	*Russia*	*Angara-A5 Persei*	*Failure*	*IPN 1*	*Russia*	*Russia*	*2400*	*GEO*	*Tech/Demo*	*Gov. Civil*
29/12/2021	China	CZ-2D(2)	Success	Tianhui 4	China	China	1000	LEO	Earth Observation	Military
29/12/2021	China	CZ-3B/G3	Success	TJS 9	China	China	3000	GEO	Signal Intelligence	Military
30/12/2021	*Iran*	*Simorgh*	*Failure*	*Unknown (3 satellites)*	*Iran*	*Iran*	*30 (each)*	*LEO*	*Tech/Demo*	*Gov. Civil*

4.3.2 ESPI Database definitions

Launch outcome

- Success: launch attempt performed nominally, spacecraft injected in the intended orbit.
- Failure: launch attempt led to the loss of the payloads (destruction, unrecoverable orbit).
- Partial failure: launch attempt led to a recoverable harm for the payloads (damage, orbit).

System categories

- Satellite: standard spacecraft designed to orbit the Earth and comprised of a bus/platform and one or more payloads.
- Cubesat: spacecraft designed according to the cubesat standard and comprised of one or more units (U) of 10x10x10cm.
- Space Station Module: element of a space station including habitats, nodes, structure, external platforms and other permanent or temporary parts.
- Transfer Vehicle: spacecraft designed to transfer cargo or humans to a space station.
- Space Exploration System: specific spacecraft designed for space exploration purposes including probes, landers, rovers and other systems with a mission outside Earth orbit.
- Space Plane: reusable spacecraft with advanced manoeuvring capabilities including the capacity to land autonomously.
- Servicing Vehicle: spacecraft with advanced Rendezvous and Proximity Operations capabilities, designed to provide services to other satellites (e.g. life extension, refuelling, inspection).
- Dummy payload: passive object without operational payload (e.g. mockup, passive target…).
- Attached package: system remaining attached to the launcher upper stage.

Mass categories

- Large spacecraft (>500kg)
  - Extra heavy-class: More than 8,000kg
  - Heavy-class: Between 2,000 and 8,000kg
  - Medium-class: Between 500 and 2,000kg
- Small spacecraft (<500kg)
  - Mini-class: Between 100 and 500kg
  - Micro-class: Between 10 and 100kg
  - Nano-class: Less than 10kg

Orbits

- GEO: an orbit at an altitude of approximately 36 000 km from Earth.
- MEO: an orbit at an altitude between 2000 and 36 000 km from Earth.
- LEO: an orbit at an altitude between 100 and 2000 km from Earth.
- HEO: highly elliptical orbit, an elliptical orbit with a high eccentricity.
- Escape: an orbit beyond Earth orbit with an eccentricity higher than 1.

Missions

- Telecommunication
  - Telecommunication services by satellites
  - Automatic Identification System: detection and tracking of ships
  - Satellite Data Relay:telecommunication relay for other satellites
- Remote sensing
  - Earth Observation: observation of the Earth for an operational purpose (not scientific)
  - Meteorology: study of the Earth atmosphere with a focus on weather forecast (not scientific)
- Navigation
  - Navigation: Global Navigation Space Systems (GNSS) and Satellite-Based Augmentation Systems
- Human spaceflight
  - Cargo Transfer: transfer of supplies to a space station
  - Crew Transfer: transfer of astronauts to a space station
  - Space Station Infrastructure: supply of a space station's element
- Science
  - Astronomy: remote study of celestial bodies and phenomena
  - Biology: study of life and living organisms
  - Earth Science: study of the Earth
  - Planetary Science: study of planets, moons, asteroids, comets
  - Space Science: study of the space environment and of the functioning of the Universe
- Military-specific
  - Early Warning: detection of missile launches through infrared observation
  - Signal Intelligence: interception of electronic signals
  - Space Situational Awareness: detection and tracking of objects in orbit
- Technology / Demonstration
  - Technology / Demonstration: testing of new systems or technologies
- Other
  - In-Orbit Servicing: provision of services to another spacecraft
  - Radio Amateur: radiocommunication for amateur purpose
  - Other/Unknown: missions not falling in the above definitions

Markets

- Governmental civil: the spacecraft is primarily intended to serve the mission of an organisation providing a public service or having scientific research objectives.
- Military: the spacecraft is primarily intended to serve armed forces operational needs.
- Commercial: the spacecraft is primarily intended to serve a commercial market and to make profit.
- Education: the spacecraft is primarily intended to serve an academic or training purpose from system design to operation.
- Dual: the spacecraft is intended to serve both military and civil purposes.

4.4 Space Activity Highlights in 2021

Virgin Orbit succeeds in putting a payload in orbit for the first time


Credit: Virgin Orbit/Greg Robinson

After a first failed attempt in May 2020, Virgin Orbit successfully launched its **LauncherOne** rocket for the first time on January 17th, 2021. Contrary to other small launch companies, Virgin Orbit offers an air-launch system, meaning that the rocket launches from under a flying plane and not vertically from a spaceport. With this success, LauncherOne was the first liquid-fuelled, horizontally-launched rocket, to reach orbit. During the mission, Virgin Orbit deployed ten spacecraft built by universities and launched in the frame of NASA's Educational Launch of Nanosatellites (ELaNa) programme. The system launched again, successfully, on June 30th.

A remarkable launch for India

Credit: NewSpace India Ltd.

On February 28th, a PSLV rocket carrying one satellite for Brazil and 18 secondary payloads for Indian and American customers was launched by ISRO from the Satish Dhawan Centre. This launch was a first **for several reasons**: it was the first launch of India for the year 2021; it was the first dedicated commercial PSLV mission commissioned by NewSpace India Limited, a public company established under the Indian Department of Space in 2019; finally, the primary payload, the Amazônia-1 satellite, is the first satellite entirely developed by Brazil, to be used for the monitoring of deforestation in the Amazon region.


Credit: CASC

Long March 7A successfully reaches orbit

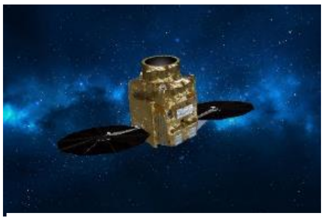
On March 11th, the second launch of the new **Long March 7A** rocket successfully reached orbit for the first time, one year after the first flight of the rocket in March 2020 failed because of a loss of pressure after upper stage separation. The rocket is able to launch up to 7 tons to a geostationary transfer orbit and can be used for lunar and deep space missions as well as future Beidou launches in highly elliptical orbit. Long March 7A is part of the new generation of Chinese launchers, which uses liquid propulsion. Chinese authorities have been secretive about the payload to be launched and have described it as a "technology verification" spacecraft.

OneWeb continues the deployment of its constellation


Credit: OneWeb

On March 25th, for the first 2021 launch of Arianespace, 36 more OneWeb satellites were put in orbit with a Soyuz spacecraft launched from the Cosmodrome of Vostochny, in Russia. This was the second launch for OneWeb since the company has emerged from bankruptcy in November 2020 and resumed launches in December 2020. With **another launch** conducted on July 1st by Arianespace, the company was able to deliver its high-speed low-latency connectivity services above the 50th parallel, which includes regions such as the United Kingdom, Canada, Alaska, Northern Europe, Greenland, and the Arctic Region. In some of these places, demonstrations of the service took place later in the year. The company has now launched 428 satellites in orbit.

Return to flight for Vega

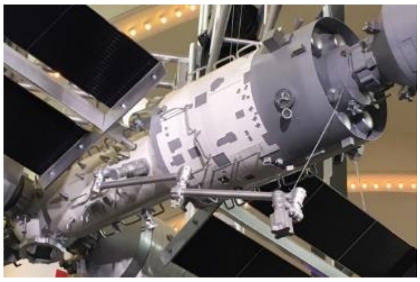


Credit: Airbus

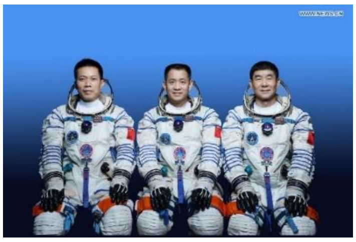
On April 29th, the European launcher Vega performed its **first flight since its failure** in November 2020. The launch proceeded without any issue. Its primary payload was the first satellite of Airbus' Pléiades Neo constellation (Pléiades Neo 3), which was launched together with five small spacecraft. These optical imagery satellites will provide images with a resolution of 30 centimetres to the commercial market, a feature that only Maxar is currently offering. Pléiades Neo is an important project for Airbus, as it represents its largest private investment, for a constellation cost of €600-700M, and will be used for the next 10-12 years. Unfortunately, Pléiades Neo 3 suffered an **equipment issue** little time after (but not related to) launch, which led Airbus to file an insurance claim for the satellite. However, this issue has not affected the capacity of the satellite to meet customers' commitments, according to the company.

China launches Tianhe

On April 29th, a Long March 5B rocket sent to low-Earth orbit **Tianhe, the core module** of the new Chinese Space Station. Tianhe weighs 22 tons and its length is of 16.6 meters. It represents a next step for China in human spaceflight, as the previous manned laboratory of the country weighed only 8 tons. Tianhe will be complemented by two experimental modules, called Wentian and Mengtian. Moreover, Xuntian, a Hubble-class space telescope, is also planned and will be able to dock to the station. Overall, eleven launches will be necessary to build the whole space station, which will weigh around 66 tons. Although the launch proceeded without any major issue, **the uncontrolled re-entry** of the core stage of the launcher created some concern. This problem also happened in May 2020, after the first launch of the Long March 5B rocket.



Credit: China Space Report



Credit: Xu Bu/Xinhua

Following the launch of Tianhe, a first cargo mission was sent to the outpost in May, and the first crewed mission, **Shenzhou 12**, was launched on June 16th. The crew, which was composed of three astronauts, including two veterans, reached the station in six hours and a half and remained onboard for three months. It was followed by **Shenzhou 13** in October, which stayed six months in orbit, the longest duration for Chinese taikonauts since the start of the country's space programme. Shenzhou 13 is also considered as the last mission of the "technology demonstration phase" of the Tiangong space station programme. Both crews have conducted several spacewalks, including the first one for a Chinese woman.

SpaceX reaches two major milestones

On May 9th, SpaceX launched a new group of 60 Starlink satellites with a Falcon 9 and recovered the booster used for the launch. This launch was a milestone for the company, as this was **the 10th time** that this booster was used, an objective set in 2018 by the company for its reusability efforts: a booster should fly ten times before requiring significant maintenance.

Credit: Stephen Marr/NASASpaceflight.com

However, more recently, Elon Musk announced that Falcon 9's first stages could now be launched until they fail, to be able to identify their limits. They would nonetheless be used on Starlink launches to avoid losing the payload of a customer. Moreover, on May 26th, SpaceX reached two other milestones. First, it performed the 100th consecutive successful launch of a Falcon 9 rocket. Second, it achieved the **completion of the first "shell"** of its constellation. After their entry into operational orbit, SpaceX was able to deliver high-speed broadband to 80% of the world, including in some remote areas. At the end of 2021, the company had launched 1942 satellites in orbit for its constellation.

Launch of European Robotic Arm and new ISS module Nauka


Credit: NASA/Shane Kimbrough

On July 21st, Russia launched **a new module** to the International Space Station with a Proton-M, a rocket that had not been used since July 2020. The module, called Nauka (or Multipurpose Laboratory Module), is the first one to be added to the ISS since 2016. To make space for Nauka, the 20-year-old Pirs module was decommissioned, making it the first module of the ISS to be deorbited.

Once in orbit, the spacecraft suffered technical problems with its main engines as well as an antenna and docking target, which did not prevent it from docking to the ISS, although with difficulties, on July 29th. After the docking, **Nauka unexpectedly fired its thrusters**, changing the orientation of the station, but the situation was quickly managed.

Nauka was also carrying the **European Robotic Arm**, a 11-meter device that will be used as the main manipulator on the Russian part of the ISS.


Credit: Roscosmos

The launch of Nauka was followed by the launch of another **new module** by Russia on November 24th. This module, called Prichal, will provide a new docking port for future crew and cargo spacecraft. The module was launched with a modified Progress spacecraft and docked to the Nauka module. Prichal was the final planned piece of the Russian segment of the space station, which led Dmitry Rogozin, head of Roscosmos, to state that "the formation of the Russian segment of the International Space Station has been completed".

Successful return to flight of Ariane 5


Credit: Arianespace

On July 30th, the Ariane 5 rocket **returned to flight** through the launch of two GEO satcom for Embratel and Eutelsat. It was the first flight of the rocket in almost one year, as Ariane had not flown since August 2020. One of the reasons for this long gap was the detection of a problem with the fairing during the latest flights of the launcher. Therefore, the Ariane 5 launched with a modified fairing, to reduce the vibrations underwent by payloads. One of the two payloads was Eutelsat Quantum, developed in cooperation by ESA, Airbus and Eutelsat through a public-private partnership.

The spacecraft is the world's first **software-defined satellite** to be deployed in orbit. The operator will be able to completely reprogramme it while in orbit in order to adapt its services to business requirements. In particular, the spacecraft's throughput and coverage zones can be modified. It will also be able to react more quickly to interference.

A new step for the Landsat programme

On September 27th, an Atlas 5 rocket carried the **Landsat 9 satellite** to space. The spacecraft is the latest of the Landsat programme, thus continuing an effort jointly conducted by NASA and the U.S. Geological Survey for almost fifty years. The imager of Landsat 9 can provide four times more shades in its wavelength bands than its predecessor Landsat 8. The two satellites will be phased in their orbits to provide a revisit rate of eight days. These satellites will also be phased with Copernicus' Sentinel-2 spacecraft to decrease even more the revisit time.

Credit: ULA

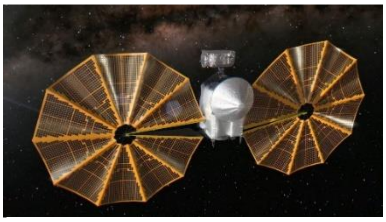
The launch, which was conducted by ULA, also brought to space four CubeSats: two of them to conduct astronomy and space science missions and two other, sponsored by various military organisations, to allow the company **CesiumAstro** to test its phased array antenna technology.

A Russian movie crew in orbit

On October 5th, Russia launched a crewed Soyuz spacecraft to the International Space Station. This launch **was noteworthy** as it carried the actress Yulia Peresild and the film director Klim Shipenko, who filmed scenes for an upcoming movie called *Vyzov* ("Challenge"). They stayed 12 days in the station and recorded around 30 minutes of footage. A few additional scenes were shot just after they came back to Earth on October 18th.

Credit: Roscosmos

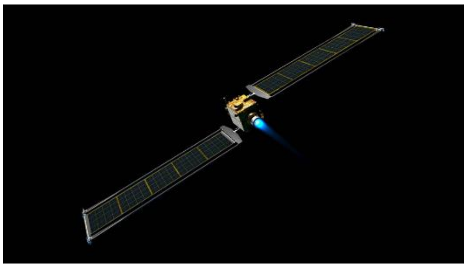
NASA sends two probes to asteroids for science and planetary defence



Credit: NASA

On October 16th, an Atlas 5 rocket launched the Lucy spacecraft for NASA. The mission will, for the first time, study **Trojan asteroids**, which fly around Jupiter. More precisely, the spacecraft will fly by one main belt asteroid and study seven Trojans. Contact with these asteroids is planned for 2033. While the launch occurred without any issue, it appeared that one of the solar panels **did not fully lock** after its deployment. However, it has not prevented it from generating power.

A few weeks later, on November 24th, NASA launched its first planetary defence mission, the **Double Asteroid Redirection Test** (DART) mission onboard a Falcon 9. Its objective is to impact the moonlet of the Didymos asteroid to measure the deflection that it will create on the trajectory of the space object. The mission will allow to assess if such a technique would be efficient should an asteroid threaten Earth in the future.



Credit: NASA

DART is accompanied by **LICIACube**, an ASI contribution built by Argotec, which will take images of the crash. Although the deflection will be measured by terrestrial telescopes, an ESA mission (Hera) is set to launch in November 2024 and to head towards the same asteroid to collect more details on the exact consequences of the DART mission.

South Korea launches its first national rocket

On October 21st, South Korea launched the **first rocket fully developed domestically**, called Nuri. The development of the rocket cost around $1.6 bn according to South Korean authorities. While most of the launch occurred normally, the rocket did not manage to reach orbital velocity and to deliver its payload (a dummy satellite) in orbit due to a premature shutdown of the third stage's engine. A second launch of Nuri is planned for May 2022, and will this time carry an operational satellite.

Credit: Wikipedia

France launches three new military SIGINT satellites

After having launched a military telecommunications satellite in October, France sent to orbit **three new military satellites** with a Vega launcher on November 16th. This constellation, called CERES, will perform signal intelligence missions. They are the first operational spacecraft conducting this mission for France, after the launch of several demonstrators in the past decades (Cerise, Clementine, Essaim, Elisa). This is also the first European system able to detect radars and communication means from space. To reach this objective, they will fly in formation (triangle) in order to geolocate the source of the signals.

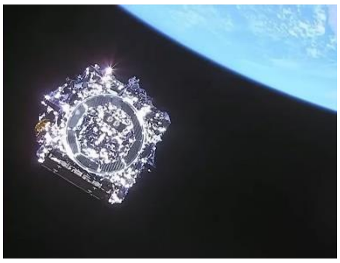
Third and last test for the Angara-A5 rocket

Credit: mil.ru

On December 27th, Russia performed a new test of its Angara-A5 rocket, the new heavy-lift launcher of the country. The Angara-A5 already underwent two tests, in December 2014 and December 2020, which were successful. On this third and last test for the launcher, a new upper stage, Persei, was integrated to put in geostationary orbit a dummy payload. However, even though the launch of the rocket fared well, **a problem occurred** with the engine of the upper stage, which prevented a correct orbital insertion and left the dummy payload stranded in LEO. Despite this issue, Russian authorities announced that the test was a success.

Launch of the James Webb Space Telescope

After ten years of construction and several delays, the **James Webb Space Telescope** (JWST), the successor of Hubble and most powerful telescope ever launched to space, was sent to orbit by an Ariane 5. The launch occurred on Christmas day and did not encounter any difficulty. It was so successful that no major correction was required from the JWST, which allowed to save fuel, thus allowing the duration of the mission to be doubled (from 5 to 10 years). In the following days, several elements of the telescope were activated, including its five-layer sunshield and its primary and secondary mirrors. The JWST is expected to reach its destination, the L2 Lagrange point, on January 27th.



Credit: NASA TV

Some noticeable failures in 2021

Among the 144 launches taking place in 2021, a few of them (10) failed. Beyond the Angara-A5 and Nuri rockets failures, other missed launches are noticeable. Most of them are due to private companies developing new launchers:

- The second launch of the Hyperbola-1 rocket developed by the Chinese company iSpace failed while the first flight of the launcher, in August 2019, succeeded and made iSpace the first Chinese private company to put a payload in orbit. The third launch of the rocket, in August 2021, also failed.
- The company Astra conducted its first commercial launch on August 27th, which spectacularly failed due to the interruption of an engine one second into the flight. As a result, the rocket moved first sideways before lifting off and could not follow its planned trajectory, hence the decision to abort launch for security reasons.
- The first launch of Alpha, the rocket developed by Firefly Aerospace, failed to reach orbit because the launcher went out of control and the flight termination system was eventually activated to avoid casualties on the ground. The failure was traced back to the premature shutdown of one of the rocket's four engines, which created issues when the rocket reached supersonic speeds.

Beyond these commercial events, another important failure is the one of ISRO's GSLV, which occurred in August. The rocket, which was a new version whose fairing was modified to accommodate larger spacecraft, failed five minutes after lift-off due to a problem with the upper stage. It led to the loss of the payload, EOS-3 (formerly known as GISAT-1), an Earth observation spacecraft planned to be placed in geostationary orbit to monitor the Indian subcontinent and serve as a quick response tool in case of natural disaster or other short-term major events.

Authors

Sebastien Moranta, Concept and Editing

Sebastien is Research Manager at the European Space Policy Institute. Prior to supervising the research activities of the Institute, he was a Senior Associate at PricewaterhouseCoopers Advisory and Industry Analyst at Eurospace. Sebastien managed multiple studies for public and private organisations in the space sector and worked on a variety of space policy issues.

Jules Varma, Management and Production

Jules is a Research Fellow at the European Space Policy Institute (ESPI). At ESPI his work focuses on the space economy and New Space related activities. Prior to joining ESPI, he worked at the United Nations Environment Programme in the economy division. He holds a MSc. in the department of Space and Climate Physics from University College London (UCL) as well as a ME in Climate Change Science from the University of Melbourne.

Tomas Hrozensky, Policy & Programmes

Tomas is a Research Fellow at the European Space Policy Institute (ESPI) in Vienna, Austria. Previously he was a visiting Fulbright Scholar at the Space Policy Institute of the George Washington University in Washington, DC and a researcher for the Space Security Index 2017 project. Tomas holds an M.A. and Ph.D. in international relations from the Matej Bel University in Banska Bystrica, Slovakia.

Sara Dalledonne, Policy & Programmes

Sara is a Research Fellow at the European Space Policy Institute (ESPI). Prior to joining ESPI, she worked at the Institute of Air and Space Law (McGill University) as Research Assistant. She holds an L.L.M. in Air and Space Law from McGill University, an L.L.M. in International Trade Law from the International Training Centre of the ILO (University of Turin) and a 5-year Law degree from University of Bologna.

Lina Pohl, Policy & Programmes

Lina is a Research Fellow seconded by DLR at the European Space Policy Institute (ESPI). Prior to joining ESPI, she worked at the DLR International Relations Department as Assistant to the Head of Department and as Research Assistant. She holds a Master in Political Science from the University of Cologne.

Clémence Poirier, Industry & Innovation

Clémence is a Research Fellow seconded by CNES at the European Space Policy Institute (ESPI) in Vienna, Austria. She holds a master's degree in International Relations, International Security and Defence and a bachelor's degree in Foreign Applied Languages from University Jean Moulin Lyon III, France.

Matija Rencelj, Industry & Innovation

Matija is a Research Fellow at the European Space Policy Institute (ESPI). Prior to joining ESPI, he spent two years at the European Space Agency (Strategy Department), and previously worked at the European Commission (Cabinet-level), a corporate law firm, and in the aviation industry. He holds an LL.M. in Air & Space Law from McGill University and a law degree from the University of Ljubljana.

Mateusz Walczak, Economy & Business

Mateusz is a seconded Young Graduate Trainee from the European Space Agency. He runs the Secretariat of the European Centre for Space Economy and Commerce. He holds a B.Sc. in Quantitative Methods in Economics and a MA in Global Business, Finance and Governance from SGH Warsaw School of Economics, and a MA in CEMS International Management.

Mathieu Bataille, Launches & Satellites

Mathieu is a Research Fellow at the European Space Policy Institute, whose research activities mostly focus on security and defence topics. He worked previously at the Studies Department of the French Air Force. He holds a master's degree in Political Science and International Relations from Sciences Po Paris.

Clara Lepin, Research Intern

Clara was an intern at the European Space Policy Institute. She holds a B.A. in Economics from Paris-Dauphine University and a B.A. in Geography from La Sorbonne University. She currently interns at the French Embassy in Chile for their economy division.

Michelle Hermes, Research Intern

Michelle was a Research Intern at the European Space Policy Institute (ESPI). Prior to joining ESPI, she worked in the Legislative Affairs Office at NASA Langley Research Center in Hampton, Virginia, USA. She holds bachelor's degrees in Government and German Studies from the College of William & Mary in Virginia, USA.

João Falcão Serra, Research Intern

João is a Research Intern at the European Space Policy Institute. Previously, he worked as a Research Assistant for Professor Dr. Walter Dorn, from the Royal Military College of Canada, and was an intern at the European Space Agency and the Portuguese Embassy in Turkey. He holds a LLM in European and International Law and a B.A in Political Science and International Relations from NOVA University Lisbon.

Rodolfo Zontini, Research Intern

Rodolfo was a Research Intern at the European Space Policy Institute. He holds a M.Sc in International Relations from LUISS University as well as a Masters in Space Policies and Institutions from the United Nations Association of Italy (SIOI-UNA Italy). He also holds a B.A. in Politics, Philosophy and Economics from LUISS and was an exchange student at the Institut d'Études Politiques de Paris.

About ESPI

Policy & Strategy

Economy & Business

Security & Defence

International & Legal

ESPI is the European think-tank for space. The Institute is a not-for-profit organization based in Vienna, World capital of space diplomacy, providing decision-makers with an informed view on mid to long-term issues relevant to Europe's space activities since 2003.

ESPI is governed by a General Assembly of member organisations and supported by an Advisory Council of independent high-level experts.

ESPI fulfils its objectives through various multi-disciplinary research activities leading to the publication of books, reports, papers, articles, executive briefs, proceedings and position papers, and to the organisation of conferences and events including the annual ESPI Autumn Conference.

Who we are	What we do
Independent think-tank specialised in space policy	Research and analysis on major space policy issues
Multinational team with interdisciplinary expertise	Monitoring of global space trends and policy developments
Part of a network of European and international partners	Organization of thematic conferences and workshops

Download our reports, check out our events and subscribe to our newsletter online

www.espi.or.at

Schwarzenbergplatz 6 | A-1030 Vienna, Austria | (Entrance: Zaunergasse 1)
Phone +43 1 718 11 18 - 0 | E-Mail: office@espi.or.at

ESPI

European Space
Policy Institute

Schwarzenbergplatz 6, 1030 Vienna
(Entrance: Zaunergasse 1)

+43 1 718 11 18 - 0
office@espi.or.at

www.espi.or.at