The future of the European space sector

How to leverage Europe's technological leadership and boost investments for space ventures

European Commission

European Investment Bank
The EU bank

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Prepared for:
The European Commission

By: Innovation Finance Advisory in collaboration with the European Investment Advisory Hub, part of the European Investment Bank's advisory services

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Forewords

Space has always been a source of inspiration to explorers and scientists. From physics to chemistry, from material sciences to engineering, the pursuit of space has produced revolutionary technologies and vastly broadened humankind's scientific knowledge. It has also improved our everyday life in many ways — the European Space Agency estimates that for every Euro spent in the sector there has been six Euros benefit to society.

Until recently, space used to be synonymous with government spending: the enormous costs and risks involved made the sector generally inaccessible to private players. Today, major technology advancements and a new entrepreneurial spirit are rapidly shaping a new space economy. The sector sees the emergence of new private actors who see unrivalled commercial opportunities in space exploration and exploitation thanks to frontier technologies and the data revolution.

Europe has historically been at the forefront of space exploration, investing massively in space infrastructures such as in the Copernicus and Galileo programmes. It still boasts academic and scientific excellence but it is at risk of losing out on the next wave of space innovation unless it seizes the opportunity to stimulate more investment in the new space sector.

It is against this backdrop that I welcome this timely market assessment by our EIB advisory services coming ahead of defining space policy decisions. It not only highlights the disruptive forces transforming the space sector, challenging the old and new players alike; it also gives a clear roadmap on how we can leverage our current public financial support schemes at national and EU levels to pull in the much needed private capital. I particularly welcome the idea of setting up a "Space Finance Forum" to bring together the expertise of financial, industrial and academic stakeholders to explore and pilot new patient financing mechanisms and catalyse private investment in the sector.

Last but not least I would like to thank my colleagues at the European Commission for the excellent collaboration and senior sponsorship throughout the study. We at the EIB are committed to mobilise our technical expertise and financial firepower and work with you to keep Europe at the forefront of the New Space era!

Werner Hoyer
President of the European Investment Bank

Towards a European approach to "New Space"

Europe — the Member States, the EU, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) — has achieved many successes in space with breakthrough technologies and exploration missions, such as EU space projects: Copernicus — Europe's Earth observation system — or Galileo, the satellite navigation and geo-positioning system, ESA's exploring missions such as Rosetta or BepiColombo, as well as unique Earth observation and meteorology capabilities, such as Meteosat, and world-leading commercial telecommunications and launch systems with the Ariane family and Vega. Europe represents today the second largest public space budget in the world with programmes and facilities spanning different European countries.

Between 2014 and 2020, the EU alone will invest over EUR 12 billion in space activities. It owns world-class space systems with Copernicus EGNOS and Galileo. With 33 satellites currently in orbit and over 30 planned in the next 10–15 years, the EU is the largest institutional customer for launch services in Europe. Nowadays, space technologies, data and services have become indispensable in the daily lives of European citizens.

The international space context is changing fast — global competition is increasing with new entrants bringing new ambitions in space and space activities are becoming increasingly commercial with greater private sector involvement. Major technological shifts, such as digitalisation, miniaturisation, artificial intelligence or reusable launcher, are disrupting traditional business models in the space sector, reducing the cost of accessing and using space. The European space sector needs to adapt to seize business opportunities stemming from those changes so that Europe can keep its leadership and strategic autonomy in space. In this context, the Space Strategy for Europe, proposed by the Commission and enriched with the political orientations of the Council and Parliament set a high ambition for Europe to remain a space power and embrace the challenges ahead.

Realising these ambitions requires fostering investments and an entrepreneurial space ecosystem in Europe.

Numerous Union programmes and initiatives accompany the early stages or scaling up of start-ups, notably through the Union's Investment Plan and its European Fund for Strategic Investments (EFSI) or the Union Framework Programme for Research and Innovation. They have helped to stimulate a number of investments into the space sector. Likewise, the recently launched VentureEU is expected to facilitate this process further.

Looking ahead, the Commission has made ambitious proposals for the next Multi-annual Financial Framework (MFF) of the Union for the period 2021–2027. These include a dedicated Space programme for a total of EUR 16 billion, space research addressed by Horizon Europe, the next Union Framework Programme for Research and Innovation, and space investments addressed by the Invest EU programme. Access to finance remains as one of the identified bottleneck to space entrepreneurship in Europe. For the first time, the EU Space Programme proposes specific provisions to support the emergence of a "European New Space". And precisely smart financing for space is at the heart of this strategy and will rely on synergies among all the programmes as well as between European and national levels.

The analysis and recommendations of this report will help to shape the concrete solutions in the implementation of those programmes to stimulate more investments in space in Europe.

Therefore, I am pleased to introduce this report prepared for the European Commission by the European Investment Bank through the collaboration between Innovation Finance Advisory and European Investment Advisory Hub.

I would also like to extend our special thanks to all stakeholders who have contributed to this work.

Elżbieta Bieńkowska
Commissioner for Internal Market, Industry, Entrepreneurship and SMEs

Executive Summary

Europe boasts a strong space sector. This is largely the legacy of successful space programmes, particularly those on satellite navigation and Earth observation, mostly built on public support. However, the space sector is undergoing unprecedented transformation and development on a global scale. Major technology advancements, a new entrepreneurial spirit and a renewed policy focus have put the space sector under the spotlight on the global innovation stage.

Such rapid and constant transformation calls for new approaches to funding and supporting space ventures.

The global space economy grew by 6.7 % on average per year between 2005 and 2017, almost twice the 3.5 % average yearly growth of the global economy. One particular contribution to this growth has been the "NewSpace" phenomenon: a series of technological and business model innovations that have led to a significant reduction in costs and resulted in the provision of new products and services that have broadened the existing customer base.

Glossary

NewSpace: a global trend encompassing an emerging investment philosophy and a series of technological advancements leading to the development of a private space industry largely driven by commercial motivations.

The transformation of the space industry has seen space companies attract over EUR 14.8 billion of investment since 2000. Moreover, it is picking up: total investment in space companies grew by a factor of 3.5 in 2012–2017 compared with the previous six-year period. Additionally, since 2000, over 180 angel- and venture-backed space companies have been founded. Venture capital (VC) firms represent the majority of investors in space companies, with around 46 % of overall investments. Angel and VC investors combined make up around 66 % of the investors in space ventures. In fact, US-based investors account for around 66 % of the 400+ worldwide investors in space companies.

Space economy overview

In the global space economy, satellite services represent the largest sector (around 37 %), closely followed by ground equipment. Earth observation is the biggest user of satellite manufacturing and launch services, and remains a key driver for the overall industry.

Glossary

Space and ground segments: based on their location, space infrastructures can be divided into two segments: those with assets in space and those with assets on Earth. The ground segment includes launch facilities, mission control centres and transmission and reception stations.

Space hardware and space applications have been important users of innovations in industries outside of the space industry. Advances in manufacturing technologies, miniaturisation, nanotechnology, artificial intelligence and reusable launch systems have driven market disruption in the space industry, for example, through **falling costs in satellite manufacturing and launch vehicles.** Scientific and technological progress go hand in hand and can lead to disruptive innovation, resulting in a new market with a radically different value proposition. **Space is therefore an enabler for several industry verticals**. For example, space-based infrastructure projects such as Galileo serve as precursors for many space-related applications in segments such as location-based services and agriculture. Thus, even though some of these technologies may be competing with the space industry for investment, the space industry in fact provides important incentives for other technologies.

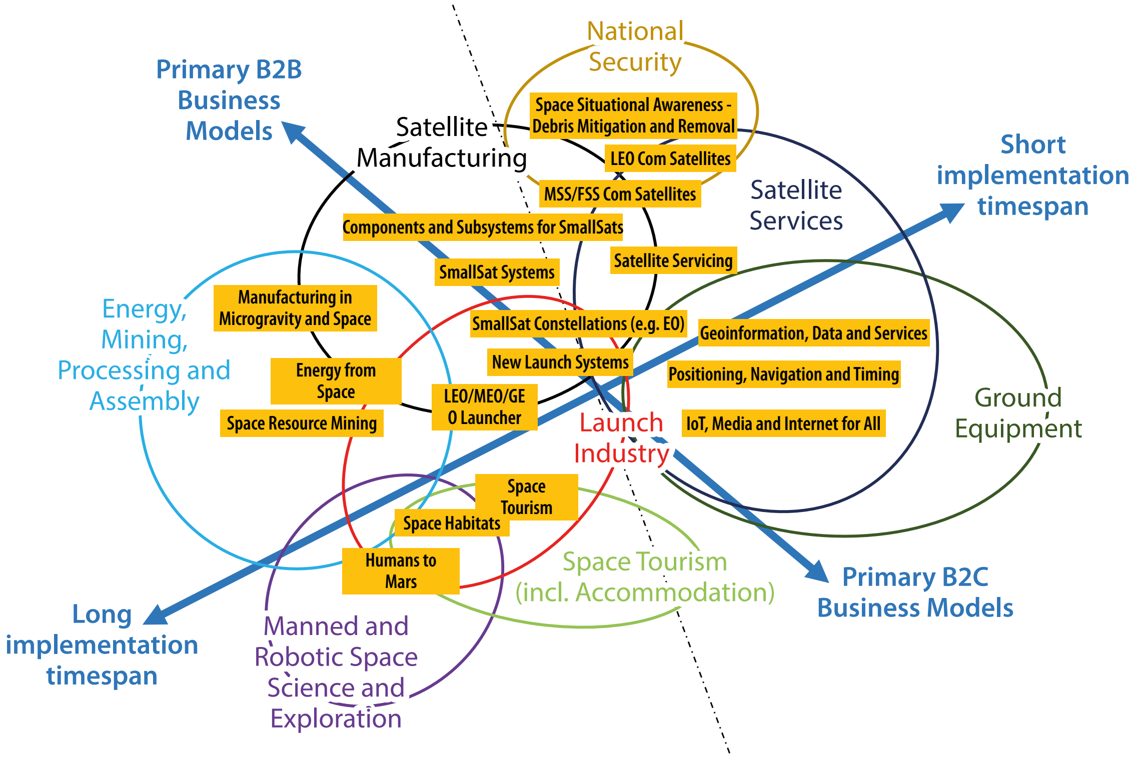

Figure 1: A landscape of space business services, business models and segments

The landscape of space services, along with their interdependent parties, provides a basis for a risk assessment of business segments, which is analysed in detail as part of this study. Generally speaking, business models predicated on a business-to-consumer (B2C) model, or with a **shorter implementation time span, come with lower risk levels** than business-to-business (B2B) models or those with longer implementation time frames.

Overall, while the prospects for the future development of the space market are positive, with growing investments from private sources signalling the increasing attractiveness of the commercial aspects of space, some market segments and business models remain significantly riskier than others due to the **high upfront investments, immature markets and high technological and regulatory uncertainty**. At the other end of the spectrum, asset-light value-added-services have become the **most attractive business segment,** as they offer the best market opportunities and the lowest risk levels.

While European firms remain competitive with regard to many innovations that have impacted the space industry, such as micro- and nanoelectronics, digital transformation and convergence, and optical and ubiquitous communications, **this leadership has rarely translated into a commercial advantage within the space sector**. One of the reasons for this dissonance between European innovation and competitive advantages is the lack of upstream activities in Europe, as US firms dominate the upstream sector. European technology leaders are not active enough in space themselves, and the technology transfer is not effective enough. Additionally, risk capital funds are in limited supply for ventures that are looking to commercialise their innovative technologies. The scarcity of scale-up funding in Europe is a critical shortfall, which often leads to a flight of talent and companies to the US, where the financing landscape is currently more favourable.

Table 1 encapsulates the various risks associated with different market segments and business models.

	Risk assessment of market segments and business models for five discriminators							
	Launch industry	Satellite manufacturing	Satellite services	Ground equipment	National security	Crewed and robotic space science and exploration	Space tourism (incl. habitation)	Energy, mining, processing and assembly
Product/technology	◑	◔	◑	◑	◑	◑	◕	●
Asset intensity	●	◕	◑	◔	◑	●	●	●
Demand	◑	◔	◔	○	◔	◕	◕	●
Competitive landscape	◑	◑	◔	◕	◔	◑	◕	◑
Regulation	◕	◑	◕	◔	◑	◑	◕	◕
Risk summary	◕	◑	◑	◔	◑	◕	◕	◕

Table 1: Risk assessment of market segments and business models for five discriminators
Legend: ○—Low Risk ●—High Risk

Glossary

Upstream and downstream sectors: the upstream sector covers activities that lead to the development of space infrastructure, including R&D, production of satellites and launchers and the deployment of such infrastructure. The downstream sector primarily relates to the commercial activities based on the use of data provided by space infrastructure, such as broadcasting, communication, navigation and Earth observation.[i]

Funding landscape

When assessing the existing funding landscape for space companies in Europe, it is instructive to understand the current needs for, and uses of funding. To inform this study, a comprehensive sample of **over 40 space companies** was interviewed throughout the EU and beyond. Most companies highlighted the importance of public funds and public sector instruments, which often represent the only accessible source of capital. In addition, 40 % of interviewees noted that public financing often served as a **precondition for accessing private risk capital.**

The European public funding landscape is relatively strong. New programmes such as Horizon Europe and InvestEU will build on the success of Horizon 2020 and the European Fund for Strategic Investments (EFSI), which mobilised funds for research and innovation. A coherent and integrated suite of dedicated funding instruments for space companies is, however, lacking. While seed-stage support mechanisms have successful programmes such as the European Space Agency (ESA) Business Incubator and Acceleration Centres and the Copernicus Start-Up Programme, the total volume of early-stage investments is small and rather fragmented, and only specific space segments are adequately covered.

On the investor side, **more than 20 entities** were consulted. In their assessment of the space industry, a key difference noted in comparison with general tech is the **delayed inflection points of space businesses,** which are subsequently reflected by their higher capital need **and the general lack of market maturity**.

Most of the space companies interviewed seek financing for R&D and product development, relying on venture capital and private equity to meet their needs. However, as Figure 2 shows, a gap can be observed in space-focused private funding for the early-stage and growth phases. Additionally, the **total volume of investment lags far behind** private investment in the US. While funding conditions in early-stage finance are expected to improve thanks to, among other things, the InnovFin Space Equity Pilot and other national initiatives, the **investment landscape today is suboptimal and poses a risk for the commercialisation of space technologies in Europe.**

i European Space Policy, European Parliament, Jan 2017.

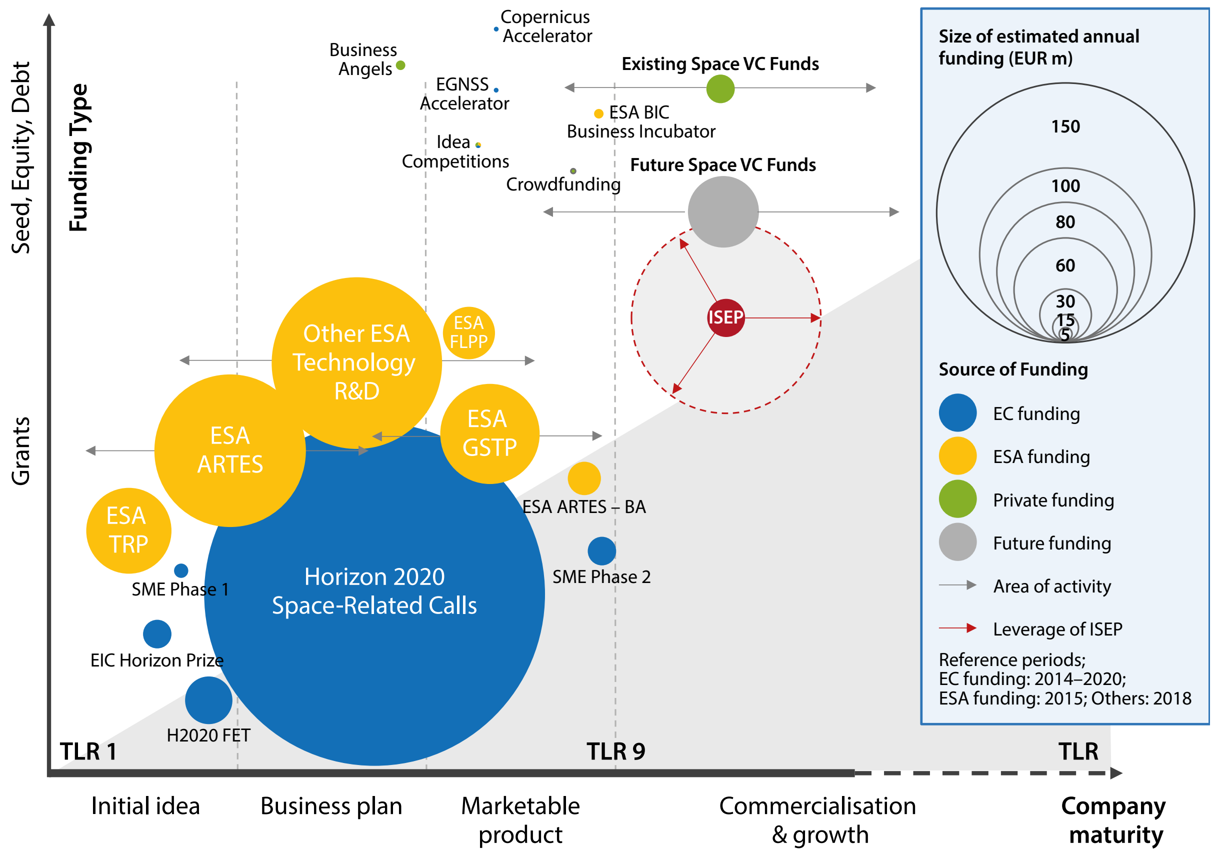

Figure 2: Overview of space-focused financial instruments in Europe and estimated annual funding volume; ESA funding represented in this graphic does not include technology developments carried out as integral part of specific development programmes

Key findings

Through the various stakeholder interviews on both the demand and the supply sides, 11 key findings concerning funding hurdles for space companies in Europe were garnered and are summarised in the following table.

	Key finding	In detail
		Financing challenges
1	**The European space sector experiences funding hurdles similar to those of other tech companies, particularly at scale-up phase**	• Not only is the volume of European VC investment lower, venture capitalists invest with smaller tickets, and growth capital is particularly hard to find • Business loans from commercial banks are nearly inaccessible
2	**Companies in both the upstream and downstream sectors of the industry struggle with access to finance, but for different reasons**	• Upstream companies face long development cycles, are capital-intensive and operate in a limited market with many business risks • Downstream companies sell to emerging markets (with predominantly governmental buyers) and to unsophisticated customers
3	**The space ecosystem lacks investors with a space background and space investment expertise**	• It will still take years for the European space sector to exploit the full potential of the mobility of people between the triangle of corporate, entrepreneurship and investment roles
4	**European space entrepreneurs feel there is a lack of private financing sources and keep an eye on the US**	• Most space entrepreneurs are looking for private capital outside of the EU • The wave of NewSpace investments in the US, with larger funding rounds and investors with greater risk appetite, are enticing to European firms

		Market maturity and sector risks
5	Space innovations have a longer development cycle than general tech	• The space hardware development cycle is considerably longer than in general tech; however, NewSpace is closing the gap
6	Investors are mostly concerned by market maturity	• Immature markets with questionable demand, technology risks and high capital needs are the key risks from the perspective of space investors
7	Investors do not see the exit opportunity (yet)	• Large system integrators do not yet have a tradition to invest in external innovation • Investors perceive the lack of exits as a sign of new or failing markets and therefore a risk for financial returns
8	The lack of follow-on finance has led to a number of early initial public offerings (IPOs)	• Europe has seen a few small space IPOs over the last two years despite a decline in the overall small IPO market • IPOs are seen by the entrepreneurs as a sizable funding source but also as a scalable funding source
		Role of the public sector
9	European public innovation instruments play an important role in unlocking private capital for the space sector	• 40 % of the companies seek public funding as it is a precondition for private investment • Public funding serves as a seal of approval in the market
10	The landscape of space sector support mechanisms is rather fragmented, and procurement is geared towards the traditional value chain	• Entrepreneurs find it hard to navigate through the different possible funding options • The traditional European upstream space industry is used to a large institutional market of traditional public procurement and R&D grant programmes • Industry associations and entrepreneurs in both the upstream and downstream sectors indicate a lack of public anchor tenants to stimulate the sector
11	Public authorities around the globe are stimulating the setting-up of venture capital funds dedicated to the space industry	• France, Luxembourg and Japan are examples of governments initiating VC funds to bridge the funding gap for space companies

Five recommendations

From the key findings laid out in the table above, five policy and finance-related recommendations were formulated.

SUPPORT FOR THE ECOSYSTEM

1. Strengthen the ecosystem of public support mechanisms by introducing more flexibility and more commercial orientation

INNOVATIVE PULL MECHANISMS FROM THE PUBLIC SECTOR

2. Develop and deploy innovative pull mechanisms from the public sector (e.g. innovative procurement and industrial policies) to stimulate technology development and its commercial uptake
3. Adopt a strengthened European defence policy as a driver for market development across all space business segments

ACCESS TO FINANCE

4. Increase the volume of risk capital and catalyse additional private investment into the sector

ADVISORY AND SOFT MEASURES

5. Establish a "finance for space" forum with representatives from the finance community, academia, policymakers and industry to bridge the information gap and develop innovative financing solutions for the space sector

Recommendation 1: Strengthen the ecosystem of public support mechanisms by introducing more flexibility and more commercial orientation.

The European space strategy, set out in October 2016, highlights the importance and potential of the space industry as a catalyst for larger economic growth and calls for more market uptake, new commercial applications and services to maximise the socio-economic benefits of EU space programmes and EU space assets.

On the funding side for early stage companies, Europe has a rather wide array of grant programmes at EU and national level (such as the European Space Agency's Business Incubator Centres, Copernicus Start-Up Programme and European Global Navigation Satellite System accelerator). While they have been successful in supporting a number of space start-ups, not all market segments are adequately covered; upstream markets and NewSpace companies are often ineligible for several support mechanisms, with the general support environment remaining rather fragmented. Additionally, **identifying and accessing the right instrument can be rather time consuming,** and these programmes often present quite prescriptive terms for accessing their funds, which limit the ability of companies to react to new developments and pivot their business if needed.

This could be remedied by a **more open, less prescriptive and more integrated system of public support mechanisms**, both on the funding side and for other supporting measures. Aside from covering more market segments and reducing information asymmetries between supply of and demand for finance, this system could involve the following.

More flexibility in qualifying applicants. The existing support mechanisms could do more to keep their **programmes open and inclusive with respect to other tech entrepreneurs**. This would serve to attract serial entrepreneurs from information and communications technology (ICT) who would be able to transfer their entrepreneurial mentality and business knowledge to help with the maturation of the start-up space ecosystem.

More flexibility in grant allocation. Adjustable timing, project scope and outcome, etc., would enhance the economic impact of the grants and give firms the necessary flexibility in their development.

More flexibility in blending grants with other financial instruments. At the same time, to **reduce the risk profile** of space companies and improve their commercial focus, grants could be structured as a catalytic tool for private finance. Closer synchronisation of grants with private funding would **improve public grant allocation**.

Additionally, easily understandable, investor-oriented grant agreements would better prepare space firms in business and market aspects. In all these respects, the European Innovation Council—a new EU initiative to be rolled out as of 2019—is poised to introduce a step change in the European landscape of finance for innovation. European space companies should take advantage of this.

The public sector has also a strong role to play in stimulating market demand and technology uptake by promoting more favourable policies and regulatory frameworks. With recommendations 2 and 3, we explore some of these solutions.

Recommendation 2: Develop and deploy innovative pull mechanisms from the public sector (e.g. innovative procurement and industrial policies) to stimulate technology development and its commercial uptake.

The success of firms such as SpaceX, Blue Origin and Sierra Nevada is largely due to industrial policies of innovative procurement, first customer approach and anchor tenancy, all models that have been employed in the US over the last few years (and are described in more detail in the report). Although Europe has a comparable model with innovation procurement (pre-commercial procurement/public procurement of innovative solutions), what has made the US model so successful is a commitment to being "**technology agnostic**". The government ultimately procures a service rather than a product powered by a specific technology.

To foster a globally competitive space economy, European institutions and space agencies could consider similar roles and policies. By defining projects in terms of **well-established key performance indicators**, such as availability, performance levels and cost per unit, European and national space institutions would, among other things, engage more actively with NewSpace and promote space entrepreneurship as a means of growing the sector. For example, potential projects could focus on bridging the digital divide by ensuring Internet access for all, developing a mobile distress communication service for the EU population or even establishing and operating an Earth observation service that could provide, by mobile phone, updated information on visible, infrared and ultraviolet spectra, etc., say, every 10 minutes.

Recommendation 3: Adopt a strengthened European defence policy as a driver for market development across all space business segments.

The transformation of Earth observation services from purely military to partially commercial emphasises the potential **dual-use character of space services**. Due to the strong overlap of military, safety and security user needs, any system that serves one of these users will likely be able to prevail in the other sectors as the business conditions will be more favourable for such undertakings than for a total "outsider/newcomer", with no or limited exposure to the safety/security/military requirements. As such, an appropriately **reinforced European defence policy** could provide many opportunities for space companies across all segments and may allow more innovative space products to flourish and be prepared for scaling-up for commercial markets more rapidly. In addition, such a move would also help to avert negative effects that may emerge if the International Traffic in Arms Regulations are restricted by the US and certain technologies suddenly become unavailable to European companies and institutions.

The proposed budget for the next Multiannual Financial Framework presents a **new European Defence Fund**, with an overall budget of EUR 13 billion, to boost Europe's ability to protect and defend its citizens.

The fund is poised to offer EU-funded grants for collaborative projects which address emerging and future defence and security threats and bridge technological gaps. While the fund is modest compared to the Member States' national defence budgets, it opens the door for more strategic cooperation on space programmes in addition to existing cooperation, such as on governmental satellite communications.

Beyond industrial policies, access to finance remains a critical challenge for the sector. In the report, we will see how, despite the improving financing conditions, lack of financing hinders the growth of promising European companies and technologies. Recommendation 4 looks at how to address this shortfall.

Recommendation 4: Increase the volume of risk capital and catalyse additional private investment into the sector.

Accessing risk capital at scale remains a challenge for European space companies and even more so for the NewSpace segment, being less mature and with still largely unproven business models. The lack of specialised investors, the limited size of European VC funds and their relative risk aversion compound the challenge.

For all these reasons, more risk capital is needed. European institutions are well positioned to bring about change and stimulate further investment in the sector. A number of possible directions, all complementary and not mutually exclusive, are listed below.

- Expand and, to the greatest extent possible, replicate the **Fund-of-Funds (FoF) model spearheaded by the InnovFin Space Equity Pilot (ISEP)**. ISEP will channel EUR 50 million of the EU budget, potentially matched by additional EIB Group financing, to invest in a number of space-related VC funds.
- Build on the experience of the **European Fund for Strategic Investments (EFSI) and InvestEU, its successor programme** in the post-2020 programming period to further cater for the financing needs of space companies and projects.
- Support and, to the greatest extent feasible, contribute financially to **Member States-driven initiatives addressing the risk capital shortage in the space sector**. The financing programmes recently announced by Luxembourg and France are good examples, and not the only ones. EU institutions are also well placed to provide *ex ante* coordination mechanisms between such initiatives and share best practices for others to replicate these models.
- Consider establishing **co-investment programmes with the corporate venture** arms of European aerospace companies. Funding by the EIB Group and national promotional banks could be leveraged in this way.

- Consider the deployment of more (public, or public and private) **project-finance risk-sharing** solutions to finance space assets. The EIB already successfully deploys such schemes across a number of sectors, whereby it shares the risks and rewards of the development of an asset or portfolio of assets.
- Consider the use of Member States' **EU Structural Funds** by way of risk finance in support of the space sector.

As we will see in the following sections, the European space sector requires new approaches and models to address the financing and information gaps among its stakeholders. Recommendation 5 aims to tackle these gaps by establishing common ground between different communities of stakeholders.

Recommendation 5: Establish a "finance for space" forum with representatives from the finance community, academia, policymakers and industry to bridge the information gap and develop innovative financing solutions for the space sector.

The information gap between the space sector and the finance sector is mutual—**space lacks knowledge about finance and finance lacks knowledge about space**. A regular **"finance for space" forum** could help **bridge the gap** by convening key stakeholders, identifying specific financing needs and discussing/developing potentially new models and (co)financing solutions for the European space sector, as well as raising awareness of existing funding instruments. It could also contribute to an exchange of knowledge and technical expertise between investors and space companies and identify projects that could benefit from available funding instruments. **The EC and/or the EIB Group would be well placed to play this advisory and federating role**.

Particular focus could concentrate on identifying, raising awareness and developing innovative funding models and other supporting instruments targeting the specificities of the space sector and its risks. A few areas that would require further consideration include:

- access to satellite insurance for entrepreneurs with limited or no flight heritage;
- financing solutions such as export credit, factoring, supply chain finance, alternative solutions (versus equity) to alleviate the burden associated with pre-funding of launch costs for young satellite companies, etc.;
- brokering and financing access to space for European smallsat companies to aggregate **demand and increase bargaining power vis-à-vis launch providers, while also diminishing the risks that the launch companies face;**
- **advisory functions and soft measures in support of the European space sector, etc.**

Summing up, more must be done to cement Europe's role as a global player and influencer in the current industrial climate in space tech. Accordingly, EU institutions have the responsibility of not only setting ambitious goals but also developing innovative industrial policies, instruments and models to support the space sector going forward.

This report assesses the current investment landscape, identifies gaps in financing across the space value chain and proposes key recommendations and solutions to improve the existing conditions.

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1. Access to finance for a competitive space industry

1.1. Background of the study

The launch of Sputnik 1 in 1957 announced the start of the space era and propelled the Space Race forward, with the United States and the Soviet Union battling for supremacy in spaceflight capabilities. This had a profound effect on the industry, with new technologies being developed and implemented at a rapid rate. Today, a **new space race is occurring, with competition between private companies** rather than nations; a phenomenon **commonly referred to as "NewSpace"**. The new space race was heralded by the emergence of a commercial space industry and has opened previously **unexplored avenues to growth and innovation**. The role of space has become more apparent as an enabling infrastructure for the **digitisation of industries,** as a **basis for new business services,** and as an area of **economic growth**, a trend recognised by governments across the globe.

The Treaty on the Functioning of the EU (TFEU), which came into force on 1 December 2009, established a clear **mandate**[ii] **for the European Union (EU) to engage in space**; culminating in an overarching European space policy, which was announced in October 2016. The European Space Strategy highlights that given the large and growing dependence on space technologies, data and services, the space industry has the potential to be a **catalyst for large economic growth and to cement Europe's role as a global player and influencer**. Although Europe already boasts a strong space sector—representing the second largest public space budget in the world—with the industry undergoing rapid and constant transformation due to the influx of new private entrants, more must be done to keep up with the changes and to secure Europe's position.[iii]

The strategy highlights a fundamental component that is critical to an entrepreneurial ecosystem, namely **access to finance**. For nascent businesses to thrive, funding opportunities are imperative. Part of the European Commission's plan to support the whole space supply chain is to **introduce new sources of financing** and **support new founders** across the single market. In addition, the Commission aims to work with the European Investment Bank (EIB) to gain a clearer understanding of the current financing conditions in space and to develop new techniques and approaches to financing.

The present study aims to contribute to shaping the European policy actions in support of space industries by **assessing the current investment landscape and identifying gaps in financing across the value chain as well as proposing potential solutions** (see the study objectives in Table 2).

#	Study Objectives
1	Analyse and segment the market to assess the availability and effectiveness of existing public and private funds and financing mechanisms
2	Investigate the conditions for investment and lending to identify potential funding gaps across the value chain
3	Recommend policy options to remove potential financing hurdles after review and analysis of the gathered evidence

Table 2: Study objectives

ii TFEU, Title I—Article 4, Title XIX—Article 189.
iii European Commission, Space Strategy for Europe, COM(2016) 705 final, 2016.

1.2. Methodology

Throughout the study process, an **investor perspective** was applied to gain a profound and tangible understanding of their investment rationale, combined with a thorough **assessment of market needs** to identify the root causes of the funding gap in the European space industry.

An initial exercise **segmented the market**, providing an analysis of the different innovative business models in the space industry, as well as trends in terms of investment and financing. This action eventually developed an analytical framework based on the space sector value chain, grouping 22 market domains into 8 market segments. It explored these market segments of space **business models** and elaborated on the specific **technology and innovation trends** that drive their industry opportunities, while considering their finance needs and providing a **risk assessment in terms of market or technology readiness**, among others.

As part of the stakeholder consultation, **demand-side interviews** were held with over 40 companies and provided a comprehensive understanding of space enterprises' experiences with financial institutions, and the conditions they meet in the market. A comparable survey was undertaken on the **supply side**, with over 20 investors with a varying affinity to the sector, which gathered information from market participants to assess the rationale, the willingness, the risks and the barriers for investors to engage in the sector. The interviews comprised quantitative as well as qualitative questions in order to assess the access to finance conditions in depth. A sample description of the companies and investors interviewed can be found in Sections 3.1. The information acquired proved to be of vital importance in formulating recommendations for improving the financing structures and conditions in Europe. Added to this, the surveys validated the results of the market segmentation and investment trends hypotheses defined earlier in the process.

Additionally, a **mapping of the different financial instruments and financing sources** available for European space enterprises, including both public and private sector instruments, was undertaken. The study applied the funding chain methodology in order to map relevant investors and intermediaries. Based on the gathered information, an analysis of **the European access to finance conditions** was developed, categorising the main findings while investigating the merit of further public intervention at EU and national level.

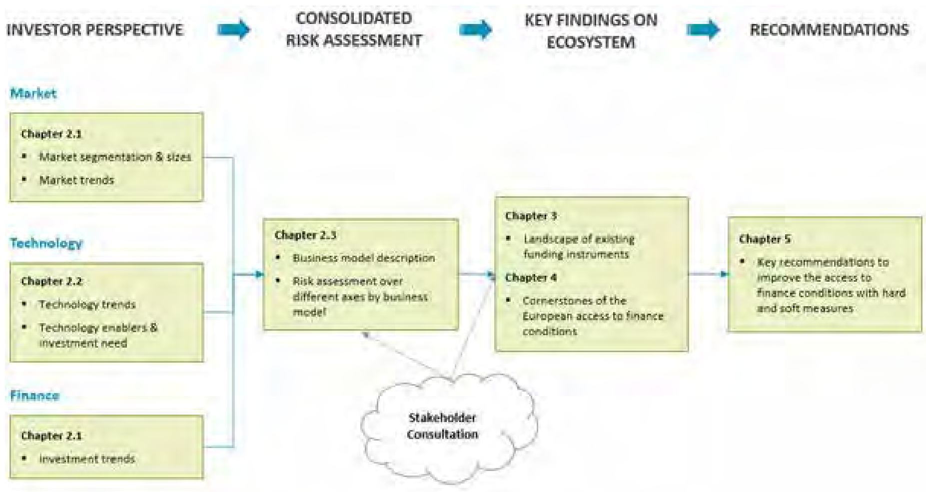


Figure 3: Research process

Finally, **recommendations for financial, regulatory and policy solutions** were developed to address the various obstacles and challenges. These were made as part of an iterative process, with intense interactions between investment experts and market participants, and were complemented with an earlier review of best practices in the EU Member States (MS), US and Japan.

2. The space sector and its business models

2.1. Segments in space and space applications market

2.1.1. The international space sector—a changing economy

The **global space economy reached EUR 309 billion in 2017,**[1] **having grown on average by 6.7 % p.a. between 2005 and 2017** (Figure 4).[iv] With approximately one quarter of this amount attributed to government budgets[v] and three quarters to commercial revenues, the global space economy is significantly influenced by the global economy, thereby subjected to periods of stagnation and of growth. The most recent economic upswing happened in 2010–2014, providing an average growth of 6.2 % p.a.,[2] a value that surpassed the growth of the overall global economy, which grew at 4.4 % p.a. over the same period.[3]

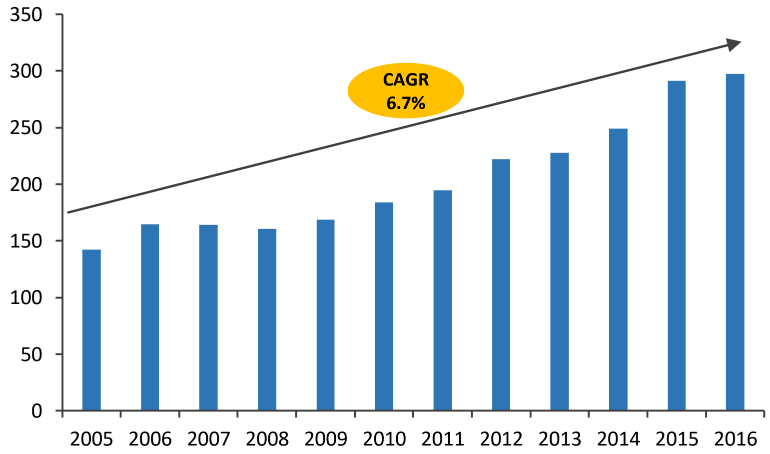


Figure 4: The size of the global space economy [bn EUR][4]

The **overall space economy consists of both revenue-generating commercial space activities and government investments in space**. While governments were the driving forces in the 20th century (e.g. the Apollo programme, International Space Station (ISS) and the Global Positioning System (GPS)), commercial activities are now setting the pace, accounting for EUR 229 billion or 76 % of the global space economy in 2016. In contrast, the US government spent EUR 39.8 billion on defence and non-defence space efforts in 2016, while non-US government space investments made up EUR 28.9 billion.[5]

Starting with the emergence of the private spaceflight industry and miniaturised satellites, traditional boundaries and business models are changing radically. This rise of new entrants has brought with it **new opportunities for innovations in products, services and processes**, which, in turn, have created spillover effects to various industries

iv Although the space economy is of remarkable size, the Internet—connecting devices, people, processes and data in an integrated global network—is poised to grow to USD 19 trillion in 2026 (with USD 14 trillion coming from the private sector and USD 5 trillion from the public sector), owing to initiatives such as smart cities and infrastructure. By 2020, there are likely to be 50+ billion connected devices [Source: The Global Outlook 2016: Spatial Information Industry report, prepared by Cooperative Research Council for Spatial Information (CRCSI), November 2016].

v Close to 50 nations have government space budgets, 9 of them over EUR 900 million, and nearly 20 under EUR 90 million [Global Space Industry Dynamics, Bryce Space and Technology, 2017].

both inside and outside the space sector. To adapt to technological changes, established space companies increasingly (are forced to) seek revenues outside the traditional realm of institutional space. Many space companies find it difficult to engage on commercial terms or have limited financial reserves for the necessary investments. Figure 5 outlines the spectrum of space business services according to their level of maturity.

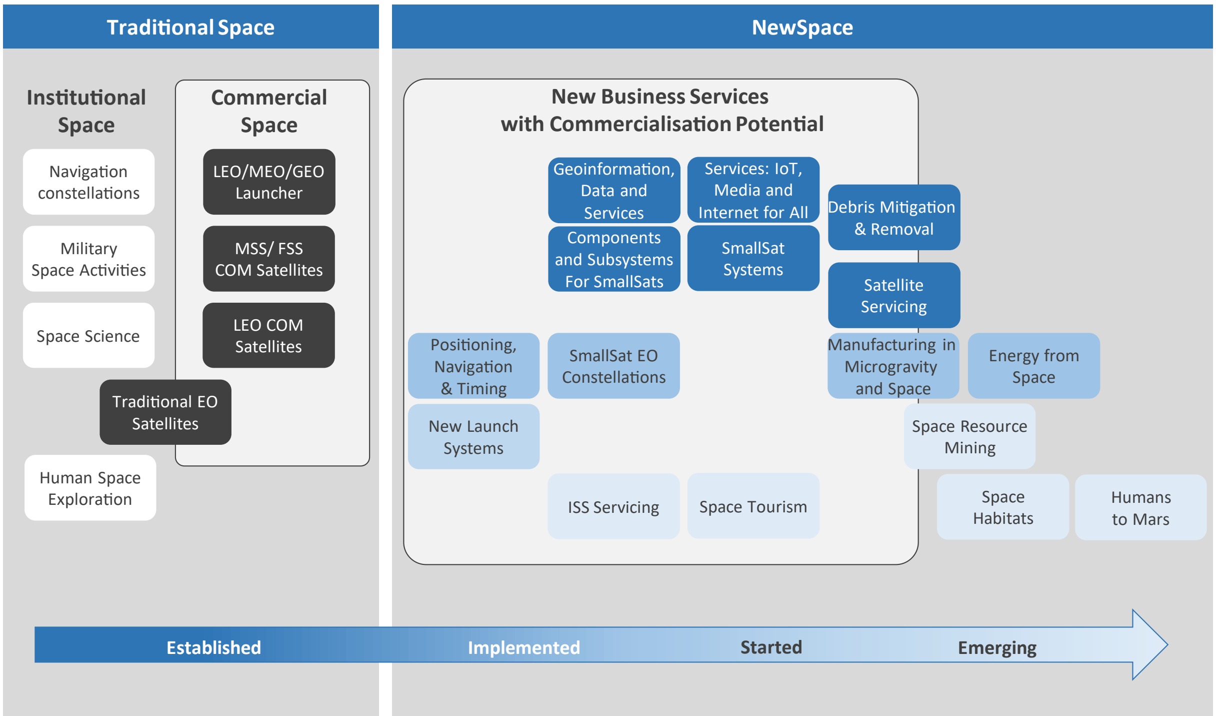


Figure 5: Existing and new business services[6]

Albeit rather recent, the commercialisation of space will intensify in the coming years as the space sector experiences rapid growth in new approaches to space development. The so-called **"NewSpace" trend thrives upon technology and business model innovations that permit a significant reduction in cost, the provision of new products and services and a broadening of the customer base** (see Figure 5). These are accompanied by increased returns for companies and investors, resulting in the onset of a whole new wave of commercial activities within the space sector.

A clear indication that this NewSpace movement is picking up speed is the fact that space ventures have attracted over EUR 14.8 billion of investment, including EUR 3.3 billion in debt financing, since 2000 (as indicated in Table 3). In the same time frame, over 180 angel- and venture-backed space companies have been founded, with 18 of these companies having been acquired at a total value of EUR 3.6 billion.[7]

Investment into space ventures [m EUR]				
Investment Type	2000–2005	2006–2011	2012–2017	Total (2000–2017)
Seed Prize/Grant	615	220	1.123	1.957
Venture Capital	228	306	4.680	5.214
Private Equity	224	946	185	1.354
Acquisition	0	429	2.488	2.916
Public Offering	0	0	19	19
Total Investment	1.067	1.900	8.494	11.461
Debt Financing	0	3.007	321	3.328
Total with Debt	1.067	4.907	8.815	14.789

Table 3: Volume and types of investment into space ventures[8]

Investors in these NewSpace companies are based primarily in the US, which is home to about two-thirds of the

400+ investors that have been identified around the world. Of the non-US investors, 15 % are in the UK, followed by Japan (19 %), Israel (15 %), Canada (14 %), Spain (12 %), India (10 %) and China (9 %).

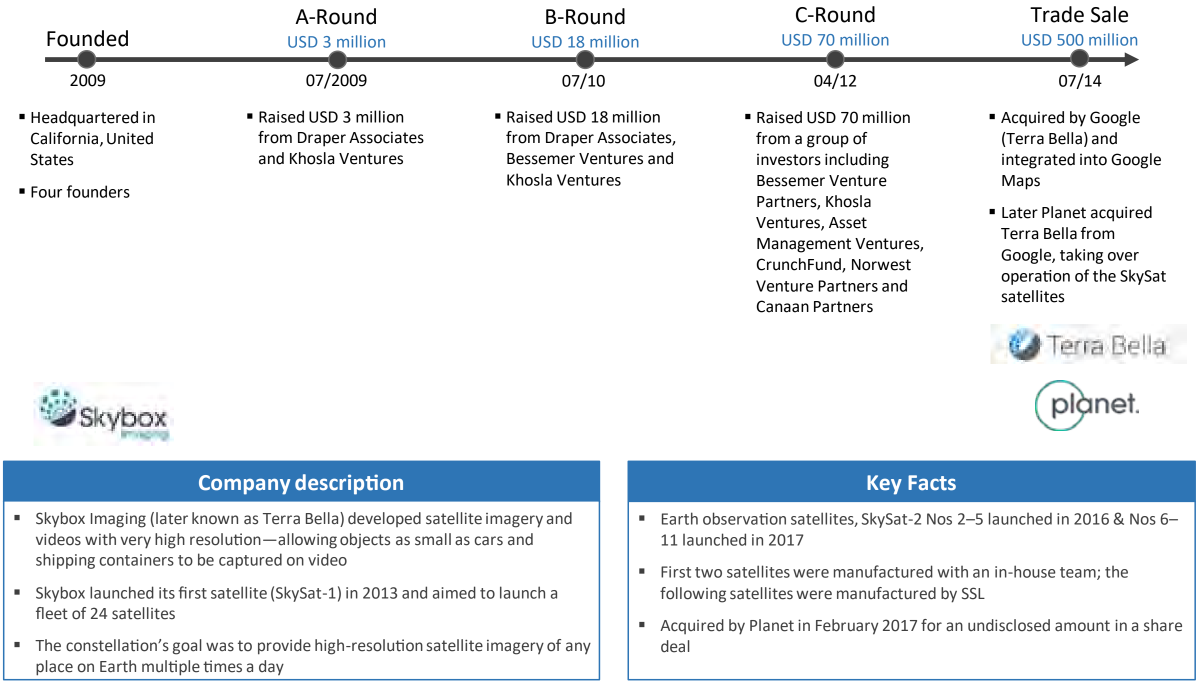


Figure 6: Venture capital investment in Skybox[9]

In terms of the number of investors by type, **venture capital (VC) firms (46 %) represent the largest number of investors in space companies, followed by angel investors (25 %). Together these two investor groups comprise two-thirds of the investors in space ventures.** Private equity (PE) firms (6 %), corporations (19 %) and lenders (4 %) make up the remaining third. Together, these entities can raise significant funds, which is showcased by the investment portfolio put together to finance Planet (at that time still called "Planet Labs") with USD 206 million, as well as Skybox, which saw its first investment round of USD 3 million in 2009 and its final takeover by Google in July 2014 for a total price of USD 500 million, representing an internal rate of return (IRR) of 62 %, and an investment multiple of 11 times.[10]

Figure 7 depicts the growth of investments in space ventures. **There has been tremendous growth in investment in new space companies**, with a relative variation of nearly 80 % between 2000–2005 and 2006–2011, and not less than 347 % between 2006–2012 and 2012–2017.

The period 2011–2017 accounts for nearly two-thirds of the investments in NewSpace over the last 15 years. This is not a singular trend; in 2016, space generated nearly EUR 1.42 billion in venture investment in a single year,[11] a remarkable figure, bearing in mind that the space arena had never reached over EUR 95 million in venture investment annually prior to 2014.[12]

Key Takeaways

- The **global space economy reached EUR 309 billion in 2016**, featuring a compound annual growth rate (CAGR) of 6.7 % between 2005 and 2017, at times outperforming the overall global economy
- The **overall space economy consists of both revenue-generating commercial space activities** (approximately three quarters) **and government investments** (approximately one quarter) in space
- **"NewSpace" thrives upon technology and business model innovations** that allow a significant reduction in costs, the provision of new products and services and a broadening of the customer base
- Space ventures have attracted over **EUR 14.8 billion of investment since 2000**
- **Venture capital (VC) firms (46 %) represent the largest number of investors in space companies**, followed by angel investors (25 %). Together these two investor groups comprise two-thirds of the investors in space ventures
- **Investors in NewSpace are based primarily in the US**, which is home to about two thirds of the 400+ worldwide investors. Of the non-US investors, 19 % are in the Japan, followed by the UK (15 %), Israel (15 %), Canada (14 %), Spain (12 %), India (10 %) and China (9 %)

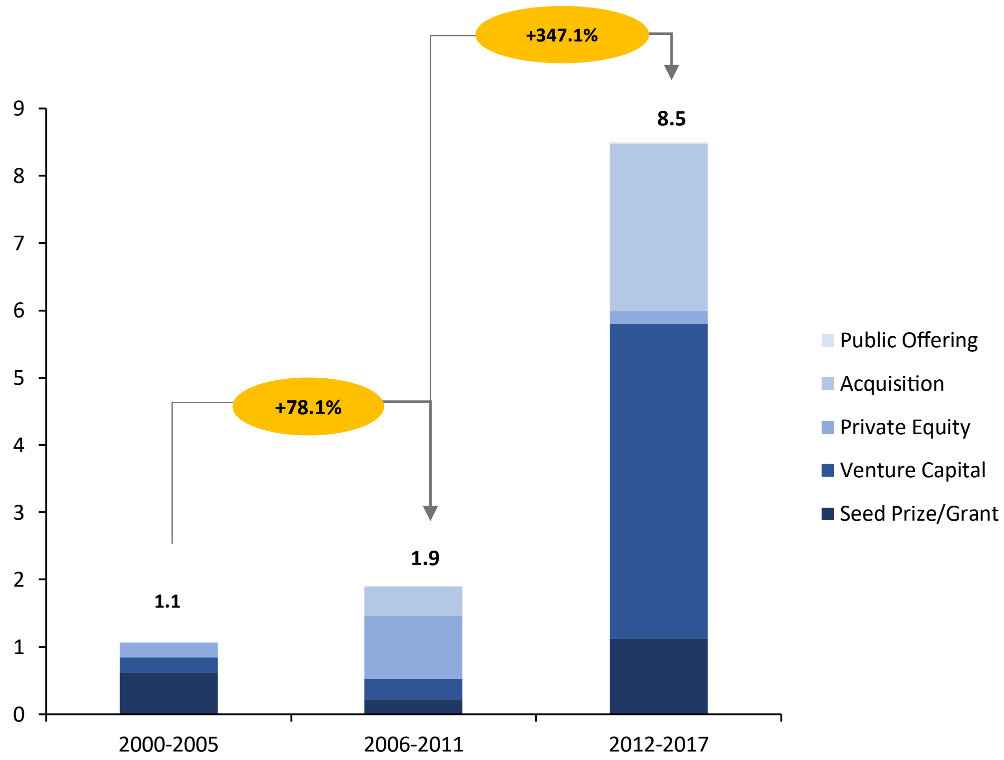


Figure 7: The diverse investments in space ventures in 2000–2017 [bn EUR][13]

2.1.2. The traditional and new space market—market segment and sizes

Agile design, commercial-off-the-shelf, digitalisation and miniaturisation, dual-use, spin-in, venture capital and valley of death have become keywords synonymous with the ongoing change within the space realm. Today's business models thrive not only on technological improvements, but also on **shorter generation cycles, aggressive spin-in approaches and a consequent trade-off between risk, cost and time to market.** NewSpace is the buzzword of the hour, complementing and enlarging traditional space, as depicted in Figure 5.

Although connected to space, NewSpace is distinct from traditional space. "Space", within NewSpace is not perceived as the ultimate raison d'être for any project to commence but is rather **used as the ultimate lever to expand a service's reach to the global level**, ensuring economy of scale benefits. This "outside the traditional box approach" that characterises NewSpace allows the **transformation of the old market segments, and access to new market segments** such that particular needs can be met competitively.

Figure 8 depicts the space sector value chain, outlining activities, services and applications from the conception, design and construction, and launch and operation, to the final data retrieval and generation of value added services.

The space sector value chain pictured in Figure 8 features 22 domains, which have been clustered into 8 market segments, which can be subdivided into 4 sub-areas:

- **fully established**, comprised of (1) "Launch Industry", (2) "Satellite Manufacturing", (3) "Satellite Services", (4) "Ground Equipment" and (5) "National Security", and hence market segments, featuring several players, competing in a market with several commercial and institutional users;
- **implemented**, featuring (6) "Crewed and robotic Space Science and Exploration", and hence segments that are partly implemented, meaning that activities within this segment follow market rules although the market is limited (e.g. only institutional);
- **started**, like (7) "Space Tourism", i.e. market segments that are not yet established but have been started and are actively pursued (e.g. by Virgin Galactic and Blue Origin);

- **emerging**, (6) "Energy, Mining, Processing and Assembly", a segment complementing the others, formed by currently emerging domains, and hence with companies and start-ups raising the first funds and investments to explore these new business areas.

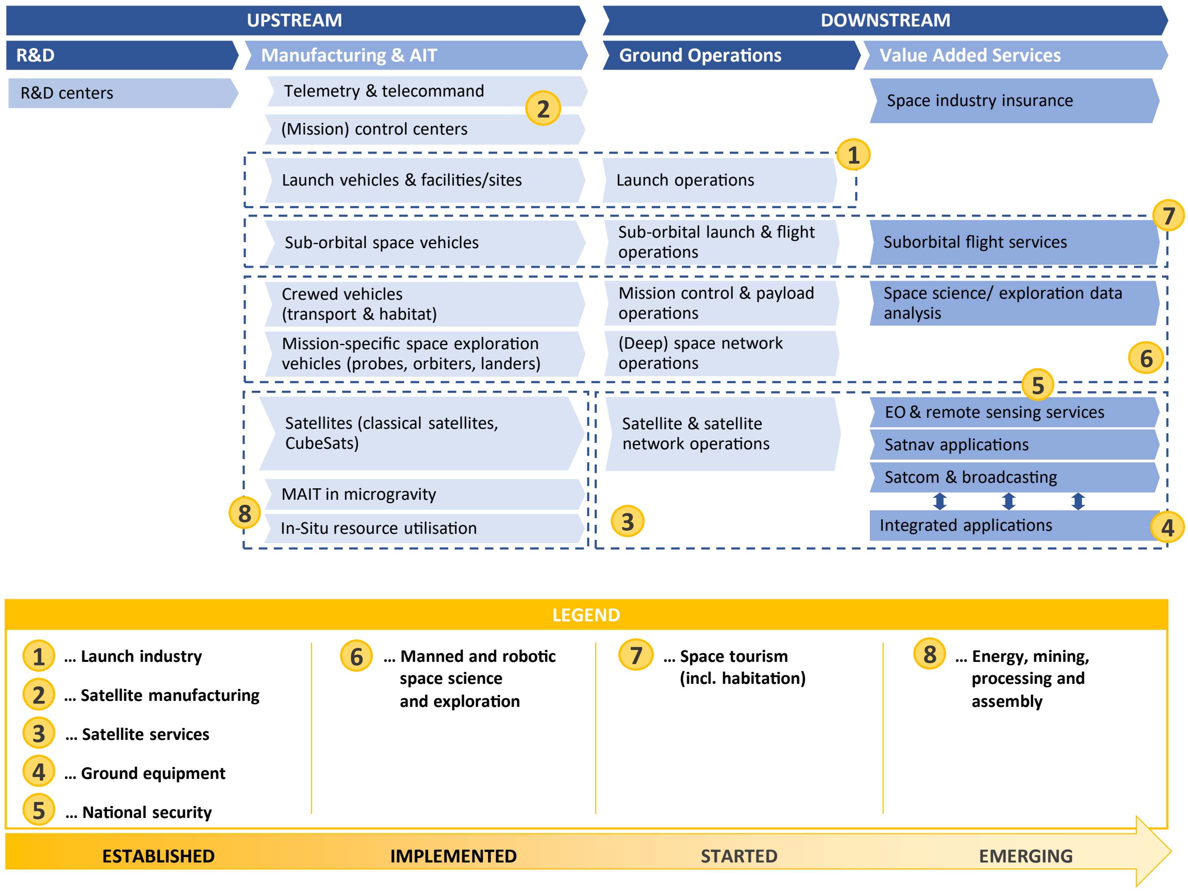


Figure 8: Space sector value chain with 22 market domains grouped into 8 market segments[14]

As symbolised by the arrows in Figure 5 and Figure 8, **this distinction follows both the evolution and nature of business, therefore allowing classification of the listed segments/domains into "traditional space" and "NewSpace"** as depicted in Figure 5.[15]

The **market segments and domains,** whose interconnection and position within the space sector value chain are depicted in Figure 8, have a different history, evolution and business nature. Market sizes differ, as can readily be seen in Figure 9. They are comprised of several domains, which may be more or less commercially oriented, focusing, for example, on business-to-business (B2B) and/or business-to-consumer (B2C) business models.

The global space economy reached a size of EUR 308.7 billion in 2017.[16] **79 % of that value, or EUR 238.2 billion, accounts for the satellite industry**, which is comprised of the established and implemented market segments listed in Figure 8. In the future, "space tourism" and "energy, mining, processing and assembly" may become important business areas. For the time being, however, these industries are still in their infancy and unable to contribute.

Although it is much smaller than the other segments, the satellite manufacturing segment is of great strategic value as it provides an insight into the other segments. It can be used to find out in detail what types of missions were launched and what kind of satellites were manufactured (Figure 10).

As can be seen on the left-hand side of Figure 10, **Earth observation (EO) was the biggest user of manufacturing and launch services in 2017**; 49 % of all spacecraft launched were to embark on an EO mission. Commercial communication satellites followed, with 18 %, while meteorology acquired third place with 15 %. It is interesting to note that 37 %

of all satellites launched in 2016 belonged to the CubeSat class, amounting to 36 satellites in total, making up the majority of the commercial Earth observation satellites.

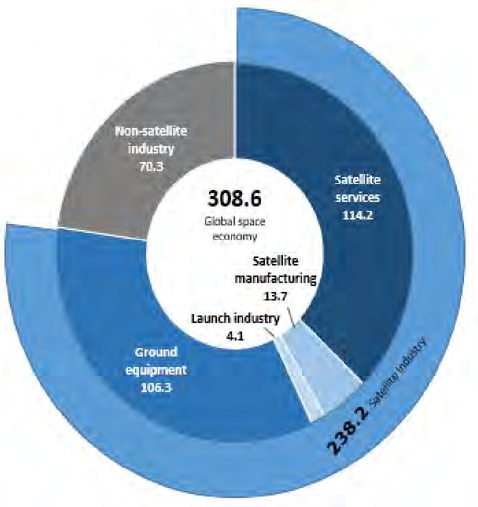


Figure 9: The state of the global space economy and of its market segments in 2017 [bn EUR][17]

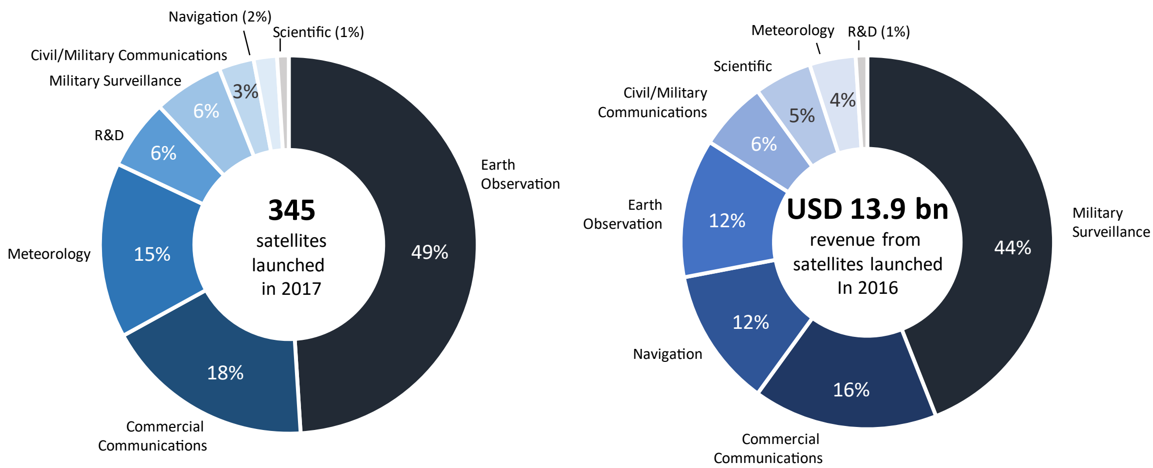


Figure 10: Assessment of the satellites being manufactured and launched in 2016/2017[18]

The right-hand side of Figure 10 shows a slightly different picture, as it ranks the spacecraft launched in 2016 by their value, putting the satellites serving military surveillance (reconnaissance) clearly in first place with 44 % of the total value of EUR 12.6 billion (36 % of the value in 2015). **Owing to the stringent requirements that a military reconnaissance satellite has to fulfil** (high resolution, several observation bands, high service availability while providing flexibility in its flight patterns) and the limited supplier base, **these types of systems are rather costly**. Commercial communication satellites were again ranked second with 22 %, a significant drop from the 42 % that the commercial communications domain had accounted for in 2015. Third place was occupied jointly by navigation and (commercial) Earth observation, featuring a value of 12 % each. A key insight of this assessment, which provides direct evidence for the belief that NewSpace thinking has found its place within the space realm is the fact that **CubeSats represent less than 1 % of the total value of all spacecraft launched in 2016 while accounting for 37 % of all launched satellites**. Bearing this in mind, it is clear that NewSpace allows the rollout of demand-driven, commercially set-up and (mostly) privately financed space missions serving B2C or B2B models.

As all of the market segments discussed above are comprised of different domains, it is important to note which domains and sub-areas belong to which segment. While Figure 9 provides an overview, Table 4 features a further detailed description of the eight market segments, listing established and entering proponents of the respective business sectors.

Segment	Description	Proponents Examples
Launcher Industry	Companies that develop launch vehicles and facilities to provide access to near and outer space. These companies also provide launch services, sometimes complemented by rockets sourced from other suppliers (e.g. Soyuz being launched by Arianespace). With the advent of smallsats this domain has received a new impetus to develop micro launchers such as Electron.	• Arianespace • Blue Origin • Rocket Lab • SpaceX • The Spaceship Company • ULA • Vega
Satellite Manufacturing	Companies that develop and build satellites for satellite applications and services for commercial, civilian and military users. With the advent of the CubeSat standard, small, mini, micro and nano satellites complement classical—big—satellites.	• Airbus Defence & Space • ISIS • OHB • Planet • SSL • ThalesAleniaSpace
Satellite Services	Companies that provide satellite services by single satellites or constellations, in low Earth orbit (LEO), medium Earth orbit (MEO), geostationary orbit (GEO) or any other orbit deemed appropriate. Typical services involve satellite communication, Earth observation, satellite navigation and integrated applications.	• DigitalGlobe • OneWeb • Orbcomm • Planet • SES • Spire
Ground Equipment	Companies that develop hardware and software for mission control centres, telemetry and telecommand systems (e.g. Deep Space Networks), as well as GNSS receivers and communication terminals (e.g. VSAT).	• Hughes Network Systems • ND Satcom • Terma • ViaSat
National Security	Companies that provide services and applications in the interest of national security, including satcom, Satnav, Remote Sensing and Space Situational Awareness. This domain is more concerned by service availability than cost.	• Airbus Defence & Space • Boeing • Lockheed Martin • OHB • Satellite Imaging Corp.
Crewed and robotic Space Science and Exploration	Companies that manufacture specific crewed and robotic exploration vehicles such as probes, orbiters and landers, support the operation of these vehicles and/or perform the retrieval and processing of the data acquired during the science or exploration mission. With the renewed interest in crewed exploration beyond LEO (e.g. cis-lunar space), new players emerge, often originating from space tourism ambitions or incentive prices (Google Lunar X-Prize).	• Airbus Defence & Space • Astrobotic • Boeing • MDA • Moon Express • PT Scientists • Sierra Nevada Corp. • SpaceX
Space Tourism (incl. Habitation)	Companies that manufacture and operate space vehicles as well as habitats in space, providing access to space for everyone that can afford the ticket and is fit enough for flight. So far space tourism has focused on suborbital flight, but once this step has been successfully reached orbital flight will certainly follow. NASA is supporting the development of this domain by its ISS cargo resupply contracts and commercial crew awards.	• Airbus Defence & Space • Axiom Space • Blue Origin • Boeing • Sierra Nevada Corp. • Virgin Galactic
Energy, Mining, Processing and Assembly	Companies that aim to manufacture goods in space, building upon resources in space (e.g. solar energy), on the moon, asteroids or on Mars. While asteroid mining has attracted some interest, space-based energy harvesting is waiting for the first serious start-ups.	• Deep Space Industries • MDA • Planetary Resources • Shackleton Energy Corp.

Table 4: Market segments with descriptions and proponents[19]

By the end of 2016, 1459 operational satellites were in orbit, serving commercial communications, Earth observation, government communication, navigation, science and other purposes. The number of satellites has significantly increased in recent years; in 2012, it was a flock of 994 satellites that provided the satellite network in space.

Out of these 1459 satellites, **520 are stationed in the geosynchronous orbit**. While the former operational lifetime limit of commercial satellites was only 15 years, more and more (mostly larger communications) satellites have exceed this lifetime limit; at the end of 2016, 247 satellites launched before 2002 were still actively used. Nonetheless, on average, 144 new satellites are launched—replacing old ones and/or providing new services—every year.

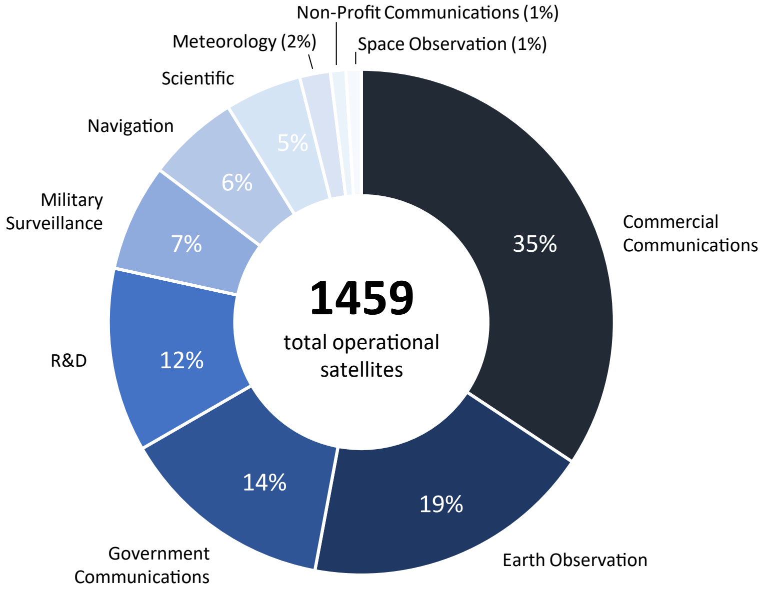


Figure 11: Operational satellites by function, as of 31 December 2016[20]

While Figure 10 and Figure 11 may suggest Earth observation is closely trailing satellite communication, the reality looks entirely different; satellite communication remains, commercially, the most vibrant market domain by far (as exemplified by Figure 12).

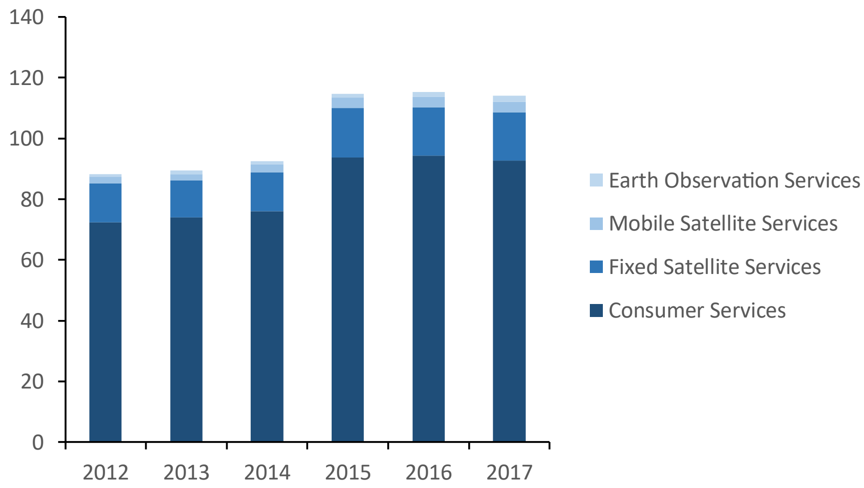


Figure 12: Global satellite service revenues [bn EUR][21]

Consumer services (such as satellite TV, satellite radio and satellite broadband) form the mainstay, accounting for 81 % of the revenue stream. Fixed Satellite Services (FSS) such as transponder agreements follow at 14 %, leaving a miniscule share of the total revenue stream for Mobile Satellite Services (MSS) and Earth observation services.

Table 5 provides an in-depth description of the satellite services segment, detailing its commercial importance.

Out of the three key market domains, **Earth observation is currently experiencing the biggest change in its business models** as the ever-improving capabilities and the miniaturisation of sensors, satellites and computers allow the convergence of the commercial with the civilian and military domains.

Domain	Description	Proponents
Earth Observation	Upstream (components/satellites/constellations) and downstream companies that provide or use Earth observation data (Copernicus or other). These also encompass data analytics companies using Earth observation data in various application domains, as well as mapping and surveying companies.	• DigitalGlobe • Planet • SATLANTIS • Dauria Aerospace • Rezatec
Satellite Navigation	Companies that provide GNSS space hardware or GNSS receivers, as well as companies that deliver downstream applications and services from Galileo/European Geostationary Overlay System (EGNOS) and other GNSS constellations.	• Garmin • Trimble • Septentrio
Satellite Communications	Companies that operate in the field of telecommunications. These include companies that operate satellite constellations, the ground segments for constellations or satellite communication terminals.	• SES • IntelSat • Inmarsat • ViaSat

Table 5: The three key market domains of the satellite services segment[22]

		High Res (<1m)	High revisit (<1dy)	Sensor Description	System Size	Sat Mass [kg]
Large Satellites	Airbus D&S			Optical and radar	4	1,000
	DigitalGlobe			Optical	5	2,800
	MDA			Radar	1	2,300
	DMCii			Optical	6	450
	ImageSat			Optical	3	350
	UrtheCast			Optical and radar	24	1,400
	Astro Digital			Optical	30	20
Small Satellites (<20kg)	Axelspace			Optical	50	95
	BlackBridge (Planet)			Optical	5	150
	BlackSky Global			Optical	60	50
	Capella Space			Radar	30	TBD
	XpressSAR			Radar	4	TBD
	GeoOptics			Radio occultation	24	115
	HawkEye360			RF mapping	21+	TBD
	Hera Systems			Optical	48	24
	ICEYE			Radar	50	<100
	PlanetiQ			Radio occultation	12	22
	Planetary Resources			Optical	10	TBD
	Planet			Optical	100+	3
	Satellogic			Optical	25+	35
	Spire Global			Radio occultation	50	3
	Terra Bella (Planet)			Optical	24	120

Planned

Figure 13: A plethora of new and established players compete in the Earth observation domain, offering services based on different satellite systems[23]

Today (as shown in Figure 13), it is a mix of established Earth observation companies and new ventures, such as Planet, SATLANTIS and others that ride the new wave of commercial opportunities, building upon and fuelling the development of the sector by making use of:

- **smaller and cheaper satellites** performing high-resolution Earth observation and remote sensing;
- the build-up of **cost-effective constellations**;
- **better processing capabilities** and hence faster data delivery;
- an **extension of sensor capabilities** to cover several optical bands as well as radar;
- the **build-up and replenishment of an Earth observation system in a relatively short amount of time** (months instead of years).

All these capabilities both **contribute to commercial attractiveness** and **trigger the interest of military users**, who look for cost-effective solutions that can complement their highest-class reconnaissance systems, thus increasing both resilience and service availability levels.

The following case study provides some insights into space reconnaissance, which represents the military way of performing Earth observation.

Key Takeaways

- **Today's business models thrive not only on technological improvements**, but also on shorter generation cycles, aggressive spin-in approaches and a consequent trade-off between risk, cost and time to market.
- **Earth observation was the biggest user of manufacturing and launch services in 2017**; 49 % of all spacecraft launched were to embark on an Earth observation mission.
- **CubeSats represent less than 1 % of the total value of all spacecraft launched in 2016**, while accounting for 37 % of all launched satellites.
- By the end of 2016, 1459 operational satellites were in orbit, serving commercial communications, Earth observation, government communication, navigation, science and other purposes. The number of satellites has significantly increased in recent years from 994 in 2012.
- **Satellite communication remains, commercially, the most vibrant market domain**, with consumer services (such as satellite TV, satellite radio and satellite broadband) forming the mainstay, accounting for 81 % of the revenue stream.
- Today, a mix of **established Earth observation companies** and **new ventures** such as Planet, SATLANTIS and others **ride the new wave of commercial opportunities.**

2.1.3. Case study: the convergence of commercial Earth observation and space reconnaissance[vi]

The power of Earth imagery became obvious to the general public for the first time on 11 September 2001. Due to the terror attacks on the World Trade Center and other sites, all aeroplanes were banned from the US skies for several days. Consequently, it was up to EO satellites such as IKONOS to provide exclusive images of "Ground Zero", as depicted in Figure 14.

Launched two years earlier and operated by DigitalGlobe, IKONOS was the first of its kind: a commercial Earth observation satellite providing images in four visual bands with a resolution as good as one metre, demonstrated on the right-hand side of Figure 14, where a close-up clearly shows cars driving along the highway on the waterfront.

EO was one of the early applications of spaceflight. When the first rockets were launched into space after World War II, science and reconnaissance were the main drivers. **Over time, space saw an ever-increasing military utilisation for purposes such as:**

- navigation (GPS);
- space reconnaissance (especially observation of foreign intercontinental ballistic missiles (ICBMs);
- control of own ICBMs and long-range guided missiles (performed by US/USSR);

vi This is an excerpt; the complete case study is provided in the Annex.

- communication;
- the Strategic Defense Initiative (SDI).

The SDI was a proposed missile defence system intended to protect the United States from an attack by ballistic strategic nuclear weapons (ICBMs and submarine-launched ballistic missiles (SLBMs)). Announced by US President Ronald Reagan in 1983, efforts to develop SDI systems continued from the 1980s up to 1993, when the political support for SDI collapsed due to the end of the Cold War.[24]

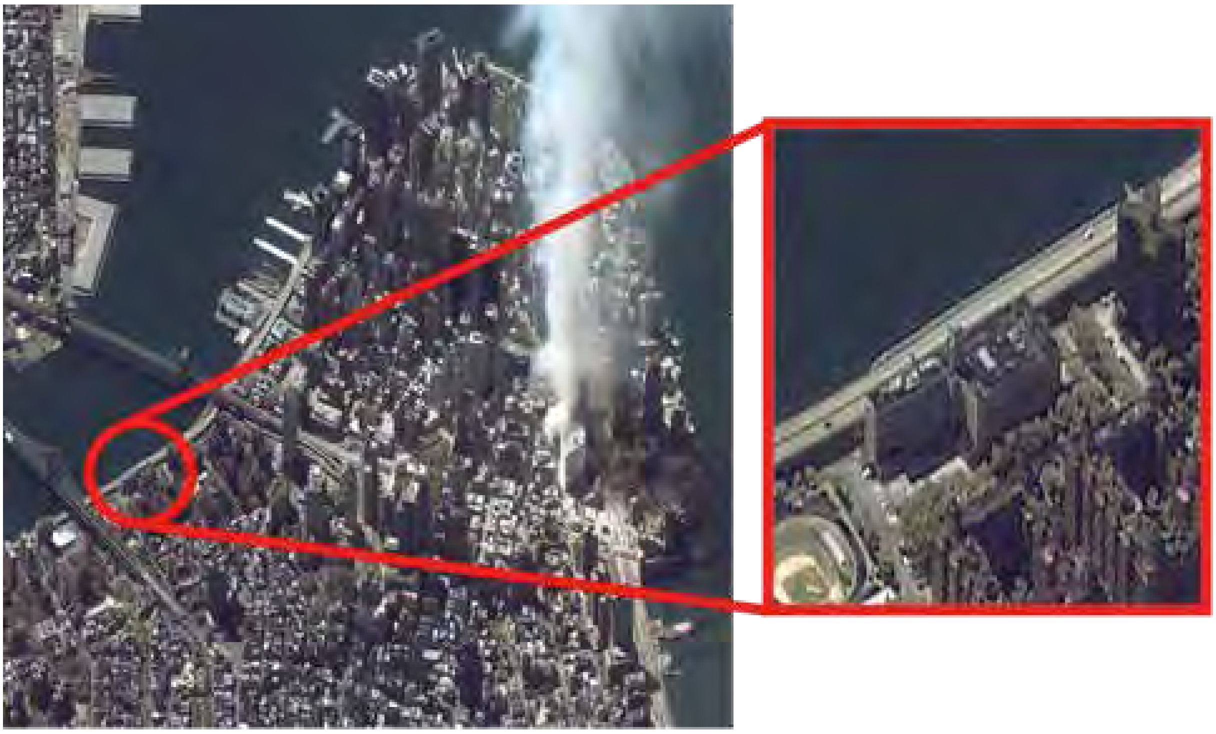


Figure 14: Downtown Manhattan as seen by the IKONOS Satellite on Sept. 12, 2001[25]

While **reconnaissance had always played an important role in times of conflict**, the end of World War II and the start of the Cold War gave it a clear primary role, fuelled by the two buzzwords "bomber gap" and "missile gap". Both Cold War terms were used in the US in the 1950s and 1960s for the perceived superiority in the number and power of the USSR's bombers and missiles compared with the systems available to the US. **Quantifying the bomber and missile gaps was the task of the hour, and efforts were made to obtain reconnaissance data** of the presumed large numbers of bombers and missiles hiding behind the Iron Curtain.

The tool of choice to obtain such information was the **U-2, a US high-altitude reconnaissance aircraft**, built by the Lockheed Skunk Works in 1957. With a range of more than 6000 nautical miles, a service ceiling of nearly 25.9 km and an endurance of 12 hours, the U-2 was believed to be out of range of Soviet radar, interceptors and incoming missiles.[26] Although the shooting down of a U-2 in 1960 proved that this assumption was wrong, the event itself did not halt the use of the U-2 as a reconnaissance aircraft. It did, however, push forward the satellite reconnaissance programmes, notably **Project Corona**, a US strategic reconnaissance satellite programme that started in June 1959.

The Corona programme was a series of US strategic reconnaissance satellites produced and operated by the Central Intelligence Agency (CIA) Directorate of Science & Technology with substantial assistance from the US Air Force (USAF). The Corona satellites were used for photographic surveillance of the USSR, the People's Republic of China and other areas from 1959 to 1972.[27] When Corona was launched, charge-coupled device (CCD) systems were still futuristic science fiction. The state-of-the-art camera system relied on chemical film that had to be stored, moved forward on a reel, exposed image-by-image and finally processed in a chemical laboratory. Launched by a THORAD-AGENA booster, the satellite was delivered in a 186 km x 280 km polar orbit. Early satellites had a mass of 780 kg. Later generations were as heavy as 2000 kg. **102 out of the 145 missions were very successful**: in total, 860 000 photos were shot, capturing a land area of nearly 2 billion square kilometres on 39 000 film canisters. The **resolution of the black and white images was astounding: a range of 1.5–1.8 metres was feasible**. The **complexity of such a 19-day mission** is depicted in the picture sequence in Figure 15.

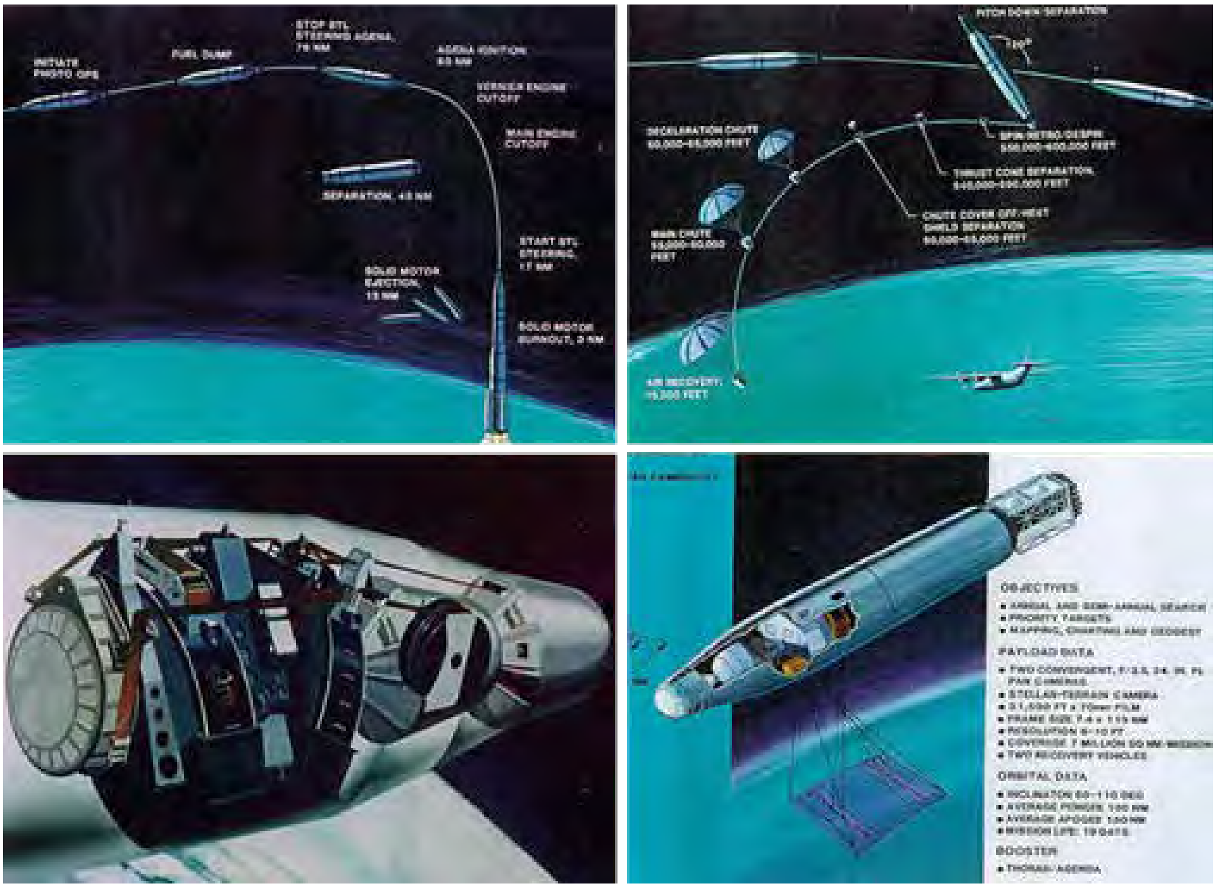


Figure 15: A typical sequence for a Corona reconnaissance mission[28]

After Corona, spy satellites became the tool of choice for the reconnaissance demands of the US Air Force, Army, CIA, NRO and others. Consequently, **several generations of reconnaissance satellites followed, each performing better than their forebear**s. The most modern optical US spy satellites, such as KH-11 and KH-12, feature resolutions better than 10 cm. Radar-based systems have a limited resolution of 1 m, due to the difference in wavelength between visible light and microwaves, as well as volume and mass limits for launching large mirrors and/or microwave antennas. This drawback of radar satellites is largely offset by their observational capabilities at night or when a particular patch of land or sea is hidden beneath clouds. In addition, radar satellites enable different applications from optical satellites, and hence can largely complement humanity's picture of planet Earth.

Today, many countries use EO satellites and rely on the continuous view of Earth. The reason for doing so ranges from purely commercial and civilian purposes to 100 % military-focused objectives, with a **floating dual-use area** in between.

Triggered by the success of spy satellites, **the security dimension of space has increased over time**. Today, space is used for navigation, space reconnaissance, control of own or foreign missiles, communication purposes, early warning and more. At the same time, EO has proven its worth for applications beyond reconnaissance, such as urban planning, environmental monitoring and protection and tracking applications.

Consequently, EO has a **dual-use character**, which makes it **attractive for public–private partnership (PPP)** programmes and projects. While Europe's Copernicus programme showcases the dual-use EO programme, GeoEye, COSMO-SkyMed and TerraSAR are other examples of EO satellites built in a PPP fashion, **serving the interests of both civilian and military users**.

While resolution is always a key specification of every EO satellite, one particular difference between typical commercial/civilian and military/security users is the maximum time that it may take until an acquired image is made available to the user and how quickly a specific area of interest can be revisited. Time is of the essence—particularly for the military/security user. In a military campaign one wants to know as quickly as possible what adversaries (and own assets) are doing, how a campaign is progressing and how things are developing ("**change detection**"). Therefore, image transmission and processing needs to be fast, and several satellites need to be able to provide a frequent observation of the area of interest. Many satellite image providers offer a fleet of different satellites. **As the applications and services in the space and security domain have increased, so have the number of players.** It is now one of the most vibrant application domains in space (see Figure 16).

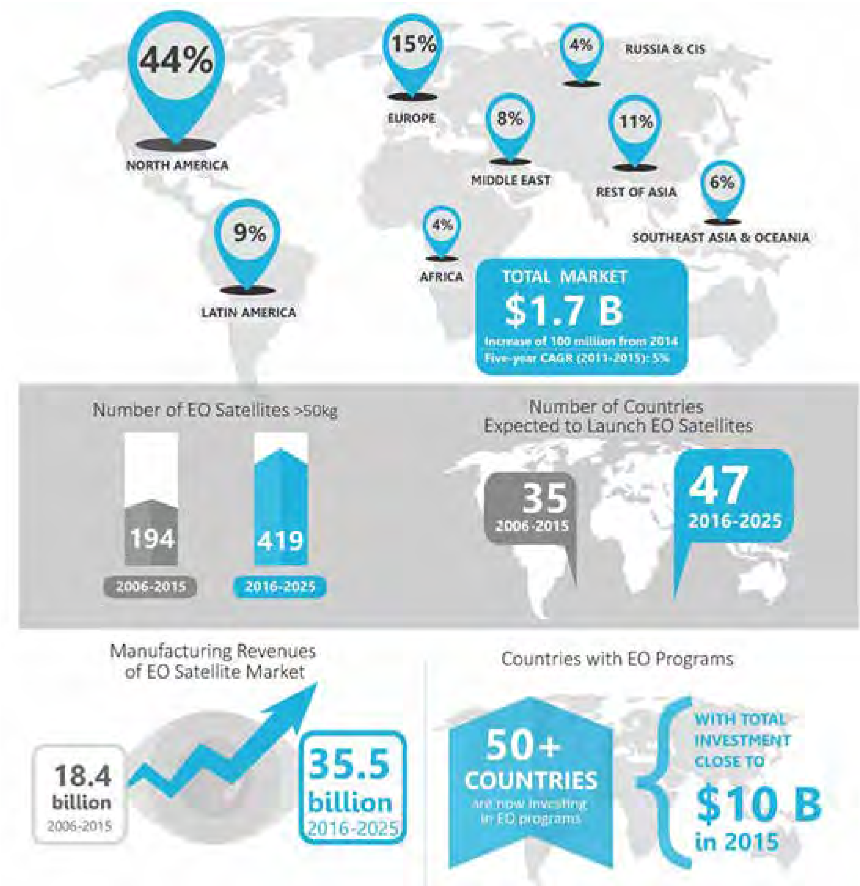


Figure 16: Existing and forecasted commercial data demand in the Earth observation market for different regions, 2015[29]

As picturesque as a high-resolution image of a particular place on Earth may be, several applications and services, e.g. harvest forecasting, deforestation monitoring, EO data collection for insurance purposes and urban planning do not demand Earth observation data in the centimetre range. For such applications, resolutions in the order of 2.5 m–5 m are sufficient. In addition, these resolutions are also preferred for "change detection" approaches employed by military users, best realised by a mix of very few high-resolution satellites and a large constellation of low-resolution satellites. While the high-resolution satellite will observe the areas of interest once every few days or weeks, a **fleet of low-resolution satellites will provide a very frequent and wide coverage, making it easy to detect any changes**. If these exceed a certain threshold and hence require the observer to take a closer look, a higher resolution satellite is tasked to make an up-to-date observation of the area of interest and the complete change detection observation cycle starts again.

It is exactly this balance of low cost versus limitation in resolution and high cost versus superior spatial resolution that has driven the rollout of EO/space reconnaissance constellations to support the change detection methodology employed by the military. **The convergence of the commercial with the civilian and military EO world allows new business models and is fuelled by technology trends, thriving on spillovers, agile developments and the digital**

transformation (see Sections 2.2.4, 2.2.6 and 2.2.7 in particular). Ultimately, these changes in the ecosystem allow a plethora of new and established players to compete in the EO domain, offering services based on different satellite systems.

Key Takeaways

- **Space has seen ever-increasing military use.** Triggered by the success of spy satellites, the security dimension of space has increased over time.
- **Today,** space is used for **navigation, space reconnaissance, control of own or foreign missiles, communication purposes, early warning** and more.
- Consequently, **Earth observation has a dual-use character**, which makes it attractive for PPP programmes and projects.
- The "**change detection**" approach employed by military users is best realised by a mix of very few high-resolution satellites and a large constellation of low-resolution satellites.
- The **convergence of the commercial with the civilian and military EO world** allows new business models and is fuelled by technology trends, thriving on spillovers, agile developments and the digital transformation.

2.2. Technology trends contributing to market disruption

In the following sections the top technology trends disrupting the space and space application market are identified and characterised, thereby explaining the innovation type and potential high-level funding needs.[vii] A summary is given in Table 6, and while many of the technologies have an impact across all business model segments, those with highest disruption are highlighted. The follow-on sections will provide further insights into the different technology trends, particularly highlighting

- **affected market segments,**
- **embedded enabling capabilities**, which come along with this trend,
- **innovation type** (see Table 7), and
- **specific financing needs**, which may be attributed to this particular trend.

	Launcher Industry	Satellite Manufacturing	Satellite Services	Ground Equipment	National Security	Crewed and robotic Space Science and Exploration	Space Tourism (incl. Habitation)	Energy, Mining, Processing and Assembly
Acceleration of generation change/obsolescence	○	○	○	●	○	○	○	○
Advanced manufacturing technologies/3D printing	○	○	○	○	○	●	●	●
Micro- and nanoelectronics/advanced telemetry and telecommand	○	○	○	●	○	○	○	○
Agile development and industrial standard implementation	○	●	○	●	○	●	○	●
Artificial intelligence (AI)/Man–machine interface (MMI)	○	○	●	●	○	○	○	●
Change detection and data fusion	○	○	●	○	●	○	○	●
Digital transformation and convergence	○	○	○	●	○	○	○	○
Evolved expendable/reusable launcher systems	●	○	○	○	○	●	●	●
Miniaturisation and nanotechnology	●	●	●	●	●	●	●	●
Optical and ubiquitous communications	○	○	○	○	●	●	○	●

Table 6: Trends impacting business model segments

Scientific and technological progress go hand-in-hand, and, similar to science, **technological progress is not always sustaining (hence evolutionary or revolutionary) but sometimes disruptive**. A sustaining innovation does not

vii An exhaustive list of the current state of European space technology is available in the 2017 edition of the European Space Technology Master Plan (ESTMP), published jointly by ESA and the European Commission. The ESTMP can be accessed via: http://www.esa.int/Our_Activities/Space_Engineering_Technology/Europe_s_Master_Plan_for_space_technology_by_ESA_and_the_EU.

significantly affect existing markets, while a disruptive innovation creates a new market by providing a different set of values, which ultimately (and unexpectedly) overtake an existing market. Further details and examples for these innovation patterns are provided in Table 7.

Innovation Type	Description	Example
Evolutionary innovation	A type of sustaining innovation that improves a product in an existing market in ways that customers are expecting.	Fuel injection for gasoline engines, displacing carburettors.
Revolutionary innovation	A type of sustaining innovation that is discontinuous and/or radical, as well as unexpected, but nevertheless does not affect existing markets.	Automobiles in the late 19th century, being sold in few numbers as an expensive luxury item.
Disruptive innovation	An innovation, which creates a new market by providing a different set of values, which ultimately (and unexpectedly) overtakes an existing market.	Introduction of the lower-priced and affordable Ford Model T, which displaced horse-drawn carriages.

Table 7: Types of innovation—from sustaining to disruptive[30]

2.2.1. Acceleration of generation change/obsolescence

Element	Assessment
Affected market segments	1–8, strong driver for 4 (see Figure 8)
Enabling	Shorter generation cycles, better performance, reduced costs
Innovation type	Sustaining–evolutionary (see Table 6 and Table 7)
Specific financing needs	Limited (electronics can be easily sourced from multiple suppliers; as long as the access to a free and open market is guaranteed, there is no specific need to set up a dedicated financing tool)[viii]

Moore's Law predicts a doubling of transistor density on a very large-scale integration (VLSI) chip every two to three years. This exponential growth of capability permits faster and/or smaller electronic systems, with performances and costs that outperform earlier systems by orders of magnitude. A **clear example of Moore's Law is comparing a top-notch portable computer ("Osborne Executive" 1982) with the first Apple iPhone (2007)**. About 25 years of exponential growth, with probably 10 VLSI chip generations in between, have led to the following evolution of the respective features (Figure 17).[ix]

Feature	Osborne Executive (1982)	Apple iPhone (2007)
Weight	100	1
Volume	500	1
Clock speed	1	100
Cost	10	1

Figure 17: Comparison of two computer systems, 25 years and 10 generations apart: Osborne Executive 1982 versus Apple iPhone 2007[31]

Over time, the ever-increasing capabilities and dropping costs of electronics and microprocessors were noticed by different industrial sectors; **today there is not likely to be a single sector that does not employ microprocessors** to provide telecommand and telemetry functionality or use them to optimise chemical, physical and biological processes in order to improve efficiency, reduce the footprint of employed resources or allow new services, better flexibility, etc.

viii This may change, however, if a tightening of export regulations (such as the International Trafficking of Arms Regulation (ITAR)) prohibits access to electronic devices. Such a move may happen if certain devices were considered to be of high military and or strategic value—in this case Europe would have to set-up its own strategic devices/parts list and a dedicated financing regime will have to be set up to ensure that several European suppliers maintain this particular technology.

ix For simplicity, the table features relative values, normed at the lowest unit per comparison feature.

The two- to three-year-generation frequency of Moore's Law has a profound effect, as it leads to a trend of swifter generation changes in all areas where electronics play a role. A modem car model is obsolescent after six years (10–20 years ago, car models lasted for nine years or more), and so are its major components. Today, **the obsolescence of electronic components is one of the most significant issues for any long-term programme**. Locomotives, ships, aeroplanes, power plants—which may last for 30–40 years (or even longer)—all require a mid-life electronics upgrade to overcome obsolescence issues.

Space is no exception to this faster generation change/obsolescence trend. The aerospace sector features a cycle of the order of seven to ten years, approximately five times slower than that of the ICT sector. Currently, the very costly accessibility of space assets (e.g. space qualification or launcher cost) prohibits the acceleration of the space generation cycle to align itself with that of the ICT sector. The maintenance activities performed at the Hubble Space Telescope (HST) and the ISS, however, have shown that space systems can be improved and upgraded, and electronics may be changed by systems that are better performing (and in some cases exchanged and/or augmented by **photonics**). One can therefore assume that **the faster generation change/obsolescence trend will sooner or later prevail in most space market segments.** The advent of commercial activities related to in-orbit maintenance/servicing and to a more frequent and cheaper access to space already lead in that direction.

2.2.2. Advanced manufacturing technologies/three-dimensional printing

Element	Assessment
Affected market segments	1–8, game changer for 6–8 (see Figure 8)
Enabling	Reduced complexity costs, manufacturing in space and on other celestial bodies
Innovation type	Disruptive (see Table 6 and Table 7)
Specific financing needs	Medium (R&D and bridge financing to further develop and commercialise space-qualified printers)

Whether it is space, aviation, automotive, software or any other sort of industry, according to Stephen Wilson and Andrei Perumal, "**Complexity costs are the single biggest determinant of your company's cost competitiveness**".[32] As stated in their book and depicted in Figure 18, complexity costs are different from any others, as they follow a geometric growth: complexity costs do not just rise in proportion to the amount of complexity (whether product, process or organisational) in the business; they rise exponentially with greater levels of complexity. This geometric nature of complexity cost growth separates it from other forms of cost.

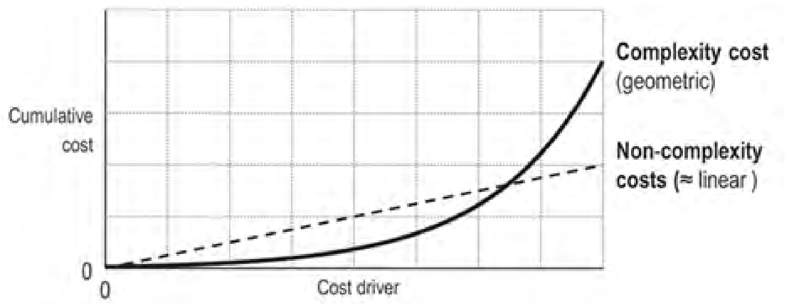


Figure 18: Complexity costs rise exponentially[33]

Complexity costs, all non-value-adding, are driven by the overall number of items—the overall level of complexity. While complexity is simply the number of things, complexity costs are the non-value-adding costs associated with having a number of things. Consequently, **reducing the complexity of a product** (e.g. Space Shuttle, A380, a rocket engine such as the SSME or F-1) **is key to reducing its cost.** In addition, this strategy will also **increase the reliability and maintainability of the product.** All these factors are of great importance for any system, and even greater importance for systems that need to be commercially competitive.[34]

Clever mechanical designs and the transfer of functionality from hardware to software are good measures to reduce the complexity of technical systems. The advent of **advanced manufacturing technologies/three-dimensional (3D) printing has provided engineers with a powerful tool to reduce complexity** even further, as one can now design and manufacture complex systems in one piece without the need to combine and fasten elements together. NASA experiments on-board the ISS have proven that 3D printing in space works.

2.2.3. Micro- and nanoelectronics/advanced telemetry and telecommand

Element	Assessment
Affected market segments	1–8, game changer for 4 (see Figure 8)
Enabling	Holistic observation, control of processes, health monitoring, predictive maintenance
Innovation type	Disruptive for the IoT-element of it (see Table 6)
Specific financing needs	Limited (electronics can be easily sourced from multiple suppliers)

Moore's Law has a profound effect on everything that uses electronic systems. CPUs, microprocessors and computer systems are directly affected, whereas sensors, however, exceed these systems by far in number and have seen drastic improvements by Moore's Law. The concerning improvements relate to both performance increases and the miniaturisation of components. Today, a **suite of sensors is available to observe a plethora of processes, providing a wealth of data, which can be used for health monitoring and predictive maintenance of systems**. Table 8 provides an overview of sensors that are currently utilised within the automotive and transport sector.

Typical sensors used in the automotive and transport industry		
Air flow meter	Knock sensor	Tire-pressure monitoring sensor
Air–fuel ratio meter	MAP sensor	Torque sensor
AFR sensor	Mass flow sensor	Transmission fluid temperature sensor
Blind spot monitor	Oxygen sensor	Turbine speed sensor
Crankshaft position sensor	Parking sensors	Variable reluctance sensor
Defect detector	Radar gun	Vehicle speed sensor
Engine coolant temperature sensor	Speedometer	Water sensor
Hall effect sensor	Speed sensor	Wheel speed sensor
	Throttle position sensor	

Table 8: Typical sensors used in the automotive and transport industry[35]

The trend of recording more and more system data and transmitting it online to the system provider's data storage centre (telemetry) where it will be analysed and processed in real time so corrective measures can be devised and transferred to the system concerned (telecommand) is, per se, not disruptive, as telemetry and telecommand were always an integral part of every space mission. What is disruptive, however, is the fact that **the inter-connectivity concerns more and more sectors and acquires an ever-increasing amount of data from more and more sensors, ultimately providing new and holistic views on systems and processes to users and operators**.

The drivers for this sensor and data inflation are health monitoring and predictive maintenance techniques. The latter are designed to help determine the condition of in-service equipment in order to predict when maintenance should be performed. This approach promises cost savings over routine or time-based preventive maintenance, because tasks are performed only when warranted. Bearing all this in mind, it is no surprise that the aircraft sensors market was valued at USD 1.59 billion in 2016 and is projected to reach USD 2.25 billion by 2022, at a CAGR of 6.01 % from 2017 to 2022. **Considering the vast increase of IoT-connected devices, one can expect that more and more sectors will embark on using advanced telemetry and telecommand algorithms**.

2.2.4. Agile development and industrial standard implementation

Element	Assessment
Affected market segments	1–8, high impact on 2, 4, 6 and 8 (see Figure 8)
Enabling	Flexible designs, minimum viable product strategies, staggered rollout sequences
Innovation type	Sustaining–Revolutionary (see Table 6 and Table 7)
Specific financing needs	Limited (it is more business philosophy than classical engineering)

Agile development is an approach from the IT sector, which has recently seen its introduction into space along with the NewSpace trend.[36] It is based on agile software development, an umbrella term for a set of methods and practices based on the values and principles expressed in the Agile Manifesto. It represents an approach to software development under which **requirements and solutions evolve** through the collaborative effort of self-organising cross-functional teams, their customer(s)/end users(s)[37] and advocates, adaptive planning, evolutionary development, early delivery and continuous improvement. It encourages rapid and flexible response to change.[38]

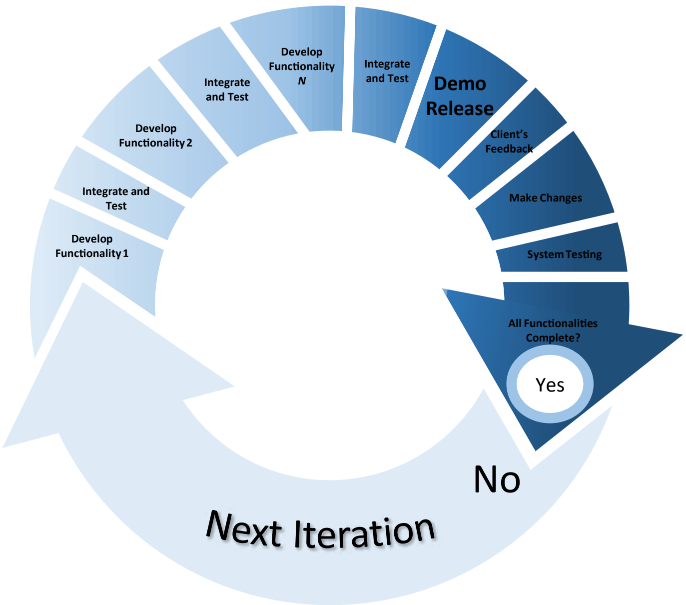


Figure 19: Agile development cycle[39]

Figure 19 outlines the agile (software) development approach. It is **an iterative and cyclic improvement process that offers a minimum viable product early in the process, which can be used to test out markets, raise interest and test certain aspects** with respect to customer satisfaction. Acknowledging that this process does not produce a fully fledged product in the first cycle, typical buzzwords associated with agile development are "pilots", "releases" and "patches"—all words in common use in the computer, software and mobile phone industry.

Agile development is in **stark contrast to classical space project management**, which features a series of well-defined project phases and reviews, cumulating in a structured **project management approach (European Cooperation for Space Standardization (ECSS)), which has been devised to minimise failures and risks**. It calls upon an early selection of the mission's target and objectives, and performs a well-orchestrated process in down-selecting systems, payload and operational activities to ensure mission success. Numerous reviews serve as review and decision points, allowing a thorough assessment of the selected systems and technologies. Lessons learned from other missions are thus able to be considered, thereby avoiding making the same mistakes twice.

While there will always be a necessity to plan, design and manufacture space missions to such high standards, **the increased commercialisation of space has triggered a different design philosophy, showcased by NewSpace**. It focuses on the rollout of demand-driven, commercially set-up and (mostly) privately financed space missions, serving B2C or B2B models. As these missions are often operating in the low Earth orbit (LEO), where the environment is well known and less harsh than deep space, the systems employed can often make use of commercially available ones, which will readily fulfil the specific environmental requirements. Today's industrial standards published by the International Standards Organisation (ISO), Deutsches Institut für Normung (DIN), etc., call for electronic components to survive high g-loads and shocks, have strict requirements on the electromagnetic compatibility of equipment and look carefully into the safety of power storage systems. In addition, computer, tablet and mobile phone producers are forced by the market to minimise mass, volume and power consumption while providing the highest possible processing power, to allow a suite of apps and programmes to operate flawlessly.

With the advent of cheap electronics that can readily survive a rocket launch (the gravitational forces when a mobile phone hits the ground are larger than the shocks during a rocket launch) and are powerful yet small, lightweight and power-economical enough, the race is on to design space systems by making use of industrial standards and Agilent design. **Space systems like the EO constellation of Planet, the IoT/machine-to-machine (M2M) constellation of Orbcomm and the ADS-B/AIS-Radio Occultation constellation of Spire are proponents of this NewSpace design and business philosophy**, where market proximity rates higher than perfect quality.[40]

2.2.5. Artificial intelligence/man–machine interface

Element	Assessment
Affected market segments	1–8, high impact on 3, 4 and 8 (see Figure 8)
Enabling	Autonomous operations, better management of on-board resources, higher performance, easier and faster data interaction with computer systems
Innovation type	Sustaining–revolutionary for weak AI/disruptive for strong AI (see Table 6)
Specific financing needs	Medium to high (R&D and strategic investments to build up a whole industry sector)

Artificial intelligence (AI) was defined in 1956 at the Dartmouth Conference, and two flavours emerged: strong and weak. While strong AI is connected to an "appropriately programmed computer with the right inputs and outputs [which] would thereby have a mind in exactly the same sense human beings have minds"[41] **the weak version is something that we already see today in the form of a machine with narrow intelligence**, designed to solve a specific task, such as the optimisation of processes or time series analysis (see Figure 102).

Apple's Siri is a good example of a **narrow intelligence, augmented with a novel man–machine interface** (MMI). While Siri improves the data input and output, and hence enables an easier and faster data interaction with computer systems, it still operates within a limited predefined range; there is no genuine intelligence, no self-awareness and no life, despite Siri being a sophisticated example of weak AI. In contrast, HAL 9000[x] features a similar MMI to Siri, but is a master example of a strong AI—although, of course, HAL is pure science fiction.[xi]

While it may take decades until humanity has mastered strong AI, the appearance of **weak AI to solve particular issues for space missions is not too far away**. As stated in Section 2.2.4, the performance capability of modern software and its adaptability enable the use of imperfect hardware. High-performance computers allow the use of AI algorithms with inherently stronger autonomy. **Bearing in mind that operational costs can range from 4 % to 32 %,[42] two-digit savings in satellite operations costs might be possible**. These savings can be accrued by using a specialised AI implanted on board the satellite, which will, for example, optimise the satellite's trajectory to better satisfy requirements related to optimal observation of targets on the ground, the avoidance of space debris, the establishment of good communication links to the ground or with other space systems, while minimising the need for propulsive manoeuvres and fuel consumption. The extent to which deep learning algorithms can be used for these tasks remains to be seen.

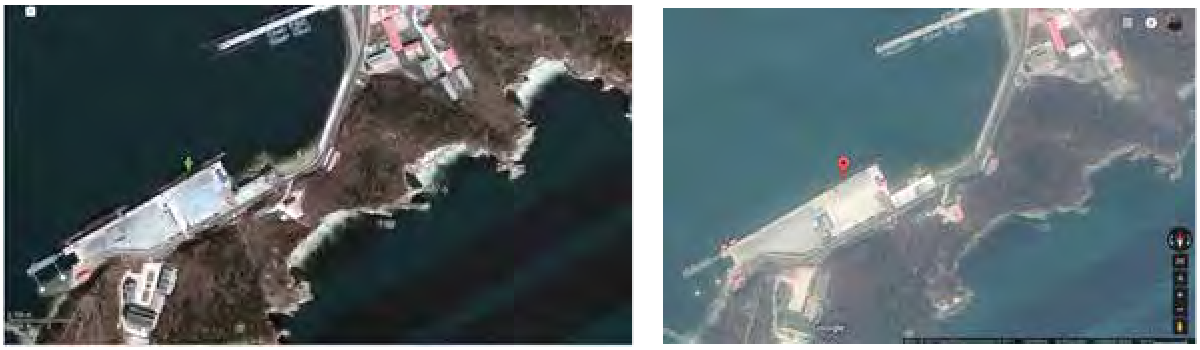
2.2.6. Change detection and data fusion

Element	Assessment
Affected market segments	1–8, game changer for 3, 5 and 8 (see Figure 8)
Enabling	Cost-effective observation and analysis of specific points of interest, correlation of images and time sequences with other data (also from ground and other sources)
Innovation type	Sustaining–Revolutionary (see Table 6 and Table 7)
Specific financing needs	Medium to high—it is not so much a technology topic but more a matter of whether Europe wants to have its own player(s) that can provide this service, which is highly relevant for security

A mix of high-resolution observations of the order of tens of centimetres and observations of the order of 2.5 m–5 m are preferred for the "**change detection**" approaches employed by military users to swiftly assess if a particular place

x The on-board computer of the spaceship "Discovery One" in the sci-fi movies "2001" and "2010".

xi Critics state that it is good that strong AI has not advanced yet, as it may pose a huge risk to the survival of humanity of interest has seen improvement, degradation or other changes. While the high-resolution satellite will observe the areas of interest once every few days or weeks, a **fleet of low resolution satellites will provide a very frequent and wide coverage, making it easy to detect any changes**. If these exceed a certain threshold, and hence require the observer to take a closer look, a **higher resolution satellite is tasked to make an up-to-date observation of the area of interest** and the complete change detection observation cycle starts again (see Figure 20).



26 November 2012 | 10 November 2017

Figure 20: Long-term changes within a Chinese naval base, as seen from space[43]

Figure 20 gives an example of the change detection process, with two satellite images depicting the same Chinese naval base with a time difference of approximately five years. The **data that can be extracted from these images are highly relevant for military users as they allow them to assess the readiness and capabilities** of this specific actor.

With computers becoming increasingly powerful and accessible with every new generation (cloud computing), the processing of power-intensive data algorithms such as change detection and data fusion becomes more feasible. The combination of in situ and/or ground-based data with space-borne data can provide interesting insights. Establishing the correlation is not always easy, as there is a near endless number of combinations of data. The advent of new algorithms based on weak AI (see Section 2.2.5) will certainly help to more quickly identify those fusion algorithms that feature stronger correlations.

2.2.7. Digital transformation and convergence

Element	Assessment
Affected market segments	1–8, game changer for 4 (see Figure 8)
Enabling	Data archiving, search within and comparison of data sets, lower entry hurdles to data processing, manipulation and visualisation
Innovation type	Disruptive, as showcased by global information storage capacity (see Table 6)
Specific financing needs	Limited to medium (electronics can be easily sourced from multiple suppliers; the development of specific software may not be easily outsourced and requires skilled personnel)

Digital transformation, as well as several other trends that we see in electronics and communication and which form the ICT revolution, is based on Moore's Law. Although Moore's Law itself is not disruptive, the digital transformation is if we consider the exponential growth of the global information storage capacity, representing the world's technological capacity to store, communicate and compute Information (see Figure 105). The growth of **storage capacity goes hand-in-hand with the growth of data generation** (see Table 40); when CERN started its Large Hadron Collider (LHC) in 2008, the yearly data amount stored for later analysis was 20 petabytes (PB). With the recent upgrades in particle detectors and experiments, the annual data generation is forecasted to increase by a factor of 10 (hence 200 PB p.a.) by 2022.

Besides making it easier to search for data and to compare and cross-correlate data sets, digital transformation is a key element in what has been described as technological convergence. Several definitions for the term **convergence** exist, but in essence they all describe it as **a trend or process describing the evolution of technology services and industry structures in such a way that several different technological systems sometimes evolve towards performing similar tasks**.

Different flavours of convergence exist, such as **digital convergence**, which aims to pull four industries into one conglomerate: ITTCE (information technologies, telecommunication, consumer electronics, and entertainment). Digital convergence is a fact, as is **media convergence**, the interlinking of computing and other information technologies, media content, media companies and communication networks. By 2014, another convergence, the NBIC—**nanotechnology, biotechnology, information technology and cognitive science**—had emerged.

As far as space is concerned, digital transformation and convergence have a profound effect on the way data is generated, stored, processed, analysed and presented. Powerful computers allow the emulation of tasks by software for which one had to obtain specific—and costly—hardware some years ago (e.g. software defined radio (SDR) can nowadays emulate GNSS signals). Although the software may be very specialised and costly, requiring skilled personnel to develop it, it is certainly cheaper and more adaptable than any hardware solution. With computers becoming so powerful and versatile they are able to fully use the trend of convergence: they can nowadays handle tasks that were previously so specific that their processing required special tools and equipment. **Digital transformation and convergence significantly lower the entry hurdles**, as all the hardware and experts needed to operate computers can nowadays be substituted—at least to a certain extent—by skilled personnel who resort to software-based methodologies to perform the tasks in question.

2.2.8. Evolved expendable/reusable launcher systems

Element	Assessment
Affected market segments	1–8, game changer for 1, 6, 7 and 8 (see Figure 8)
Enabling	Cheaper and hence more frequent access to space; enlargement of the space market; new business models in space
Innovation type	Disruptive, as it will extend humanity's sphere of influence beyond LEO and into space (at least the near solar system) (see Table 6)
Specific financing needs	Medium to high (building a rocket requires high upfront investment, dedicated safety analysis; a competitive launch platform; synergies with advanced materials (e.g. carbon fibre), which withstand higher temperatures, high density power systems; improved control algorithms can reduce rocket and launch costs significantly)

Spaceflight is (still) expensive. **The cost of sending 1 kg of mass into LEO is typically rated at between USD 10 000 and USD 20 000.** Even though miniaturisation has helped to reduce some of the costs, satellites and spacecraft used to weigh hundreds to thousands of kilograms, and hence the launch into space became a major cost item. For several decades, satellite communication was the only sector that could commercially afford launch prices, which would amount to around USD 115 million. This amount had to be paid to obtain a dedicated launch into the Geostationary Transfer Orbit (GTO) by a Russian Proton-M rocket. As one can see within Figure 21, launch prices fluctuated considerably over time, as the number of satellites to be launched into the geostationary orbit (GEO) varied between 12 and 28 per year.

The advent of small satellites and CubeSats offering good performance at a mass in the tens of kilograms (and hence at a fraction of a classical big space mission) has changed the ecosystem considerably. **With increased demand, rocket launch start-ups** such as SpaceX, Rocket Lab, Vector Space Systems, Blue Origin and Virgin Galactic/The Spaceship Company **moved into the launch sector**, aiming to compete with Arianespace, ILS, ULA and others. While SpaceX, Blue Origin and Virgin Galactic/The Spaceship Company aim to create synergies with their space tourism activities, Rocket Lab, Vector Space Systems and others focus entirely on the Micro Launcher segment, which deliberately provides launch services for very small satellites with masses of a few hundred kilograms.

Optimised for this specific part of the launch service market segment, **Rocket Lab et al. offer dedicated launch capabilities, but at a price tag of the order of USD 25 000/kg** or more (much more expensive than the USD 10 000/kg launch cost benchmark). Similar to the economy of scale, rockets become more cost effective the bigger they are—a rocket that can launch twice the payload mass will not be twice as expensive in operational costs, while engineering costs will not scale 1:1.

As the competition unfolds due to new entrants, launch prices drop. The next generation of launchers is expected to feature launch prices well below the USD 10 000/kg threshold. Based on data from companies such as the FAA and NASA, **Goldman Sachs assumes an average price drop of 38 %** (Figure 22).

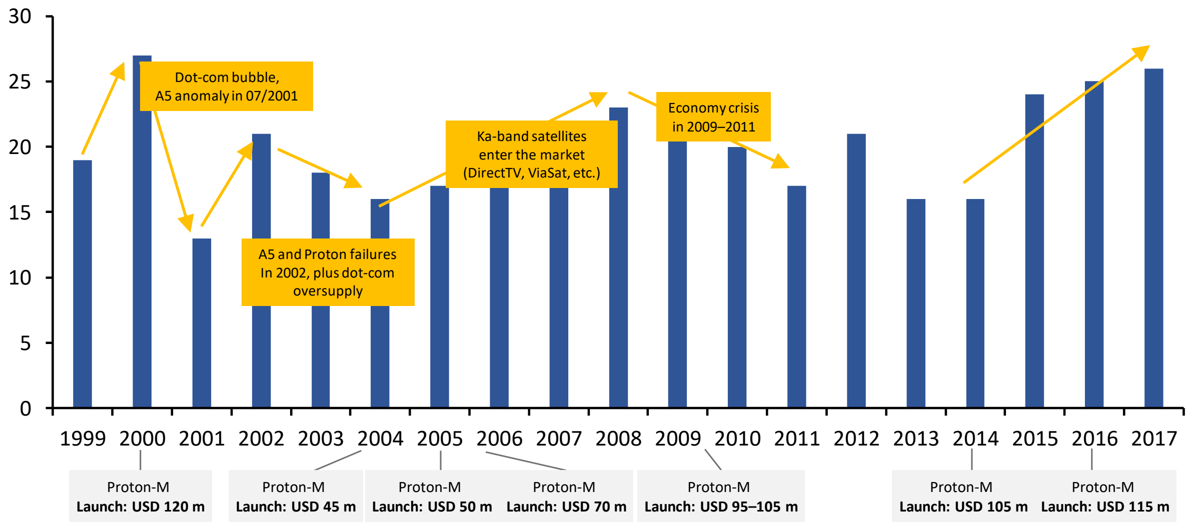


Figure 21: Price fluctuations between 2000 and 2017 for a dedicated Proton-M launch[44]

Prior generation		Next generation		Change
Rocket	$/kg to LEO	Rocket	$/kg to LEO	%
Proton	4.565	Angara A5	4.167	–9 %
Ariane 5	8.476	Ariane 6	4.762	–44 %
Falcon 9*	4.654	Falcon 9 FT*	2.719	–42 %
N/A	N/A	Falcon Heavy*	1.654	N/A
H-IIA/B	6.818	H3	5.000	–27 %
GSLV	9.400	LVM3	7.500	–20 %
Saturn V	22.857	SLS	3.268	–86 %
Atlas V/Delta IV	11.093	Vulcan	6.378	–43 %

Figure 22: Dropping specific launch costs for the next generation of launchers[45]

It remains to be seen whether presumed specific launch costs of USD 1654/kg for SpaceX's Falcon Heavy are sufficiently low to allow a rollout of space-based solar power systems, lunar bases, asteroid mining concepts and a crewed mission to Mars.

2.2.9. Miniaturisation and nanotechnology

Element	Assessment
Affected market segments	1–8, nanotechnology is a game changer for everything (see Figure 8)
Enabling	Cheaper and smaller systems, stiffer and highest performing structures, self-repairing and self-replicating systems
Innovation type	Sustaining–evolutionary for miniaturisation (see Table 6 and Table 7) and Disruptive for nanotechnology
Specific financing needs	Limited to high (miniaturisation is mostly thriving on Moore's Law and some advances in new materials, while nanotechnology does still require a considerable amount of R&D to develop the "universal assembler", miniature power control and distribution unit (PCDU), nanoscale energy storage systems, nanoscale control systems and computers, etc.)

There are those who say that miniaturisation gave the US the leading edge in the space race. If one compares the size and mass of Explorer 1, the first satellite by the United States (13.9 kg, 205 cm length, 16 cm in diameter), with Sputnik 1 of the USSR (83.6 kg and a sphere with a diameter of 58 cm) and bears in mind that Sputnik 2 (a circular cone with 2 m diameter and a height of 4 m, and a mass of 508.3 kg), launched less than a month after Sputnik 1 with the very same R-7 rocket, the Russian rockets were certainly more powerful than the US ones. **The only way the United States could compensate this launcher performance gap before stronger rockets became available to them was**

to miniaturise their satellite (sub)systems to the utmost. This gave a lot of impetus to the development of modern electronics and led to the replacement of tubes by transistors, having a profound effect on integrated circuits (IC), microprocessors and VLSI electronics, with their continued evolutionary development being governed by Moore's Law.

Although nanotechnology may seem a mere extension of miniaturisation—since it takes miniaturisation to the atomic level—this statement could not be further from the truth. **Nanotechnology entails a profound change in how we will interact with nature, as it allows us to directly manipulate matter at the atomic level.** Space will benefit in numerous ways from nanotechnology. **Nano-medicine** will support the immune system such that it will augment the natural repair mechanism to an extent that astronauts will be able to survive radiation doses far beyond levels where today health risks start to emerge. **Nano-based computers and robotics** will allow faster and more robust computer and robot systems, supporting swarm intelligence and behaviour. The most profound effect, however, will come from **nanomaterials** (e.g. carbon nanotubes and nanoballs, graphene). In this respect, nanotechnology takes the promise of **advanced materials** (e.g. super-alloys such as gamma-titanium-aluminide or metal–ceramic matrices, carbon fibre reinforced plastics (CFRP), as well as combinations of CFRP and other resin materials with metals) further, to unprecedented levels. Additional information on the implications of nanotechnology within the space industry can be found within Section 6.2.9.

2.2.10. Optical and ubiquitous communications

Element	Assessment
Affected market segments	1–8, high impact on 5, 6 and 8; however, space is more the enabler and not so much the benefactor (see Figure 8)
Enabling	Ubiquitous communication, machine-to-machine data exchange, holistic insights into events ongoing worldwide
Innovation type	Disruptive, as it is at the root of mobile Internet (see Table 6).
Specific financing needs	Medium to high (R&D and bridge financing need to be provided to further develop and commercialise space-based optical communication systems)

Already trialled (e.g. with SILEX between Artemis and SPOT 4), space optical communication is a necessary extension to cope with the data generation and transportation demands of the future. In addition, the radio frequency (RF) spectrum is already overcrowded, not leaving too much space for new services that demand bandwidth for data transmission.

While **NASA, ESA (European Data Relay System (EDRS), Figure 23) and JAXA (Japanese Data Relay System) have set up space optical systems, R&D efforts are still ongoing, and standards are yet not entirely harmonised (e.g. wavelengths of 1550 nm and 1064 nm) and a network of ground stations is yet to be built.** Consequently, it will take a while until commercially available systems are entering the market.

The advantages of optical communications are manifold. When NASA conducted its **lunar laser communication demonstration (LLCD) in 2013, data was returned from the moon at a ground-breaking record of 622 megabits per second, the equivalent of streaming more than 30 HDTV channels simultaneously.**[46] Consequently, space optical communications play a key role in NASA's future plans for crewed missions to deep space using the Orion spacecraft.

ESA's EDRS is already operational. EDRS-A has been in orbit since 2016; EDRS-C will follow in 2019. EDRS-D is in the planning stage. The Copernicus Sentinels 1 and 2 series use a laser communications terminal (LCT) working at 1064 nm, offering a data rate of 1.8 Gb per second over a distance of 80 000 km.[47]

The follow-up to EDRS is dubbed **GlobeNet, poised to start in 2023**. It is an EDRS evolution, featuring multiple laser terminals on board EDRS-D. Phase B has started, with investment coming from Airbus D&S. GlobeNet will provide data relay services to the Pacific Rim. Ground segments are to be installed in Australia and Japan to allow a global quasi-real-time service such that Sentinel data taken over the Pacific will be delivered to Europe via a GEO–GEO link.

Given the advantages of space optical communications, a **data relay will enable** the following applications:

- space network technology for all kind of constellations or backbone capabilities;

- space–air communications (aeroplanes, uncrewed aerial vehicles);
- LEO–ground communications (e.g. for SAR or security applications);
- GEO–ground (high-throughput satellites, feeder links);
- vision of "all optical satellite" (on-board photonics and laser communications);
- quantum technologies/quantum key distribution systems.

Figure 23: Schematic of the European Data Relay System (EDRS)[48]

As a commercial market is yet to emerge, it is key to enable an environment where ventures related to space-based communications systems can flourish. These are likely to carry out their activities in NewSpace mode, with a business model building on the following pillars:

- space is ***not a destination***;
- space is an ***enabler*** for a variety of business verticals;
- space accelerates and expands business verticals by providing ***new, disruptive ways of doing business*** that are ***faster, cheaper and better***.

Under this mantra, **governments may catalyse and accelerate space-related businesses**. Space-based infrastructure projects (such as Galileo) **can serve as precursors for space-related applications**.[49] **The globalisation of data access by installing and operating** one or two **ubiquitous communication constellations** and the data stream truncating function by means of an **optical communications links system** will be key to allow for global **autonomy applications and services**. This will trigger the advent of a suite of **novel commercial apps and services**.

2.3. Risk assessment of space business models

According to Bank of America Merrill Lynch (BofAML) and Morgan Stanley, the prospects of future development of the space market are very positive. While both put the 2017 space market at around USD 350 billion, the prospects are such that:

- **Morgan Stanley** expects the market to triple to a value of **USD 1.1 trillion by 2040 (a CAGR of 5.1 %)**, while
- **Bank of America Merrill Lynch** expects the market to octuple over the next three decades, to reach a value of at least **USD 2.7 trillion (a CAGR of 7 %)**.

"A raft of new drivers", BofAML said, is pushing the "Space Age 2.0", such as reusable launchers, the growth of private ownership in the market, investments by more than 80 countries and falling launch costs from small launch vehicles. In addition, space needs to be seen as "a hotbed for disruptive technologies". Today's benefit from satellites is nearly immeasurable, and massive projects such as the ISS or the Stratolaunch aircraft are possible only through the industry's growth. "We are entering an exciting era in space where we expect more advances in the next few decades than throughout human history"—the key aspects of "Space Age 2.0" are summarised within Figure 24.[50]

Figure 24: "Space Age 2.0" in a nutshell[51]

Investments of USD 16 billion since 2000 are a clear indication that the commercial aspects of space are becoming more and more attractive. These aspects are showcased by the NewSpace movement, which constantly tests out new business models across all market segments (see Figure 8).

Figure 25 shows a simplified **landscape of business model segments** (such as satellite services and ground equipment, satellite manufacturing, launch industry, national security, space tourism, energy, mining, processing and assembly, as well as crewed and robotic space science and exploration—see Figure 8) **and business services** (yellow boxes; see Figure 5), along with their interdependencies, a classification in terms of business character (B2B or B2C) and implementation time span.[xii]

The classification in terms of interdependencies, business character and implementation time span in Figure 25 provides a risk assessment along these dimensions. Acknowledging that market opportunities are, in general, more favourable in a B2C dominated sector and that entry hurdles are lower in business segments where projects and business models may be realised within short time frames or where it is possible to thrive on short generation cycles, we can infer that the associated business models are less risky on the upper right-hand side of Figure 25 and come along with higher risk levels on the lower left-hand side.

When performing this type of risk assessment, it turns out that business models within the ground segment, satellite service, national security and (at least partly) satellite manufacturing market segments come along with the best market opportunities and lowest risk levels. **The highly successful pure-play commercial space companies such**

xii Figure 26 showcases specific and exemplary business models out of the whole space sector value chain (Figure 8). An exhaustive list of business models is provided in Table 9.

as ViaSat, Intelsat, Inmarsat, SES and Eutelsat,[xiii] as well as most of the successful NewSpace ventures like Spire, Planet, Orbcomm, OneWeb, ISIS—and to a certain extent SpaceX, Blue Origin, Rocket Labs—are concentrated in the upper right corner.

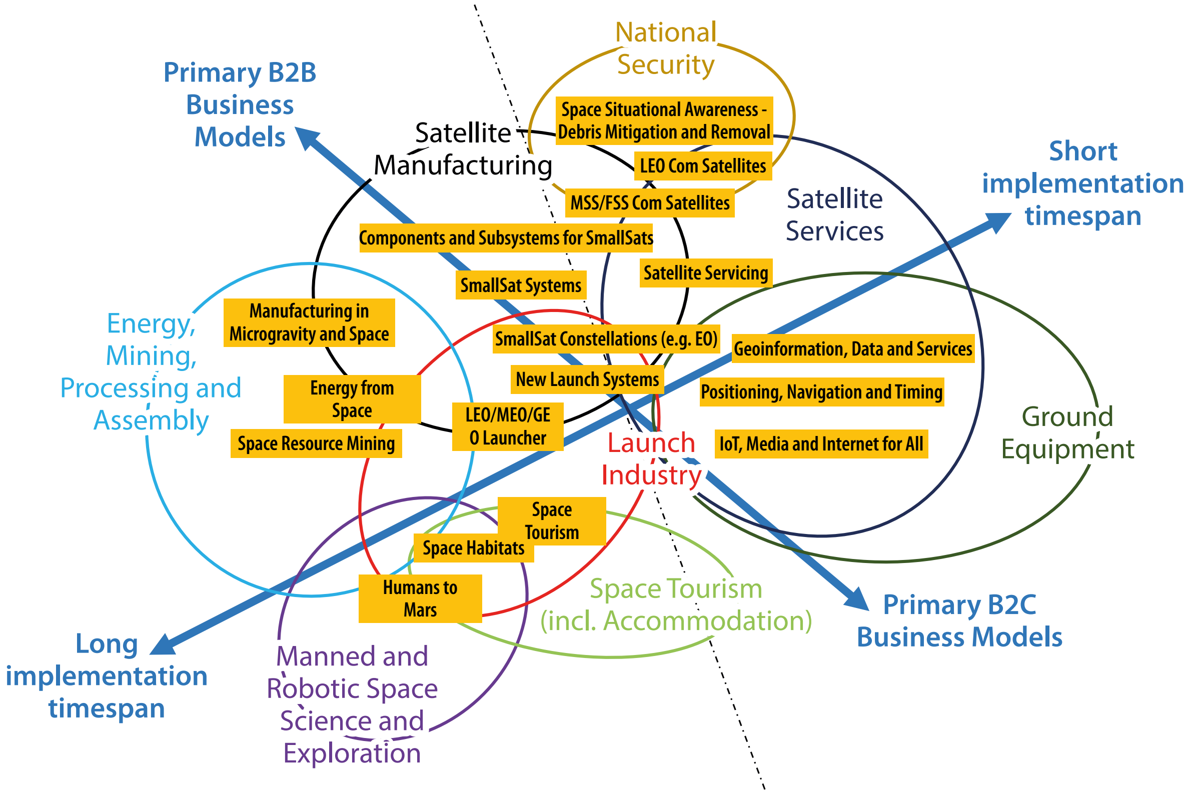


Figure 25: A landscape of space business services, business models and segments[52]

Another factor to be taken into account when assessing the specific risks is the influence of technology trends—space is experiencing an ever-increasing technology flow ("spin-in") from other industrial sectors (primarily IT, aviation and automotive) and gearing up for short generation cycles. A **comparison of the business models and of the technology trends** that primarily govern the ongoing innovation process within the respective market segments provides the following picture (Table 9).

Based on the data provided in Table 9 and the previous sections, it is possible to compare business models and market segments with a defined set of risks, such as product/technology, assets, demand, competition and regulation. Doing so for the different business models, within the predefined market segments (see Figure 8), leads to an assessment depicted in the following table, which represents a summary of the further detailed Table 11, which is provided on pages 50–51 of this report.

Business models that require high upfront investments (Figure 25) are confronted with risky regulatory environments (e.g. outer space and moon treaty) **and those whose market segments have been defined but not started yet are the riskiest models**. As such, in situ resource-utilisation business models that focus on the harvesting, conversion and distribution/transmission of solar power in space (space-based solar power system), as well as on the resource extraction (mining) on celestial bodies such as the moon (helium-3, metals, ice, volatiles), the asteroids (metals including rare earths, minerals) and Mars (CO_2, ice, metal, minerals) are endeavours with the highest risk profiles. As an emerging market segment, prone to significant altering market forces, activities are far from being commercial. Asteroid mining has attracted some interest, yet space-based energy harvesting is waiting for the first serious start-ups.

xiii The BofAML report only list five "pure play" companies defined as having 100 % of sales in the space business. All five work with satellites, with ViaSat and Intelsat SA being based in the US, while Inmarsat, SES and Eutelsat are based in Europe.

On the other end of the risk scale are the value-added services that build upon classical and established satellite services, such as satellite communication, satellite navigation and Earth observation. Technical improvements within receivers, mobile phones and the whole computer and electronics sectors have allowed a shift from expensive hardware to flexible software. This permits faster generation changes and agile design, and thus the possibility to try new markets at very low upfront costs. Consequently, **the ground segment and the value-added service domain have become the most attractive business segments**—numerous players compete in these markets, while new services and apps are rolled out at a very high rate.

Business model segment	Business model	Business services	Primary technology trend(s)—Section 2.2
Launch industry	Launch vehicles & facilities/sites	• Development and manufacturing of launch vehicles (LV) and facilities for small, medium and heavy payloads, crewed and uncrewed • Payload integration	• ***Evolved expendable/reusable launcher systems:*** • Cheaper and more frequent access to space • Enlargement of the space market • New business models in space
	Launch operations	• Provision of launch services with own and sourced rockets • Payload integration • Spaceport operations • Launch broker services • B2B (satellites) and B2C (tourism)	
Satellite manufacturing	Satellites (classical satellites, CubeSats)	• Development and construction of satellites and components for satellite applications and services for commercial, civilian and military users • Provision of: • CubeSat Kits (e.g. ISIS) • Satellite testing services	• Agile development and industrial standard implementation and • Miniaturisation and nanotechnology: • Flexible designs • Minimum viable product strategies • Staggered rollout sequences • Cheaper and smaller systems • Stiffer and highest performing structures • Self-repairing and self-replicating systems
Satellite services	Satellite & satellite network operations	• Provision of satellite services by single satellites or constellations, in LEO, MEO, GEO or any other orbit deemed appropriate • B2B (VSAT network, truncating) • B2C (DTH video, HTS)	• ***Artificial Intelligence (AI)/Man-Machine Interface (MMI)*** and • ***Change detection and data fusion:*** – Autonomous operations – Better management of on-board resources – Higher performance – Easier and faster data interaction with computer systems – Cost-effective observation and analysis of specific points of interest – Correlation of images and time sequences with other data
	EO & remote sensing services	• Operation of EO systems and constellations • Provision of EO data (Copernicus or other) • Processing of EO data • Data fusion and value-added services activities with EO data (mapping, surveying, etc.)	
	Satnav applications	• GNSS operations • Provision of downstream applications and services from Galileo/EGNOS	
	Satcom & broadcasting	• Operation of satellites and constellations • B2C–Consumer services (satellite TV, radio, broadband) • B2B–FSS and MSS (transponder agreements, managed network services incl. in-flight services)	
	Integrated applications	• Provision of combined multiple satellite-enabled value-added services, e.g. two or more of satcom, EO and satnav	

<table>
<tr><th>Business model segment</th><th>Business model</th><th>Business services</th><th>Primary technology trend(s)—Section 2.2</th></tr>
<tr><td rowspan="6">Ground equipment</td><td>Telemetry & telecommand</td><td>• Development and manufacturing of hardware and software for telemetry and telecommand systems (e.g. deep space networks)</td><td rowspan="6">• Acceleration of generation change/obsolescence,
• Micro- and nanoelectronics/ advanced telemetry and telecommand,
• Digital transformation and convergence ,
• Agile development and industrial standard implementation,
• Artificial Intelligence (AI)/Man–Machine Interface (MMI):
– Shorter generation cycles
– Better performance
– Reduced costs
– Holistic observation
– Control of processes
– Health monitoring
– Predictive maintenance
– Data archiving
– Easier search within and comparison of data sets
– Lower entry hurdles to data processing, manipulation and visualisation
– Flexible designs
– Minimum viable product strategies
– Staggered rollout sequences
– Easier and faster data interaction with computer systems</td></tr>
<tr><td>(Mission) control centres</td><td>• Development and manufacturing of hardware and software for mission control centres (workstations, etc.)</td></tr>
<tr><td>EO & remote sensing services</td><td>• Provision of specific EO hardware (systems, components)
• Development and operation of change detection algorithms</td></tr>
<tr><td>Satnav applications</td><td>• Provision of
– GNSS hardware and receivers
– Chipsets for location-based services in mobile devices
– GNSS augmentation and anti-spoofing/jamming systems tailored to specific market needs (air, road, maritime, rail, etc.)</td></tr>
<tr><td>Satcom & broadcasting</td><td>• Provision of satcom hardware and software (e.g. VSAT)
• B2C–Provision of Consumer equipment for satellite TV, radio, broadband and mobile satellite terminals</td></tr>
<tr><td>Integrated applications</td><td>• Provision of specific hardware and software (algorithms) to combine data streams, perform data fusion, etc.</td></tr>
<tr><td rowspan="5">National security</td><td>Mission control & payload operations</td><td>• Operation of satellite systems in the interest of national security, including satcom, Satnav, Space Reconnaissance, Space Situational Awareness, etc.
• Provision of services and applications relevant for the national security sector</td><td rowspan="5">• Change detection and data fusion,
• Optical and ubiquitous communications:
– Autonomous operations
– Better management of on-board resources
– Higher performance
– Easier and faster data interaction with computer systems
– Cost-effective observation and analysis of specific points of interest
– Correlation of images and time sequences with other data
– Ubiquitous communication
– Secure Machine to machine data exchange
– Holistic insights into events ongoing worldwide</td></tr>
<tr><td>EO & remote Sensing services</td><td>• Provision of specific EO hardware (systems, components)
• Development and operation of Change Detection algorithms</td></tr>
<tr><td>Satnav applications</td><td>• Provision of GNSS augmentation and anti-spoofing/jamming systems tailored to specific market needs (air, road, maritime, rail, etc.)</td></tr>
<tr><td>Satcom & broadcasting</td><td>• Provision of:
– highly reliable and ubiquitous satcom hardware and software (e.g. VSAT)
– encoded communication systems
– key distribution systems</td></tr>
<tr><td>Integrated applications</td><td>• Provision of specific hardware and software (algorithms) to combine data streams, perform data fusion, etc.</td></tr>
</table>

Business model segment	Business model	Business services	Primary technology trend(s)—Section 2.2
Crewed and robotic space science and exploration	Crewed vehicles (transport & habitat)	• Design and manufacturing of crewed vehicles (Soyuz, Orion, Dragon) and habitats (as on the ISS)—in the future these vehicles will leave LEO and venture further into deep space (cis-lunar space, L1/L2, moon, asteroids, Mars) • With the renewed interest in crewed exploration beyond LEO (e.g. cis-lunar space), new players, often engaged in space tourism or in incentive prices like the one initiated by Bigelow start to enter the field.	• ***Advanced manufacturing technologies/3D printing,*** • ***Agile development and industrial standard implementation,*** • ***Evolved expendable/reusable launcher systems*** and • ***Optical and ubiquitous communications*** – Reduced complexity costs – Manufacturing in space and on other celestial bodies – Flexible designs – Minimum viable product strategies – Staggered rollout sequences – Cheaper and hence more frequent access to space – Enlargement of the space market – New business models in space – Deep -space communication with high data rates – Secure Machine to machine data exchange
	Mission-specific space exploration vehicles (probes, orbiters, landers)	• Design and manufacturing of specific robotic exploration vehicles like probes, orbiters and landers • The advent of incentive prices, like the Google Lunar X-Prize, has brought new player into that domain	
	Mission control & payload operations	• Operation of specific crewed and robotic exploration vehicles like probes, orbiters and landers • Operation of payloads on board crewed and robotic exploration vehicles	
	(Deep) space network operations	• Provision of and data transfer operations over long distances and/or with high data rates requiring specific equipment (e.g. big dishes and/or laser communication terminals (LCT)) • Future vision: planetary Internet	
	Space science/ exploration data analysis	• Retrieval and processing of the data, acquired during science or exploration mission, including the feedback loop to the payload operations (e.g. to repeat specific measurements)	
Space tourism (incl. habitation)	Sub-orbital space vehicles	• Design and manufacturing of sub-orbital space vehicles as well as habitats, providing access to space for everyone that can afford the ticket and is fit enough for flight.	• ***Advanced manufacturing technologies/3D printing*** and • ***Evolved expendable/reusable launcher systems:*** – Reduced complexity costs – Manufacturing in space and on other celestial bodies – Cheaper and hence more frequent access to space – Enlargement of the space market – New business models in space
	Sub-orbital launch & flight operations	• Operation of sub-orbital space vehicles (Virgin Galactic, Blue Origin, XCOR, etc.) as well as habitats (Bigelow) • NASA is supporting the development of this domain by its ISS cargo resupply contracts and the commercial crew awards.	
	Suborbital flight services	• B2B—launch of payloads • B2C—selling of space tourism flight, along with training, medical check-up, etc. • So far space tourism focuses on suborbital flight, but once this step has been successfully reached, orbital flight will certainly follow. NASA is supporting the development of this domain by its ISS cargo resupply contracts and the commercial crew awards.	
Energy, mining, processing and assembly	MAIT in microgravity	• Manufacturing, assembly, integration and testing of systems and goods in space	• ***Advanced manufacturing technologies/3D printing,*** • ***Agile development and industrial standard implementation,*** • ***AI/MMI,*** • ***Change detection and data fusion,*** • ***Evolved expendable/reusable launcher systems,*** • ***Miniaturisation and nanotechnology,*** • ***Optical and ubiquitous communications***
	In-situ resource utilisation	• Harvesting, conversion and distribution/transmission of solar power in space (space based solar power system) • Resource extraction on celestial bodies such as: – the moon (helium-3, metals, ice, volatiles) – asteroids (metals including rare earths, minerals) – Mars (CO_2, ice, metal, minerals) • While asteroid mining has attracted some interest, space-based energy harvesting is yet waiting for the first serious start-ups	

Table 9: Market segments, business models and primary technology trends

Risk assessment by business model segment							
Launch industry	Satellite manufacturing	Satellite services	Ground equipment	National security	Crewed and robotic space science and exploration	Space tourism (incl. habitation)	Energy, mining, processing and assembly
LV MAIT—launch vehicle manufacturing, assembly, integration and testing	Sat MAIT—satellite manufacturing, assembly, integration and testing	Sat/Net OPS—satellite & satellite network operations	TM/TC MAIT—telemetry/ telecommand manufacturing, assembly, integration and testing	SEC MC/PL OPS—security mission control and payload operations	CV&H MAIT—crew vehicles and habitat manufacturing, assembly, integration and testing	SOSV MAIT—sub-orbital space vehicles manufacturing, assembly, integration and testing	EMPA MAIT—energy, mining, processing and assembly manufacturing, assembly, integration and testing
LV OPS—launch vehicle operations		Sat-EO Services—satellite Earth observation services	MCC MAIT—mission control centre manufacturing, assembly, integration and testing	SEC EO S&S—security Earth observation systems & services	MSSEV MAIT—mission specific space exploration vehicles manufacturing, assembly, integration and testing	SOSV OPS—sub-orbital space vehicles operations	EMPA ISRU—energy, mining, processing and assembly in situ resource utilisation
		Satnav apps—satellite navigation applications	EO GND S&S—Earth observation ground systems & services	SEC Satnav S&S—security satellite navigation systems & services	MC/PL OPS—mission control and payload operations	SOFS—sub-orbital flight services	
		Satcom services—satellite communication services	Satnav GND S&S—satellite navigation ground systems & services	SEC satcom S&S—security satellite communication systems & services	DSN OPS—deep space network operations		
		Integrated apps—integrated satellite applications	Satcom GND S&S—satellite communication ground systems & services	SEC integrated apps S&S—security integrated applications systems & services	S/EDA—science/ exploration data analysis		
			Integrated apps GND S&S—integrated applications ground systems & services				

Table 10: Assessment of the risk profile of the different business model segments with the eight market segments (green = lowest risk, red = highest risk)

All other business segments take a role in between the two extremes, with space tourism and crewed and robotic space science and exploration showcasing high business risk profiles. Space tourism is mostly hampered by the as yet unclear market size and looming risk that a catastrophic failure might halt or at least shrink the market considerably. Crewed and robotic space science and exploration face very high cost risks, as the systems involved are of the one-off type and the institutional market behind the models allows only a few missions per year. Competition is limited, but the entry hurdles are very high, as safety and reliability constraints are very demanding.

The **launch industry is similarly risky**; in comparison with near state-actors like ULA, ILS or Arianespace, the development and manufacturing of a launcher system is a playground for wealthy individuals such as Elon Musk and Jeff Bezos. Their investments in SpaceX and Blue Origin are more strategic than purely commercial considerations.

- It should not come as a big surprise that **Europe's role within the NewSpace and Space Age 2.0 movement is rather limited**. European firms may be leaders for specific technologies, such as
- micro- and nanoelectronics/advanced telemetry and telecommand,

- change detection and data fusion,
- digital transformation and convergence,
- miniaturisation and nanotechnology,
- optical and ubiquitous communications.

This leadership, however, is barely translated into a competitive advantage within the space sector. The reasons for this are multi-faceted.

For one, **specific technology champions are not active enough in space or the associated technology transfer is not effective enough**. An example of this type of shortfall can be seen within the micro- and nanoelectronics/advanced telemetry and telecommand area, where the highly innovative automotive and aviation industries are working on an ever-increasing sensor suite to perform health monitoring and predictive maintenance of systems. On the other hand, this European expertise is not materialising in the form of companies offering these services/applications/systems within the space domain.

Another shortfall is the **missing strategic upstream–downstream interlink**, such as can be seen in the change detection and data fusion segment, an area where several European players are active in the value-added services sub-segment, building upon data provided by Copernicus and other EO satellites. While the downstream part is covered by European firms, the upstream segment is led by the US. For example, the firm Planet is much connected to the US security sector—50 % of its business is related to NRO, CIA, etc. Although the highest financial revenues are made in the downstream sector, one should not forget that the upstream part is often the decisive and guiding element when it comes to future developments.

Finally, **the commercialisation of technologies and the start-up of firms are costly endeavours**. Grants are indispensable to develop the technologies; however, high-risk, medium-term financing systems need to be in place to get technologies on the market and through the "valley of death". The lack of financiers such as VC funds is a critical shortfall within Europe, often leading to a "firm brain drain", when both talents and companies leave Europe to obtain the financial resources in Silicon Valley or elsewhere. Start-ups leave just before they become scale-ups and create both jobs and wealth.

Given these framework conditions, the build-up of a European champion for a specific market segment is a question of

- **available funding** (to overcome high upfront costs),
- **friendly regulations**,
- the **availability of a market demand**, which may call for an anchor tenant that will guarantee a certain pick-up of a provided service

The United States has showcased the power of supporting start-ups by guaranteeing that a certain service pick-up, with the DoD and NASA, is supporting the development of launch vehicles through ISS cargo resupply contracts and commercial crew awards.

Key Takeaways

- **Space is not a destination; space is an enabler** for a variety of business verticals.
- **Space-based infrastructure projects** (such as Galileo) can serve as precursors for space-related applications.
- **Business models** within the ground segment, satellite service, national security and (at least partly) satellite manufacturing market segments come along with the **best market opportunities and lowest risk levels.**
- **Business models, which require high upfront investments, are confronted with risky regulatory environments** (e.g. outer space and moon treaty) and those whose market segments have been defined but not started yet are the **riskiest models**.
- **The ground segment and the value-added service domain** have become the most attractive business segments.
- **Europe's role within the NewSpace and Space Age 2.0 movement is rather limited, because**
  - specific technology champions are not active enough in space, or the associated technology transfer is not effective enough,
  - a strategic upstream–downstream interlink is missing,
  - the commercialisation of technologies and the start-up of firms are costly endeavours and high-risk funds are not readily available.

Risk assessment of market segments and business models along five discriminators

	Launch industry	Satellite manufacturing	Satellite services	Ground equipment	National security	Crewed and robotic space science and exploration	Space tourism (incl. habitation)	Energy, mining, processing and assembly
Product/technology	◑ The principal design of rockets is unaltered, innovation is geared towards reducing specific launch prices, increasing the flight rate, as well as building up the highest possible success rate, Space-X and Blue Origin are trying to (re)introduce reusable rockets	◔ Well-known systems, limited innovation (besides CubeSats), small-sats as pilots for technology try-outs (esp. agile development, miniaturisation and industrial standard implementation)	◑ New services (NewSpace) building upon constellations, new sensors and algorithms allow for cost-effective and market extensions, shorter generation cycles allow swifter innovation introduction	◑ New products evolving, building upon new powerful algorithms, Moore's Law, digital transformation and convergence	◑ New change detection algorithms lead to the merging of a few big high-res satellites with a constellation of low-res EO sats, strong R&D in cryptography	◑ Conservative segment due to high safety constraints (crewed), data transfer operations over long distances and/or with high data rates will require specific equipment (e.g. big dishes and/or Laser Communication Terminals (LCT))	◕ Space tourism companies try old and new designs, such as gliders and rocket (Virgin Galactic, XCOR, Sierra Nevada, Blue Origin), SpaceX and Blue Origin are trying to (re)introduce reusable rockets	● First trials on manufacturing, assembly, integration and testing of systems and goods in space based on the ISS experience and on experiments on board, ISRU, etc. have not been tried yet, lots of technologies still to be developed
Asset intensity	● High upfront costs for machinery, test stands, launch ports (mostly subsidised); extensive testing required, limited COTS components available, but 3D printing reduces complexity	◕ Expensive manufacturing (clean room) and testing systems required, more and more COTS components reduce costs	◑ The advent of powerful computers has allowed increased autonomy and is making the operations less expensive, COTS and outsourcing reduce costs further	◔ Digitalisation and the shift from hardware to software has significantly reduced the upfront costs	◑ The requirements for high reliability and security limit sourcing and increase costs	● Expensive manufacturing (clean room) and testing systems required, the utilisation of COTS components is limited, ECSS standards apply	● High upfront costs for machinery, test stands, launch ports (mostly subsidised), etc., extensive testing required, limited COTS components available, but 3D printing reduces complexity	● Very high upfront costs (launch, space qualified components, subsystems and systems), challenging operation
Demand	◑ Increasing demand from the NewSpace sector and for small-sat and CubeSats constellations (micro launchers)—synergies with space tourism, new business models in space	◔ Altered consumer behaviour (IPTV versus analogue TV) might slow down demand for big Telco-Sats, increasing demand for small to medium sats/constellations with short generation cycle	◔ Altered consumer behaviour (IPTV versus analogue TV) might slow down demand for big Telco-Sats; however, several new space services, e.g. ADS-B and AIS form space/M2M communications, IoT; in addition, EO is seeing high demand	○ Satnav and Earth Observation services see high demand, satcom will be indispensable for IoT and M2M	◔ Unpredictive actors within a multipolar world have triggered a bigger security demand (institutional market)	◕ Limited institutional market but with renewed interest in crewed exploration beyond LEO (e.g. cis-lunar space), in the future crewed vehicles will leave LEO and venture further into deep space (Cis-lunar space, L1/L2, moon, asteroids, Mars)	◕ Space tourism (incl. Habitation) activities have started, however the market has not been tried yet, a catastrophic failure might lead a halt to the segment, NASA is supporting the development of this domain by its ISS cargo resupply contracts and the commercial crew awards	● AMF serves as first commercial 3D-printer in space; asteroid mining has attracted some interest; space-based energy harvesting is waiting for the first serious start-ups

Risk assessment of market segments and business models along five discriminators	Launch industry	Satellite manufacturing	Satellite services	Ground equipment	National security	Crewed and robotic space science and exploration	Space tourism (incl. habitation)	Energy, mining, processing and assembly
Competitive landscape	◑ Triopoly for commercial launches (Arianespace/ SpaceX/ILS), new players incoming have to show high success rate	◑ Players mostly known with some new actors in the smallsat sector; high upfront costs and reliability requirements limit competition for the big satellites	◔ Limited competition; however, novel services provide opportunities for new players to enter this restricted segment (NewSpace)	◕ High; several players compete on this market and the entry costs are relatively low	◔ Limited competition due to institutional market and demands for high reliability and service continuity	◑ New players, often engaged in space tourism or in incentive prices like the one initiated by Bigelow start to enter the field	◕ Several players compete on this market, which has not been tried yet and is currently very limited in size	◑ Very limited; few companies such as Planetary Resources, Deep Space Industries and the Shackleton Energy Corporation
Regulation	◕ New regulation for toxic propulsion systems (REACH) upcoming; return of rocket stage (space debris?)	◑ New regulation for toxic propulsion systems (REACH) upcoming; so far, voluntary actions to reduce space debris	◕ Limited space and frequencies for certain orbits; satcom frequencies under pressure by terrestrial networks (WiMax); so far voluntary actions to reduce space debris; constellations may not get launched as intended, due to restrictions of space and frequencies	◔ Industrial standards and RF regulations are the dominant factors	◑ Military systems are often exempted from certain regulations; however, ITAR and similar regulations are taken very seriously	◑ ECSS and similar standards, as well as ITU/RF regulations, are the dominant factors	◕ In the US the FAA has eased up the certification regime by using the spaceport approach, acknowledging that a full-fledged licensing/ certification process as used in aviation would likely kill the market segment due to very high upfront costs; situation in Europe is unclear	◕ Outer space and moon treaty prevail, which pose a significant risk; what might and can be done? In addition, ECSS and similar standards, as well as ITU/RF regulations, are the dominant factors
Risk summary	◕	◑	◑	◔	◑	◕	◕	◕

Table 11: Risk assessment of market segments and business models along five discriminators
Legend: ○—Low Risk ●—High Risk

3. The funding landscape for space companies

Following the analysis of the space markets, technology trends and the associated key risks in Chapter 2, an initial assessment of the funding paths and opportunities for space companies is provided in this chapter. The **key funding instruments available on the supply side from public and private sources are further examined**. To understand the family of funding instruments of the public sector better, Section 3.2 describes the underlying funding schemes and their overarching objectives, before providing an overview of space-focused funding instruments with their relative size in Section 3.3, and discussing the client-facing public and private funding instruments in Section 3.4 onwards.

3.1. Funding needs, paths and preferences

Space companies appreciate the speed and ease of acquiring private capital but are also keen on the non-dilutive nature of public funding

A **comprehensive sample of over 40 space and space application companies** was interviewed to gain further insight into their access to finance, from both public and private sources. A **good coverage of EU-28 was achieved**, ensuring a broad insight into the finance conditions in Europe.

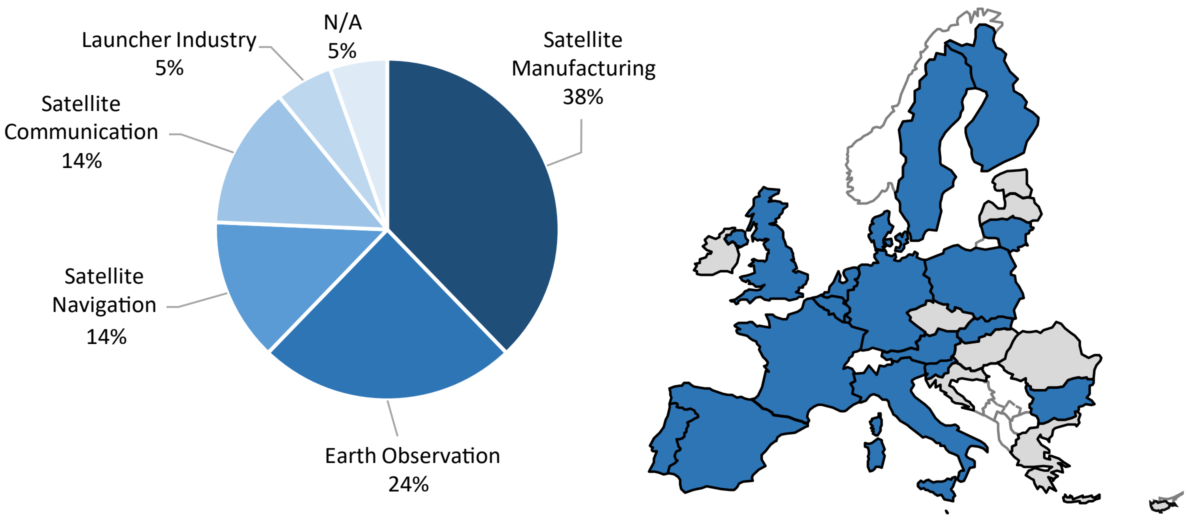


Figure 26: Classification by business segment and geography of companies surveyed

Most interviewees were CEOs of their organisations. The other respondents were various C-suite officers within their companies, including COOs, CTOs and CSOs.

While there is variation in revenues reported by the sample of space companies, most report strong revenue growth in the last three years, with the majority not yet reaching profitability.

The top use of financing is for R&D and product development, with more than 80 % of the organisations sampled identifying it as a need.

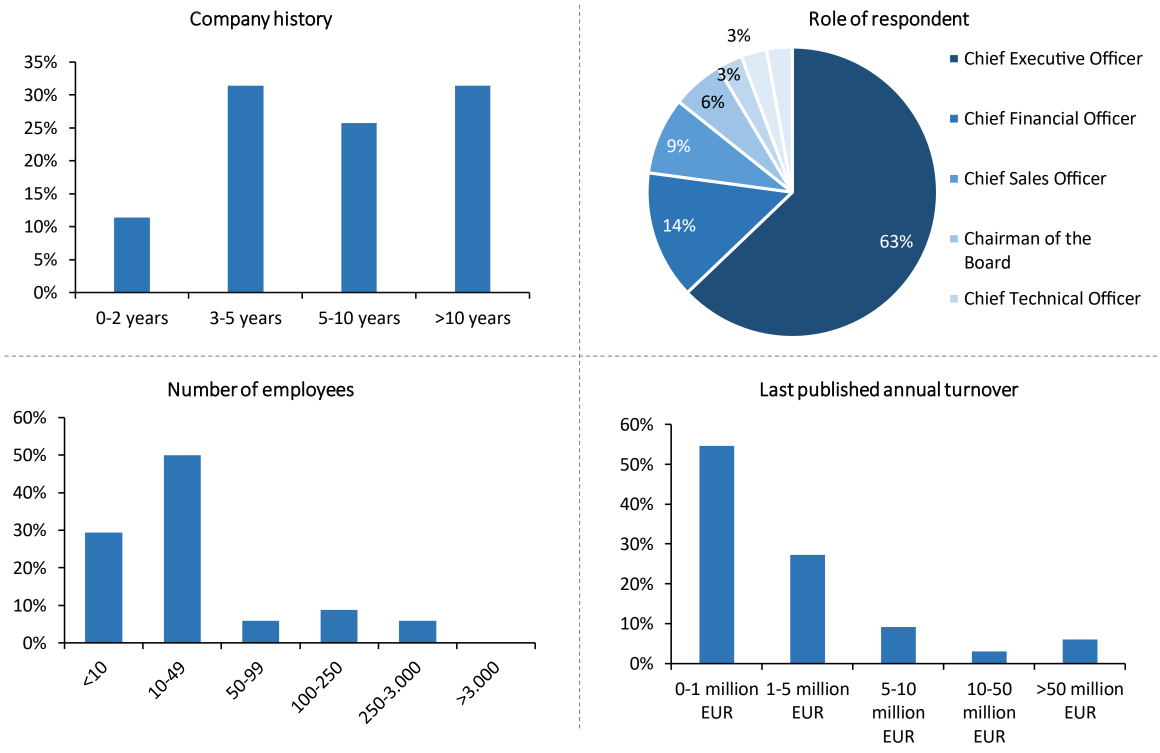


Figure 27: Distribution of the sample group

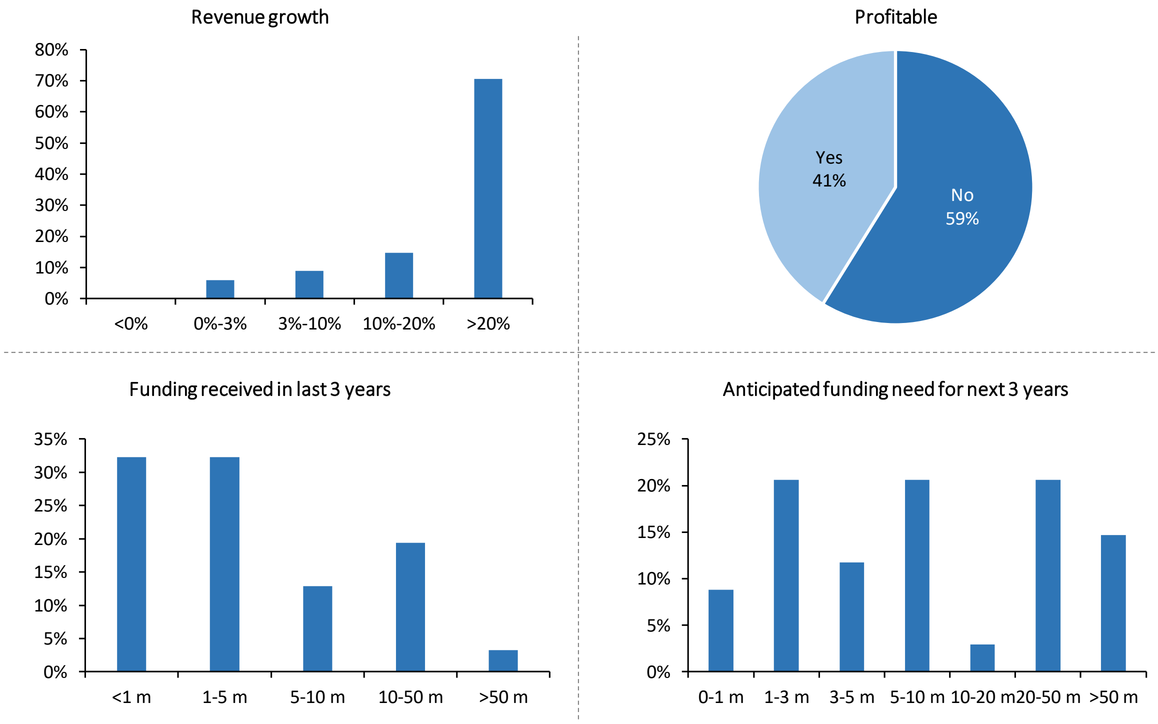


Figure 28: Growth, profitability, funding need and requirements

The **most common source of future funding the sample companies are looking to is venture capital/private equity**. There were a number of considerations raised when the sample companies were asked why they looked to private financing instruments. Popular among these considerations were the **ease of access, volume and speed**.

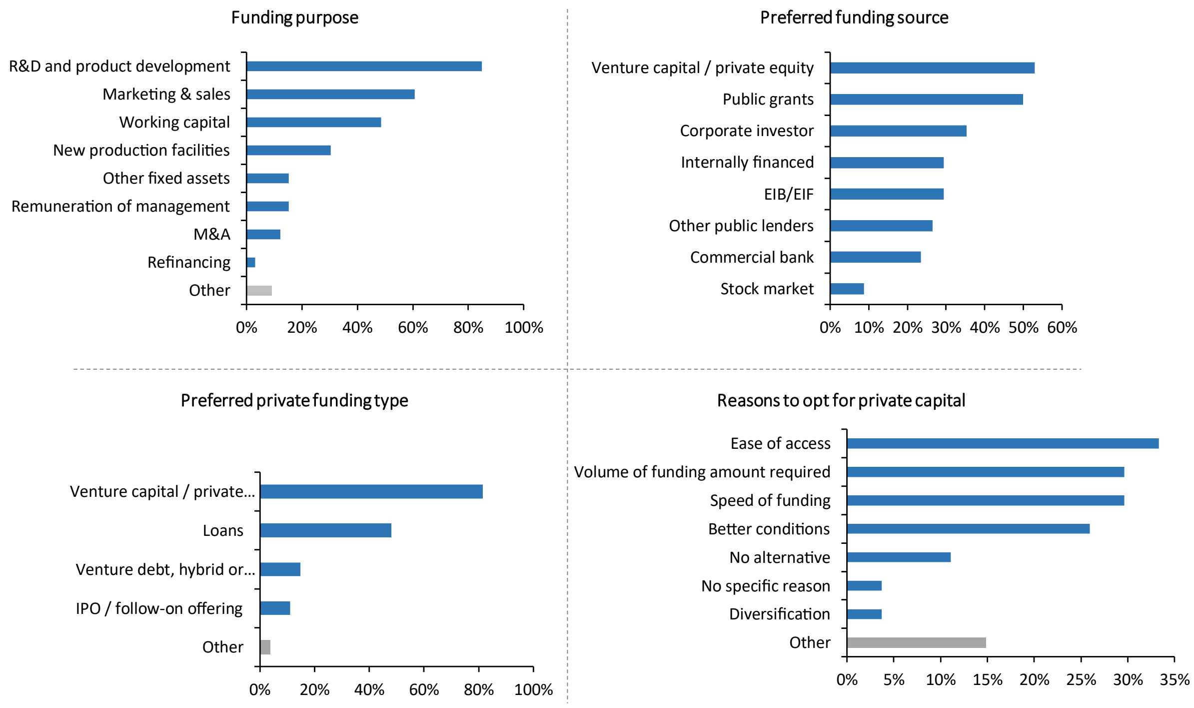


Figure 29: Funding purpose & preferred (private) funding sources

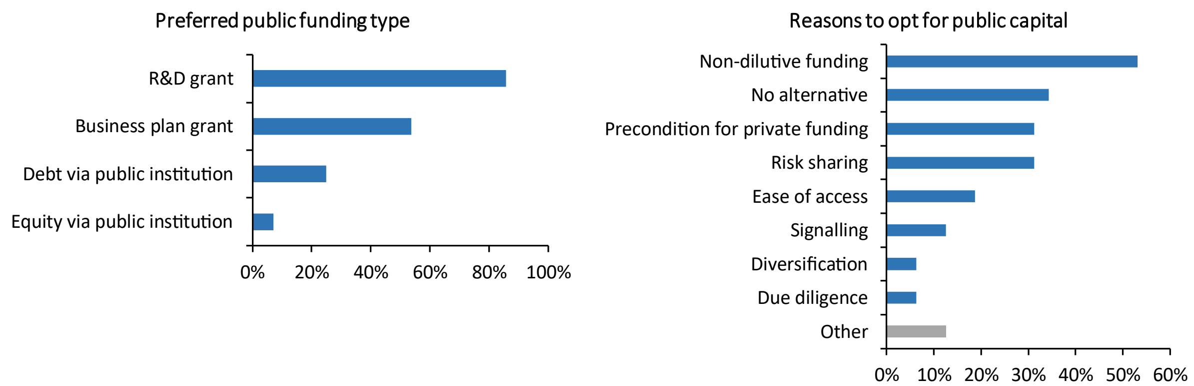


Figure 30: Preferred public funding sources and rationale

The most popular public instruments are **R&D grants, used by more than 85 % of the subjects**. When asked why the companies chose to use public funds, more than half of our respondents suggested **better conditions due to the non-dilutive nature** of this funding. Other common reasons were public funding being a precondition for private funding, having no alternative and risk sharing between the company and the government institution.

Team, team, team… space investors highlight the importance of the management when selecting their investments

The interviews with space-related financiers aimed to target a representative sample of the **players involved in the capital-based side and with certain level of affinity to the space sector**. Of the sample, nearly half identified as venture capital and over a quarter as business angels. For the **more than 20 companies in our sample**, the reporting individuals are primarily partners at their firm.

The size of assets managed by these firms are varied yet skewed towards larger amounts, but with good coverage of all investment fund sizes. Nearly all investors interviewed have invested or intend to invest in space companies, while a significant number of them have no particular focus on space.

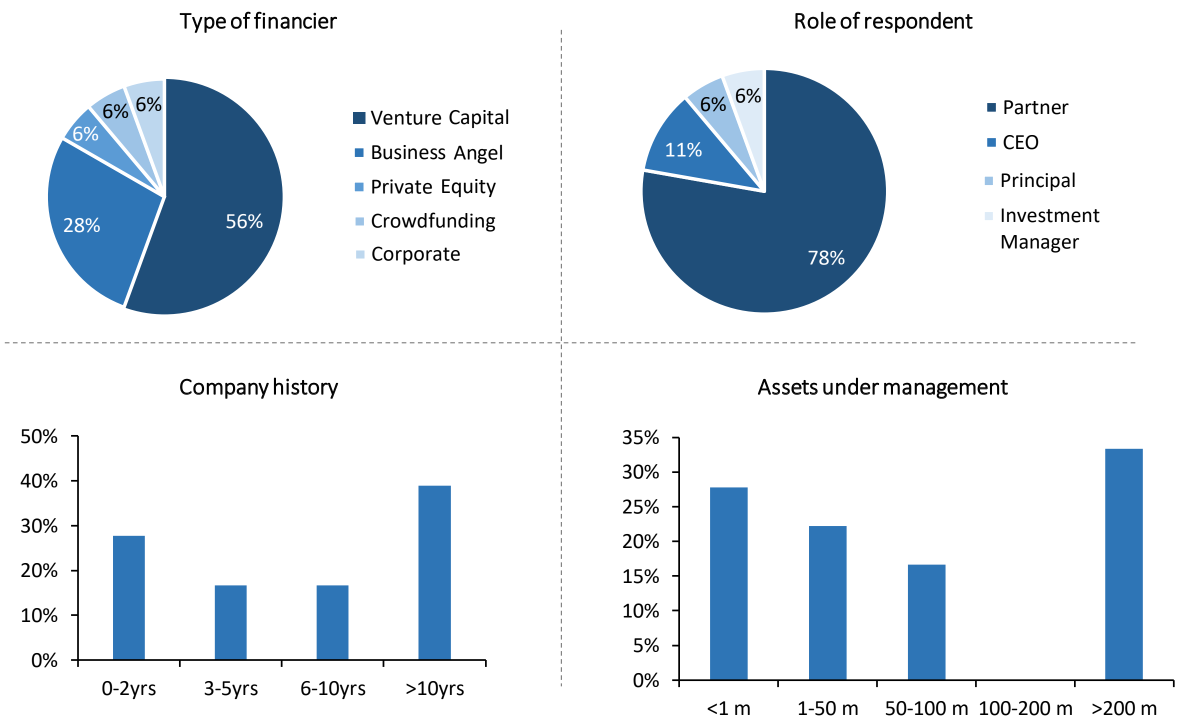


Figure 31: Descriptors of financier sample

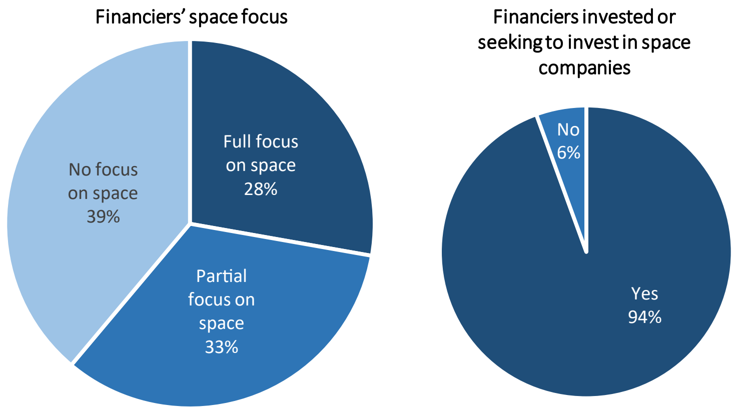


Figure 32: Space affinity of financier sample

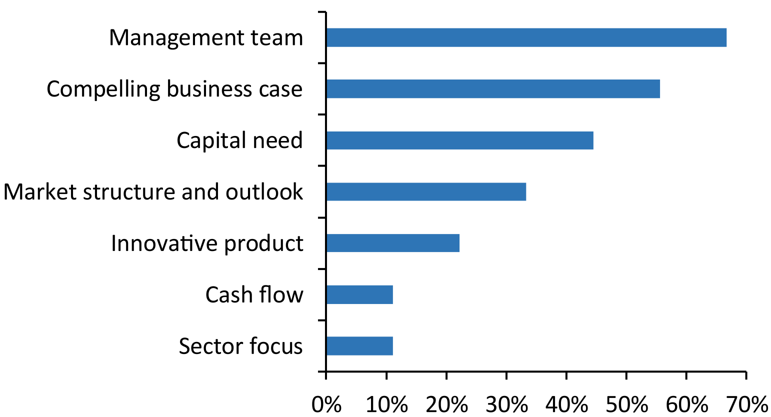


Figure 33: Frequency and classification of key criteria our sample organisations use to assess space-related ventures.

Nearly every financier in our sample **invests in companies through equity capital**, while several simultaneously provide other types of funds, such as debt financing and convertible loans.

Amongst the financiers, most **identified management teams as a key area of assessment**, making it the most common criterion used. Following closely, however, was whether or not a requesting company provides a compelling business case (not mentioning any scale to measure persuasion). Most of these criteria are, according to most respondents, not different from those applied by any investor. **A key difference with general tech is, however, the later inflection point, where the businesses start to take off. This can be observed in deep tech as well, reflected by a greater capital need.**

One respondent shared further insight into their consideration of space-related companies, claiming that a **key criterion for space companies is a proper business model**. They warn there are plenty of engineers and scientists in the space sector, yet **only a few teams have business backgrounds**.

3.2. Introduction to the European funding schemes

Several funding schemes for innovation are in place in the EU and include specific instruments or funding elements for the space sector. The funding schemes are initiated by the following public institutions and their agencies.

- Through its executive agencies, the **European Commission** manages the European Union Framework Programme for Research and Innovation (Horizon 2020) and the Competitiveness of Enterprises and Small and Medium-Sized Enterprises (COSME) programme, while it oversees the implementation of the European Structural and Investment Funds (ESIF) programme through national and regional authorities across Europe.
- The **European Investment Bank (EIB) Group** consists of the EIB itself and the European Investment Fund (EIF). Inter alia the EIB Group implements the European Fund for Strategic Investments (ESFI), a pillar of the investment plan for Europe and a joint initiative of the European Commission and the EIB Group to boost the European economy through mobilisation of private finance for strategic investments.
- **National ministries and regional/local authorities** and their agencies provide additional funding for R&D in Europe. There are a multitude of different funding schemes available, some based only on national funds and others with the support of European institutions.
- The **European Space Agency** (ESA) is another major actor when it comes to investment in space-related R&D in Europe. The **ESA funds a wide range of different R&D programmes** aiming to foster a high level of competency in the European space sector. Some of these programmes are mandatory for its Member States and financed from the general ESA budget, while others are optional and financed by additional financial resources made available by participating Member States.

Figure 34 provides **an overview of the public funding schemes** available in Europe and their respective instruments, which are directly or indirectly **relevant for small and medium-sized enterprises (SMEs) in the space sector**. Under the next EU multiannual financial framework (MFF) the proposal is to simplify the landscape of financial instrument under the unified umbrella of InvestEU.

European Union Framework Programme for Research and Innovation (Horizon 2020)

The **EU's flagship Horizon 2020 research and innovation programme** is the largest scheme of its kind, with EUR 75 billion of funding available over a seven-year period (2014–2020) for innovative projects. During its final three years (2018–2020) alone, Horizon 2020 will provide investments of around EUR 30 billion in research and innovation. Funding through Horizon 2020 comes mainly in the form of grants, but also through procurement and prizes as well as financial instruments such as loans, equity, quasi-equity and guarantees. Namely, under **InnovFin—EU Finance for Innovators**, part of Horizon 2020, the Commission, in cooperation with the EIB Group, has set aside approximately EUR 2.7 billion from Horizon 2020's budget.

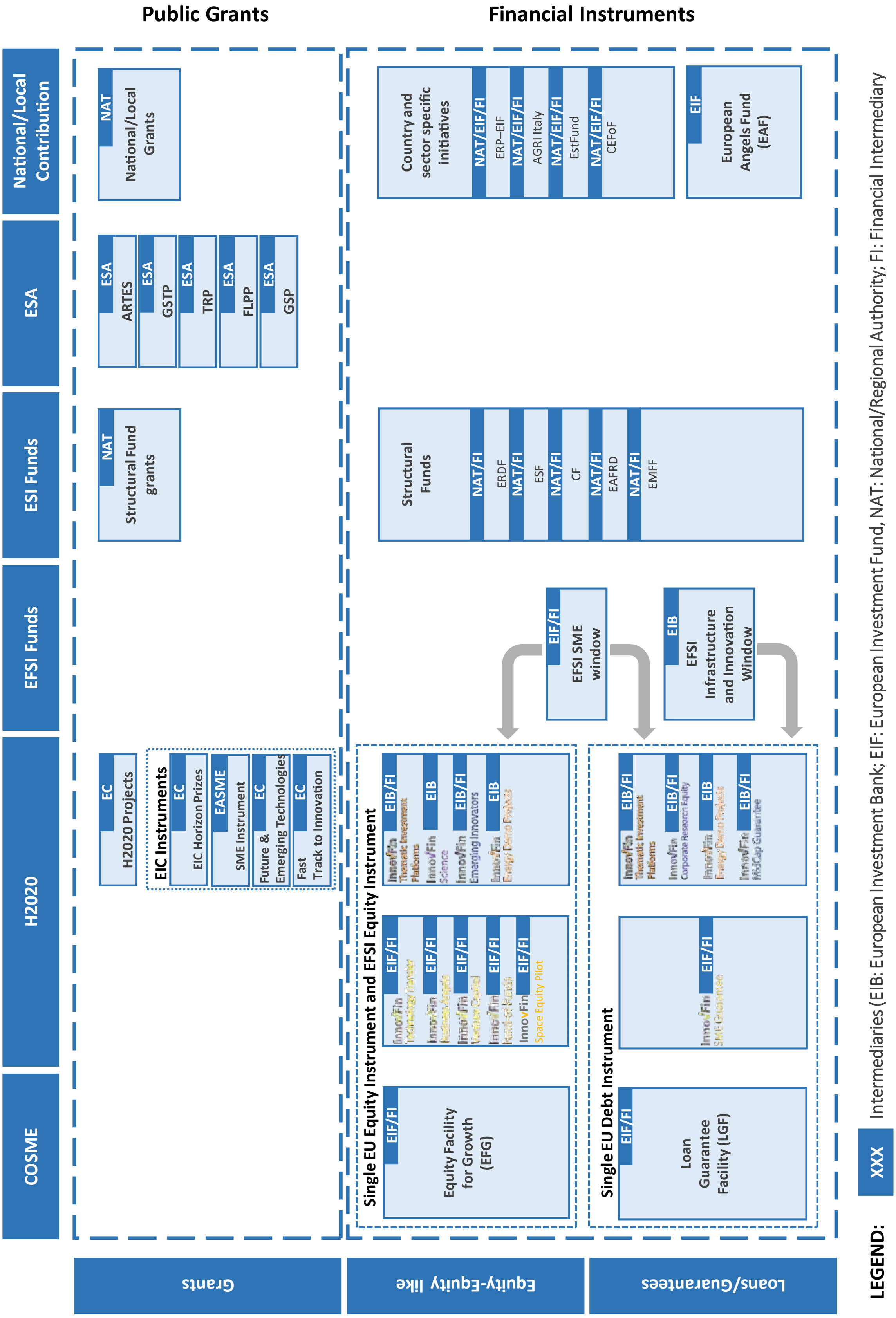


Figure 34: Existing European financing programmes/instruments for SMEs and mid-caps

The InnovFin tools include loans, guarantees and equity-type funding, which can all be tailored to the innovators, whether they are an SME, a large company or a research institution. The tailored financial products are made available either directly to the recipient or through financial intermediaries such as development banks, private banks and investment funds. One tool is the InnovFin Thematic Investment Platforms, which catalyse third-party financing for thematic areas and provide access to finance via debt or equity-type products through financial intermediaries and fund managers.[53] One of the instruments that will be implemented by the EIF to support space SMEs and mid-caps, is the **InnovFin Space Equity Pilot** (ISEP), under the Single EU Equity Financial Instrument. ISEP will provide access to risk finance for innovative enterprises in the space sector through a dedicated financial instrument aiming to **leverage a EUR 50 million contribution from the EU budget over 2018–2020**.

A recently created EUR 410 million venture capital fund-of-funds programme is **VentureEU**, which debuted on 10 April 2018. As a pan-European venture capital fund-of-funds programme, it is designed to enable the rapid growth of innovation by boosting the amount of risk capital available to promising European companies. Six VC funds are set to share in EU seed funding of up to EUR 410 million, which they will use to kick-start their mission of raising of EUR 2.1 billion of private investment. By leveraging the EUR 2.1 billion to trigger up to EUR 6.5 billion of investment from institutional investors such as pension funds, the intention is to significantly **increase the VC funding available to European start-ups and scale-ups**. The six funds will each have 12 months to raise their share of the EUR 2.1 billion. The cornerstone investment fund they will share is made up of EUR 200 million from Horizon 2020's InnovFin Equity initiative, EUR 105 million from COSME and EUR 105 million from the Juncker Plan's European Fund for Strategic Investments.

Horizon 2020 also funds projects through dedicated instruments for SMEs, which are designed for activities that are close-to-market. The **SME Instrument** has EUR 1.4 billion available for funding from 2018 to 2020 and is split into three phases, each with different forms of financing and mentorship support.

Under the title **European Innovation Council (EIC) pilot**,[54 & 55] the **following elements** will focus on **support for innovative companies and entrepreneurs**, who have the potential to scale up their businesses rapidly. Firstly, the **SME Instrument**[56] has approximately EUR 1.4 billion available for funding in the 2018–2020 period. It is an instrument dedicated to fund activities of SMEs that are close-to-market and is split into three phases, each with different forms of financing and mentorship support. Secondly, the "**Future and Emerging Technologies**" (FET)[57]—open actions have been equipped with EUR 650 million from 2018 to 2020 in order to radically capture new lines of technologies through as-yet unexplored collaborations between advanced multidisciplinary science and cutting-edge engineering. Thirdly, an annual amount of EUR 100 million will be made available through the "**Fast Track to Innovation**" (FTI)[58] support programme under Horizon 2020. Close-to-the-market innovation activities such as new or improved products or services are funded, with the main restriction being the need for commercialisation within three years of the start of the project. This instrument is similar in nature to the SME instrument, with a key difference being large companies and research institutes can be funded as well as SMEs. Fourthly, inducement prizes, the so-called **EIC Horizon Prizes**,[59] are awarded under the framework of Horizon 2020 to projects that meet a specifically defined challenge. Lastly, in 2019, **Exploratory Actions** will explore the opportunities that crowdfunding provides to foster breakthrough innovations, with a budget of approximately EUR 20 million through InnovFin financial instruments.

SMEs are also supported through PPPs established through TFEU Article 185, **Eurostars**, in place since 2007 and implemented through EUREKA (a publicly funded, intergovernmental network spanning over 40 countries). Eurostars is dedicated to supporting niche markets of research-performing SMEs; using a bottom-up approach, it funds projects that help to improve the lives of people around the world, with a funding pool of over EUR 1 billion contributed by national budgets of Member States. Eurostars is co-funded by the EU through Horizon 2020.

The ninth framework programme to succeed Horizon 2020 is dubbed **Horizon Europe** and will launch in January 2021. This programme, with a proposed budget of EUR 97.9 billion, will be the largest ever research and innovation funding programme. It is designed around three pillars: open science, global challenges and open innovation.[60]

Competitiveness of Enterprises and Small and Medium-sized Enterprises (COSME)

Apart from Horizon 2020, the European Union has a dedicated funding programme for SMEs. The COSME[61] scheme aims to support SMEs with better access to finance, as well as access to markets and business support. With a budget of EUR 2.3 billion, COSME uses two main financial instruments to provide access to finance via intermediaries. The **Loan Guarantee Facility** (LGF) provides guarantees to financial institutions so they may provide more loans and lease finance to SMEs, while the **Equity Facility for Growth** (EFG) provides risk capital to equity funds investing in SMEs. The use of both instruments greatly expands the number of SMEs able to obtain funding. COSME also contributes to the newly created VentureEU programme. The macro instruments of COSME are deployed by the EIF itself or through intermediaries, such as banks or fund managers.

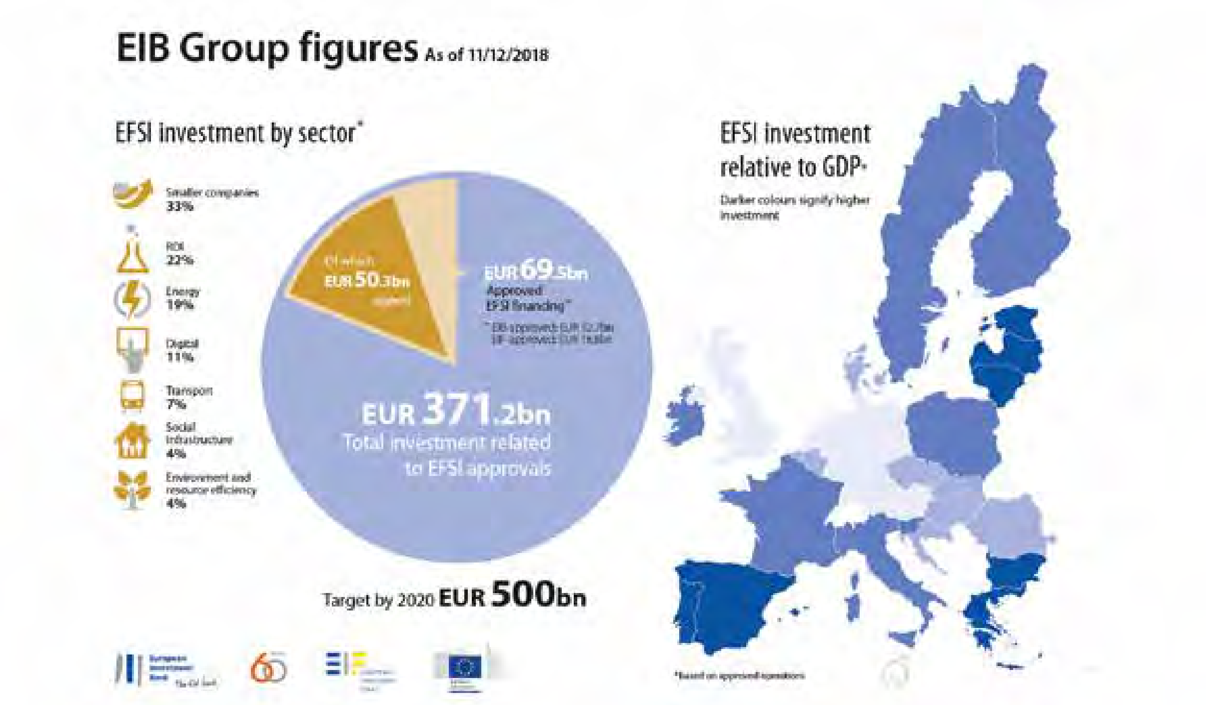


Figure 35: EFSI Dashboard—EIB Group Figures[62]

European Fund for Strategic Investments (EFSI)

In November 2014, the EC announced the **Investment Plan for Europe**, an innovative response to an ongoing economic slowdown caused by a low EU-wide demand. The plan was developed by the Commission as a method to remove obstacles to investment and to use financial resources more effectively. Its main instrument is the **European Fund for Strategic Investments**, which is implemented in cooperation between the European Commission and the EIB Group. First implemented in 2015, EFSI was initially a EUR 16 billion guarantee from the EU budget, complemented by a EUR 5 billion allocation of the EIB's own capital. In September 2017, the EFSI was reinforced and extended until 2020. **A total financing volume of EUR 43 billion** was to be made available from **2015 to 2020 through EFSI's Infrastructure and Innovation Window and their SME Window**, mobilising at least EUR 500 billion in additional investments to the economy by mid-2020. The current status is depicted in Figure 35. The EFSI will boost existing financial instruments available under the COSME and Horizon 2020 programmes. The growing engagement of the EIB Group in the Horizon 2020 programme is a step towards enhancing links between EU funds and innovation funding, and could become important for the design of the EU innovation framework programme that will succeed Horizon 2020, namely Horizon Europe.

The most recent policy strategy communication outlining the European Union's economic strategy was published by the EC in September 2017. It was called "*Investing in a smart, innovative and sustainable Industry: A renewed EU industrial Policy Strategy*," and focused on creating a holistic package with the goal of a stronger and more competitive EU Industry. The EU again identified **the investment in innovative SMEs as a critical vector** to accomplish the EU's core objective of creating growth and jobs. This communication named the following five key elements:

- investments (e.g. European Fund for Strategic Investments EFSI);
- innovation (e.g. Horizon 2020 programme);
- circular and low carbon economy;
- completion of the single market;
- skills, digitisation and the international (trade) dimension.

Each of these key elements has **links to national and regional policies such as industrial transformation and modernisation.**

Research Innovation and Digitisation Window InvestEU Fund

Building on the success of EFSI, InvestEU is the future umbrella fund proposed to centralise many of the existing financial schemes that will anchor all centrally managed financial instruments inside the EU in a single, streamlined structure.[63] The fund provides an EU guarantee to mobilise public and private financing in the form of loans, guarantees, equity or other market-based instruments, to strategic investments in support of R&D through a dedicated investment window. Within Annex II of the InvestEU regulation, space is listed as an eligible area of intervention. With a contribution from the proposed EU budget of EUR 15.2 billion, InvestEU is expected to mobilise more than EUR 650 billion of additional investment across Europe.[64]

European Structural and Investments Funds (ESI)

The **European Structural and Investments Funds** (ESI Funds)[65] are implemented through all forms of funding including financial instruments (loans, guarantees, equity) created **to implement regional policies of the European Union that are aimed at reducing regional disparities in Europe**. ESI Funds make a total of approximately **EUR 450 billion available for the period 2014–2020**. ESI Fund programmes are approved by the Commission and implemented by the Member States and their regions through nationally co-financed multiannual programmes. ESI Funds consist of five distinct funds: the European Regional Development Fund (ERDF); the European Social Fund (ESF); the Cohesion Fund (CF); the European Fund for Rural Development (EAFRD); and the European Maritime and Fisheries Fund (EMFF). For the period 2014–2020, financial instruments in growth and jobs, including investments in SMEs, are a more important vehicle through which the ESIF policy objectives are implemented.

European Space Agency funding

Apart from the European Union, the ESA, beyond its procurement for satellite missions, offers funding instruments to support companies involved in space R&D. In the reference year 2015, the **ESA**[66] **made approximately EUR 390 million of funding available to support R&D activities in space**. The ESA maintains R&D programmes that cover the whole product cycle, from basic studies and space research to product and application development.

A large part of space-specific funding by the European Union and the ESA is associated with the three European space programmes: Galileo, Copernicus and EGNOS; funds for research and innovation activities are provided in their support. Combined funding for three programmes[67] is more than EUR 11 billion over the 2014–2020 period.

The ESA funding programmes that are described in detail later in this chapter do not include ESA funding of technology developments carried out as integral part of specific development programmes.

National and regional funds

National and local grants, together with country and sector-specific initiatives in the EU Member States, complement the picture of the funding available in Europe. For example, the ESA[68] has estimated that approximately **EUR 180 million is made available annually for space technology R&D by national European space programmes** in the form of grants and subsidies, with more than half of this budget available in Germany. National and local contributions increasingly include financial instruments. The EIF, a part of the EIB Group, is partnering with national institutions to support EU policy objectives and to provide a range of tailored financial solutions to complement existing national schemes in support of SMEs. Examples of such financial instruments are the EUR 500 million German

ERP–EIF co-investment growth facility to boost venture capital support for growth phase companies in Germany, as well as the EUR 260 million ESIF fund-of-funds programme for Greece to boost entrepreneurship and to create a lasting impact on local businesses.

The **European Angel Fund** (EAF), with a **value of EUR 320 million**, is an initiative advised by the EIF with national funds. The EAF provides equity to business angels and other non-institutional investors to co-invest in innovative companies.

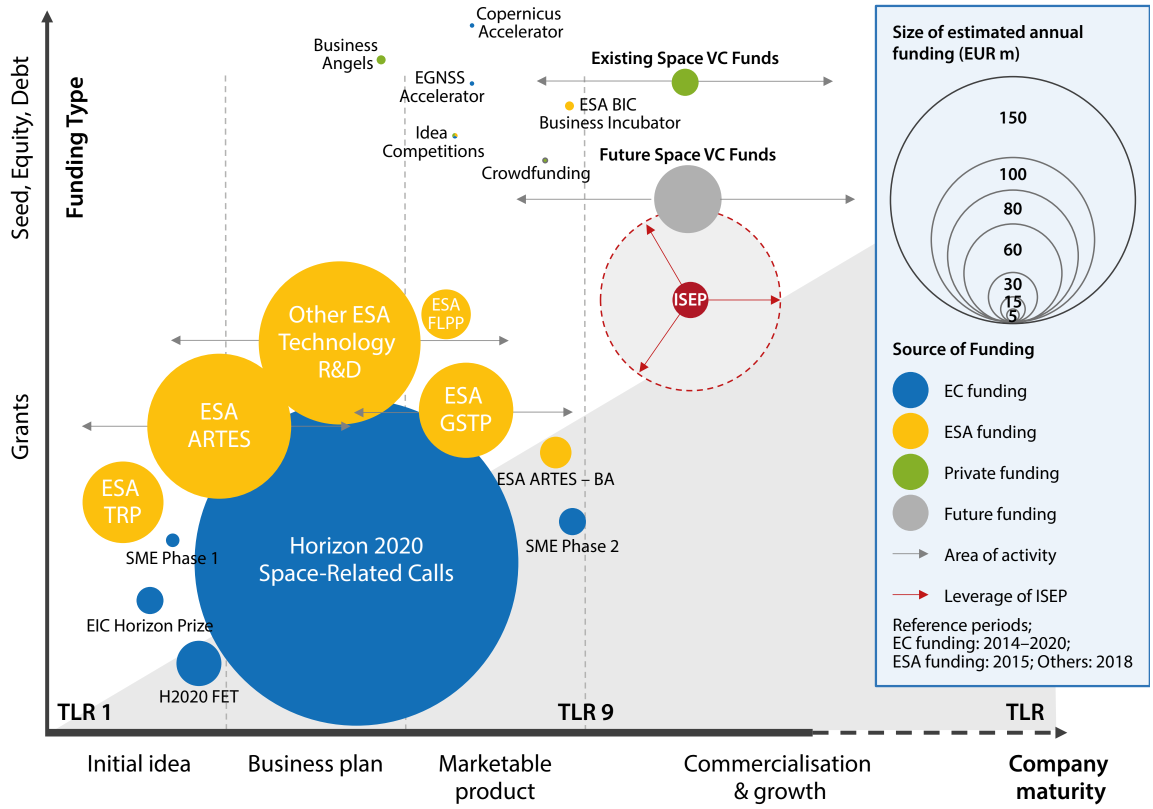


Figure 36: Overview of space-focused financial instruments in Europe and estimated annual funding volume[xiv]; ESA funding represented in this graphic does not include technology developments carried out as integral part of specific development programmes

3.3. Overview of dedicated funding instruments for the space sector

The two main players in the field of funding for space research and space technologies are the EC and the ESA. These are complemented by private financiers, who make funding available in the form of equity, debt or hybrid products. Many funding instruments are available from public and private sources in Europe. However, only some have a dedicated funding department or focus on space. An **overview of the funding instruments that are relevant for the space sector and are directly accessible** from an end user's point of view is described in the following sections. The infographic in Figure 36 shows a synthesis of the estimation of all available funding instruments available, per year, for SMEs in the European space sector, and their relative importance.

The directly available funding instruments are sorted according to the different **development phases of a product**, covering the full cycle from the initial idea to achieving a marketable product and the expansion of business activities. This corresponds roughly to the technology readiness level (TRL), which estimates the maturity of a technology, from basic technology research to a system test on a scale of 1 to 9. The funding instruments are classified according to the **provider of the financial instrument** (i.e. EC, ESA or private sources) and the estimated **annual size of the funding** available.

xiv Note that the budgets for procurement of space assets is not included, only the R&D funding where companies themselves are driving the direction of the use of funds, and that therefore directly benefit the companies' development.

While sizeable amounts are available in funding instruments for space companies in the early stages of their R&D development, **a gap can be observed for space-focused funding for the commercialisation and growth phases**, typically led by financiers from the private side. The seed-stage instruments, on the other hand, have fragmented coverage of the different space segments.

Key Takeaways

- Space companies appreciate the **volume, speed and ease of acquiring private capital but are also keen on the non-dilutive nature of public funding**. In addition, public capital may be the only accessible funding source, and serves as a precondition for fundraising private risk capital.
- Investors in the sector highlight the importance of a complementary management team and compelling business case. A **key difference with general tech** is, however, the later **inflection point where the businesses start to take off**, as can also be observed in deep tech, **reflected by a higher capital need.**
- The Commission is revamping its research programme Horizon 2020 for its new multiannual financial framework. The new programme, dubbed **Horizon Europe**, will expand the initiatives under the **European Innovation Council** pilot of Horizon 2020, which includes the highly successful SME instrument.
- Similarly, **InvestEU** will build on the success of EFSI, and is expected to mobilise EUR 650 billion of investment.
- Dedicated funding instruments for space companies are, however, lacking in comparison to the R&D investments that are made in the sector. The **seed stage is fragmented, with only specific space segments being well covered**. The funding conditions in early stage finance, with a very limited number of existing space funds, could be improved significantly by the InnovFin Space Equity Pilot (ISEP). In short, the **investment landscape is suboptimal, and poses a risk to commercialisation of space technologies and capitalising on the R&D investment made in the sector.**

3.4. Fostering innovation with R&D grant instruments

Several R&D grant instruments are available for SMEs and corporates in Europe that are active in the space industry. The largest sources of this type of funding are the EC and the ESA. Both have developed a range of technology support programmes that foster innovation at different levels of TRL. Only the instruments at European level are discussed in more detail, as each Member State has its own instruments at national or regional level.

Horizon 2020 Grants[69]

Summary

- **Objective**: to enable the European space research community to develop innovative space technologies and operational concepts "from idea to demonstration in space", and to use space data for scientific, public or commercial purposes.
- **Number of space projects funded to date:** 231.
- **Total space funding**: EUR 1479 million (to date—also used for procurement, infrastructure & in-orbit demonstration/validation (IOD/IOV) activities).
- **Funding amount per project**: EUR 2.3 million (average).

The **Leadership in Enabling and Industrial Technologies (LEIT)—Space under Industrial Leadership is the dedicated part of Horizon 2020 for the space sector. For the final three years (2018–2020)**,[70] the Horizon 2020 grants will focus on the market uptake of European space programmes, underpin space business and entrepreneurship, fund space technologies and science and support security aspects as well as access to space.

The budget is divided into three calls, of which the **Space Call is the largest, with approximately EUR 100 million per year**, funding space activities in the following areas: Earth observation; space business; space technologies; science and exploration; a secure and safe space environment.

Under the **European Global Navigation Satellite System (EGNSS) call**, market uptake activities for the European Galileo programme and the European Geostationary Overlay System (EGNOS) are financed in 2019 and 2020 with **EUR 20 million per year**. Complementary to the Horizon 2020 grants is the **Fundamental Elements** funding mechanism, which aims to develop market-ready chipsets, receivers and antennas, providing a total amount of EUR 111.5 million for projects, to be carried out over 2015–2020.[xv]

xv Established by the 2013 GNSS Regulation following the Regulation (EU) No 1285/2013 of the European Parliament and of the Council of 11 December 2013 on the implementation and exploitation of the European satellite navigation systems

The **Other Actions** fund the evolution of Galileo, EGNOS and GNSS through implementation of R&D **with approximately EUR 28 million per year** as well as the improvement of performances of the Space Surveillance and Tracking (SST) at the European level.

EIC Horizon Prize[71]

Summary

- **Objective**: to solve a major challenge facing society and to boost breakthrough innovation.
- **Number of space projects funded**: two dedicated to space.
- **Total space funding**: EUR 10 million for the Low-Cost Space Launch prize and EUR 5 million for the Early Warning for Epidemics prize.
- **Funding amount per project**: EUR 5–10 million.

The **EIC Horizon Prize is also part of the EIC pilot programme**. Each prize is awarded to whomever best meets a major challenge facing society, with the goal of boosting breakthrough innovation across sectors. The solutions need to be innovative and feasible, with affordable implementation options in all development and exploitation phases, and, therefore, economically viable.

Until 2020, six prizes with a **total budget of EUR 40 million are available**. In 2018, the **Low Cost Space Launch challenge with a prize of EUR 10 million** was opened for proposals with the objective of developing a low-cost launch system to deliver small satellites into low Earth orbits. **Early Warning for Epidemics** is the second Horizon challenge with ties to space and with a prize purse of EUR 5 million. A reliable and cost-effective early warning system for epidemics should include and integrate big data derived from space-borne data in the EO domain.

Horizon 2020 FET Open Instrument[72]

Summary

- **Objective**: to turn Europe's excellent science base into a competitive advantage.
- **Number of space projects funded**: 11.
- **Total space funding**: approximately EUR 40 million over the period 2014–2017.
- **Funding amount per project**: from EUR 100 000 to several EUR million.

The **Future and Emerging Technologies (FET) Open instrument**, part of the EIC pilot, funds radically new technology and emphasises the collaboration between advanced multi-disciplinary science and cutting-edge engineering. Approximately **EUR 40 million** has been allocated for space-related research so far. The FET has three lines of action funding new ideas and long-term challenges: FET Open funds research on ideas for new future technologies; , FET Proactive nurtures emerging technologies to enable a critical mass; FET Flagships are 10-year initiatives that foster the collaboration of hundreds of scientists to solve ambitious scientific and technological challenges.

ESA TRP Programme[73]

Summary

- **Objective**: to research basic principles observed from actual system completion to experimental proof of concept.
- **Number of space projects funded**: 150 contracts per year.
- **Total space funding**: EUR 50 million per year.
- **Funding amount per project**: EUR 50 000–150 000.

ESA's basic **Technology Research Programme** (TRP) finances research from the observation of basic principles to actual system completion, to experimental proof of concept in **all technology disciplines and applications relevant to the space sector**. TRP covers technology activities with low TRL (TRL 1–3). TRP is based on the "Innovation Triangle" concept, which requires the collaboration of three different entities: an inventor, who is funded with approximately EUR 50 000, a developer funded with approximately EUR 150 000 and a customer who is expected to co-fund the project. **An annual budget of approximately EUR 50 million is available** under TRP and, on average, 150 contracts are funded per year.

ESA ARTES Programme[74]

Summary

- **Objective**: to develop innovative satcom products, services, systems and partnerships.
- **Number of space projects funded**: over 100 contracts per year.
- **Total space funding**: approximately EUR 110 million per year.
- **Funding amount per project**: EUR 0.5 million–1.5 million for core competitiveness, EUR 0.6 million–2 million for business applications.

ESA's Advanced Research in Telecommunications Systems (ARTES) programme offers both business support and a funding framework for participating businesses. It funds projects from concept to system prototype demonstration in a space environment and has an **annual budget of approximately EUR 90 million.** The programme also provides multi-disciplinary expertise and business knowledge to SMEs and international consortia. ARTES is divided into several elements. The ARTES **Core Competitiveness Programme** merges two former self-standing elements, ARTES Advanced Technology (AT) and ARTES Competitiveness & Growth (C&G). Approximately 90 projects are funded per year within the AT element that has an annual budget of approximately EUR 50 million, whereas EUR 20 million are available in the C&G element.

The mission of the ARTES **Core Competitiveness Programme** is twofold:

1. to be ESA's main programme for preparatory development of satellite communication technology where ESA issues calls to support, with 100 % funding, the long-term development of equipment in the AT programme, from initial idea to breadboard or engineering model level, and
2. to fund in the C&G programme, in which up to 75 % of industry proposals concern the further development of prototypes of space-qualified or industrialised products, supporting the development, qualification and demonstration of products such as a satellite payload or a user terminal.

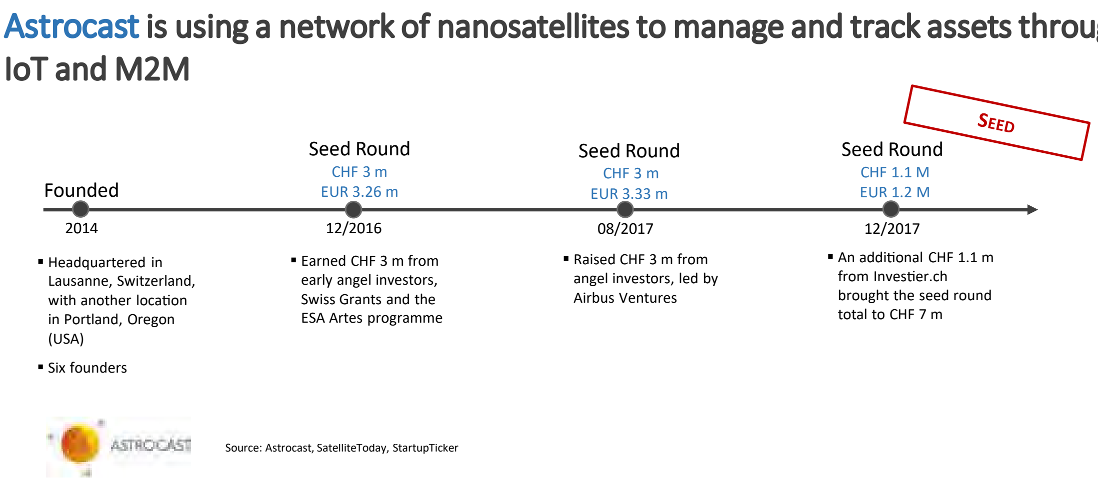


Figure 37: Example of ESA ARTES funding

Core Competitiveness also includes the ARTES **Entry** element, which provides a 75 % funding up to EUR 250 000 for newcomers to the satellite telecommunications industry during the technology, product and demonstration phase. This targets European SMEs with less than 250 employees and less than EUR 50 million yearly turnover.

The ARTES **ESA Business Applications** (BA), formerly known as the Integrated Applications Promotion, is another ARTES element with a focus on funding SMEs. It expands the scope of ARTES as it **funds and supports business from any sector that intends to use space**. Besides satellite telecommunications, ESA BA funds projects using EO, satellite navigation, space weather and space technologies to develop new commercial services. The vision is to improve the lives of all people on Earth through space technology and cross-fertilisation across disciplines, allowing the development of applications (e.g. in the health, energy or transport sectors). **A yearly average budget of EUR 20 million funds projects with grants as zero-equity funding between EUR 60 000 and EUR 2 million.**. In total, the programme has invested more than EUR 190 million in over 500 businesses. ESA BA is organised into three elements:

kick-start activities, open competitions and direct negotiations. Applications are open all year and businesses can either apply to a thematic opportunity or submit an open application under direct negotiations.

Other ESA Technology R&D

Other ESA programmes that are part of the ESA R&D activities are the European GNSS Evolution Programme (EGEP), the Science Core Technology Programme (CTP), the Earth Observation Envelope Programme (EOEP), Life & Physical Sciences in Space (ELIPS), the European Transportation and Human Exploration Preparatory activities (ETHEP) and the Robotic Exploration of Mars (EXOMARS). Together they make an R&D budget of approximately **EUR 100 million available for the European and Canadian industries per year**. The technology programmes cover a multitude of activities and fund projects ranging from low to high TRL (TRL 1–7).

ESA FLPP[75]

Summary

- **Objective**: to develop future launchers with low development and production costs.
- **Number of space projects funded**: approximately 14 contracts per year.
- **Total space funding**: ca EUR 30 million per year.
- **Funding amount per project**: up to several million euro.

The **Future Launchers Preparatory Programme** (FLPP) provides funding to activities related to the **development of technologies for future European launch vehicles** and improvements to existing launch vehicles. FLPP finances technology with TRL 3 or lower that is deemed promising. The programme helps develop them from basic principles to actual system completion and flight qualification, through test and demonstration, to TRL 9. **The goal to develop future launchers with low development and production costs is supported by an annual budget of approximately EUR 30 million** under the FLPP.

ESA GSTP[76]

Summary

- **Objective**: the development of new technologies and projects.
- **Number of space projects funded**: approximately 70 contracts per year.
- **Total space funding**: EUR 60 million per year.
- **Funding amount per project**: EUR 150 000–EUR 1 million.

The **General Support Technology Programme** (GSTP) is aimed towards the development of new technologies and projects. **GSTP covers all technology disciplines except telecommunications**, which is covered by the ARTES programme. GSTP aims to take concepts and component prototypes with a lower TRL (usually TRL 3–4) to actual system completion at TRL 5–6, to in-orbit qualification through test and demonstration at TRL 7–9. GSTP consists of several elements, one of which offers the space industry a funding mechanism for submitting unsolicited proposals for market-oriented technology activities at any time. The GSTP has a budget envelope of approximately EUR 90 million per year; however, on average, **industrial contracts worth EUR 60 million are funded per year.**

3.5. Start-up support and seed instruments for space businesses

Start-up support and seed instruments for start-ups and SMEs are small to modest sources of funding or in-kind benefits, which include business coaching and technical expertise. This section provides a summary of start-up support and seed capital instruments available to SMEs at the European level that are specifically dedicated to the space sector.

Copernicus Hackathon Programme[77]

Summary

- **Objective**: creation of innovative business ideas based on Copernicus EO data.
- **Number of space projects funded**: 20 hackathons every year for two years.
- **Total space funding**: total funding pool of EUR 1.2 million.
- **Funding amount per project**: no cash prize—winners enter the Copernicus Accelerator.

The Copernicus Hackathon Programme was announced in 2017 and launched in autumn 2018. The programme will financially **support the organisation of 20 hackathons every year for two years**. Copernicus Hackathons are sprint-like events in which computer programmers and subject experts collaborate intensively to **develop software based on Copernicus data and services**, thereby addressing a predefined challenge with a useful solution. The challenges are inspired by global problems such as climate change or health challenges by using EO data.

GSA Hackathons[78]

Summary

- **Objective**: to look for passionate coders who want to shape the future of location-based services and GEO–IoT.
- **Number of space projects funded**: 11 winners selected per year.
- **Total space funding**: yearly prize pool of EUR 3000, plus additional prizes provided by technical partners.
- **Funding amount per project**: EUR 1000.

Since 2016, the European Global Navigation Satellite Systems Agency (GSA) has organised **two-day hackathons in European locations**. With a focus on the development of location-based services and GEO–IoT, these hackathons bring creative heads together to create applications in some of the following domains: geo marketing and advertising; mapping and geographic information systems; fitness, sport and mobile health (mHealth); smart mobility. Typically prizes of EUR 1000 are awarded by GSA and other prizes are awarded by technical partners of GSA.

Farming by Satellite[79]

Summary

- **Objective**: to promote Europe's GNSS and EO services in agriculture.
- **Number of space projects funded**: three winners selected per year.
- **Total space funding**: yearly prize pool of EUR 8000
- **Funding amount per project**: between EUR 1000 and EUR 5000.

Since 2012, Farming by Satellite has been awarding prizes to promote the use of the GNSS and EO in agriculture. Farming by Satellite is organised by **the GSA**, in cooperation with the **European Environment Agency** (EEA). Individuals and teams of up to four can contribute ideas and innovations regarding any type of agriculture in any part of Europe. The competition is open to all students and young people below the age of 32. **The first prize is EUR 5000; second prize is EUR 3000 and third prize is EUR 1000.**

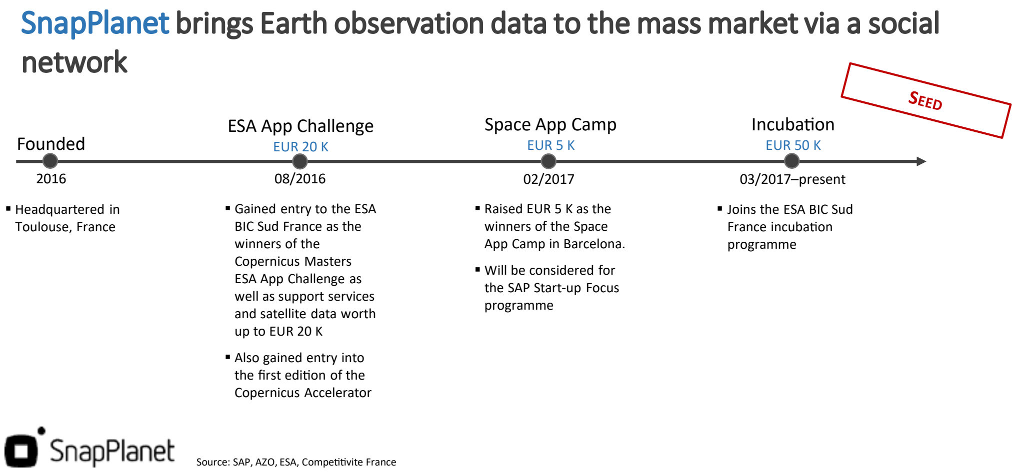


Figure 38: Example of a Copernicus Masters winner

Copernicus Masters[80]

Summary

- **Objective**: creation of innovative products & services based on Copernicus EO data.
- **Number of space projects funded**: 15 winners selected per year.
- **Total space funding**: EUR 1.5 million of cash prizes and non-financial support (2017).
- **Funding amount per project**: cash prizes between EUR 5000 and EUR 10 000 plus non- financial support.

The **Copernicus Masters** was introduced in 2011 by the ESA to foster the user uptake of Copernicus services and support the creation of innovative products and services based on the EO data produced by the Copernicus programme. Every year, approximately **15 winners are selected** by the organisers and **awarded cash prizes between EUR 5000 and EUR 10 000.** Prizes also include non-financial **benefits such as consulting, data packages and technical support**. In 2017, **prizes worth a total of EUR 1.5 million** were awarded to the winners of the competition.

European Satellite Navigation Competition (ESNC)[81]

Summary

- **Objective:** to award the best services, products and business ideas using satellite navigation in everyday life.
- **Number of space projects funded**: 26 projects per year.
- **Total space funding**: yearly prize pool of EUR 1.3 million (2017).
- **Funding amount per project**: up to EUR 10 000.

The **ESNC** is a yearly international **innovation competition** targeting the most **forward-thinking applications based on satellite navigation in Europe**. It aims to foster innovative ideas and solutions for commercial applications of satellite navigation technology. Since its inception in 2004, 11 500 entities have participated, competing for an **annual prize pool worth approximately EUR 1.3 million,** consisting of cash, business coaching, patent consulting, technical support, access to testing facilities, prototype development, marketing support, feasibility studies, access to experts and further access to public funding.

Copernicus Accelerator[82]

Summary

- **Objective**: to turn promising ideas into reality and successfully enter them into the market.
- **Number of space projects funded**: 50 participants from the Copernicus ecosystem.
- **Total space funding**: yearly funding pool of EUR 250 000 (2017).
- **Funding amount per project**: EUR 5000 for mentor.

The **Copernicus Accelerator offers customised business development programmes for start-ups and entrepreneurs** from Copernicus Participating Countries and associated countries. Established in 2016, the Copernicus Accelerator is a 12-month coaching and training programme including two bootcamps, with 50 participating businesses from the Copernicus ecosystem such as the Copernicus Masters competition and the Copernicus Hackathons. Despite the high technical quality of the emerging businesses, many entrepreneurs require business and market support to fulfil their innovative potential. The 50 mentees are paired with over 40 mentors who each have an EO or business background and will provide customised advice (e.g. how to access financial resources or expand internationally).

E-GNSS Accelerator Programme[83]

Summary

- **Objective**: to enable the winners of the ESNC to accelerate their business ideas and start real commercial ventures.
- **Number of space projects funded**: the top three winners of the ESNC selected per year.
- **Total space funding**: yearly prize pool of EUR 186 000.
- **Funding amount per project**: EUR 62 000 of non-financial support.

The E-GNSS accelerator programme is an idea competition (similar to the ESNC) and as such is open to a wide variety of applicants, from individuals, researchers and start-ups to corporations. The top ten winners of the ESNC are invited to present in front of a high-ranking expert panel on how further incubation services would enable them to accelerate their business ideas and to start real commercial ventures. Of these top ten winners, three candidates are selected to receive 12 months of incubation and acceleration support. This support is co-financed by the Commission and valued at **EUR 62 000 each**.

Copernicus Incubation Programme[84]

Summary

- **Objective**: to turn the most innovative and commercially promising ideas into reality and successfully enter the market.
- **Number of space projects funded**: 20 European start-ups from the Copernicus ecosystem.
- **Total space funding**: yearly funding pool of EUR 1 million.
- **Funding amount per project**: EUR 50 000 of non-financial support.

The Copernicus Incubation Programme supports the market entrance of the most promising business applications based on Copernicus data. The programme gives **EUR 50 000 to 20 European start-ups each year**, to fund up to 85 % of the total costs of their **incubation in the support programme of an organisation of their choice** (e.g. ESA BICs or any other incubation or acceleration programme). On top of this, the programme provides additional advantages such as network opportunities and tools for start-ups to improve their business design or pitch decks. The application procedure is designed to be lean and efficient, with multiple selection rounds per year. The first two selections of start-ups started their incubation in 2018, and the next selection round is due to open in spring 2019.

ESA Business Incubator Centres (BICs)[85]

Summary

- **Objective**: to work with and inspire entrepreneurs to turn space-connected business ideas into commercial start-up companies.
- **Number of space projects funded**: 140 start-ups in 18 European BICs funded per year.
- **Total space funding**: EUR 7 million per year.
- **Funding amount per project**: approximately EUR 50 000 of grants and non-financial support.

Incubators are well established and widespread in Europe, providing an array of support mechanisms and services such as office space, mentoring and networking opportunities—but typically only very limited amounts of capital. The ESA BICs are geared towards accelerating, innovating and unlocking each start-up's commercial potential of space-related companies. Currently, **18 ESA BICs have been established in 15 European countries** and support on average 140 start-ups per year. As the ESA BICs have open calls for proposals, applications can be submitted at any time. Applicants must present an idea based on a space-related technology, expertise or application, and must target the non-space market. The company must not be more than five years old and must be located in the country of the preferred ESA BIC. The BICs provide a number of services, including **funding up to EUR 50 000 for product development** and securing of Intellectual Property Rights (IPR), a work environment for up to 24 months, business development support, access to VC, loans and grants or technical support.

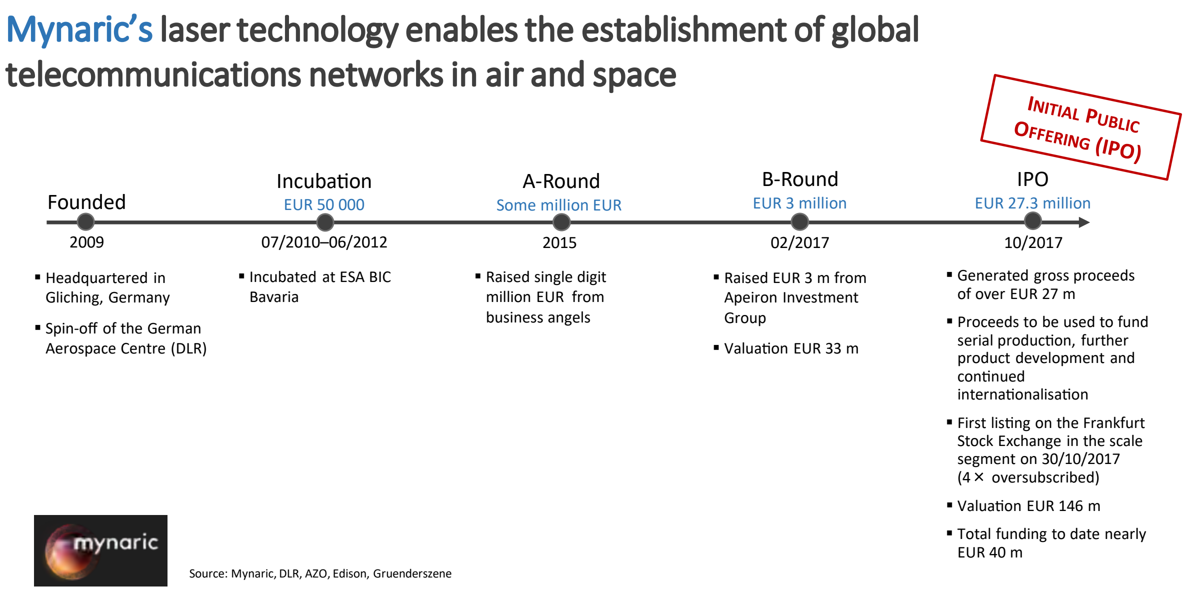


Figure 39: Example of an ESA BIC incubatee

Crowdfunding

Summary

- **Objective**: to build a bridge between new space investors and space entrepreneurs.
- **Number of space projects funded**: unknown.
- **Total space funding**: unknown.
- **Funding amount per project**: variable.

Crowdfunding offers an alternative source of funding into space ventures. **Small amounts of money are raised from a large number of people** in exchange for a share in the venture. Several online platforms exist today. An example of a space-focused platform in Europe is SpaceStarters.

Business Angels[86]

Summary

- **Objective**: to provide the capacity to invest, bringing both finance and experience to small businesses.
- **Number of space projects funded**: unknown.
- **Total space funding**: unknown—angels invested EUR 6.7 billion across industries (2016).[87]
- **Funding amount per project**: typically, between EUR 25 000 and EUR 100 000.

Angel investors are **wealthy individuals who provide capital for a business venture, most often in exchange for equity.** They are private investors who provide their own capital to start-ups, generally in a sector in which they have previous professional experience. Some of these investors form groups called angel networks in order to share scouting efforts, pool investment capital and provide business coaching to the companies in the investment portfolio. Angels form an important source of financing for start-ups, but the statistics available on angel investors are limited. A key strength of business angels is that many of them provide "smart capital", bringing valuable industry experience and a network of contacts within the sector in addition to financial support. On the downside, business angels tend to invest locally and often act alone, making it difficult for founders to gain access if they are not aware of the market practices in the VC industry.

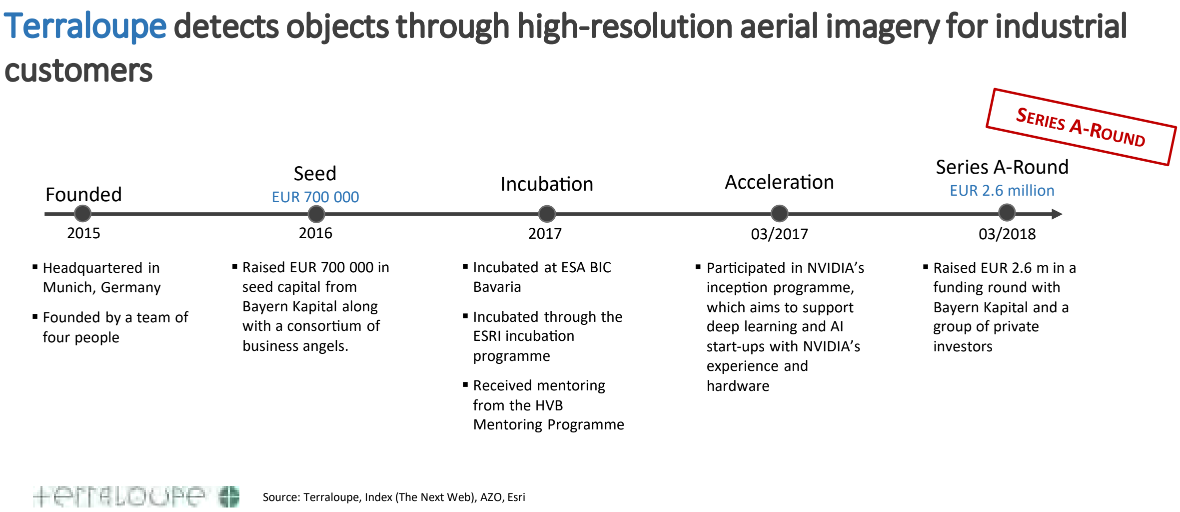


Figure 40: Example of business angel funding

Business angels are still not as common in Europe as in the United States, where several high-net-worth individuals—mostly from the IT sector—have either founded or supported space companies in the past decade. **The European Business Angel Network (EBAN) is an example of an early-stage investor network in Europe**. This network, active worldwide, brings together early-stage investors that have an interest in investing in space companies to share knowledge. EBAN recently launched EBAN Space to develop Europe's space ecosystem and foster cooperation between early-stage and high-level actors within the industry.

Horizon 2020 SME Instrument[88]

Summary

- **Objective**: to support highly innovative SMEs with close-to-market activities though a phased approach.
- **Number of space projects funded**: approximately 20 per year in phase 1 and 10 per year in phase 2.
- **Total space funding**: EUR 14–16 million per year.
- **Funding amount per project:** EUR 50 000 (phase 1) to EUR 2.5 million (phase 2).

The **Horizon 2020** SME instrument is a part of the **European Innovation Council Pilot** (EIC pilot), currently running from 2018–2020. The SME instrument **supports highly innovative SMEs with close-to-market activities through a phased approach**. SMEs from the EU and associated countries can apply. Since 2018, there has been no space-specific call or topic, and market disrupters in any sector can apply. Four independent experts judge the proposals received on the basis of three award criteria.

Phase 1: approximately 2000 proposals are submitted for each cut-off, with roughly 5–8 % receiving funds. Companies receive business innovation grants of **EUR 50 000 over six months for feasibility assessments**. An analysis of past grants showed that approximately 20 SMEs in the space sector receive such funding in any given year. Phase 1 also provides the company with up to **three days of business coaching**, delivered by an expert with specific niche knowledge.

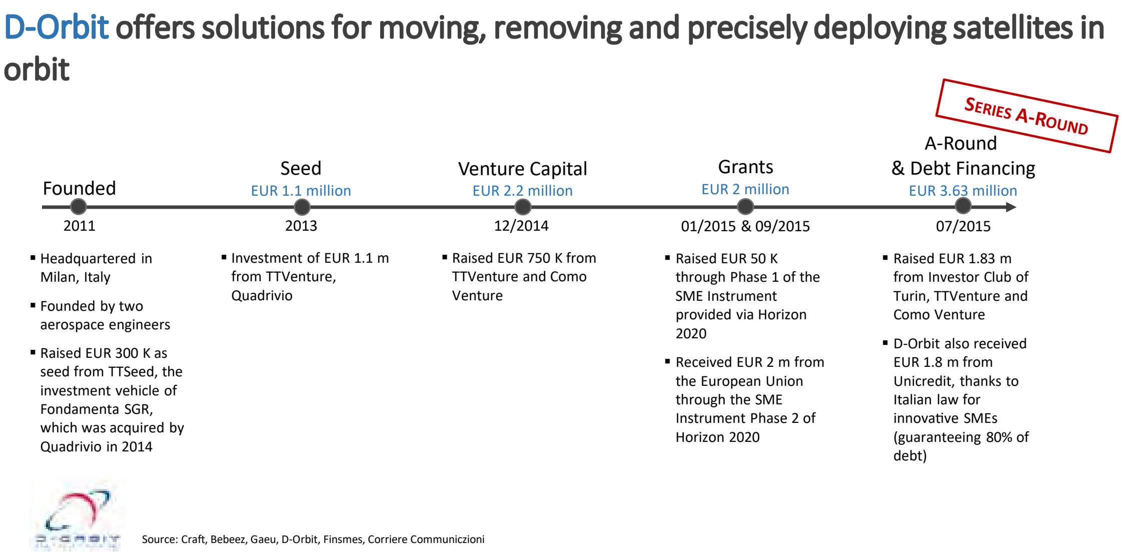


Figure 41: Example of SME Instrument funding

Phase 2: approximately 1200 proposals are submitted for each cut-off, with roughly 5–8 % succeeding in receiving funding. Between 2014 and 2017, on average 10 space projects were funded with EUR 14–16 million per year. Companies receive business innovation grants of between **EUR 500 000 and EUR 2.5 million** for **innovation development and demonstration purposes** at a funding rate of 70 %. Phase 2 also provides the company with up to **12 days of business coaching**. Phase 2 now also includes **Acceleration Services**, formerly called Phase 3, which **do not provide any financial funding** but deliver a **wide range of business acceleration services and facilitated access to risk capital**, as well as an environment where all SME grantees can communicate with investors, consumers, other companies and public procurers. Since 2017, the Executive Agency for Small and Medium-sized Enterprises (**EASME**) has also enabled companies to participate in oversea trade fairs and corporate events.

3.6. Commercialisation and growth with venture capital and private equity

When technology development has matured, and the technology risk has lowered, the last stage of a company's product development can start, and the product will soon be tested in its final form and under operational conditions, ready for initial market commercialisation. Obtaining **funding for market entry of the product or service**, and **to expand the production facilities** are essential steps in growing a business.

Currently, Europe has less financing available than the United States for this stage in a company's maturity (see Section 4.1). At this stage, public funding typically ceases to be provided directly to companies, with the public sector rather participating in a company's equity or debt through private fund managers and financial intermediaries. **Venture capital** and **private equity** provide equity risk capital to companies in early-stage and growth stage. VC is, technically speaking, a subset of PE, with the most notable difference being that VC funds raise capital to specifically invest in early-stage start-ups with growth potential, while there are many different types of PE funds that exist today and are classified by their investment strategy.

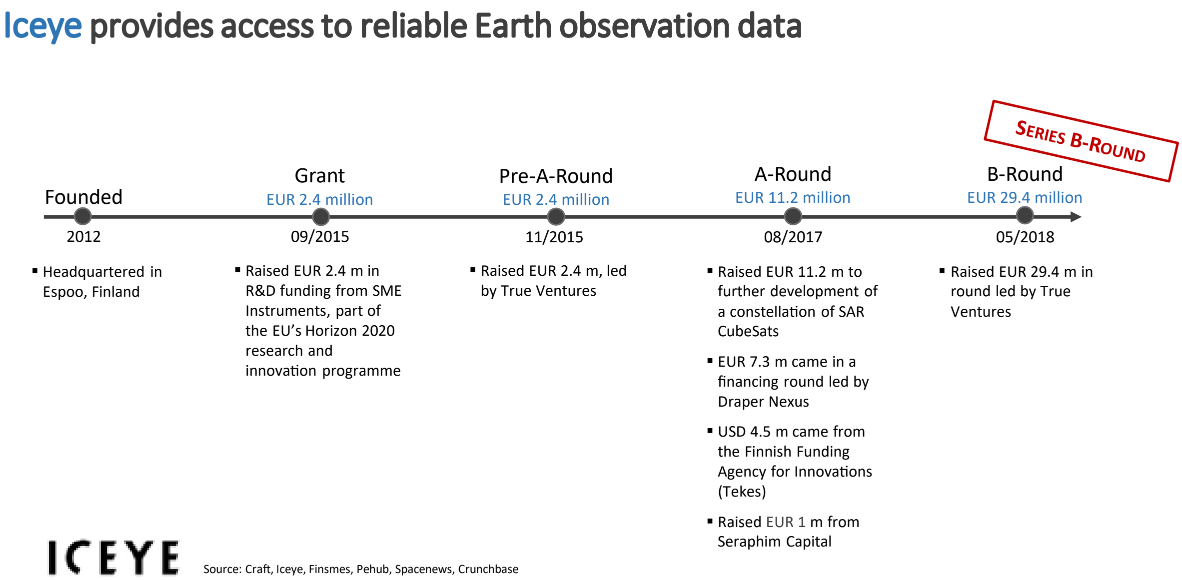


Figure 42: Example of venture capital funding

VC funding is only provided to a hand-picked selection of companies that are deemed to have an extra-ordinary growth potential or have already demonstrated considerable growth. VC funds invest equity capital in these high-growth companies in exchange for an ownership stake.

Figure 43 provides an overview of VC funds that have invested in space-related businesses in recent years. With **Seraphim Capital, Europe has a second VC fund that focuses on the space sector, following the Open Sky Technology Fund launched in 2010. Seraphim was launched in 2016 with the strong backing of the British Business Bank and has approximately GBP 70 million available for investment in both software (downstream) and hardware (upstream) opportunities.**

Governments and their agencies are initiating thematic funds for space (applications). For example, the Centre National d'Études Spatiales (CNES), the French space agency, is providing a cornerstone investment in a newly initiated VC fund and the Luxembourg government has announced it will launch a space VC fund in the foreseeable future (see Section 4.11 for more details).

3.7. Funding space companies with debt financing

Debt financing is a valuable source of financing for businesses with a lower risk profile, while innovative start-ups or young SMEs experience difficulties in accessing this source of capital due to their lack of financial track record and assets (see Section 4.1). Debt financing is better suited for more established SMEs or corporates that have existing commercial products and long-term contracts. In the aftermath of the financial crisis, commercial banks have been particularly reticent to provide capital to SMEs. There have been several studies (from the ECBxvi) in recent years that document the difficulty of debt financing for SMEs.

No debt funding instruments exist dedicated to financing companies in the space sector. This should not come as a surprise, however, as thematic funding dedicated to a sector is in general atypical, and products focus on horizontal themes.

In the private capital markets, space companies have received **business loans** from commercial banks, and satellite **project finance** from commercial lenders or institutional investors, as well raising from the capital markets by issuing **bonds**. For example, in March 2018, SES successfully launched and priced a bond offering to sell senior unsecured notes for a total amount of EUR 500 million, bearing a coupon of 1.625 % p.a., the lowest in the company's history.[xvii]

xvi https://www.ecb.europa.eu/pub/pdf/other/SAFE_website_report_2014H2.en.pdf?56935ca239cc0aab853703c9b2103145.

xvii https://www.ses.com/de/node/10421.

Investor	Portfolio Companies
ACT Venture Capital	ferfics, Parrot Technology, Arralis, Pilot
ATOMICO	Mapillary, Lilium, ONTRUCK, Orbital Systems, HAIL
BayBG	tiramizoo, CargoGuard, NavVis
Bayern Kapital	terraloupe, COORDINATE, parcelLab
Caixa Capital	fever, PLDSPACE, Eat Tasty
Capricorn	sensolus
CONVENTURE	
COPARION	libify, VIMCAR, parcelLab, reactive robotics
Dendera	Orbital Systems
DIGITAL+ PARTNERS	NavVis
Digital Ventures	Connected Signals, TALIXO, WHAT3WORDS
EARLYBIRD	movinga, obilet
ForceOverMass	zencargo, WHAT3WORDS, Hummingbird Technologies
HAMBRO PERKS	WHAT3WORDS
heliad	libify
HessenKapital	MAPCASE
High-Tech Gründerfonds	ORBEX, cevotec, reactive robotics, locr, enercast, IQ evolution, synoptics, Valispace, PARKTAG, blickfeld, COORDINATE
investiere	Astrocast, insolight, arviem, lunchgate, nezasa
Invium Partners AB	GOMSPACE
IQ CAPITAL	Oxford Space Systems, Focal Point
JamJar	home run, WHAT3WORDS
	eblana photonics, Arralis, ALPHA, ACRA, S3 Semiconductors

Investor	Portfolio Companies
	CABEO
kibo ventures	minube, iContainers
Hilti ventures	ThrustMe, Zenly
LIFELINE ventures	ICEYE, HAPLET
Longwall Ventures	Oxford Space Systems
MIG AG	NavVis
mustard seed	rapido, WHAT3WORDS
Notion	FIVE AI, localz, shutl
OHB	BLUE HORIZON
Practica Capital	nano avionics, Trafi
	sensolus
RedSeed	
REDSTONE	TALIXO, WHAT3WORDS
ROSEN GS-RD INVEST	Orbital Systems
SERAPHIM CAPITAL	spire, ICEYE, NIGHTINGALE, ALTITUDE
Technology Ventures	tiramizoo
Stena	Orbital Systems
TARGET PARTNERS	NavVis
Tengelmann ventures	INTRANAV, blickfeld
TGFS	NAVENTIK, MAPCASE
TT ventures	
VenturesOne	
Vitamina K	
VITO ONE	building radar, CrateDB, HOMEDAY

Figure 43: An overview of relevant investors with space-related portfolio companies in recent years

Case Study

Europe's all-electric satellite platform[xviii]

In 2016, the EIB lent OHB System AG, one of Europe's leading space companies, EUR 30 million to finance research and development under ESA's Electra programme, in which OHB is developing a fully electric satellite propulsion platform designed to substantially reduce satellite's propellant mass and increase its propellant life and re-allocation capabilities. The **loan is backed by a guarantee from EFSI**. EIB Vice President Ambroise Fayolle also stressed that this first-time cooperation with OHB underscored "the role of public sector lenders in stimulating the mobilisation of private capital to foster innovation in a dynamic and sustainable way." EC Vice-President Jyrki Katainen, responsible for jobs, growth, investment and competitiveness, said: "Supporting research in the latest space industry technologies is a key component of the Commission's space strategy."

Other examples of EIB lending for space companies:

- Arianespace: EUR 121 million for Soyuz in 2005;
- Inmarsat: EUR 225 million for Alphasat in 2009;
- Sener (EFSI project): EUR 110 million for renewable and space technologies in 2017;
- Terma (EFSI project): EUR 28 million for space and radar technologies in 2017;
- Skeleton Technologies (EFSI project): EUR 15 million quasi-equity for ultracapacitors in 2017.

On the public side, several government incentives (generally in the form of guarantees) have been created to alleviate credit concerns for commercial banks, e.g. to offer long-term debt with little or no interest added to the equity raised by early stage companies. The EIB provides debt products through financial intermediaries such as the range of InnovFin products available under the Single EU Debt Instrument. The bank also provides debt products directly, as in the case of OHB System.

Export financing by export credit agencies is an important part of the international export framework. So far, export financing has been a national activity, with differing conditions and success rates between the players involved. American and French companies have achieved visible competitive advantages through the extensive support of EXIM and Bpifrance Assurance Export (formerly part of Coface), as have Canadian companies, through Export Development Canada (EDC). The UK's export-credit agency, on the other hand, is trying to make a stand by supporting projects that hold as little as 20 % UK content. In contrast, the US and France are most comfortable guaranteeing loans only when the majority of the work is done in these nations.

Export-credit agencies typically guarantee up to 85 % of a contract's value at lower rates than those available from commercial banks. Satellite owners can then use the export-credit support as a reference when seeking equity. Export financing has established itself as a valuable tool in promoting advanced technology such as aerospace projects and satellites. When the German KfW (originally called Kreditanstalt für Wiederaufbau) started its financing operations in 1950, it was tasked with financing export transactions on a medium- to long-term basis, as commercial banks at that time were only entering into short-term commitments. Consequently, German systems exporters lacked suitable financing options. The financing of shipbuilding was among its first operations; aircraft financing (e.g. Airbus) followed, and over time the annual volume of KfW's export financing commitments rose from EUR 81.8 million to over EUR 511.3 million.[89]

Among the various players, the Organization for Economic Cooperation and Development (OECD) lists 23 European Official Export Credits Agencies that are involved in the Export Credit Group (ECG) work, listed in the Annex (see Table 42).

xviii EIB, 2016.

Key Takeaways

- Europe has **reasonably good access to public funding dedicated to space**, but private funding sources are lagging behind. Several R&D funding programmes exist at both European and national level, in addition to funding programmes supporting the early development of a company itself—most notably the SME Instrument of the EU's Horizon 2020.
- **Seed stage support mechanisms have successful programmes** such as the ESA Business Incubator Centres and the Copernicus Start-up Programme on a pan-European scale, complemented with several initiatives at a national level. These programmes, however, have fragmented coverage of the different space segments.
- VC in Europe is investing in space companies, mostly on the downstream application side. The **total volume of investment is lagging public funding in Europe and private investment in the US**. The criteria to assess space investments are very similar to those used when assessing other investment opportunities in tech or deep tech.
- It is key to have a **thought-through business model**, which is not an easy task for a sector with plenty of engineers and scientists yet only a **few teams with business backgrounds**.
- Established satellite operators with large space projects receive funding through more complex financial products, such as project or export credit finance.

4. Key findings about access to finance conditions for space companies in Europe

The analysis of market sizes, market trends and investment volume (Section 2.1) combined with technology assessment (Section 2.2), the abridged risk matrix (Section 2.3), the description of public and private funding instruments and its volumes (Chapter 3) and many stakeholder interviews have led to **11 key findings concerning access to finance for European space companies**. The key findings concerning funding hurdles that are largely applicable to all technology areas in Europe are summarised in Section 4.1, whereas the other sections in this chapter characterise the specificities of the space ecosystem and its access to finance conditions.

4.1. The European space sector experiences similar funding hurdles to other tech companies, particularly during the scale-up phase

European space start-ups, despite their unique features, are subject to the same macroeconomic dynamics and trends as their peers in other industries. Although the EU is fertile ground for scientific research, technology and innovation, **European start-ups are struggling to reach the same maturity levels as their American counterparts**. As of 2016, Europe had produced only 26 "unicorns" (i.e. start-up companies with a market valuation over USD 1 billion), compared with 109 in the US and 59 in China.[90]

The financial and sovereign debt crises across the globe have contributed to a suboptimal investment climate since 2008.[91] Since this period, SMEs and start-ups, the backbone of the European economy, have become especially topical. In a report on the public consultation that preceded the EC's Start-up and Scale-up Initiative, **71 % of the respondents identified access to finance as the major barrier to European start-ups scaling up their business.**[92] Indeed, despite other hurdles, such as excessive bureaucracy, risk aversion or high compliance costs with regard to employment and tax regulations, the growth of European start-ups' is mainly constrained by the funding gap between their needs and the availability and accessibility of funds.[93 & 94]

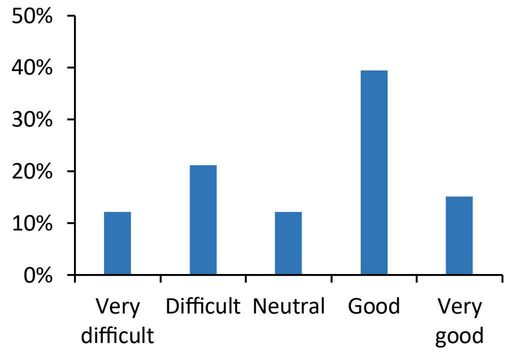


Figure 44: Surveyed companies' assessment of their own access to finance

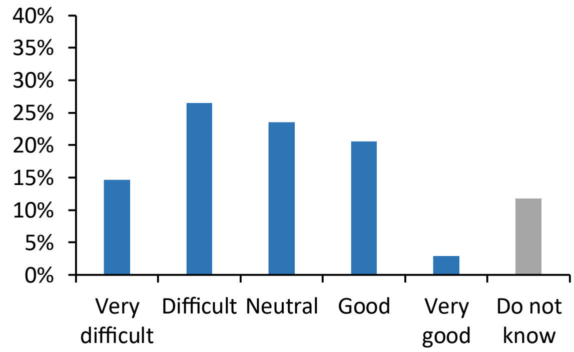


Figure 45: Surveyed companies' assessment of the sector's access to finance

The **space sector companies surveyed reaffirmed this hypothesis**; when asked about their view on access to finance for the European space sector in general, their perception remained quite negative (Figure 45, even though they perceived their own access to finance as quite positive, see Figure 44).

	Key finding	In detail
		Financing challenges
1	The European space sector experiences funding hurdles similar to those of other tech companies, particularly at scale-up phase	• Not only is the volume of European VC investment lower, venture capitalists invest with smaller tickets, and growth capital is particularly hard to find • Business loans from commercial banks are nearly inaccessible
2	Companies in both the upstream and downstream sectors of the industry struggle with access to finance, but for different reasons	• Upstream companies face long development cycles, are capital-intensive and operate in a limited market with many business risks • Downstream companies sell to emerging markets (with predominantly governmental buyers) and to unsophisticated customers
3	The space ecosystem lacks investors with a space background and space investment expertise	• It will still take years for the European space sector to exploit the full potential of the mobility of people between the triangle of corporate, entrepreneurship and investment roles
4	European space entrepreneurs feel there is a lack of private financing sources and keep an eye on the US	• Most space entrepreneurs are looking for private capital outside of the EU • The wave of NewSpace investments in the US, with larger funding rounds and investors with greater risk appetite, are enticing to European firms
		Market maturity and sector risks
5	Space innovations have a longer development cycle than general tech	• The space hardware development cycle is considerably longer than in general tech; however, NewSpace is closing the gap
6	Investors are mostly concerned by market maturity	• Immature markets with questionable demand, technology risks and high capital needs are the key risks from the perspective of space investors
7	Investors do not see the exit opportunity (yet)	• Large system integrators do not yet have a tradition to invest in external innovation • Investors perceive the lack of exits as a sign of new or failing markets and therefore a risk for financial returns
8	The lack of follow-on finance has led to a number of early initial public offerings (IPOs)	• Europe has seen a few small space IPOs over the last two years despite a decline in the overall small IPO market • IPOs are seen by the entrepreneurs as a sizable funding source but also as a scalable funding source
		Role of the public sector
9	European public innovation instruments play an important role in unlocking private capital for the space sector	• 40 % of the companies seek public funding as it is a precondition for private investment • Public funding serves as a seal of approval in the market
10	The landscape of space sector support mechanisms is rather fragmented, and procurement is geared towards the traditional value chain	• Entrepreneurs find it hard to navigate through the different possible funding options • The traditional European upstream space industry is used to a large institutional market of traditional public procurement and R&D grant programmes • Industry associations and entrepreneurs in both the upstream and downstream sectors indicate a lack of public anchor tenants to stimulate the sector
11	Public authorities around the globe are stimulating the setting-up of venture capital funds dedicated to the space industry	• France, Luxembourg and Japan are examples of governments initiating VC funds to bridge the funding gap for space companies

Table 12: Summary of key findings

Start-ups' funding needs depend on their maturity (Figure 46). Enterprises in the early stage are generally cash-flow negative without any sizeable track record, and therefore require a high risk tolerance from potential investors, typically venture capitalists. In addition, the high issuance and compliance costs, legal fees and administrative requirements lower the accessibility of public equity capital. As a result, IPOs are not an ideal scenario for European early stage companies. Between 2000 and 2008, there was an annual average of 200 small IPOs, counting for 8 % of the total number of IPOs. After 2009, these figures dropped to an average of 120 IPOs and 5 %, respectively.[95]

At the same time, bank loans are difficult to obtain for early stage start-ups. Deutsche Bank Research even observed a considerable deterioration in bank loan and credit line availability between 2010 and 2015 for SMEs that are less than two years old.[96] This is **due to the perceived lack of transparency in the evaluation of their credit risk**, but also the strengthened balance sheet requirements for banks, accompanied by prudent risk and capital management. The EU addressed this by implementing an SME Supporting Factor (SF), reducing banks' capital requirements for credit risk on exposures to SMEs, but research has shown that micro/small firms were not able to benefit from this measure.[97]

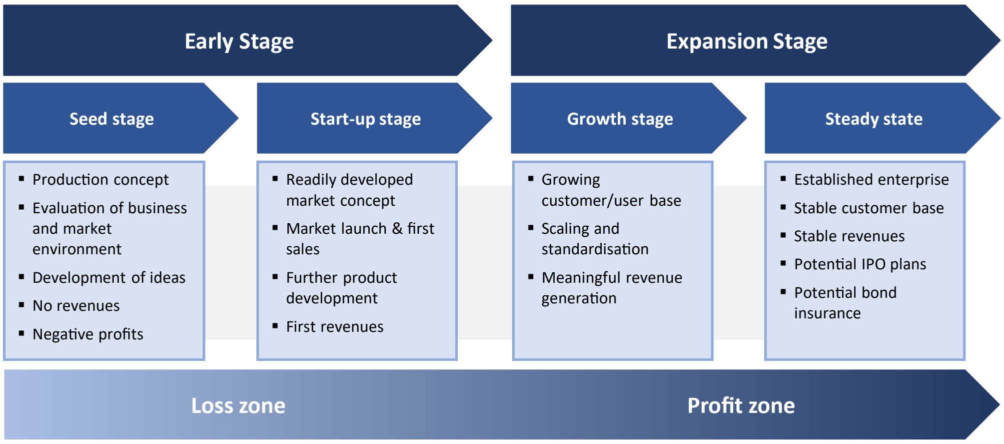


Figure 46: Growth stages of a start-up[98]

Interview Quotes	
	• Access to credit is not attractive if you are personally liable, and it doesn't match with the needs of entrepreneurs. • The company has no good experiences with banks. They were asking for a credit line, like we are an "atypical" company; we don't have a fixed set of income every month (predictable). We could not even get a credit line on a credit card, even though our liquidity was good. • Banks did not understand the space industry too well, so that was a hurdle. The university vouched for the company and that helped. • A high interest rate bank loan (bridge loan) was offered. There was no connection between the loan and the collateral when receiving the interest rate offer. • For loans the situation really changed in the last two years; the situation was really hard before.

Table 13: European space executives on lending

As a consequence, early stage start-ups resort to alternative financing solutions. These include internal financing (family, friends, fools), crowdfunding, business angels or VC. In particular, VC funds, which focus on investments in early-stage start-ups with growth potential, are often the only option for these enterprises. The European VC market is, however, lagging the United States, whose market is deeper and more developed, as exemplified by Figure 47. In the 2016 public consultation on the EC's Start-up and Scale-up Initiative, stakeholders suggested that "the lack of scale of EU-based venture capital funds is a significant issue for companies attempting to scale up".[99] Despite the exceptional growth rates of European VC money over the last 10 years, supported by a significant capital inflow from the US and Asia, the absolute amount of venture capital funding in Europe has remained low.[100] The demand for equity risk financing among Europe's SMEs and mid-caps considerably exceeds the available supply, with an estimated annual gap of up to EUR 70 billion (recent estimates suggest annual EU-based demand between EUR 50 billion and EUR 80 billion and place supply at approximately EUR 11.5 billion).[101] As the space industry accounted for approximately 2.4 % of the global investments in 2017,[102] and the EU accounted for 10.7 % of the global investments,[103] we can deduce the annual gap in the European space industry is between EUR 0.9 billion and 1.6 billion.

Promising European start-ups consequently face a trade-off between cutting growth and reducing expenses, an early IPO or acquisition (the average mergers and acquisitions (M&A) valuation in Europe is significantly lower than in the US) **or moving to better VC ecosystems** such as the US, which is what many eventually do.[104] The reasons for this impasse are manifold.

First, Europe's less developed VC-landscape may be rooted in the **risk-averse mindset of its investment culture**. As mentioned before, early stage start-ups require a high risk tolerance from their investors due to their opaqueness, limited track-record and a high degree of technological, regulatory or market risk. This is especially the case for hardware technology start-ups or those targeting emerging but immature markets, and is particularly applicable to space start-ups, as confirmed by the respondents in our interviews. The public consultation under the Start-up and Scale-up Initiative supports this view—respondents advocated a cultural change by banks and financial institutions concerning access to finance for bankrupt entrepreneurs looking for a second chance, who currently maintain a negative credit score for a long time.[105]

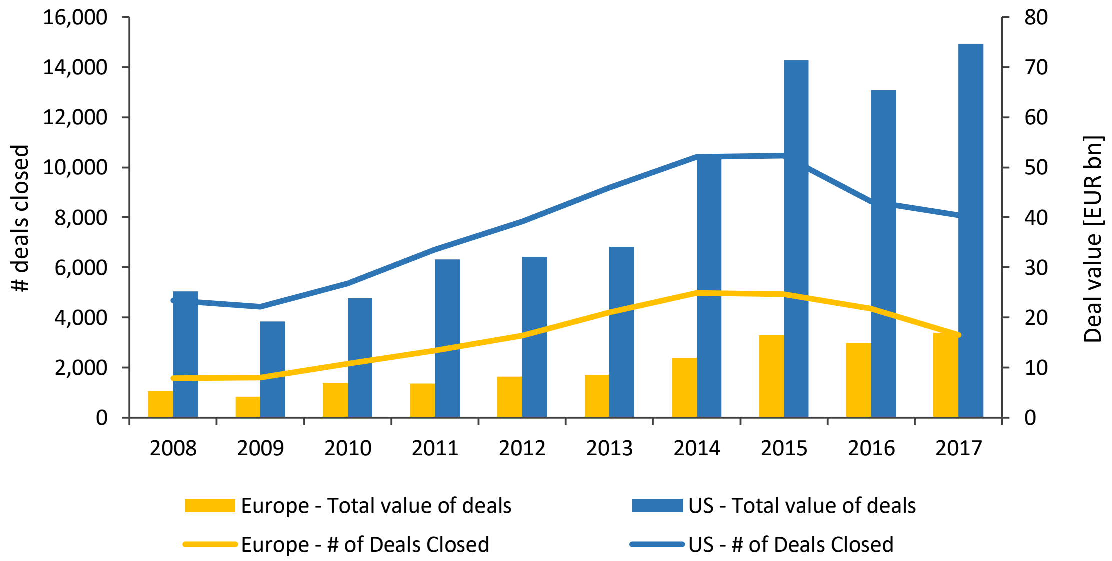


Figure 47: VC activity in the US and Europe per year[106]

Interview Quotes

- Europe, generally speaking, is cash rich and there is a very limited amount of that wealth that goes into productive innovative companies, such as those in the space sector.
- Funds cannot support anything, as the individual funds are too small. The risk structure in the portfolio is too low: Series A is evaluated in Europe with [US] Series B type of metrics. Companies then are 10 times less financed than they would be elsewhere.
- Funds that have focus on hardware are missing; that is a shame because Europe's strength is in hardware (from university level on); this is a mismatch in the European system. Lots of opportunities get lost.

Table 14: European space executives on investment funds

Second, **VC funds in Europe invest with smaller tickets than their counterparts outside of the EU**, which creates a hurdle for deep tech such as upstream space companies. The funds are considerably smaller than their US counterparts: EUR 56 million on average compared with EUR 156 million in the US, leading to a comparative disadvantage in their ability to support high-value start-ups.[107 & 108] One should thus consider the fact that, unlike in the US, pension funds in many EU Member States are not permitted to invest in VC.[109] Besides their limited scale, there are high levels of fragmentation, short-term vision and an excessive focus on digital technologies compared to deep-tech.[110] As a result of subsequent supply-and-demand dynamics, deals in Europe are cheaper than in the US, although the technical talent pool is equally qualified. The international investment community therefore considers the EU to be underfished.[111] Since 2015, however, there has been a steadily increasing aggregate deal value, in parallel with a drop in the amount of deals closed, signifying a higher relative deal value. This may be due to European entrepreneurs becoming more ambitious at building larger companies, while EU-based VC funds move towards a smaller number of high-volume deals.[112]

Third, the **regulations, terms and conditions for investment are not standardised across the different Member States**, creating a hurdle and compromising the potential for upscaled, EU-wide venture capitalists to develop. In the public consultation under the Start-Up and Scale-Up Initiative, 40 % of entrepreneurs reported that scaling up their company across borders was harder than expected due to legal, regulatory and administrative barriers. Some respondents stated that Member States' national legislation and tax regimes concerning investment, stock options, profits and company structure hinder the optimal use of cross-border VC within the European Union.[113]

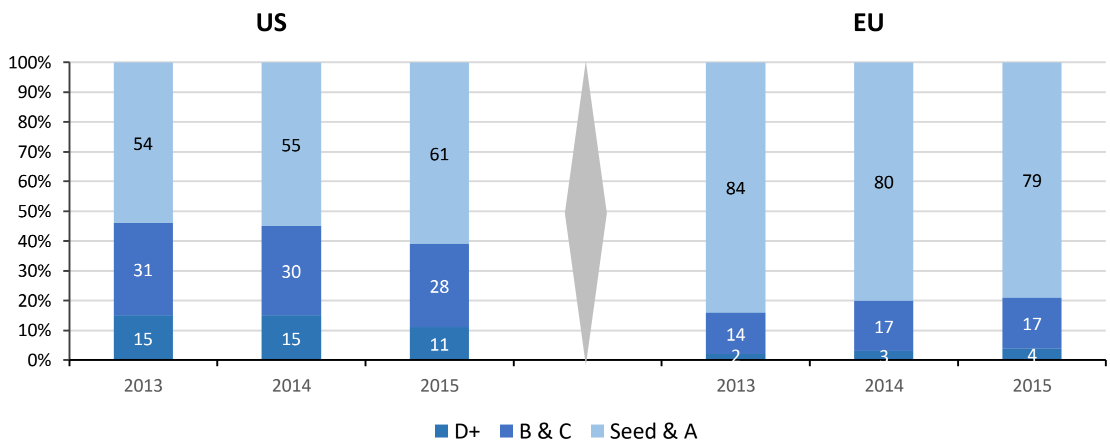


Figure 48: Ratio of growth stage deals in the US and the EU[114]

However, early stage start-ups are not the only beneficiaries from VC. Enterprises in their growth stage, who have generated their first revenues and built up a certain customer base, need to scale up and require capital to do so. In Europe, such **growth capital is particularly hard to find compared with seed or early-stage capital.** 65 % of the respondents in the public consultation for the Start-Up and Scale-Up Initiative indicated that financing hurdles were the main barrier to their scale-up process.[115] This perception is endorsed by a letter from 18 European CEOs, who called on the EC to support start-ups in their growth phase, rather than supporting innovators. According to the entrepreneurs behind the initiative, later stage growth financing, including access to IPOs and investments from pension funds and sovereign wealth funds, should be improved, while EU money should be given to venture capital funds, which are better placed to select companies to back.[116 & 117] The apparent lack of growth capital is shown in Figure 48, where **the percentage of growth stage deals is considerably higher in the US than in the EU, which is a result of the limited scale and capacity of European VC funds** as discussed above.[118]

Furthermore, the **mobility of individual professionals between entrepreneurship, corporate and investment roles is more limited in Europe than in the United States**, due to its younger VC industry and the constrained exit opportunities for entrepreneurs. Facilitating this triangle between investment, corporate and start-up could open up new funding opportunities for start-ups in their growth stage, as entrepreneurs who exited can take the role of business angels or develop their own VC funds. It may also allow easier interactions between start-ups and corporates, with an increased understanding of each other's business culture and functioning (e.g. decision-making processes).

European institutions are aware of the challenges the continent is facing and have developed a series of initiatives. In 2014, the **Investment Plan for Europe** announced **the creation of a Capital Markets Union (CMU)**, with the overarching Objective of creating better-functioning, more diversified and integrated union-wide capital markets.[119 & 120] In 2016, the EC announced its **Start-up and Scale-up Initiative**, aiming to give Europe's innovative entrepreneurs all the opportunities they need to become global companies. In particular, the initiative focuses on

- improved access to finance, through the launch of a pan-European Venture Capital Fund-of-Funds,
- second chances for entrepreneurs, and
- simpler tax filings.

The creation of such a pan-European Venture Capital Fund-of-Funds was announced in April 2018, when the EC and EIF agreed to provide EUR 410 million of funding for the **VentureEU programme** under the CMU and the Start-Up and Scale-Up Initiative.[121] The programme aims to raise up to EUR 2.1 billion to invest in the European VC markets, through the provision of cornerstone investments for new funds run by six asset managers,[122] who will run fund-of-funds vehicles. These vehicles are expected to invest in a range of industries, including ICT technologies, digital, life sciences, medical technologies, resources and energy efficiency[123 & 124] (see Section 3.1).

In March 2018, new rules for venture capital investment (the EuVECA Regulation) and social entrepreneurship funds (the EuSEF Regulation) came into force, making it easier for fund managers of all sizes to run VC funds, and allowing a greater range of enterprises to benefit from VC investments. Furthermore, the amended regulations will facilitate cross-border EuVECA and EuSEF activities.[125] In the same year, the High-Level Group of Innovators recommended the establishment of a **European Innovation Council (EIC)** in light of the discussions on a successor to the Horizon 2020 programme. The EIC would devote special attention to targeted support for deep tech innovation, including access to finance.[126]

Other than more funding, **start-ups in Europe require smart capital**, which is crucial to cross the valley of death between public grants and privately investable projects.[127] Such capital could come in the form of business angels or vertically focused venture capitalists, who provide experience and market knowledge in addition to capital investment. This is necessary because financing mechanisms should be tailored to the stage of a start-up's growth trajectory. Whereas public grants are appropriate for early stage start-ups where the risk is too high for private investment, innovative combinations of grants and financial instruments (e.g. a combination of EU grants with loans or equity from public and private financiers) can accommodate enterprises that require larger investments.

4.2. Companies in both the upstream and downstream sectors of the industry struggle with access to finance, but for different reasons

Similarly to other industries, **companies in the space sector are referred to as "upstream" or "downstream", depending on their location in the supply chain** (the closer to the end user a company is, the further downstream it is said to be). But while typical production-focused economies, such as oil and gas and automotive sectors, centre the distinction on the production process itself,[xix] the space sector enlarges and re-shapes this model by adding a whole block of "service level agreements" with all its associated elements to the production value chain. As important as the service complement is in economic terms, from a strategic point of view it has only a minimal effect on the **upstream** part of the space value chain, as it is the products that provide for the services. Hence, the upstream part of the space sector appears similar to those of other industries, encompassing R&D, the manufacturing of elements, components and sub-systems and the assembly, integration and testing of all these constituents to finally form a system or a system of systems. At this point, however, the similarity ends, as, once it has been produced, the system needs to be launched, stationed and operated in space or at its target destination, such as in a specific orbit or on another celestial body. The **downstream** part starts from this point, and it is the additional service complement that drives the value chain, as the ultimate raison d'être of the satellite or spacecraft is to provide a specific service (dependent on its telecoms, EO, satellite navigation, science payload, etc.). Consequently, all activities from launch to service provision form the downstream part of the space value chain as depicted in Figure 8 in Section 2.1.2.

Interview Quotes	
	• The European space ecosystem is similar to how the US was four to five years ago. • The sector that is en vogue at the moment is new launcher companies, which receive more money. Traditional equipment manufacturing (components) is not getting a lot of funding. • Most venture capitalists shy away from space because of the high capital expenditures (CAPEX); they only want to look at low CAPEX companies like downstream applications that are similar to the app-based economy.

Table 15: European space executives on the space sector

In the companies interviewed, irrespective of whether they are upstream or downstream, there are hurdles in accessing the finance they need. Less than half of the analysed companies indicate a sufficient level of funding available for space companies (Figure 49) and the investors have a more pessimistic view on the funding conditions, with the vast majority of them indicating a lack of funding (Figure 50).

If we put the **eight business model segments** (satellite services and ground equipment; satellite manufacturing; launch industry; national security; space tourism; energy; mining, processing and assembly; crewed and robotic space science and exploration) **out of the space sector value chain** and **business services** (yellow boxes; see Figure 25) into perspective in terms of the **implementation time span** and **primary business character**, it becomes obvious that upstream and downstream space companies face different issues in terms of doing business and accessing financial resources.

xix In the production value chain, upstream usually refers to the material inputs needed for production, while downstream is the opposite end, where products get produced and distributed (source: Chron, Bass B., 2018).

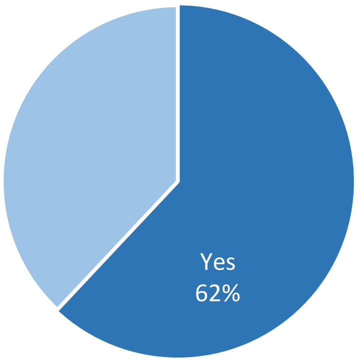


Figure 49: Companies indicating a lack of funding for space companies in Europe

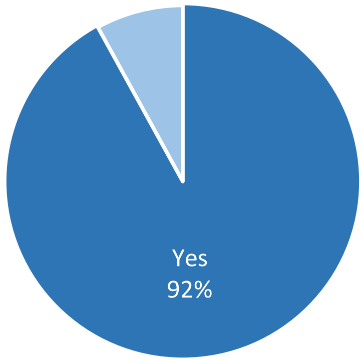


Figure 50: Investors indicating a lack of funding for space companies in Europe

Figure 51: Share of subjects mentioning segments that struggle to access financing

Upstream focused space companies (e.g. satellite manufacturing, the launch industry as well as energy, space mining, processing and assembly) are confronted with:

- **long development cycles and time-to-market constraints** (with satellite manufacturing lasting from 24 months up to 10 years—CubeSats may be produced in a few months, but revenue margins are very small);
- the need to set up **capital-intensive laboratories, production and testing facilities**;
- a limited set of buyers (**B2B business model**), often following a complicated and time-intensive procurement process ("requests for proposals" or "invitations to tender"), where **heritage** is of high importance; and
- **launch delays or business risks**, triggered by **export control and ITAR** related issues.

Interview Quotes	• The upstream sector is more difficult and everything that is not "NewSpace", such as equipment for scientific missions, or the development of new technologies for traditional commercial missions, needs a long time before in-orbit validation. Equipment for scientific missions has no guaranteed long-term profit; there is no commercial market behind, so banks are reluctant to give loans. • Everything related to low-level technologies is not obvious to finance people; technologies closer to the application/end-user side are easier for finance to understand. • For our business model (space hardware) it was easier to use public funding than private. • As an engineering company we have hurdles in employment, hardware development, export controls and payloads from other companies.

Table 16: European space executives on the upstream sector

Downstream focused space companies (e.g. satellite services, ground equipment, national security) may be better off in that they may **thrive on B2C business models, shorter time spans** and **lower entry hurdles**. Though they differ from the issues suffered by the upstream industry, the downstream still experiences sector-specific economic issues:

- **lots of downstream companies thrive on software driven innovations** such as change detection and data fusion, digital transformation and convergence, which are difficult if not impossible to protect by IPR, thereby limiting the unique selling proposition (USP) opportunities and the attractiveness to investors;

- **the emergence of many new players building** upon new business models, facing high levels of competition and limited USP opportunities in a growing but still fairly limited market—all this drives **a high mortality and/or the need to consolidate**, as the market can only absorb so many service providers;
- it is a sector where **governments are the predominant buyers**; and
- it has a fairly new market, which features **high expectation levels and a substantial share of uninformed customers**, who need to advance themselves along the learning curve.

Interview Quotes	
	• The service market is immature, whereas the institutional upstream market is proven and developed. We need a push to maturity for the service market to be considered similar to other mature markets. • The downstream services are particularly struggling with access to finance compared to the upstream. It is a problem of dimension: the downstream sector is dominated by very small companies, and they produce immaterial benefits. This makes it more complex to access finance.

Table 17: European space executives on the downstream sector

Time will tell whether NewSpace will lead to a diminishing upstream–downstream gap and whether the integral business model of Iceye or Planet—the latter building and operating several constellations of EO satellites (predominately CubeSats) and selling the service to governments and private companies—will prevail. So far Planet has managed to create and thrive on its USP of being able to observe the Earth at a reasonable spatial resolution with a very high retentive rate. Other competitors may challenge this narrative in the next few months and may force Planet to re-model its USP, e.g. by focusing its business model on one part of the space sector value chain. It may also be that Planet will stay the dominant player by continuing its M&A strategy. As this strategy has been successful twice already (acquisition of Rapid Eye and Terra Bella) ,any future competitor will have to have patience and significant capital to catch up. It remains to be seen if such capital can be provided by private investors or by governments and/or their agencies.

Private investors have also identified the current difficulty in accessing finance for the space sector in general, irrespective of whether the company is upstream or downstream (Figure 64), and for some this acts as a deterrent to invest in the sector, out of fear no co-investors or follow-on finance may be found.

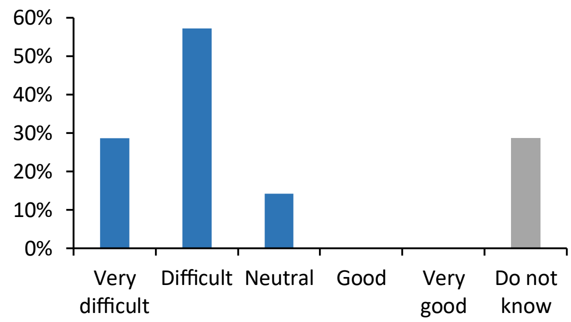


Figure 52: Investors deem the access to finance conditions to be difficult in the European space sector

Planet is merely one role model for the vibrant NewSpace movement, which disrupts the classical space business role models. As more and more space start-ups turn into scale-ups and success stories, more and more investment funding will be released, and more and more financing models will become available. Beside the investment for pure profit, in the realm of strategic interests and socio-economic returns, the access to finance will always remain a challenge—and one that needs to be managed by governments and their agencies, if only to make sure that specific services, which cannot be quantified solely in terms of financial return, stand a chance of success.

4.3. The space ecosystem lacks investors with a space background and investment expertise

Irrespective of whether a space activity is of commercial, scientific or military nature, space missions have to find the optimal trade-off with the orbital manoeuvres, delta-v, communication and power budgets, launch and payload operations involved or available budget, lifetime and project preparation, etc. Doing so requires **space-specific expert knowledge**. This is true not only for "**traditional space**", with its well-established business models such as science, satellite communication, satellite navigation and Earth observation, but also particularly for "**NewSpace**", which dwells on testing a plethora of new business concepts, some of which are merely an evolutionary improvement in traditional concepts; others, however, are radically new approaches to the way the space industry has conducted and currently performs its business services (see Figure 5 in Section 2.1.1), disrupting the industry.

This **integral need for expert knowledge** to properly set-up, manage, manufacture and operate space missions poses a specific challenge for both the entrepreneurs who seek to set-up a space business and the financiers who wish to support the endeavour. **Spaceflight is still far from the intricate knowledge stage** that ICT has reached after 40 years of development. There are people who have a holistic understanding of all the factors that make or break a space mission—including a profound process knowledge comprised of insights in the various political, financial, technological and managerial aspects. However, these sought-after persons serve in positions at space agencies and at big space industries; **only a handful of them have ventured into the start-up or the investor scene so far**.

It is this **personal mobility inside the triangle of corporate, entrepreneurship and investment roles** that forms one of the biggest strengths of the ICT sector, especially in Silicon Valley, while its absence is one of the biggest problems in the European space ecosystem. Due to the infancy of the European space start-up ecosystem, it may take another 20–30 years before this mobility in the space sector will materialise in full force in Europe. **The potential is there**—all that is required is to leverage the potential; the highly successful Silicon Valley ecosystem can serve—at least to some extent—as a role model.

Building upon successful processes in the ICT sector, Silicon Valley was the birthplace of NewSpace. **Seasoned IT entrepreneurs** have kick-started NewSpace companies with sizeable personal investments, expediting the mobility triangle, as well as well-known IT processes and technologies governed by Moore's Law, recent shifts and opportunities relating to changes in technology flows and standardisation. Europe has started to venture into the NewSpace world as well, but while a few space start-ups in Europe have been founded by serial entrepreneurs from different sectors, they lack the high personal wealth of their counterparts in the US (Bezos, Branson, Musk and Allen), thereby limiting their possibilities without significant outside investment. A promising development that may improve the situation in Europe in the mid-term is **the recent set-up of focused national/regional business angel networks for space, stimulated by EBAN Space**; providing access to local smart investments.

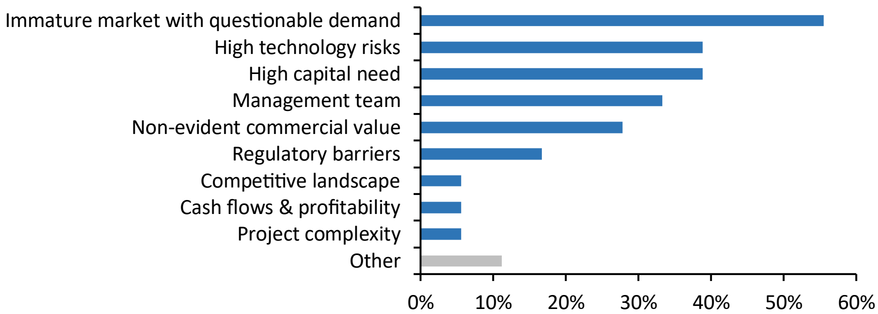


Figure 53: Frustrations with private financiers

As highlighted in Sections 3.3 and 3.4, public grants are the primary source of funding used to mitigate technological risk and raise the TRL of a product; they also serve to de-risk equity for investors, attracting venture funding for space start-ups. However, while space technologies can come with higher risk, a lack of understanding about the technology from financiers, due to lack of knowledge or expertise in the sector, can lead to misperceptions and over- or under-valuations of the actual risks and market potential. Over 40 % of space companies interviewed expressed it as a key frustration with private finance (Figure 53).

European space **companies highlight the lack of understanding by investors and lenders** regarding the market potential as well as the technology risk and the business models, and space SMEs feel such **misperceptions lead to fewer investments in the sector**. The space industry has undergone significant changes in recent years, with an emergent private spaceflight industry pioneering large reductions in the cost of access to space or related technologies. This emergence of start-up space ventures originated in the US and has been focused to a large extent on its West Coast. While the European space industry has been attempting to catch up, a **gap in the knowledge of financiers can be expected, and is indeed present**. A second frustration of European space entrepreneurs is the risk aversion of investors and lenders, followed by unease over investor attitude.

Investors, on the other hand, want to see a **clear path to revenue**, especially in markets such as the space sector that are considered **niche compared with the ICT sector**. While AI and fintech start-ups have already crossed the gap into mainstream knowledge (and are attracting huge investment from venture capitalists), the space industry can still be described as fledgling and as a result comes with a perception of greater risk.

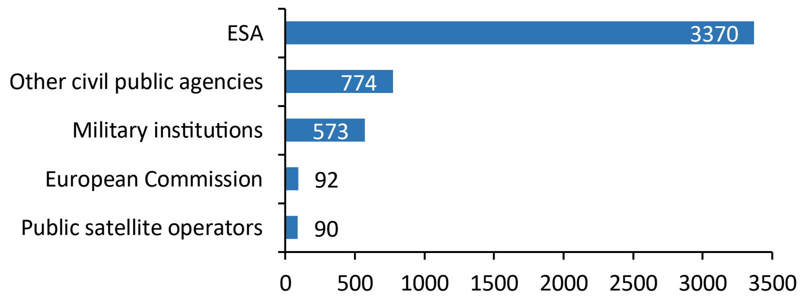


Figure 54: European space industry sales by European institutional customers in millions of euro (2016)[128]

Additionally, investors note the **lack of diversity in the customer base of space technologies**. In Europe, sales to European institutions (i.e. ESA, EU and other national agencies) have been the main driver in the industry. Institutional programmes offered by European governments **represent more than half of European industry's business**.[129] Space science, exploration, defence and security and communications form the backbone of institutional programmes and address areas related to sector security, laying down the foundations for future operational and/or commercial applications.

Interview Quotes

- There is a lack of understanding of the technology by the investors.
- Time is lost due to technologynot being understood by the investor.
- Only one bank had sufficient knowledge about the sector and the company to estimate the risk correctly and to have the willingness to take the risk.
- The company valuation that we discussed with the venture capitalists is too low.
- The banks do not give risk capital. They always require personal guarantees from the owners and managers. But when you have already given all that you have there is no more to give.
- Investors do not know the market, whether it is growing, whether small satellites are important. They only know about the static government market with the large system integrators.
- Getting the understanding that hardware investments are needed is a challenge; you cannot do it with only engineers and desks.
- Understanding of the sector is important to have in an investor, as they need to understand timelines (e.g. the differences with fast-changing internet products); it is good to align expectations.
- The investment from a known space player gave us the technical credibility and big-name visibility; other venture capitalists did not have technical understanding.
- We need to work to educate the market.

Table 18: European space executives about investors and lenders

The public sector has a significant market share in space products and services, with ESA dominating industry sales (as shown in Figure 54), albeit mostly in the upstream market. ESA also **represents 41 % of total industry sales and 69 % of European institutional customers**. While this is slightly skewed, due to the ESA's role in both the Copernicus and Galileo programmes as well as in the Meteosat development programmes and procurements, it substantiates the fears felt by investors. As a result, **venture capitalists would expect lower company valuations** to alleviate the risks of exposure.

A lack of knowledge and experience, however, is evident on both sides. **Space entrepreneurs** have had limited opportunity to fundraise on the private market, while **investors and lenders** lack investment experience in the sector, **both being early in the learning curve**.

4.4. European space entrepreneurs feel there is a lack of private financing sources and keep an eye on the US

Given the lack of capital experienced by European space companies (Figure 55) and the reticence on the part of financiers to invest in space, some entrepreneurs are starting to look outside the EU for new sources of funding. About half of the interviewed space entrepreneurs indicated they were **looking for private capital sources outside of the EU** (Figure 56). The US is a favoured destination, with entrepreneurs **attracted by the wave of NewSpace investments in the US**, followed by Asia.

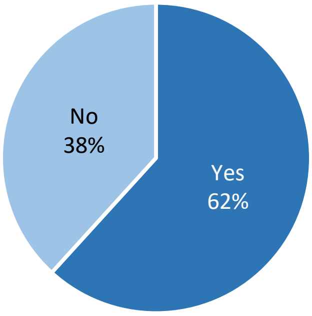


Figure 55: Was the funding raised sufficient to address the space companies financing needs?

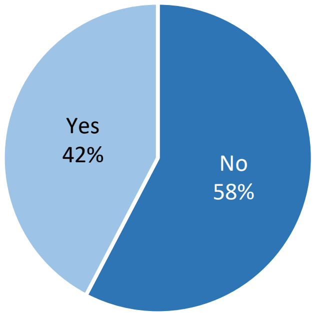


Figure 56: Are European space companies looking for funding outside of the EU?

Interview Quotes

- We are thinking that we should have moved to the US already.
- We made a deliberate decision to keep the company in Europe.
- If we do not get the capital at reasonable terms here, we will move the company to the US.
- The business plan required a certain amount of money that is not available in Europe, so we broke down the business plan into steps based on how much money the company expects to raise.
- Financing a new constellation would be much easier in the US.
- The best place to raise funds is the US for aerospace companies, more specialised funds and more funds focused on aerospace-related businesses.
- The amounts available in Europe are low; EUR 100–200 000 is really little—you can barely pay an engineer with that. It only works if you put the pressure on yourself (pay yourself less) and use labs elsewhere from public institutions for free.
- Our company has been approached by US and Asian capital and comes with a strategic network.

Table 19 : European space executives on non-EU private capital

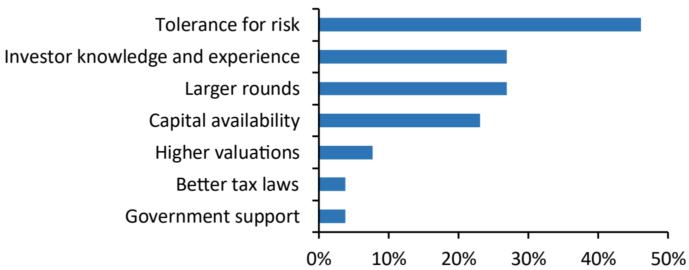


Figure 57: What is lacking in European private capital compared to other regions?

As described in Section 4.1, the US remains the flag-bearer for VC investments worldwide and these continued to lead the VC market globally in the last quarter of 2017, accounting for well over EUR 19 billion of investment during the quarter. Although both Asia and Europe had strong quarters of their own, with EUR 12.5 billion and EUR 4 billion invested, respectively,[xx] Europe's investment was still only just over one fifth of that of the US. The key reasons for this sizeable difference were highlighted by interviews with European space companies (Figure 57), in which three key areas were identified, **the most prominent by far being the tolerance for risk or the readiness/risk appetite to invest in technologies or markets at an early stage.**

Interview Quotes

- The US has the required size of funding and the risk appetite.
- Funding vehicles in Europe are very risk averse compared to US—there, more money is spent on more deals. That translates into better valuations, even with IPOs.
- Risk willingness in the US is much higher than in Europe; a US investor told us it is a bit stupid to stay in Europe.
- If you finance your company in Europe on the local investors' terms, you are working for the financier after a few years. The terms are really a problem.
- The experience of venture capitalists is not the same as in the US: less professional (e.g. how to structure the deal, the process, the timeline and the operational aspect of executing a deal). The US has lots of former entrepreneurs in the fund.

Table 20: European space executives on non-EU funding experience

Over the past few years in the US, **investment in space businesses has increased year-on-year** with the number of **venture deals increasing by nearly 70 %.**[130] The promise of high returns, reduced costs of manufacturing and launching and the increasing number of space businesses have spurred the growth in investment by US investors. In fact, nearly 40 % of the value from acquisitions in space start-ups since 2000 has come from transactions in the last three years,[131] mostly involving US companies, as shown in Table 21.

Acquired Company	Acquirer	Amount	Date
Terra Bella (US)	Planet (US)	Undisclosed amount	2017
Clyde Space (UK)	AAC Microtec (SE)	EUR 30 m	2017
OmniEarth (US)	EagleView Technologies (US)	Undisclosed amount	2017
O3b Networks (NL)	SES (LU)	EUR 665 m	2016
Mapsense (US)	Apple (US)	EUR 23 m	2015
deCarta (US)	Uber (US)	Undisclosed amount	2015
OpenWhere (US)	Spaceflight Industries (US)	Undisclosed amount	2016

Table 21: Key space acquisitions and values

US involvement and dominance in space investments is not new phenomenon. Historically, US investors have represented most space start-up investments. Since 2011, the number of venture capitalists investing in space has shot up from less than 15 to over 120.[132] With the potential returns from space technologies becoming more apparent, more **investors are attracted to the market and are subsequently including regions outside the US** in their search for commercially viable space technologies.

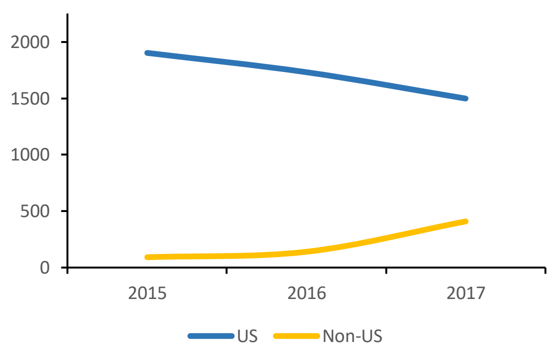


Figure 58: Seed and venture capital investment in space start-ups in millions of euro[133]

This increasing demand for innovative space start-ups is aligned with the change in and emergence of the private

xx Venture Pulse Q4 2017: Global analysis of venture funding. KPMG Enterprise (Report) (16 Jan 2018).

European space industry, with European space start-ups such as Iceye receiving investment from US VC funds such as Draper Nexus Ventures. In fact, **seed and venture capital investment in non-US space start-ups reached record highs in 2017** (Figure 58), a considerable amount of which is estimated to have been invested in European space companies.

The perception among European entrepreneurs is that US investors like **new technologies and new sectors with high growth potential**, whereas European investors like the cash cows and proven technologies, looking for the safety of *tried and true* investment. They typically are positioned more to the right (later in the life of a company) in Figure 59, whereas US venture capitalists are perceived to come in earlier, as indicated.

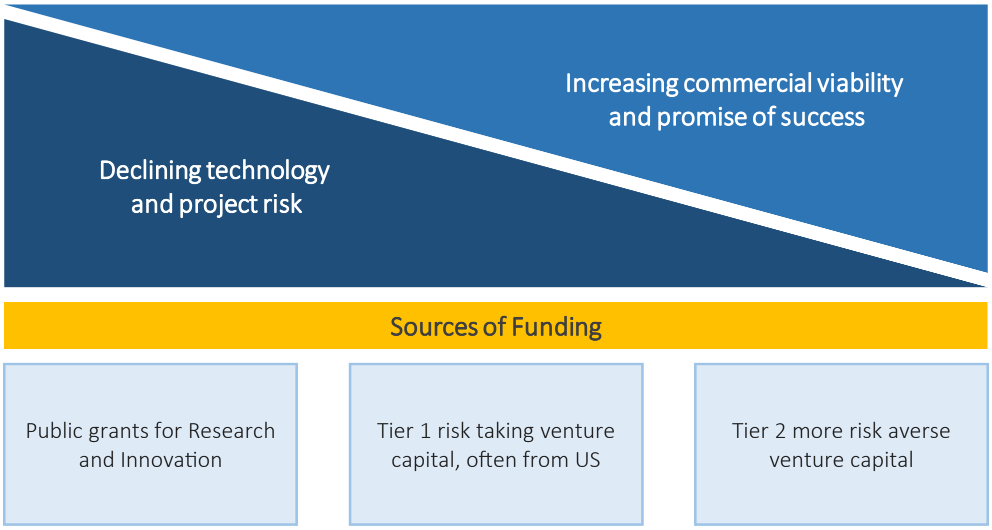


Figure 59: Funding source by start-up maturity

4.5. Space innovations have a longer development cycle than general tech

In the ICT sector, the typical **innovation and product development time span** for B2B or B2C software start-ups is 1–5 years, whereas their **productivity or harvesting time span** is 5–7 years, after which the company needs to reinvent itself and the product, or risk being replaced by newly funded competitors. These time intervals are subsequently also **reflected in the typical duration of a VC fund**, which is 10–12 years, comprising a 4- to 5-year investment period and a 6- to 7-year divestment period.

This phenomenon is described in the cash-flow J-curve (Figure 60), where the first declining negative part of the curve is the time of investment and the positive part is the time of harvesting and divestment. As an analogy for product innovation, the J-curve concept is used with the adjustment that any phase of profitability will eventually reach a plateau and will then decline, resembling an S-curve. If new efforts in product innovation and investment are made, the cycle continues, and the product remains relevant. If not, the product will fade from the market and the company will potentially go out of business. In the case of venture-backed companies, lossmaking and not-yet-mature-technology companies are frequently publicly listed through an IPO or are acquired by a corporate with a profit to investors and entrepreneurs.

For traditional space technology, especially on the hardware side, the **R&D and product development phase is at least 5 years but may take up to 15 years or longer**. These extended development phases create a **significantly longer "valley of death"** that needs to be bridged financially, represented by a longer S-curve. Nevertheless, the phase of productivity and harvesting is considerably longer, typically reaching 10–15 years, resulting in a minimum of 30 years between product development and product obsolescence. NewSpace approaches, however, reduce the initial very long research and innovation phase, **pushing the space tech S-curve to the left**, nearer to the general tech S-curve.

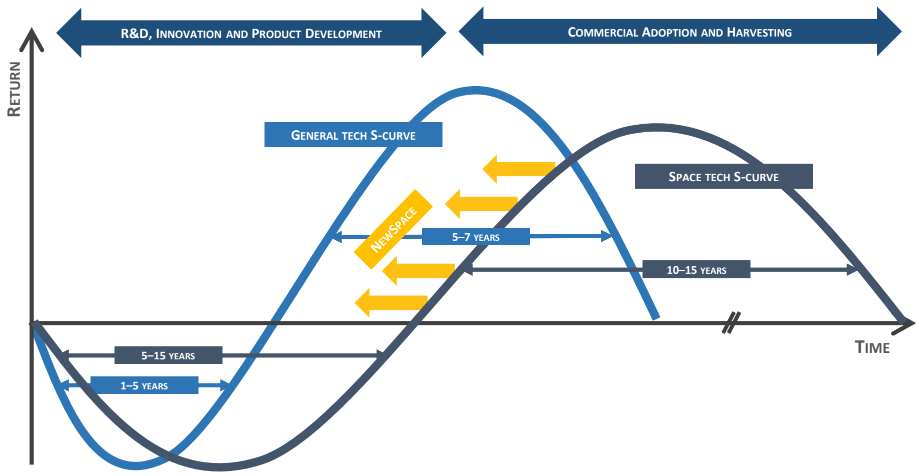


Figure 60: The space technology S-curve

NewSpace manufacturing start-ups that focus on traditional space technology incumbents as procurers of its products are likely to get absorbed into the processes and business culture of traditional space technology incumbents. Those **start-ups will need to be capable of dealing with long and bureaucratic procurement and technology integration cycles.** Alternatively, larger, established NewSpace start-ups acting as procurers of products from early stage NewSpace companies are more likely to still have the start-up DNA in their organisation, making them more flexible and open in their procurement process. This would mean that early stage NewSpace start-ups would be better off, at least in the beginning of their commercialisation phase, focusing on the few larger and more established NewSpace start-ups as procurers of their products and services; or focusing on corporates in the traditional space tech segment that have practical experience working with NewSpace start-ups.

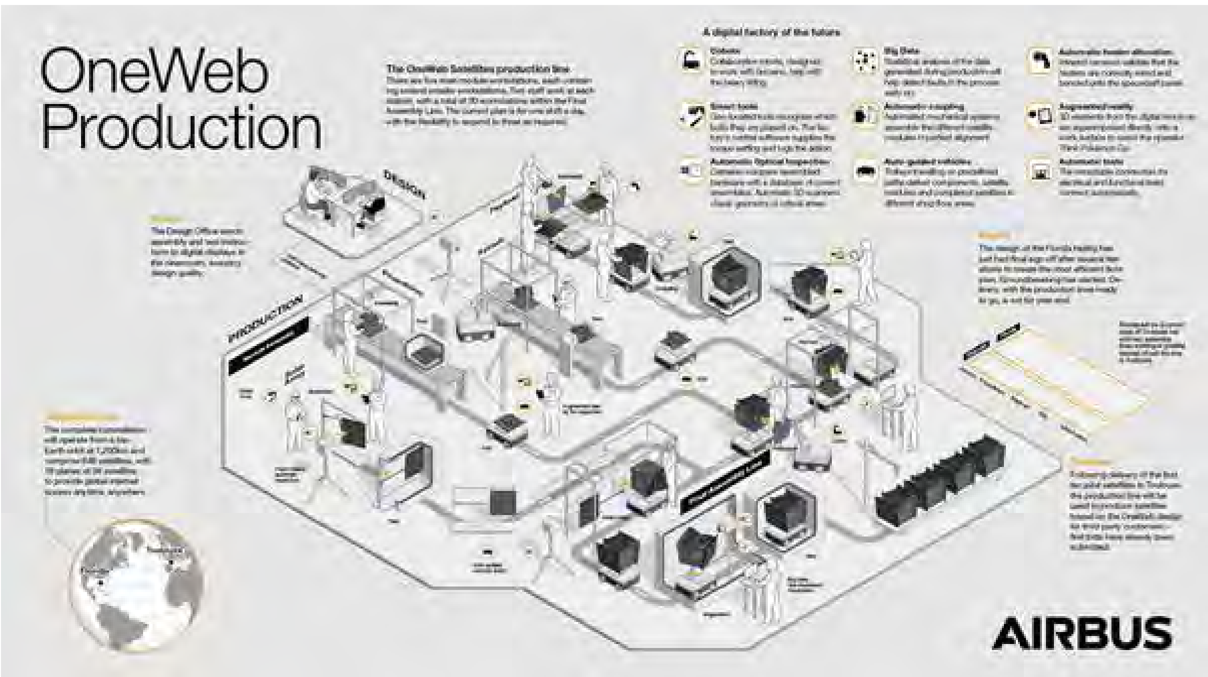


Figure 61: OneWeb and Airbus manufacturing process[134]

Similarly, NewSpace start-ups can instil innovation in the traditional space industry, which would facilitate the cooperation between both traditional and NewSpace companies and ease the business case for financing. For example, OneWeb's procurement process and requirements for the manufacturing process (as illustrated in Figure 61) are different from traditional space approaches. However, a traditional space player, Airbus, succeeded in acquiring the business and builds the satellites together with OneWeb in a joint venture. A similar joint venture approach was announced in 2018 between Thales Alenia Space and Spaceflight Industries to manufacture small satellites at scale, under Spaceflight's subsidiary Black Sky Global.

In general tech, the relatively short innovation and product development span of 1–5 years can be covered with **equity capital injections**, whereas the much longer research, innovation and product development time span of 5–15 years in space tech **requires different—more "patient"—funding models.**

Interview Quotes	
	• The timeline towards commercialisation is too long in space. • The commercial rollout is not at a pace that investors want to see. • Apart from the long development phases, the problem is that traditional space does not show strong profits. • The timeline for NewSpace hardware developments to hit the market for NewSpace can be as little as two years. This increases the willingness of financiers to take the risk. On the other hand, traditional space is far more risk averse and has a very linear approach to technology, which results in a 7- to 10-year process; which is not attractive to the investment community.

Table 22: European space executives on timeline product cycles

Focus: Space and ICT

To establish a point of comparison and reference, delving into the ICT ecosystem, which shares some similarities with the space ecosystem, can provide an idea of where the market is headed. Much like the ICT industry years ago, the space sector is on the forefront of cutting edge technology development, with high technical risks and, subsequently, high potential return on investments. Similarly, both industries were initially government-dominated and costly. Governments and institutions drove demand, with public investment constituting the main source of financing for technological development.

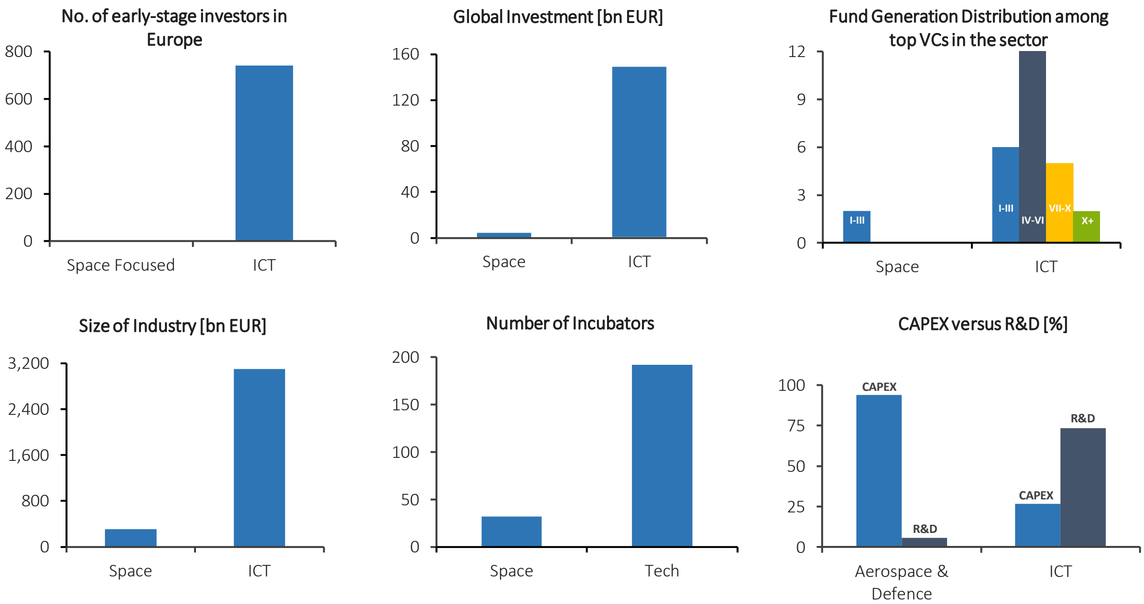


Figure 62: Overview of the differences in space and ICT[135]

Looking at the industries today, it is obvious that the **ICT industry is much more mature and larger** than that of space. In fact, the size of the space industry is only a tenth of the size of the ICT industry (as shown in the bottom left graph in Figure 62). While the development and expansion of the ICT industry has outstripped that of the space industry (an unsurprising fact, as ICT preceded most space technologies), there are some differences that underline the relative immaturity of the space industry and its funding landscape.

Focus: Space and ICT (*cont.*)
Looking at the relative breakdown of industry-wide investments into R&D and capital expenditures (CAPEX), the disparities between the ICT and aerospace and defence sectors are stark. The aerospace and defence industry overwhelmingly favours investments in CAPEX over R&D, while the ICT industry invests more in R&D. Worldwide R&D growth was driven by the ICT industry, while growth in R&D for the aerospace sector only grew at a significantly lower pace (+11.7 % versus 2.2 %).[136] **In the EU, aerospace actually had a negative contribution to R&D growth** (–5.4 %), while growth in ICT was larger in the EU (+12.7 %) than globally. These figures emphasise the respective maturities of the two sectors; while aerospace and defence companies are more focused on acquiring and upgrading their assets for long-term use, ICT companies are looking to improve their existing offerings and provide new services. Aerospace companies are still attempting to lay down the foundation and infrastructure for future growth. These differences in industry behaviours also correlate with the funding landscape of both industries. Although the space industry is one-tenth of the size of ICT, **global venture capital investment into ICT is two orders of magnitude greater than that of space**. On an EU level, the disparity is not as large, with **EU venture capital investment in ICT only one order of magnitude greater than in space**. While Europe's tech industry is creating jobs faster than the rest of the European economy and the number of unique investors participating in rounds has almost quadrupled since 2012,[137] the gap in venture capital investment between the two industries is striking. This disproportionate investment between the two industries is also evident when looking at the amount of early-stage sector-focused investors in Europe (top left graph in Figure 62), as well as the general maturity of those funds. In the space industry, only two early stage investors exist in Europe—Airbus Ventures and Seraphim Capital. Both VC funds are relatively young, as can be seen by the number of funds that they have raised. Compared to ICT, the funding ecosystem for space looks underdeveloped. Even when looking at the number of incubators and accelerators in the industry, space is far behind.

Figure 63: Gartner source of enlightenment[138]

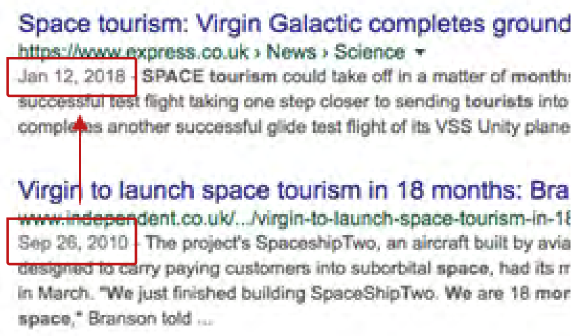


Figure 64: An illustration of the early excitement about space tourism[139]

4.6. Investors are mostly concerned by the market maturity

The Gartner hype cycle is a method for determining where new technologies are positioned in terms of their lifecycle (see Figure 63) and it is also applicable to technologies in space. The curve depicts how many technologies and applications are hyped to such a degree that inflated expectations are followed by disappointment. However, technology development continues and eventually the plateau of productivity for a particular technology is reached. For example, in 2010 there was a lot of hype around space tourism, which has subsequently not amounted to the level of expectation the public had in the time span forecasted. This may have scared away **investors that want to see a certain level of evidence of technical and market viability before investing**. Nevertheless, progress has quietly continued in the segment of space tourism, and Virgin Galactic, for example, has recently surpassed an important milestone, successfully launching a rocket plane into an altitude of 82 km, close to the 100 km altitude generally considered as edge of space.[140] Also announced, SpaceX plans a mission to fly tourists around the moon in 2023.[141]

While public funding is typically regarded as the mechanism that finances part of the technical risk and private capital is regarded as funding the market and business risks, there is evidence that the funding of disruptive technologies is limited to VC financing rather than non-dilutive public grant funding. **Public programmes, similar to corporates, do not fund disruptive technologies sufficiently**, as confirmed by an EC Staff Working Document:[142] "A Commission consultation (Call for Ideas) conducted in 2016 revealed that a large number of stakeholders consider that important gaps still exist in EU support for disruptive, market-creating innovation and other forms of support for young innovative companies, such as effective mentoring and coaching schemes; that a genuinely bottom-up approach should be introduced to allow projects from any sector(s) to apply for funding; and that the funding instrument landscape remains too complex and difficult for innovators to access." This is further confirmed by some stakeholders in the space industry (see Figure 65 and Table 23).

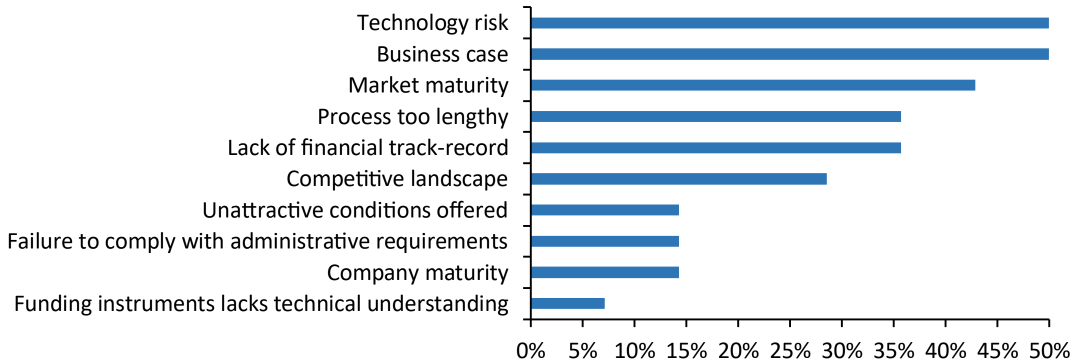


Figure 65: Identified issues in securing public finance

At European level there are voices to fund more disruptive innovation and research. In 2012, Neelie Kroes, then Vice President of the European Commission,[143] said, "First, remember that great innovation isn't about keeping the status quo: it's about challenging it. It's radical, disruptive, and sometimes non-linear – especially for emerging technologies. So, let's make space for that in Horizon 2020.… I want to try out support for truly open, disruptive innovation in ICT. Allocating perhaps 5 % of funds to create an open, agile, responsive funding instrument."

A succinct reflection of this is the small number of European companies that are considered disruptive and that have achieved breakout success status, using funding from Horizon 2020, the premier R&D funding instrument of the EU (see Figure 66).[144]

The involvement of leading companies in Horizon 2020

Comparing various lists of innovative companies with the Horizon 2020 participants, many of the top "established" innovative companies take part, but—despite many positive examples, e.g. in the health sector—**almost none of the young and quickly growing innovative companies took part in Horizon 2020**. Bigger companies and established innovators included in the European Patent Organisation top 50 European Patents Applicants, the R&D Scoreboards and Thompson Reuters' top global innovators rankings are greater beneficiaries of Horizon 2020 funds than younger innovators from Wired Europe's hottest start-ups, Deloitte's fastest growing European tech companies, Forbes' most innovative companies and CB Insights' Unicorns list. Out of the first ranking, only two have benefited from Horizon 2020 funding thus far. Additionally, CB Insights' list of unicorns indicated that 18 out of the 176 are EU-based. Yet, no company in this list is currently benefiting from Horizon 2020. On similar lines, only 12 % of the companies from the MIT Technology Review Smartest Companies list and 3 % of Forbes' "most innovative companies" rankings participate in Horizon 2020.

Figure 66: Involvement of leading companies in Horizon 2020[145]

On the private capital supply side, **corporates in Europe do not have a history of working with start-ups by acquiring innovation from outside their operation**. As can be seen in Figure 67, on average, only about one third of top European corporates have acquired at least one start-up in 2016 in order to insource innovation. This limits the capital flow to the start-up ecosystem, which is often working on more disruptive technologies and markets.

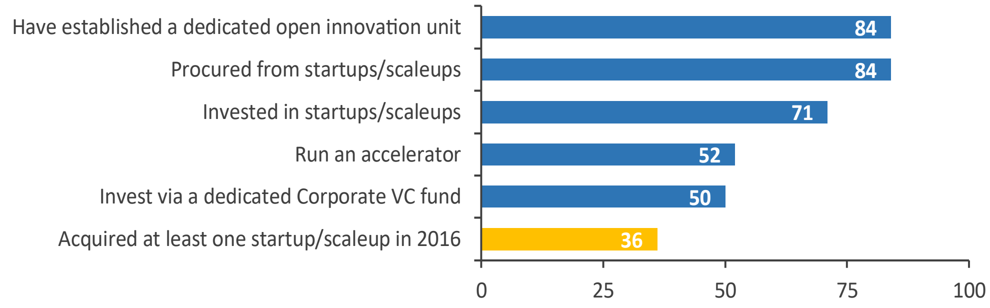


Figure 67: Innovation activity of top European corporates [%][146]

Even in the US, **only a few top-tier venture capitalists have invested in capital-intensive space companies** (Figure 68). Reasons for this may be that Tier 2 venture capitalists have not invested because the trickle-down effect in thought leadership from the Tier 1 venture capitalists' propensity to take risk has yet to take effect and that investors in VC funds are not yet ready to back such investments.[xxi]

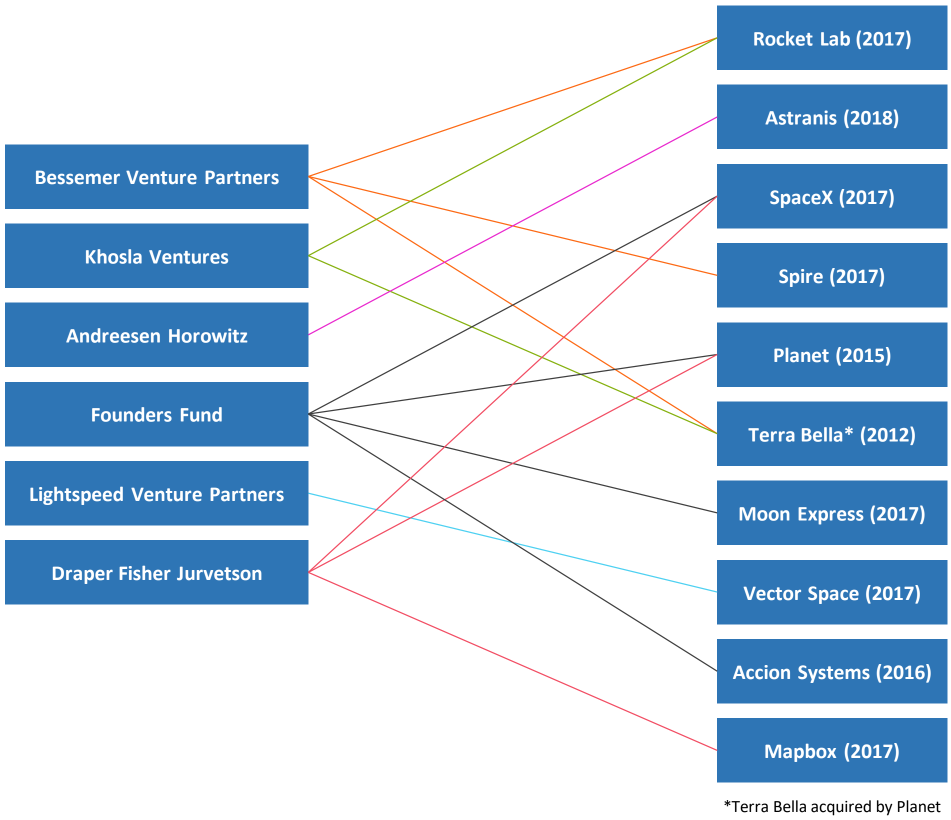


Figure 68: Venture capitalists with investment in top-tier space companies

Figure 68 illustrates the cross-ownership of top tier venture capitalists in the US of top tier space start-ups from Europe and the US. The large degree of cross-ownership by relatively few funds has multiple reasons:

- space tech investment requires very deep pockets and syndication amongst leading venture capitalists;
- space tech investments are very risky, and venture capitalists want to offset some of that risk by syndicating;
- venture capitalists want to gain experience in the sector and are tiptoeing into the market by syndicating in as many deals as possible.

xxi In a discussion with a leading FoF investor in VC funds, it became clear that the industry has not yet developed a thesis around specialised space tech VC funds (personal communication, April 2018).

Interview Quotes

- Our products are made for markets that do not exist yet.
- A large part of the EO services market is not accessible, so the market risk is high for investors.
- Our market has high growth, but it started from low figures and there are doubts about the future growth.
- Our product is linked to development of the satellite industry, so the investor's concern is how quickly this industry will develop and what the need is going to be.
- The public sector wants to invest in disruptive technology, but when it comes down to it very few grants go to disruptive technology since the markets do not exist yet. We end up funding incremental innovation.
- We are considered disruptors so there is a lot of concern.
- Advanced technology developments are struggling with funding. With more mature technologies where you can show a business case, the situation is different.

Table 23: European space executives on market and technology maturity

The relatively limited number of sizeable space investments indicates that only a few teams have reached a late-stage maturity, and the seed investment market in space technology is still nascent. The survey of European private investors indicates that **immature markets and high technology risk are the key concerns of financiers** (Figure 69) when they decide to pass on an investment opportunity in the sector.

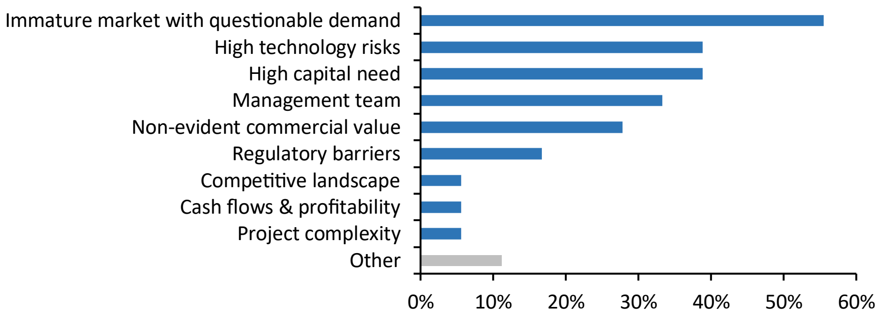


Figure 69: Why private investors have not invested in space investment opportunities

In the earliest, most risk-prone stage of technological development, the only option for entrepreneurs seems to be obtaining public grants. Later on, VC may step in to fuel commercial success as a secondary capital boost. This is for a variety of reasons, but the key barrier, at least for private finance, is the perceived technology risk (Figure 70). This is for a combination of reasons, e.g. some segments of the space market are still nascent (as described in this section), or the lack of space-specific expertise in the private investor market (explored in Section 4.3).

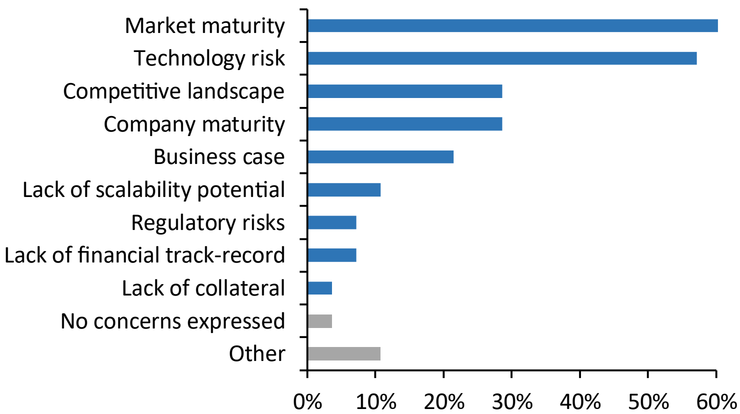


Figure 70: Identified issues in securing private finance

4.7. Investors do not see the exit opportunity (yet)

In the space industry, the large system integrators do not have a tradition of acquiring innovation from external sources, but rather expand by vertical integration or by extending their geographic footprint.

This expansion trend has been slowly changing in recent years; for example, Inmarsat has sponsored developer conferences, Airbus launched a venture fund in 2016, OHB has created an investment arm and several space corporates in Europe invested in Seraphim Capital. At this point, it is unclear whether these initiatives are a real strategy or whether the intentions of these large companies are politically motivated or marketing oriented.

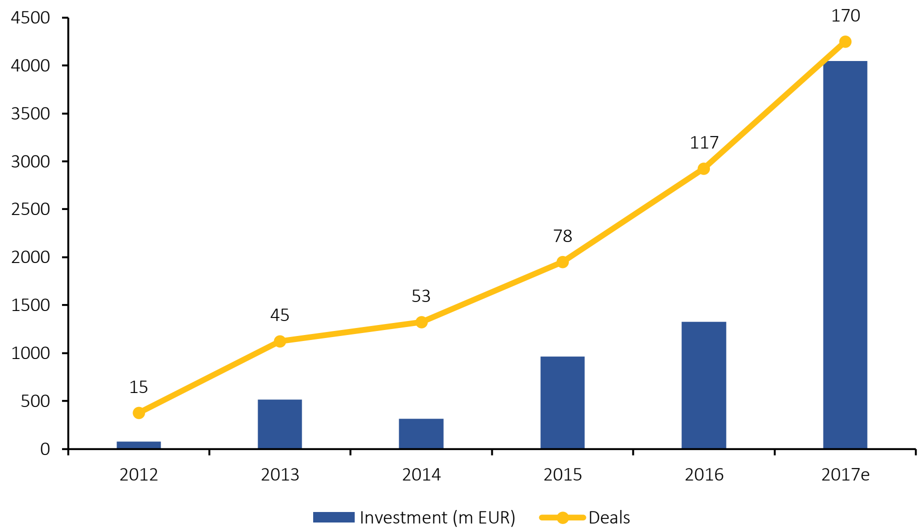


Figure 71: Auto tech global annual financing history, 2012–2017[147]

There is a relevant analogy in the automotive industry: as recently as ten years ago, **the automotive industry rarely invested in auto tech start-ups**, and subsequently many start-up **investment opportunities in auto tech were declined by venture capitalists because of unclear exit market conditions**. Approximately five years ago, the automotive industry started to acquire start-ups, which served as a wake-up call to VC investors to massively increase investments (Figure 71).[148] There is anecdotal evidence that the German automotive industry alone has earmarked EUR 2–3 billion for technology M&A in 2018–2020.[149]

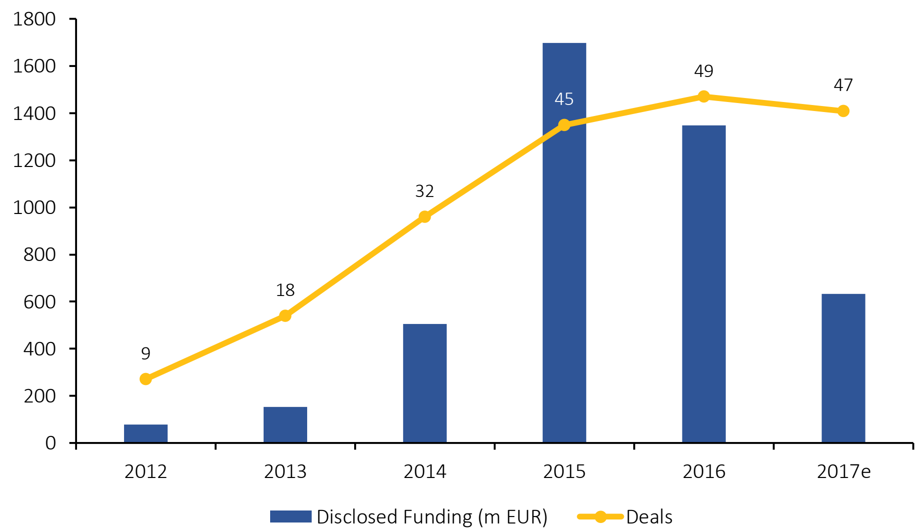


Figure 72: Space tech global annual financing history, 2012–2017[150]

If a similar pattern unfolds, the hypothesis is that, due to long innovation and adoption cycles, those **equity investors that invest in NewSpace now will face an entirely different exit landscape 5–10 years from now**, potentially reaping the benefits from their early engagement. Figure 72 illustrates investment in NewSpace since 2012 and the deal count increase of more than 500 % until 2016 (49 versus 9 deals).[151] At that point, the development kick-started sector-focused VC funds such as Seraphim Capital in Europe and other fund initiatives that are announced but still being set up (see Section 3.6).

A potentially distorting feature of this data (Figure 72) is the investment in Planet Labs in 2015, which raised over USD 140 million and accounts for much of the 2015 funding. In general, all of this funding also includes downstream software applications and data platforms that are closer to the traditional VC targets than the more aggressive and forward-thinking business ventures such as asteroid mining. It is very likely, as in other start-up segments, that **eventually a few well-funded large start-ups with the capability to reinvent the entire industry will emerge as acquirers of other start-ups** in the same sector and become the captains of that particular sector. For example, in general tech, Amazon, Facebook and Google are the largest acquirers of VC-backed start-ups in their self-created ecosystem.

Interview Quotes

- There is a lot of risk involved and is there a return that matches this risk. It remains to be proven if there is a real high return. Very few start-ups have yet created the huge returns for the investors; so far, space has burned a lot of money.
- With a lack of successful exits… as a confirmation you cannot make money in this sector.
- Even though space is sexy, there are not a lot of investors that invest in space, so there is a little bit of hesitance for the sector. There have not been a lot of exits (e.g. Planet, Spire, SpaceX, Blue Origin), so the investors have not gotten returns yet, and there is a limited group of investors in the market.
- There is no clear path to liquidity, going to break even or selling a company.

Table 24: Investors about the space sector

An interesting observation emerged from comparing auto technology and NewSpace investment deal sizes globally over the period 2012–2016: the average deal size in NewSpace is approximately 45 % larger (Table 25) than the average deal in auto tech,[152] and approximately 300 % larger than the average deal in AI.[153] This suggests that international investors in NewSpace have the **confidence in this nascent market to invest larger amounts** per deal, as required in the more capital-intensive sector.

2012–2017	Total invested	# of deals	Avg. deal size	Multiple (×)
NewSpace	4 412	200	22.06	1
Auto tech	7 249	478	15.17	1.45
AI	24 136	3 277	7.37	2.99

Table 25: Comparison of average investment deal size globally between NewSpace, automotive and AI [millions of EUR]

Going forward, NewSpace start-ups with hardware technologies (launchers, satellites) will service other software-based NewSpace start-ups (downstream applications) and the traditional space industry will have to reinvent itself to participate in the NewSpace economy (e.g. Airbus with OneWeb or Space Alliance, a Thales Alenia Space and Telespazio joint venture, with Spaceflight Industries) while continuing to operate in its existing ecosystem, serving defence and security and other high-maintenance procurers.

4.8. The lack of follow-on finance has led to a number of early IPOs

In recent years, some European space start-ups seek IPOs early in their maturity cycle in order to access financing, despite the declining trend of European small IPOs described in Section 4.1. In Table 26, seven European companies in space technology are listed that have gone public since mid-2016, with Avio being the only regular-sized IPO.

The other recent IPOs are mini-listings in start-up segments of regional stock exchanges, such as Nasdaq First North servicing the Scandinavian markets, and those that have emerged as a sort of larger-scale equity crowdfunding from the general public.

The publicly stated **opinions of entrepreneurs about these markets is generally positive**. For example, the founder of Conferize states, "funding from stock exchange listings is an overlooked opportunity" and "IPOs are a sizable funding source and a scalable funding source".[154]

However, those small IPOs in other segments of the technology market are in the ballpark of only EUR 3–10 million with a market cap of EUR 30–100 million, which is relatively low. Small cap stock is typically subject to **high volatility and many small IPOs have experienced declining share prices** since listing 6–18 months ago. For comparison, technology IPOs in the US raised a median USD 120 million in 2017.[155]

	Company	Country	Date of listing	Raised (EUR m)	Market Cap (EUR)
AVIO	Launchers	Italy	April 2017	75	365
mynaric	Laser links	Germany	October 2017	27	160
GOMSPACE	NanoSat-HW	Denmark	June 2016	10	120
AAC Microtec	SmallSat Components	Sweden	December 2016	12	27
KLEOS	In-orbit Manufacturing	Luxembourg	July 2018 (Planned)	N/A	N/A
cloudeo	Geodata Platform	Germany	2018 (Planned)	N/A	N/A
X	Space Manufacturing	Not disclosed	2018 (Planned)	N/A	N/A

Cinven sold Avio Avaiation to GE in 2013 and kept Space business, now sold to Space2 and Leonardo and those formed a merger and took it public in April 2017, stock between EUR 12 and EUR 14, relatively solid

Mynaric was oversubcribed, stock price set at EUR 54, then popped to EUR 64, now at EUR 54 again; listed in Scale segment of Deutsche Börse

GOMSpace market cap about EUR 160 m

AACM is SWE, acquired Glasgow based Clydespace in December 2017 for GBP 70 m

Table 26: European space IPOs in recent years

In contrast, there is evidence that **late-stage start-ups in the US are being held for extra-long periods** in VC portfolios and hedge funds, and private equity firms are moving downstream into late-stage VC financing, replacing or delaying IPOs in the above USD 100 million fundraising stage. The key reasons for these late-stage private financings are[156]

- to avoid the regulatory environment of Wall Street (transparency requirements such as the Sarbanes–Oxley Act),
- to avoid Wall Street "quarterly think" and adjacent non-compatibility with Silicon Valley culture, such as sell-side analysts, short sellers and arbitrage traders,
- to take advantage of forward pricing in private markets that place a premium on potential acquisition interest, rather than standalone companies in public markets,
- the availability of very late-stage pre-IPO capital in the form of large investor vehicles (more than USD 1 billion venture, growth and hedge funds) serving primarily the US market.

Interview Quotes

- During the very early stage of our business, it was easy to raise money with only an investor presentation; now that bigger amounts have to be raised it is harder, even with technical drawings, etc., in place and contracts with renowned public institutions.
- Our IPO had the aim to be an active player in the market consolidation; in the medium and long term, it is more attractive than going back to the VC market.
- There is a lack of private funding for the growth phase of funding, it becomes easier to get seed funding (up to EUR 1 million), but when you scale-up finding money for a EUR 10–20 million round is much more difficult as you are too young for private equity but too old for early stage VC.
- An IPO is a good tool to raise a larger sum of capital.

Table 27: European space executives on later stage funding

At this point, it is too early to judge whether the lack of C- or D-round capital in Europe for NewSpace is a function of the lack of private financing capacity in Europe for NewSpace in general and whether small IPOs are a new sustainable source of alternative capital.

4.9. European public innovation instruments play an important role in unlocking private capital for the space sector

While the European fund market remains smaller than that of the US, it still represents the second largest fund market in the world,[157] and is growing rapidly year on year. Over the last five years, the number of unique active investors (including funds, corporates and angels) has tripled.[158] Additionally, the size of investment funds tripled between

2012 and 2016, with corporate investment and angel investment growing by six times and five times, respectively; in all, over EUR 12 billion in new VC funds were raised in 2017.[159]

This increasing fund market provides more opportunities for the space sector. However, **while certain seed and early-stage opportunities are generally available** for space start-ups, they are only generally **obtainable for projects with a high TRL**—essentially for projects with very low technology risk and time to market. A low technological risk is desirable for investors, as the cost of being overly optimistic regarding a product or service's maturity hinders potential returns. This contrasts with start-ups from other technology industries, such as AI and fintech, which have attracted outsized interest, raising EUR 1.2 billion (twice the amount raised in 2016) and EUR 4.35 billion (triple the amount raised in 2016), respectively.[160]

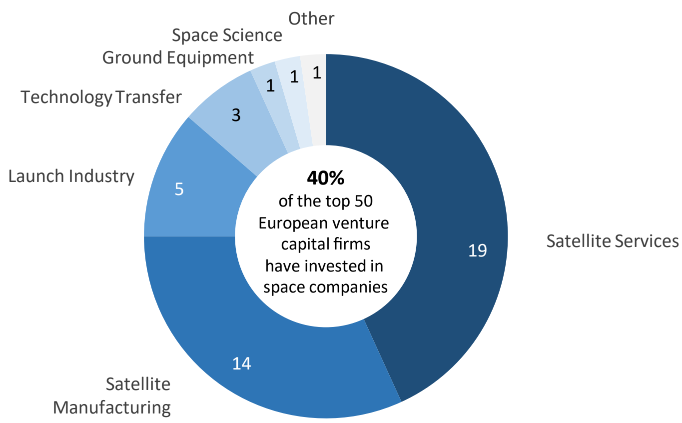


Figure 73: Analysis of the top 50 European venture capital firms

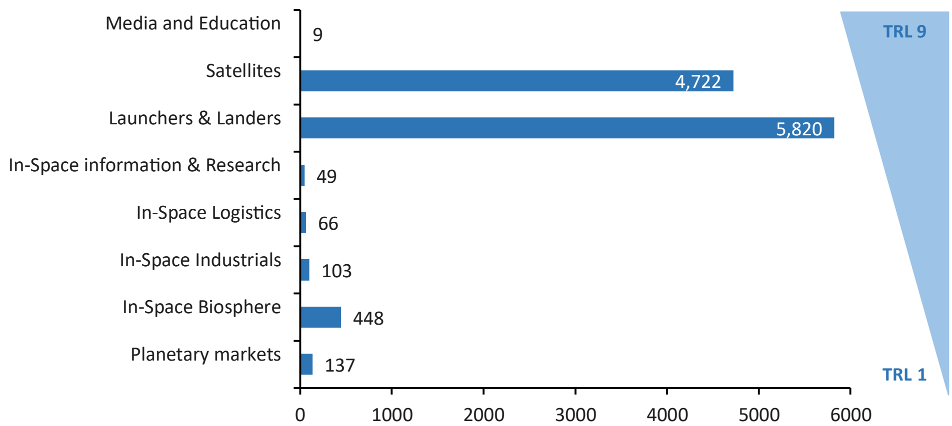


Figure 74: Investment amount in 2017 by TRL and market segment[161]

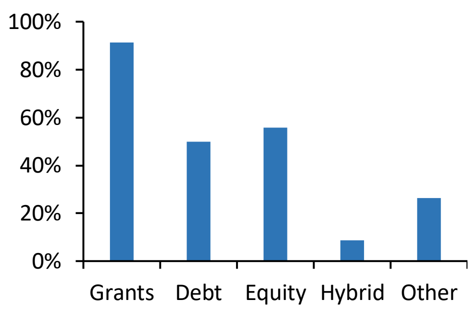


Figure 75: Type of funding instrument used

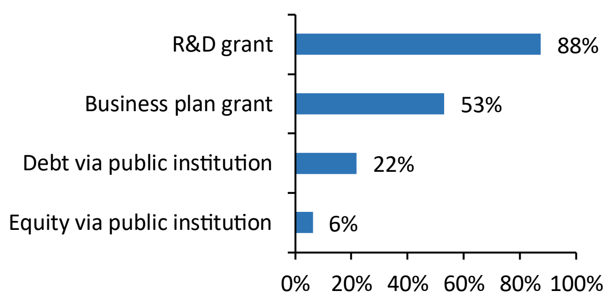
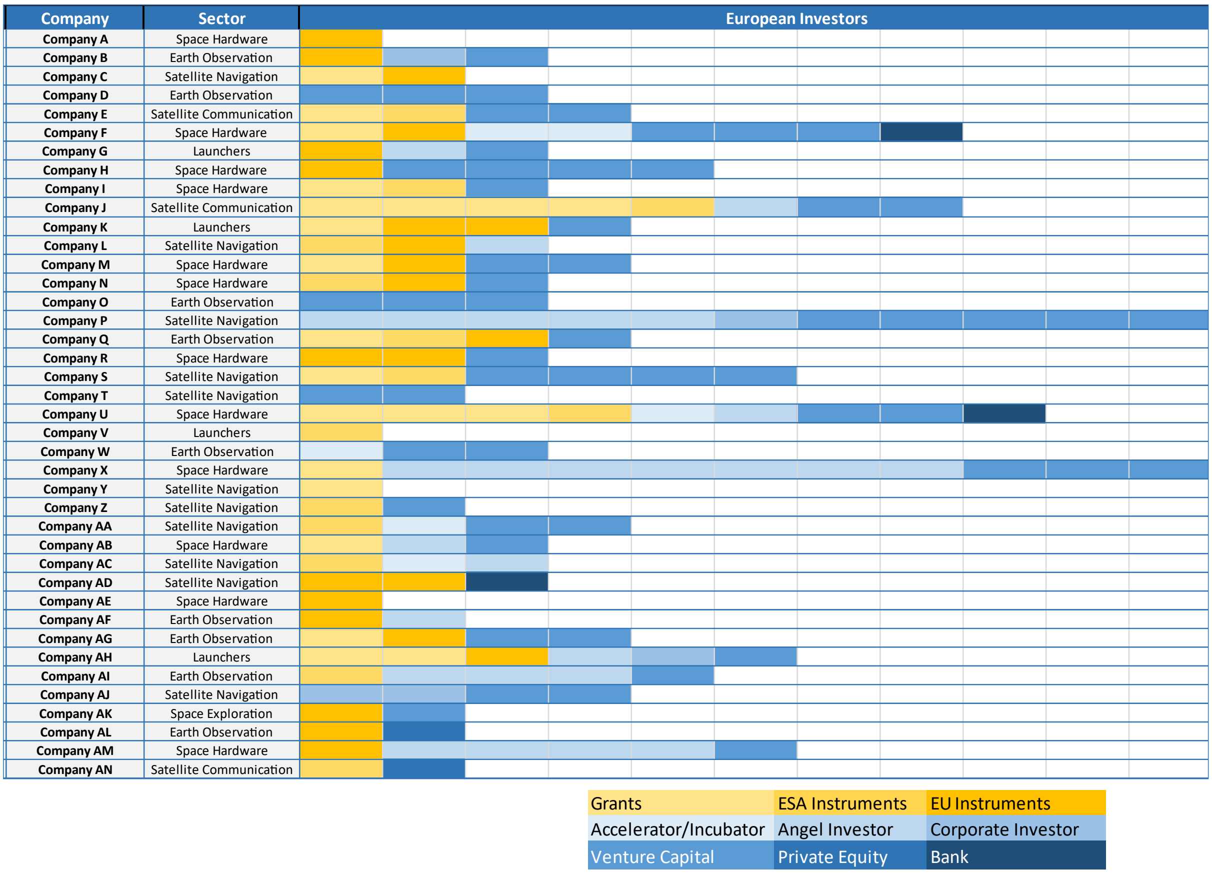


Figure 76: Type of public funding instrument used

An analysis of the top 50 European venture capital firms[162] showed that **40 % had invested in a space company** (see Figure 73), with around half of those that had invested in one company going on to invest in two or more. Of the companies that received investment, 75 % of them were in satellite services and manufacturing, two segments with a **generally lower technological risk** than the other domains (reiterated in Figure 74).

Similarly, following the analysis of a wider sample of European VC investors who had already invested in one space company (see Section 3.6), only **26 % had invested in three or more companies**. This demonstrates how even familiarity fails to increase the general lack of interest by venture capitalists in the space industry.



Source: SpaceTec Partners Analysis

Figure 77: Analysis of the funding profile of 40 space companies in Europe

The need for a low technology risk to attract venture capitalists means that **space start-ups rely on public funding to progress R&D and build their product**. In the space companies we surveyed, about 90 % (Figure 75) had received a grant at some time, showing the importance of public funding in allowing these space companies to conduct R&D and advance the technology of their offerings, with more than 80 % using R&D grants, or to develop their business, with more than 50 % using business plan grants (Figure 76) such as the Horizon 2020 SME instrument. Government grants as "seed investments" are common for several space companies, while public funding from renowned institutions such as the EC and ESA **serve as a seal of approval in the market**.

Another sample analysis of 40 space companies in Europe, shown in Figure 77, showed that over **85 % relied on some form of public capital for seed funding**, prior to raising private capital further down the road. Of those that had relied on public capital, 78 % were ESA and EU instruments, emphasising the importance of these two institutions in providing capital to entrepreneurs. European innovation instruments not only help companies with a low TRL to advance by providing capital and business support, but they **also signal technological progression and readiness to the market.**

Space companies very rarely use only public or only private funding (Figure 78), demonstrating the need for synergy between the two sources of funding.

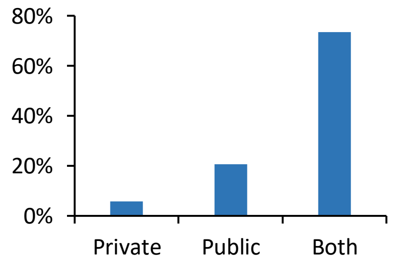


Figure 78: Breakdown of funding sources used

For many years, the ESA in particular has performed a vital role in stimulating and fostering the growth of early stage companies in the industry. The ESA's Business Incubation Centres offer successful applicants not only funding for design and prototyping but also business development support and access to important networks. Given the prestige and recognition of the ESA in the industry, association with the ESA can be vital to unlock private capital. About 35 % of space companies in the sample received funding from the ESA, with all but one going on to secure private investment later.

While public funding proves to be essential in the development of European space companies, public funding instruments typically **provide a limited mandate for a company to pivot its business model** once the funding has been awarded. Aside from the restriction in the scope of company action, public funding instruments are also time intensive with regard to the application and administration processes, and the limited capital received may be disproportionate to the time invested.

In the sample of 40 space companies, the Horizon 2020 programme accounts for 48 % of the public funding instruments obtained by space companies; and while the Horizon 2020 programme has set out measures to reduce the time taken to provide grants, **the time taken to mobilise funds is still significant** due to the number of stakeholders involved and the complex tendering process (owing to the use of taxpayer resources), which limit the speed and scope of advancement for the companies who receive the funding.

While the conditions and requirements that come with public grants can restrict companies, public financing still plays an important role in the space industry as a **precondition to private investment**. This was noted in a significant number of the interviews conducted, with about 40 % of interviewees remarking on the issue (see Figure 30 in Section 3.1). This supports the notion that public grants and European instruments can help signal progression towards technological readiness to the market.

Interview Quotes

- Space is complex to understand for a regular investor and they relate it to government. Investors do not like institutional-driven markets, so we depend on public funding.
- Horizon 2020 SME Instrument Phase 2 has been essential; we put it to good use to build a commercial company.
- European instruments are technology development oriented, which clashes with lean start-up methods.
- Our company was dissatisfied with the funding terms of the grant funding awarded: I cannot spend it on company development.
- The co-funding required from companies or external parties in some of the financing instruments is problematic for small companies. The 70 % co-funding by the public should be increased to 90 % for SMEs.
- Public funding is good to support innovative space projects.
- A lot of funding for R&D projects is available, but you need to build a consortium and cooperate with a whole lot of companies, which does not serve the development of my business.
- There are a large number of public funding instruments available, but you would need an advisor to help you choose the right one.
- EU or ESA funding serves as a signalling effect: it reduces risk for the investor.
- We used public funding to raise our profile and to establish credibility.

Table 28: European space executives on public funding

This process of going from public to private investments also provides a platform for the company to grow further. In fact, according to Beauhurst,[163] **businesses that secure both grants and equity outperform those that secure only grants or equity** and tend to raise more money and achieve higher valuations. Obtaining both grant and equity financing demonstrates that a business has both a product and a market, and in the space industry private investors are generally more willing to invest once the product-related risks have been overcome.

The key selection criteria for space companies **selecting types of funding—both public and private—is primarily based on availability** (Figure 79), which can also be attributed to both the timing (when funding is available from a particular source) and the stage that the start-up is in (does it meet the criteria for a certain type of funding?). The second most important selection criterion relates to the **non-dilution nature of public funding**.

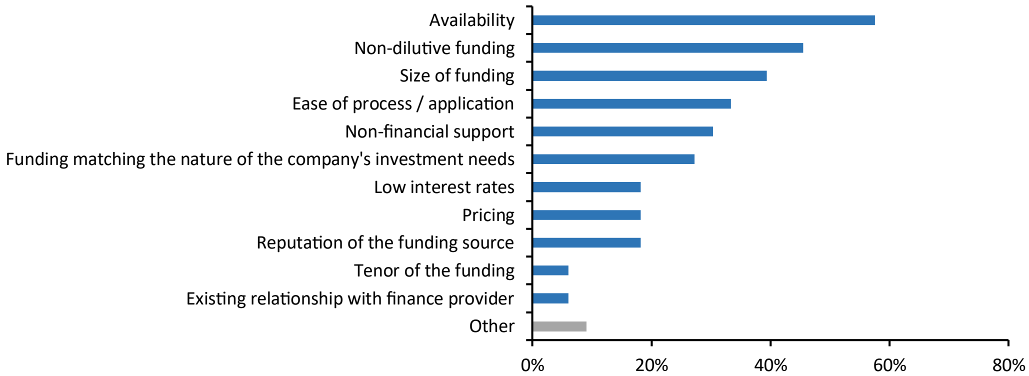


Figure 79: What European space companies look for in a financier

4.10. The landscape of space sector support mechanisms is rather fragmented, and procurement is geared towards the traditional value chain

The traditional European upstream space industry is used to a **large institutional market of traditional public procurement and R&D grant programmes**. As noted in Section 2.1.2, European institutions represent the bulk of sales and industry business, and this dominance also extends to financing. This has a positive effect on the industry, with more than half of the interviewed entrepreneurs expressing a feeling that there is **sufficient public funding available**.

In addition, when looking specifically at European grants (Figure 80; see also Figure 36) and not even considering the options available in national public funding, a good spread of different funding instrument types seems evident. Section 3.4 and Section 4.4 confirm the importance of public funding in Europe, with a lagging private capital market. In addition to European grants, most nations have several options available to start-ups to secure early-stage funding. Nevertheless, the **sizeable number of grant options available is a double-edged sword**, as they could create an overdependence on public funding that is averse to the commercial development of companies. As our research indicates (see Section4.9), a combination of public grants and private equity funding leads to the best returns.

While several financing avenues are available to entrepreneurs, sorting through them and accurately identifying the best option can be difficult, and most entrepreneurs find it **hard to identify the appropriate funding options**. Determining eligibility for specific grant opportunities can also be arduous. As funds are generally managed according to strict transparency and accountability rules, ensuring that the right one is identified can save entrepreneurs from erroneously participating in lengthy, formal application processes that can take a lot of time and effort.

Although the grant landscape can be difficult to navigate and at times impenetrable for entrepreneurs, grants remain crucial in the life of a space start-up. The key reasons to opt for public funding are threefold: entrepreneurs often seek out public instruments because they generally offer **better conditions (no dilution); they can serve as a precondition for private funding** (especially relevant in the space industry); or simply because there was **no alternative** (i.e. no option of private capital) available, as described in Section 3.1. However, one key downside to these public grants, identified by more than 60 % of space companies, is the **amount of effort required**, particularly related to administration, by public sector financing (Figure 81).

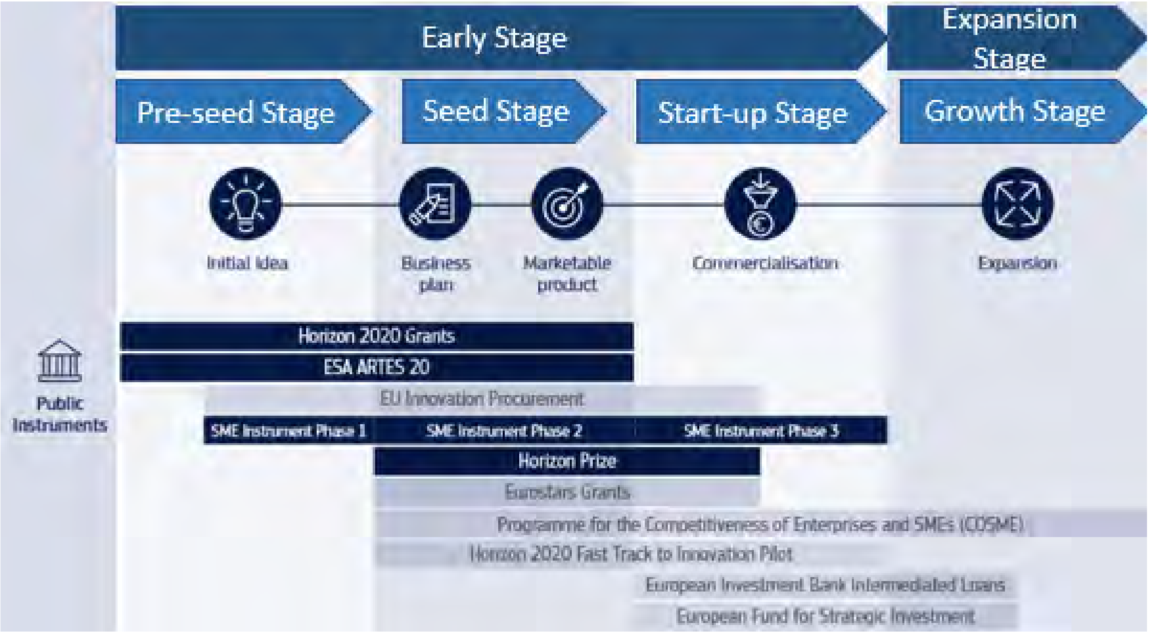


Figure 80: Public funding instruments relevant to Copernicus

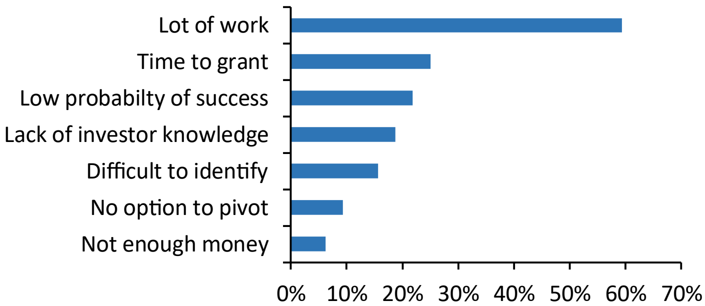


Figure 81: Frustrations experienced by European space companies with public sector financing

While space industry stakeholders believe that there is sufficient public funding available, industry associations and entrepreneurs in both up- and downstream sectors indicate a **lack of public anchor tenants** to stimulate the sector and the emergence of new players. Although the term originated from the real estate industry, generally the concept refers to the **spillover effects of large organisations**, heavily engaged in R&D, whose activities yield positive technological externalities and the attraction of other participants to the region. Industry associations recommend anchor tenancy of public authorities to stimulate the space sector across Europe.

> *"Where the commercial demand is strong, private investment can be mobilised. Where it is less strong, then a commitment to buy data – an anchor tenancy – can reduce risk and allow private sector investment alongside funding from the public sector. Only where a commercial market is absent should a fully-public, infrastructure-focused approach be considered."*
>
> EARSC, *"Copernicus Evolution: Fostering Growth in the EO Downstream Services Sector"*, June 2017

The use of **public anchor tenants has been in place in the US for several years**. NASA modified its contracting rules in 2011 to open the path for it to enter into multi-year contracts as an anchor tenant for commercial space ventures. SpaceX's rise is in part due to this change in contracting—their partnership with NASA and the contracts they won helped fund their innovation, resulting in large benefits both for NASA and SpaceX. SpaceX also used another key public anchor tenant in the US, the National Oceanic and Atmospheric Administration (NOAA), to leverage their growth, receiving a contract worth more than USD 140 million to launch (Falcon 9) and monitor the DSCOVR EO satellite. The NOAA acts as an anchor tenant to several original equipment manufacturers (OEMs), including key space companies such as Lockheed Martin and European actor Thales Alenia Space, the order of USD 200 million (Jason-3, for EO and ocean surface measuring capabilities).[164]

Other entities have also leveraged the benefits of private company anchor tenancy; defence organisations in particular moved away from owning their satellites to being anchor tenants on commercial satellites, while other large firms have partnered together to act as an anchor tenant—as seen in the case of Intelsat working with Gogo Partners to establish a shared GEO/LEO satellite network.[165]

Case Study

How NASA supports SpaceX

While partnerships between NASA and private companies are not new—the traditional aerospace companies Lockheed Martin and Boeing in the US both benefited from NASA procurement—the partnership method has changed in recent years. Rather than contracts that paid the companies back the costs incurred, along with a fixed fee or percentage, the model has changed to a "fixed-price" contract, where the actual incurred costs of the company are not considered. On the other hand, the contractor does not receive design specifications but rather design requirements, and has more much more freedom and responsibility in the actual design of the spacecraft. Additionally, the contractor has full control over the rights to the spacecraft and is able to use it for private purposes. The change in model is a result of cuts in government funding and is believed to stimulate innovation.

In that vein, SpaceX acts as a private contractor, providing services to NASA. NASA offers long-term agreements that in reality act as R&D grants to SpaceX, allowing the transfer of government funds to a private entity to support research that addresses a public need. The Space Act Agreement between NASA and SpaceX for Commercial Orbital Transportation Services was established in 2006 with an agreement to provide funding until 2012.

Some examples of services SpaceX provided for NASA:

- a contract to send cargo to the ISS;
- development of vehicles for human spaceflight to the ISS;
- design of crew services, including the spacecraft, launch vehicle, services and recovery;
- crewed test flights to the ISS;
- the launch of research satellites.

Table 29: Case study on SpaceX funding

The use of anchor tenants in Europe is relatively rare. More common in the traditional European upstream space industry is a large institutional market of traditional public procurement and R&D grant programmes. Every year, over **250 000 public authorities in the EU spend around 14 % of GDP on the purchase of services, works and supplies**.[166] The EC's public procurement strategy adopted in October 2017 aims to improve EU procurement practices by liaising with other public authorities and stakeholders.

The **Innovation Procurement programme established by the EU is an example of the new methods that public procurers are adopting**. Funded through the Horizon 2020 programme, two complementary types of procurement solutions can be used by procurers, depending on the need at hand. The Public Procurement of Innovative solutions (PPI) is geared towards near-to-market solutions, while the Pre-Commercial Procurement (PCP) is for projects that need new R&D to bring solutions to market. By co-financing the procurement costs for groups of procurers that are providing services of public interest and have similar procurement needs, the EU can provide funding and help to drive innovation from the demand side. The amount of EU funding available for PCP and PPI in the period 2016–2017 was EUR 130 million,[167] which included the call EO-2-2016 to support public procurers in PCP of solutions that include customised Copernicus information.

One form of anchor tenancy in the space sector can be observed in the so-called Copernicus Data and Information Access Service (DIAS), with four contracts to consortia of private companies, with the aim of kickstarting the development of the EO services market.

Interview Quotes	
	• With some public instruments you cannot pivot, you must execute what was proposed. • There is too much reporting; it is too restrictive in making changes. Fraud should be punished harder, while not restricting the honest start-ups/companies. • Anything that involves disruptive innovation is struggling to find public or private capital. If you are keeping jobs and the status quo as a linear extrapolation of the past, then your chances of getting funds are good, but they are exclusively coming from the public side. • Investors were concerned that a small company could not fit into a market dominated by large players. • ESA terms are onerous and strict, for example, in IP. They allow IP to be licensed to third parties, so it is not suited for NewSpace SMEs/start-ups.

Table 30: European space executives on public funding

4.11. Public authorities around the globe are stimulating the set-up of venture capital funds dedicated to the space industry

More than EUR 3 billion was invested globally into space-tech start-ups in 2017;[168] of this, almost half was invested by venture capitalists.[169] Since 2001, the number of venture capitalists investing in space has grown rapidly, with almost ten times as many venture capitalists in operation in 2017 compared with 2001. Similarly, business angels and other investors are increasingly attracted to the potential of space. With the commercial space industry continuing to expand (some estimates expect it to grow to approximately EUR 2.3 trillion by 2030[170]), the impact of space technology as a market and economic driver is becoming more apparent and lucrative. While the United States has historically accounted for most VC investment, several authorities around the globe are attempting to catch up. One measure being employed by governments to increase investment is the creation of VC funds dedicated purely to the space industry.

The first VC fund focused on space in Europe was the **Open Sky Technology Fund (OSTF) initiated by the ESA in 2011** to help create commercially viable space products. It was the second private investment fund globally, after US-based **SpaceVest, which launched in 1995** and focused on satellite and communication technologies. The OSTF was established in addition to the already running ESA BICs to continue to support start-up and early stage companies within the ESA's Member States.

In 2017, Europe's second space fund, **Seraphim Capital**, backed by a majority investment from the British Business Bank (under the Enterprise Capital Funds programme) along with European space industry giants such as Airbus, was launched. Seraphim Capital is a London-based VC fund with a global geographic focus. It **typically invests in the Series A round** and has a fund size of EUR 78 million for EO technologies and data-driven applications, among others. In March 2018, Seraphim Capital launched the Space Camp Accelerator, an accelerator programme in the UK, backed by the UK Space Agency, to fit in with the plans set out in the UK's National Space Policy, published in December 2015, to grow the market share of the UK space sector to 10 % of the global space economy or GBP 40 billion by 2030.

Similarly, the French government has taken measures to improve the development of space applications. Through the Comité de concertation Etat-industrie sur l'espace (COSPACE), the French government and its space agency, CNES, have taken steps **to centralise the efforts of all national space policy and industry players**. This collaboration has already led to the implementation of boosters, accelerators and other support structures to help drive innovative applications. As part of this overall national effort, in 2018 the French government and CNES launched CosmiCapital, **a EUR 100 million space-focused fund to financially support young companies** in the industry that are focused on the development of space technologies and other downstream services that may have a general value-added benefit to the French space ecosystem. First investments of the fund are planned for 2019.[171]

In early 2016, the Luxembourg government announced a series of measures to **turn Luxembourg into the European hub for the exploration and use of space resources, and by extension**, to develop the country into a key space nation. The government identified this field as an enabler for new business models, e.g. in the space exploration domain, and with many technology spillover effects in the short term. Luxembourg is the first European country to develop a legal and regulatory framework concerning the future ownership of minerals extracted from space. Through its national programme managed by the ESA, Luxembourg made key investments in leading and promising NewSpace players active in in situ resource utilisation (ISRU) as well as other space segments (e.g. ispace, KLEOS and Spire). The SpaceResources.lu initiative will be followed by the set-up of a Luxembourg space agency particularly suited to the needs and quirks of the NewSpace trend in close cooperation with the private sector. Leveraging their reputation in fund management and private banking, a dedicated space fund linked to the space agency, with strong involvement of private investors, will be created to complement and expand Luxembourg's existing funding options. The space fund is set to focus on early-stage investments in enterprises focused on the space industry through direct investments.

Outside of Europe, the Japanese Ministry of Economy, Trade and Industry (METI) and Cabinet Office launched in March 2018 a **"Space Business Investment Matching Platform" labelled S-Matching.**[172] S-Matching is a platform that facilitates matching between investors and companies in the space industry, with the aim of fostering the growth of space companies and technologies. The Japanese Prime Minister announced that, along with the platform, **approximately EUR 766 million of funding would be provided for space businesses over the next five years**, with support from the Japan Bank for Policy Development and Investment (DBJ) and the Industrial Innovation Organization (INCJ).

The announcement of the S-Matching platform and funding for space businesses follows a long history of Japanese state investment in space. While Japan has lagged behind the US and Europe in the development and funding of space start-ups, since 2013 it has invested EUR 95 million in space and space applications through INCJ, as shown in Figure 82.

Company	Area	Amount M€	Year
ispace	Moon landing	27	2017
i-QPS	SAR CubeSat constellation	7	2017
Dynamic Mapping	3D map using high precision GNSS	10	2017
Farmnote	Agribusiness intelligence	4	2017
Agra	Agri drones	5	2017
Astroscale	Asteroid approach/satellite rescue	25	2016
Smart Drive	Telematic terminals	5	2015
Global Brains	VC fund, investing also in space	8	2013
Incubate Fund	VC fund, early stage investments	4	2015

Figure 82: Japanese Investment in space applications through INCJ[173]

Moreover, to support the development of its space ecosystem, Japan is following the initiative of the US and Luxembourg to include potential changes in law to support companies in the space resources industry by giving them rights to the resources extracted from outer space.

Furthermore, the Japanese government hold a "**Space Development Utilisation Grand Prize**", an event wherein awards are given out to institutions and companies for space-related projects and technologies. This event works to enhance Japan's space ecosystem following their Space Industry Vision 2030 plan, which looks at doubling the space market to USD 21 billion by 2030,[174] with the awards encouraging the commercialisation of the space industry and the de-emphasis of government in the industry. Japan looks to achieve this by facilitating access to satellite data, and promoting its use, as well as supporting the space equipment industry with measures to improve the industry's international competitiveness and supporting new enterprises (e.g. by enhancing opportunities for demonstration in orbit). Lastly, Japan has created S-NET (Space New Economy Creation Network) to connect companies and individuals involved in the creation of new industries and services around space. This network focuses on business match-making and supporting business development.

For completeness, but regarding strictly private initiatives, **SBM Ventures** was founded in 2016 and is based in California, with a focus on the investment, acceleration and acquisition of successful space-related businesses. Furthermore, **Starbridge Venture Capital**, based in New York, recently started investing.

The **emergence of VC funds dedicated to the space industry is clear evidence that the trend in space investment seems set to continue in the short to mid term**. Advances in technology and falling costs have made the space industry more attractive to both entrepreneurs and investors; thus, the creation of dedicated funds by public authorities offers start-ups solutions to bridge the early-stage funding gap and grow fast.

5. Recommendations

The key findings of the analysis covering market, technology and investment trends, as well as associated risks, were distilled in Section 4. These are supported not only by the analysis performed in Sections 2 and 3 but also by an extensive stakeholder consultation on the demand and supply sides of the capital market for space. This chapter proposes **five recommendations designed to overcome the hurdles** experienced directly or indirectly in the space sector.

The Space Strategy for Europe[175] recognises the strategic importance of space for Europe, as it reinforces both Europe's role as a stronger global player and space as an asset for Europe's security and defence. The EC has identified key requirements across the value chain, such as the need for long-term investment in space infrastructure, government incentives for private investment and a cultural shift in Europe to cultivate the entrepreneurial spirit. The proposed set of recommendations **tackles most of these issues and proposes ways forward**.

SUPPORT FOR THE ECOSYSTEM

1. Strengthen the ecosystem of public support mechanisms by introducing more flexibility and more commercial orientation

INNOVATIVE PULL MECHANISMS FROM THE PUBLIC SECTOR

2. Develop and deploy innovative pull mechanisms from the public sector (e.g. innovative procurement and industrial policies) to stimulate technology development and its commercial uptake
3. Adopt a strengthened European defence policy as a driver for market development across all space business segments

ACCESS TO FINANCE

4. Increase the volume of risk capital and catalyse additional private investment into the sector

ADVISORY AND SOFT MEASURES

5. Establish a "finance for space" forum with representatives from the finance community, academia, policymakers and industry to bridge the information gap and develop innovative financing solutions for the space sector

5.1. Recommendation 1: strengthen the ecosystem of public support mechanisms by introducing more flexibility and commercial orientation

As mentioned earlier, the European space strategy calls for more market uptake, new commercial applications and services to maximise the socio-economic benefits of EU space programmes and EU space assets. Attaining this objective requires, among other things, a **less prescriptive, more open and more integrated system of public support mechanisms**, both on the funding side and on other supporting measures.

Governments around the globe are **actively supporting the early stages of space start-ups through various programmes**. At the European level, several business support schemes dedicated to the space sector exist, e.g. the ESA Business Incubator, Copernicus Start-Up Programme and E-GNSS accelerator. Initiatives have been taken at the national level in, for example, the United Kingdom, France and Poland, as well as internationally in, for example, the US, United Arab Emirates, Japan and Singapore. The programmes often include both business and technical support in addition to a pre-seed grant, office space or space data access. While mentoring schemes are available within some of the start-up support schemes at the seed stage, including the SME instrument, early stage and growth companies could also benefit from technical assistance, such as that which will be made available through the InvestEU advisory hub.

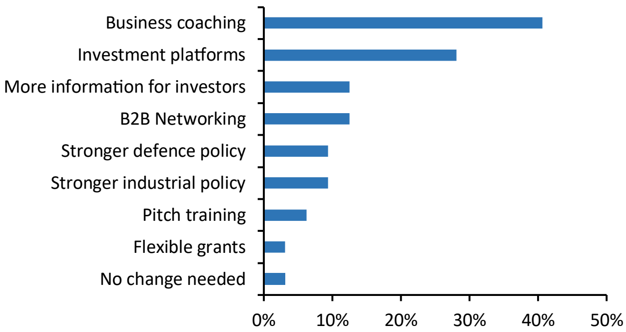


Figure 83: Ranking of soft measures perceived most beneficial by companies

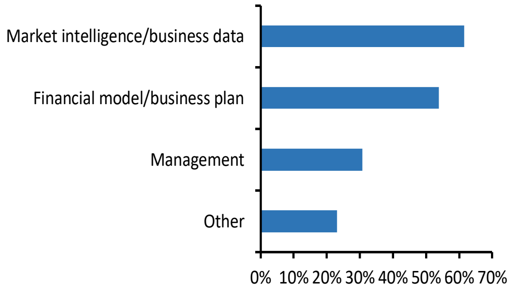


Figure 84: Most common deficiencies in investor pitches according to investors

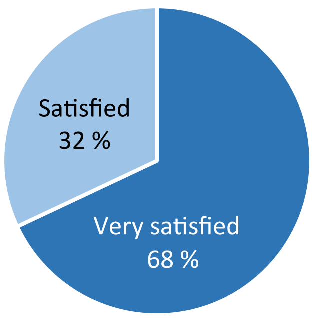


Figure 85: Satisfaction with the Copernicus Accelerator Programme[176]

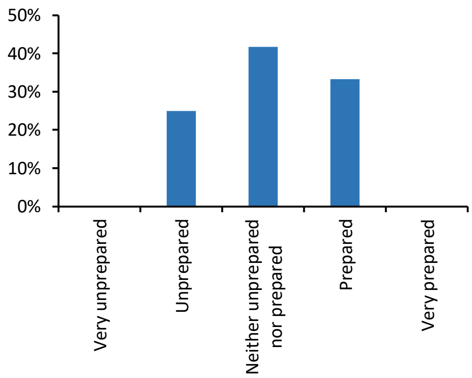


Figure 86: Preparedness of space companies applying for funding according to investors

The **start-up/business support programmes are considered successful in reducing the first hurdle of incubation** and **addressing issues with the business case and entrepreneurial skills** in the early stages of a company. While most of these programmes have been successful in supporting a number of space start-ups, not all market segments are adequately covered; upstream markets and NewSpace companies are often ineligible for several support mechanisms, with the general support environment remaining rather fragmented.

In order to further enhance the key role played by European business support schemes the following directions could be considered.

- **Reduce the fragmentation** of the various initiatives in order to provide scale and a more unified and coherent voice when it comes to supporting European space start-ups.

  Particularly on the funding side for early stage companies, Europe has a rather wide array of grant programmes at EU and national level; however, identifying and accessing the right instrument can be rather time consuming, and these programmes often present quite prescriptive terms for accessing their funds, which limit the ability of companies to react to new developments and pivot their business if needed.

  Incorporating more flexibility in the grant allocation (in terms of timing, project scope and outcome, etc.) would enhance the economic impact of the grants and give firms the necessary flexibility in their development. At the same time, to reduce the risk profile of space companies and improve their commercial focus, grants could be structured as a catalytic tool for private finance. Closer synchronisation of grants with private funding would improve public grant allocation. Additionally, easily understandable, investor-oriented grant agreements would better prepare space firms in business and market aspects.

In this respect the European Innovation Council is poised to introduce a step change in the European landscape of finance for innovation. European space companies should take advantage.

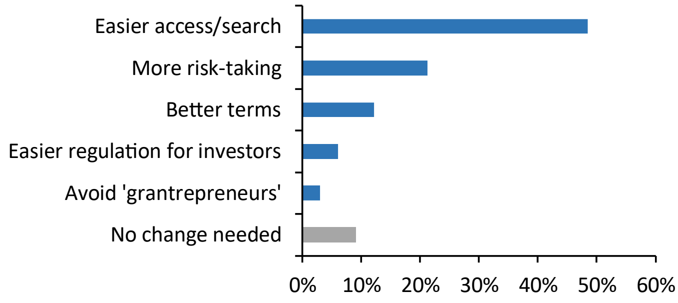


Figure 87: Space executives think public finance can improve by …

- The space start-up support schemes should **systematically engage with (and, to the greatest extent possible, leverage: Seraphim Capital's new Space Camp Accelerator is a good example) the finance community and the industry in their programmes**, so to ensure that (i) business and financial discipline is instilled early on and only the most commercially promising opportunities receive adequate funding; (ii) investors get acquainted with space technologies, space business models and their risk profiles; (iii) businesses and entrepreneurs have access to alternative funding sources and are given a longer-term perspective along the funding chain.
- **Expand the support mechanisms to "less obvious" business models**: most of the programmes focus on the downstream segment, and the NewSpace start-ups are not yet fully embraced. The EU start-up programmes should expand to include other business segments of the space sector, which are currently underrepresented (see Section 3.5).
- **Promote cross-fertilisation between the space and non-space sector**, embracing, for example, the entrepreneurial vibe from the more mature ICT sector with a stronger commercialisation mindset. As the ICT sector has a more mature start-up ecosystem, more seasoned entrepreneurs are active in the sector, and the space sector would benefit from attracting some of the serial entrepreneurs to space (see Section 4.3). One way to attract serial ICT entrepreneurs and business people is to ensure the start-up programmes are open and inclusive initiatives rather than exclusive.

Interview Quotes	
	• Space companies in early stages do not understand well what they need to write a business plan for—they do not know the key performance indicators (KPIs); in general, early stage space companies do not know much about business. • Any kind of programme would be good, such as an accelerator that will help space geeks with skills and knowledge that is required to conduct business. • Start-up programmes are nice and are being done, but they do not solve the real issue, which is the shortage of capital.

Table 31: European investors on start-up support schemes

5.2. Recommendation 2: develop and deploy innovative pull mechanisms from the public sector (e.g. innovative procurement and industrial policies) to stimulate technology development and its commercial uptake

Different public funding methods are used to fund R&D and advance technologies in Europe, as well as in the early stages of product or service development. Section 3 describes, for example, the funding available in the form of R&D grants, which is the mechanism most widely used by the EU to fund R&D, as well as mechanisms targeting specific breakthrough innovation projects such as Horizon 2020's SME instrument. The ESA funds technological developments in specific fields associated with technological needs for its space missions through procurement contracts. The procurement of its space missions naturally also includes the procurement of the technological developments needed for its one-off missions. The EU also has a **procurement instrument available that allows them to steer the development of solutions towards concrete public sector needs**, namely pre-commercial procurement under

Horizon 2020's innovation procurement. The EC has piloted this instrument in the space sector: a first PCP call in the EO segment was launched in 2015, encouraging public buyers to jointly procure development of solutions that use Copernicus information.

A complementary instrument of the EU is PPI, which relies on the concept of **the public sector acting as the first customer of innovative commercial solutions**, and which **could be particularly relevant for emerging market segments of space applications**. To date, this procurement method has not been applied for the procurement of hardware or services based on space data.

One of the **differences in access to finance in Europe and the US is anchor tenancy** (see Section 4.10), a financing model that has been used extensively in the US over the last few years. Unlike the European modus operandi, the US anchor tenancy projects aim to be "technology agnostic"—in essence the US customer obtains a service rather than product that is powered by a specific technology.

This approach is similar to the **"Power by the Hour (PBH)"** regime, coined by Bristol Siddeley in 1962 to support Vipers engines on de Havilland/Hawker Siddeley 125 business jets for a fixed sum per flying hour.[177] Under this regime, a complete engine and accessory replacement service was provided, allowing the operator to accurately forecast this cost, and relieving them from purchasing stocks of engines and accessories. In the 1980s, Rolls-Royce plc reinstated the programme to provide the operator with a fixed engine maintenance cost over an extended period of time. Operators are assured of an accurate cost projection and avoid the breakdown costs; the term is trademarked by Rolls-Royce but is common in the industry.[178] Known as PBH in the private sector, the approach turned out to be so successful that it found its way into defence and aerospace contracting under the name "performance-based logistics" (PBL).

As demonstrated by the US Navy, a PBH/PBL contract may go so far that all maintenance and upgrading efforts are outsourced to the contractor, who may even be tasked to take care of obsolescence issues. Under such a Service Level Agreement (SLA), it is the contractor that decides when a certain technical element is to be replaced by the follow-on generation—the customer plays a totally **technology agnostic** role and as long as the aircraft, train, ship or whatever system the SLA refers to can fulfil the agreed key performance indicators (KPIs), such as number of flight hours, the SLA is maintained and fulfilled.

NASA's Commercial Crew & Cargo Space Act Agreements			
	Company	Value [USDm]	Development Contract
CCDev1	Blue Origin	3.7	Launch Escape System (LES)
	Boeing	18.0	CST-100 Development
	Paragon Space Development Corp.	1.4	Air Revitalization System (ARS) Engineering Development Unit
	Sierra Nevada Corporation (SNC)	20.0	Dream Chaser (DC)
	United Launch Alliance	6.7	Emergency Detection System (EDS)
	CCDev1:	49.8	million
	Company	Value [USDm]	Further Development and Demonstration Contract
CCDev2	Blue Origin	22.0	Blue Origin capsule–ISS Lifeboat
	Boeing	92.3	CST-100 Maturation/Testing
	SpaceX	75.0	Falcon 9/Dragon transportation system
	Sierra Nevada Corporation	80.0	Dream Chaser Space System (DCSS)
	CCDev2:	269.3	million
	Company	Value [USDm]	Development of fully integrated Systems Contract
CCiCap	SpaceX	440.0	Updated Falcon 9 spacecraft—crewed demo flight
	Boeing	460.0	CST-100: CDR & Demo flight
	Sierra Nevada Corporation	212.5	Dream Chaser Space System (DCSS)
	CCiCap:	1 112.5	million
	Total Investment:	USD 1 431.6m	within 2010–May 2014

Table 32: NASA's Space Act agreements for crew transport with private firms[179]

Based upon the successes in the defence sector, PBH/PBL contracts were extended to other sectors and both the US Department of Defense (DoD) and NASA adopted them for space, taking on the role of (widely) technology agnostic anchor tenant. Typical examples are **NASA's commercial space acts and NOAA, with its commercial space data pilots**. NASA's Authorization Act of 2010 formed the basis for setting up contracts with the industry to develop new systems and services for the supply of the ISS. Three contracting rounds (CCDev1, CCDev2 and CCiCap) were set up to develop launchers, capsules, mini-shuttles and key technologies—all in all NASA had invested USD 1.4 billion into companies such as Blue Origin, Paragon, Sierra Nevada and SpaceX as well as Boeing (see Table 32).

Today, one can say that this anchor tenant strategy proved successful, with SpaceX, Blue Origin and Sierra Nevada having established themselves as reliable private space transportation companies, whose business reach extends well beyond the US. Placing these companies into the market was not a small effort, according to SpacePortal,[180] eight companies had signed Space Act Agreements with NASA to develop capabilities to transport goods and people to LEO. Five contracting rounds had seen Boeing being awarded USD 4.82 billon, followed by SpaceX with USD 3.14 billion and the Sierra Nevada Corporation with USD 363.1 million. The other companies are a mix of both well-established space firms and NewSpace companies. This programme turned out to be of great importance for all these NewSpace firms becoming established within the space business. The success of the anchor tenant programme, however, should not make us forget that the combination of public and private entities and long time factors bear the imminent risk of politicisation (as the public sector acts as a long-term procurer).

If the European Union were to consider adopting a similar technology agnostic anchor tenant role, projects that need to be followed through need to be steered by well-established KPIs, referring to availability, performance levels, cost per unit, etc. Potential PBH/PBL-based projects/programmes might centre on, among other things:

- **bridging the digital divide** by ensuring Internet access with at least X megabits per second (Mbps) to at least, say, 99 % of the EU population in at least, say, 99 % of the EU territory with an availability of at least Y %;
- providing a **mobile distress communication service** that will work with X % availability for Y % of the EU population in Z % of the EU territory under the direst circumstances (major earthquake, terror attack, etc.) in an effort to save lives and maintain/improve safety and security even when the worst things happen;
- setting up and maintaining a highly secure **quantum-key-based communication system with** X % availability, whose keys can be changed at an interval of less than Y minutes;
- **operating an EO service** that will provide updated information within VIS, IR, UV, etc., on, say, a 10-minute basis, accessible by mobile phone with a data rate as low as X kilobits per second;
- **running a tracking service** with monthly costs as low as X euro per month to address the whereabouts of children, elderly and/or handicapped that run the risk of getting lost to an extent that they may harm themselves.

Interview Quotes

- There is no consistency in programmes and road maps for European space activities and, as a consequence, in the availability of funds.
- A better convergence of the different instruments for space is needed between the agencies: a better alignment of the instruments.
- From my investor perspective, the government should act as a customer for the start-ups.
- There is a clear lack of awareness and understanding in the public institutions about NewSpace and the market space trends.
- Venture class contracts are needed from the public sector. There is a perception now with investors that they should not enter this market, as it is highly subsidised, which acts as a deterrent for investment.
- The public sector could become a customer of start-ups, like they are for the big aerospace players. This needs to be a structured and continued action.

Table 33: European investors and space executives on industrial policy

Albeit comparable with that of NASA, the ESA has embarked on a different procurement scheme with the Ariane 6 in order to safeguard the competitiveness of Europe's flagship launcher. **Key characteristics of the ESA's Industrial Policy may not, however, be ideally suited for stimulating a competitive NewSpace economy in the global context.** The so-called Geographic Distribution in the ESA's Industrial Policy, as well as its stringent ECSS standards are often mentioned as hurdles for enabling competitive NewSpace SMEs in the sector. On the other hand, the ESA actively embraces SMEs with targeted procurement actions, more attractive payment schedules and other support mechanisms through the activities of its SME Office. A recent letter sent by the CEO of Airbus to the French and German governments underlines these needs and calls for new projects and policies for Europe. **European and national space institutions should more actively engage with NewSpace** and adopt space entrepreneurship in their strategic plans to ensure their policies and processes do not undervalue the importance of NewSpace for the growth of the sector. For example, Japan's space industry is, more than Europe's, driven by public procurement, and the country recognised the need to expand the commercial market share for its space industry. Its "Space Industry Vision 2030" specifically embraces NewSpace, with initiatives such as "Space—New Economy Creation Network" (S-NET), and more aggressive measures such as S-Matching, as described in Section 4.11.

5.3. Recommendation 3: adopt a strengthened European defence policy as a driver for market development across all space business segments

Especially in the US, the **dual-use aspect of space** has been essential in the development of the sector to its present form, as described in the case study in Sections 2.1.3 and 6.3. A reinforced European defence policy would offer many opportunities for space companies across all segments and may allow more innovative space products to flourish more rapidly and be readied to scale for commercial markets. In addition, such a move would also help to avert negative effects that may emerge if ITAR is enforced and specific technology items suddenly become unavailable to European companies and institutions.

The space industry would be well advised to think proactively about dual-use when devising new services and concepts. In this way a service that is kick-started with a strong technology impetus may be **augmented by a dual-use service level line** and thus embed safety and security critical aspects as well as commercial aspects right from the start (e.g. hardened space communication systems, which may serve military, institutional and commercial purposes). Due to the strong overlap of military, safety and security user needs, any system that serves one of these users is likely to be able to prevail in the other sectors as the business conditions will be more favourable for such undertakings than for a total "outsider/newcomer", with no or limited exposure to the safety/security/military requirements.

The proposed budget for the next Multiannual Financial Framework supports a new European Defence Fund, with an overall budget of EUR 13 billion, to boost Europe's ability to protect and defend its citizens. The fund is poised to offer EU-funded grants for collaborative projects that address emerging and future defence and security threats and bridge technological gaps.[181] While the fund is modest compared to the Member States' national defence budgets, it opens the door for more strategic cooperation on space programmes, in addition to existing cooperation, such as on governmental satellite communications.

Interview Quotes	• Export regulations can ruin the business case if you make a mistake with them. • ITAR forms a bit of a hurdle—even if we are trying to procure everything in Europe, our products are not completely ITAR free. • Satellite communication is a driver for expenditure in the defence field; a first cooperation in Europe is happening, but it could be better. • A European defence policy could help companies from smaller countries to access the markets of bigger Member States.

Table 34: European space executives on defence policy

5.4. Recommendation 4: increase the volume of risk capital and catalyse additional private investment in the sector

The capital markets are generally not supplying the necessary funding, as documented in Section 4.1, with both equity and lending products lagging behind demand. Space companies struggle in both the up- and downstream markets. On the supply side, investors are uncomfortable with the market maturity and lack evidence of exit opportunities. Start-ups and SMEs struggle with the traditional supply chains, but also point out the lack of understanding by investors about the sector. This environment **leads to insufficient private capital for the sector—a situation that several governments around the globe are trying to address**, as we have seen in Chapter 4.

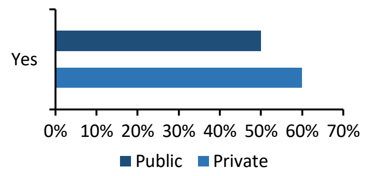


Figure 88: % of interviewed companies indicating a lack of public and private funding in Europe

Figure 89: According to space entrepreneurs private finance is lacking in …

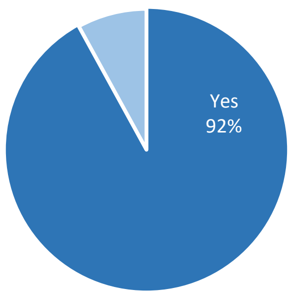


Figure 90: Investors indicating a lack of funding for space companies in Europe

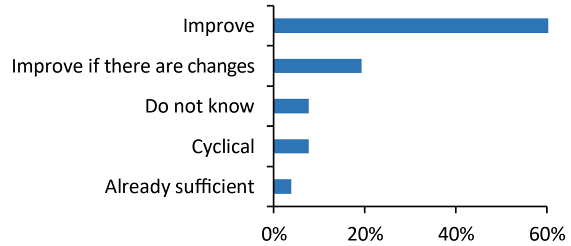


Figure 91: The finance conditions will improve in the future according to the space executives

Interview Quotes

- The diversity and volume of finance is missing. There is a market need for specialised seed/VC capital in the space.
- Evidently a fund-of-fund is the best measure because that is where the gap is. I would not know with whom to co-invest in Europe in space, other than two other investors.
- I was shocked by the risk aversion in Europe, which acts more like growth capital than venture capital.
- Seed venture capitalists prefer to invest in a later stage and not in the real seed stage, because it is better for their returns.
- Countries around the globe make available capital in the markets, Europe could do more of this as well. You have guarantee programmes existing today for angels, but they are a hassle. The EIS/SEIS in the United Kingdom is easy.

Table 35: European investors on enhancing risk profile

The interviewed investors believe access to finance for space companies to be rather difficult and propose to inject more fund-of-fund capital for the sector as the most important measure to improve the financing conditions for space companies in Europe.

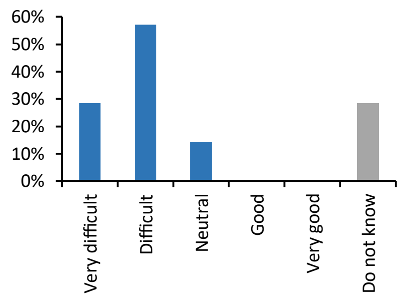


Figure 92: Investors rate the access to finance conditions to be difficult for European space companies

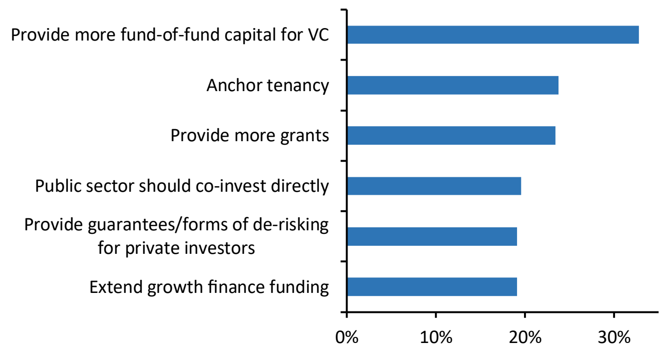


Figure 93: Investors would improve access to finance for the space sector by …

In Table 36, we summarise the main funding patterns and options by business segment and provide some general market considerations as to the prevailing funding conditions.

Traditional space supply chain		
Business segment	**Typical financing path/funding instruments available**	**General market considerations**
Large satellite manufacturing, launchers and ground equipment industry	• R&D grants and procurements • Corporate loans • Project finance • Debt and equity capital market	• The large system integrators and tier 1 suppliers typically have similar access to the capital markets as other companies in general tech. The companies serve stable institutional markets as well as established commercial markets
SMEs in satellite manufacturing, launchers and ground equipment	• R&D grants and procurements • Corporate loans	• The companies typically produce components for a subsystem in the traditional satellite supply chain • Considering the long development times and the moderate revenue potential due to, say, one-off product developments, these companies experience financing issues
Large satellite services industry	• Corporate loans • Debt and equity capital market • Project finance • Export credit agencies	• The satellite operators generally have good access to debt finance (see Section 3.7) and receive guarantees by export credit agencies
SMEs in ground equipment (incl. downstream sector)	• R&D grants and procurements • Internal financing • Venture capital for the high-growth cases • Business loans	• Financing for the downstream sector is easier, as R&D is more focused on software developments (see Section 4.2), but many applications do not yet have fully developed and proven markets, beyond institutional sales
Crewed and robotic space science and exploration	• R&D grants and procurements • Public venture capital	• At the moment a mostly institutional market with commercial robotic and crewed space exploration endeavours planned. Long development time, technology risks and market risks are hard to finance with private capital in Europe
NewSpace supply chain		
Business segment	**Typical financing path/funding instruments available**	**General market considerations**
Start-ups in satellite manufacturing, launchers and ground equipment	• R&D grants and procurements • Venture capital	• The smaller funding rounds in Europe are a major hurdle for start-ups with higher capital needs. In addition, not all market segments have proven market potential yet.
Start-ups in satellite services	• R&D grants and procurements • Venture capital • Project finance • Export credit agencies	• Start-ups in satellite services experience similar issues as those in manufacturing, launchers and ground equipment, with the added hurdle of market validation. The interaction with the end customer comes even later than in deep tech, as a satellite constellation needs to orbit in space before you can test the "prototype" with customers
Energy, mining, processing and assembly	• R&D grants and procurements • Public (and private) venture capital	• Governments such as Luxembourg and Japan have provided R&D grants or public equity in pursuit of a long-term but potentially highly valuable market • Need to identify intermediate commercial solutions to attract VC • It is still unclear how the substantial mid- to long-term capital needs of these companies will be addressed in the future

Table 36: Funding patterns and conditions

In Table 37 we further categorise the existing and potentially innovative financing instruments and initiatives both in the traditional space and NewSpace domains. This will serve as a premise for the following two (finance-related) recommendations, where we characterise the most relevant financing solutions (in bold in the table) that we believe deserve more attention and public sector input and support in both the development and implementation phases. The drivers that guided our selection were (i) the need for additional risk capital in the sector and (ii) the need for innovative financing solutions to address the specificities of space businesses.

• "Traditional Space"/traditional financing instruments • Corporate loans • Project finance • Debt/equity markets • Traditional procurement • IPOs • Export credit	• "Traditional Space"/new financing instruments • **Innovative procurement (service-based/result-driven, parameter-oriented versus technology specifications)** • **Risk-sharing instruments** • **Alternative solutions to EU/MS budget for financing major space infrastructure** • **Use of Member States EU Structural Funds by way of risk finance in support of the space sector**
• "NewSpace"/traditional financing Instruments • Project-R&D Grants • Working capital/revolving facilities • Seed/BAs/VC (limited to specific segments) • IPOs	• "NewSpace"/new financing instruments • Flexible business grants • **Dedicated space funding instruments (e.g. in orbit validation) targeting or mitigating risks specific to the space sector** • **Fund of Funds (FoF) such as InnovFin Space Equity Pilot (ISEP), combining public and private finance** • Alternative risk finance solutions (e.g. venture debt) • **Corporate Venture Capital** • **Public-driven dedicated space financing initiatives (e.g. Luxembourg and France)** • **Innovative procurement (service-based/result-driven, parameter-oriented versus technology specifications)** • New IPOs platforms on stock exchanges (not space specific, e.g. NEXT, Nasdaq North) allowing SMEs to go public • **Alternative finance for launch costs (versus equity)** • **Use of Member States' EU Structural Funds by way of risk finance in support of the space sector** • **Export credit for NewSpace** • **Supply chain finance to support tier 2 companies of prime contractors**

Table 37: Existing and new funding instruments and initiatives for the traditional and new space domains

Accessing risk capital at scale remains a challenge for European space companies. As we have seen in prior sections this holds true for early stage venture finance as well as for growth and development capital, in both the upstream and downstream sectors. For obvious reasons—being less mature and with still many unproven business models—the challenge is more acute for the NewSpace segment.

The lack of specialised investors, the limited size of the European VC funds and their relative risk aversion compound the challenge in a sector such as space.

For all these reasons, more risk capital is needed. European institutions are well positioned to bring about change and stimulate further investment in the sector. A number of possible directions, all complementary and not mutually exclusive, are presented below.

- **Expand and to the greatest extent possible replicate the Fund-of-Funds (FoF) model spearheaded by the InnovFin Space Equity Pilot (ISEP)**. ISEP will channel EUR 50 million of the EU budget, potentially matched by additional EIB Group financing, to invest in a number of space-related VC funds.

  The FoF model proves effective for several reasons.

  – It relies on market-driven investment decisions, as the funds are ultimately deployed by private actors (VC, PE funds, etc.); however, it allows the public sector to stimulate the market dynamic by selecting those funds whose investment policy is more in line with the identified market gaps.
  – It enables diversification of risk and acts as an attractive vehicle to draw new investors into the sector. It is potentially highly catalytic, especially in those funds where the FoF investor acts as a cornerstone investor or where the public sector is more ready to accept an asymmetric risk–return model than the other investors (e.g. by accepting a lower or delayed return, by providing "downside protection" to the other investors).

  - Public (EU or MS) funds otherwise traditionally used for grants are channelled to a market-based investment model with a revolving nature and high chances of significant returns.
- Support and to the greatest extent **feasible contribute financially to Member States-driven initiatives addressing the risk capital shortage in the space sector**. The financing programmes recently announced by Luxembourg and France are good examples, but not the only ones.

  The EIB Group should systematically screen such initiatives and, depending on investment policy and eligibility, consider investing in such programmes to (i) increase their firepower and (ii) provide a signalling effect to other potential investors.

  EU institutions are also well placed to provide ex ante coordination mechanisms among such initiatives and share best practices for others to replicate these models.

- **Establish co-investment programmes with Aerospace Corporate Venture arms.** Flight heritage and credibility are key components in the space sector. Validation of a given technology by an established player boosts the credibility of the company developing that technology and provides a signalling effect to investors as a stamp of approval. On the other hand, bringing a corporate/strategic investor into a young space company early on presents risks on the alignment of interests, independent growth and future technology development.

  Corporate venture capitalists are, however, part of the narrative of addressing the shortage of risk capital in Europe and their technology and investment expertise could be leveraged via co-investment programmes from, for example, the EIB Group or National Promotional Banks.

- **Consider the deployment of more (public/private) project-finance risk-sharing solutions to finance space assets**: in order to facilitate and accelerate space-related R&D investment more risk-sharing solutions (i.e. bilateral loss-sharing agreements for the development of a specific project) can be developed specifically targeting space. The EIB already successfully deploys such schemes across a number of sectors, whereby it shares the risks and rewards on the development of one asset or a portfolio of assets. Further partnerships could specifically be explored for the space sector.

- **Consider the use of Member States' EU Structural Funds by way of risk finance in support of the space sector.** European Structural Funds can be allocated by MS to financial instruments (including equity investments) in a given sector, provided there is evidence of a financing gap and market deficiency. In most MS, space may represent too restrictive an investment area for such hypothetical funds but space-related businesses, particularly in the downstream segment and with asset-light business models, would naturally be on the radar of such funds.

  A good example of this model is the Baltic Innovation Fund, an FoF initiative launched by the EIF in close co-operation with the governments of Lithuania, Latvia and Estonia in 2012 to boost equity investments made in Baltic SMEs with high growth potential. The total fund size is EUR 130 million, with each Baltic government committing EUR 26 million through their respective national agencies and the rest coming from the EIB Group. What is relevant is that a significant portion of the resources committed by national agencies are revolved resources from earlier Structural Funds' financial instruments under the Joint European Resources for Micro to Medium Enterprises (JEREMIE) framework now being reused.

5.5. Recommendation 5: establish a "finance for space" forum with representatives from the finance community, academia, policymakers and industry to bridge the information gap and develop innovative financing solutions for the space sector

The information gap between the space sector and the finance sector is mutual—**space lacks knowledge about finance and finance lacks knowledge about space**. European space executives indeed remark that identifying private funding sources in Europe is difficult (see Figure 94).

On the public supply side and as an added complexity in the space sector, there are public funding instruments not only from the EU, but also the ESA, in addition to those at national or regional level. Navigating the system is complex and, as we have seen above, the industry often lacks the financing solutions it requires to develop and deploy new technologies.

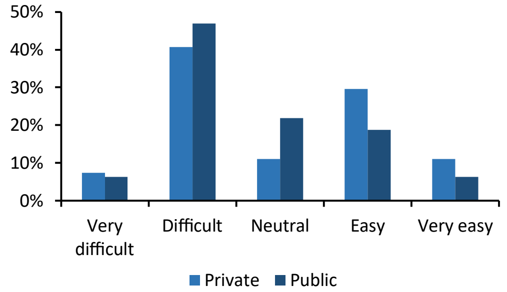


Figure 94: Ease of identifying the relevant private funding sources in Europe

A regular "finance for space" forum where the representatives from various stakeholders' groups could exchange views and incubate new ideas could help bridge this gap. The remit of this regular gathering should, among other things:

- convene key industry, finance and academia stakeholders and facilitate exchanges between demand for and supply of finance;
- identify specific financing needs and discuss/develop potentially new models and (co)financing solutions for the European space sector, adapting traditional financial engineering to space finance (e.g. asset-backed securities);
- raise awareness about existing financing instruments and programmes via dedicated access to finance workshops with real-life examples and testimonials from entrepreneurs;
- develop awareness-raising material, including case studies, to disseminate via industry associations, clusters and other forums;
- bring technical expertise to investors and intermediaries to raise awareness about the true technical risks and market potential of the sector;
- proactively identify key space players that would be eligible for EIB products or other available funding instruments and organise targeted outreach campaigns.

Interview Quotes	
	• There is a need for more information on our market, so that banks and other institutions can perform good analyses on how the companies and the sector are performing. It is impossible to have an overview of all funding sources without the help of an investment bank. • We found our investors through our wide personal network; it is harder to identify the high-net-worth individuals or venture capitalists in Europe. • It is hard to find the relevant funds in Europe; venture capitalists that fund aerospace activities are rare. There are only a few specialised funds—it is hard for generic funds to validate our business case and potential.

Table 38: European space executives on fundraising

Particular focus could concentrate on identifying, awareness-raising and developing of innovative funding models and other supporting instruments targeting the specificities of the space sector and its risks. Areas that would require further consideration include:

- access to satellite insurance for entrepreneurs with limited or no flight heritage;
- financing solutions such as export credit, factoring, alternative solutions (versus equity) to alleviate the burden associated with pre-funding of launch costs for young satellite companies, etc;
- brokering and financing access to space for European smallsat companies to aggregate demand and increase bargaining power with launch providers while also diminishing the risks that the launch companies face;
- advisory functions and soft measures in support of European space sector.

Focus: New solutions to support and finance space ventures

As explained in the earlier sections, the space sector carries a number of specific risks that are very difficult for non-space investors to assess. Therefore, space companies could benefit from targeted instruments focusing on removing particular risks associated with the sector and could thereby potentially also attract investment from non-space investors.

Below we outline a few suggestions.

- **Dedicated space funding instruments targeting or mitigating risks specific to the space sector.** One of the specific risks that entrepreneurs in the upstream space sector face is lack of flight heritage. Even if the asset operates properly in laboratory conditions, it is still possible that it will be damaged or malfunction during transit, pre-launch integration with the launch vehicle, the actual launch, or upon separation or in orbit.

  Satellite insurance, from pre-launch to in-orbit, is commercially available from specialised private insurers and may even cover loss of revenue. However, one of the areas where the **public sector could** have a catalytic role is in **providing satellite insurance to entrepreneurs** who cannot access it today.

  Even though smallsat developers traditionally have not been taking out insurance cover, this trend is changing now that a growing proportion of smallsats are launched with the objective to generate revenues. While the operators of larger constellations are still unlikely to take out insurance cover for individual satellites due to sufficient redundancy in their systems, insurance cover is becoming increasingly important for small constellations. And, despite the fact that the cost of launch insurance cover has generally been falling recently and might be as low as 4 % for established launchers, upcoming launches with the new generation of rockets that are designed for placement into LEO orbit might be prohibitively expensive due to the limited track record of the rockets.

  Such satellite insurance could potentially be deployed in collaboration with existing private insurance providers, who could be incentivised to include such satellites in the portfolio of their other insured satellites in return for a limited counter-guarantee of losses on their entire portfolio.

  One potential measure accompanying the above insurance programme might be **provision of access** (free of charge, or at a subsidised cost) **to testing facilities,** where satellites could be assessed prior to launch. This would both (i) allow the insurer to pre-select companies that have the capability to produce viable assets, thereby potentially allowing operators to take out an in-orbit cover and (ii) provide a platform for eligible companies to test their assets and improve them before the launch.
- **Export credit for NewSpace—case study on One Web.** Export finance in the form of guarantees or direct debt are typically used for facilitating the financing of infrastructure projects, often in emerging economies, but export credit agencies have also ventured into guaranteeing or financing satellite projects directly. Through such practices, they accept risks that private capital financiers are unable to carry. **Export finance** by agencies such as Bpifrance supports **internationalisation of national space manufacturing companies**. In the past, large space infrastructure projects, such as telecommunication satellites owned and operated by both established and new companies, have been funded through export finance. The involvement of national export credit agencies in the space sector, however, is concentrated in just a few Member States in Europe. The national export financiers could **increase engagement with the space sector** in the respective Member States or **broaden this activity to European level**. Such expansion of space-related financing would help advance European competitiveness and help Europe to gain significance as a satellite manufacturer and operator.

  This potential is magnified when considering the limited interlink between the upstream and downstream space segments in Europe. The intention of the Trump administration to revive Export–Import Bank of the United States (EXIM), the US export credit agency, underlines the **need for export financiers to further embrace the holistic European space market**. The fact that the geographic distribution of NewSpace companies is more varied than that of traditional space companies also emphasises this conclusion, and **transactions with NewSpace companies should be considered**. These projects feature constellations typically comprised of significantly more, smaller satellites. The question remains, however, whether the risks of small satellite constellations can be borne by an export credit agency, as the market risks associated with NewSpace markets may be deemed too high for this form of financing.

Focus: New solutions to support and finance space ventures (*cont.*)
▪ **Alternative finance for launch costs (versus equity).** Certain tranches of launch costs need to be paid up to two years before the actual launch. These costs may be substantial and, particularly for new companies, may represent an unsurmountable hurdle, as this presents a significant cash outflow long before they start generating revenues. Traditionally, entrepreneurs have been raising equity to fund launch costs, which is costly and detracts attention from the actual development of a viable space asset. Therefore, space companies could benefit from a **bridge facility** that would allow them to **defer the payment of launch costs**. Even though the bridge facility should technically function as a loan, given the high-risk nature of the undertaking (ultimately, the fund provider takes the risk that the company will not be able to produce a viable asset or that it will not able to produce it in time for launch), it is unlikely that a traditional lender would be willing to accept the risk. However, one could consider providing a **loan to pre-fund the launch costs of a portfolio of companies,** either directly or via a launcher company. By including a sufficient number of established companies in the portfolio, a lender could potentially take the risk of funding launches contracted by new companies. In addition, in order to catalyse private investment, a public body could guarantee (for example, on a first-loss piece basis) such a loan. ▪ **Alternative solutions to EU/MS budget for financing major space infrastructure.** Traditionally, major space infrastructure has been financed from the EU, ESA or member state budgets, usually in the form of direct funding. The major advantage of this funding model is that it provides certainty to the management of the company that the funding will be available when needed. In addition, such backing by a public budget also increases the confidence of any future partners of the project, be it suppliers or customers, that the project will be completed—this helps the project secure more advantageous supplier/offtake contracts and thereby drive costs down. These benefits at the project level, however, come at the expense of the rigidity and uncertainty this imposes on public budgets. **An alternative solution** has appeared and merits attention—in this **intermediate model**, a third party, for example a **bank, provides a loan** to the company that is either **guaranteed by a member state or repayable from later contributions from the public budget** to the project. This model, if appropriately structured, has the advantage of imposing a higher degree of financial discipline at the company level, resulting from an interaction with the lender and pre-agreed reporting obligations. In addition, if the lender is a reputable institution, such as a local NPI or EIB, this would furthermore preserve the previously mentioned benefits associated with the backing of the project by a solid partner. Another of the benefits would be at the level of the state budget, where it would provide an effective relief, or at least deferral, of the expenditure. It is worth noting that the immediate alternative, i.e. raising debt at the state level, would have similar effects on the state budget, but would not bring the additional financial discipline at the project level. ▪ **Factoring** is a traditional debtor-finance technique whereby a company sells its receivables (e.g. expected revenues under signed contracts) to a third party at a discount. The **emergence of factoring in NewSpace**, even though it is likely to be at a very substantial discount (potentially close to 50 %), shows that it might be a highly relevant funding option. **Public sector support of factoring arrangements** (by either co-funding or guaranteeing them) could therefore have a **catalytic effect and improve access to finance** especially for new companies and entrepreneurs. ▪ **Supply chain finance** to support the operations of tier 2 companies of prime contractors.

Focus: Brokering and financing access to space for European smallsat companies
Small satellite operators of all sorts—be they academic, institutional or commercial**—all face one particular problem: timely access to space**. While the low mass of the satellite is usually one of its best assets, as it typically lowers capital expenditure as well as development, manufacturing, assembly, integration and testing time, the inherent drawback of the small and low mass satellite system is that is too small to fill up all—or at least a critical mass of—the payload mass, which can be launched into space on a particular launcher. The VEGA, PSLV, and Falcon 9 rockets came along with payload capabilities of several metric tons,[xxii] much too high for a CubeSat, with a mass of 5–20 kg, to be considered as an important or even the "prime" customer. This prime customer role is left to telecoms or EO satellites, which have masses of several hundreds of kilograms (e.g. the 714 kg Indian Cartosat-2 series satellite for EO). If such a "heavy weight" is launched on a commercial launch vehicle (LV), it will naturally assume the role of the prime customer, who sets the time and destination of the flight. Today, with an ever stronger emerging smallsat market, the **LV providers have tuned their launch offers so that they not only match "big birds"**—as are extensively performed by Arianespace on its dual-launch Ariane 5 rocket**—but offer combinations of one or two bigger satellites with a bunch of smaller satellites**. A typical example for this big–small satellite combination is the Indian PSLV-C37 launch, which took place on 15 February 2017 at 09:28 IST from SDSC SHAR, Sriharikota.[182] While the 714 kg heavy EO satellite Cartosat-2 took on the prime customer role, the rest of the payload capability was taken on by 103(!) co-passenger satellites, together weighing about 663 kg. All 104 satellites were sent into a 505 km polar Sun Synchronous Orbit. Finding the right LV provider that will deliver the satellites for a given destination within a reasonable time frame and for an affordable price can be arduous. **Some private companies offer LV brokering services, but ultimately face the same problem: the prime customer sets the launch date**, which may be delayed again and again. These delays pose a significant risk for all sorts of smallsat operators. For the commercial operator, a launch delay of several months may render a particular part of the business plan useless; for the academic operator, the academic year may be over once the satellite is in orbit; for the institutional operator a particular need may have changed by then, and require a new type of mission. Beside the delay aspect, financing is another item of importance. While it will always cost money to have a payload sent to space, **financial risks involved with space projects (insurance, work forces, storage costs, regulatory amendments, etc.) may far exceed the pure launch costs, especially if several players are involved**. Under such circumstances, academic projects such as the CubeSat network QB50 would not be possible if the academic entities involved have to bear all financial risks on their own.

xxii VEGA: 2500 kg into LEO. PSLV: 3800 kg into LEO and 1750 kg into Sun Synchronous Orbit (Source: https://www.isro.gov.in/launchers/pslv).

Focus: Brokering and financing access to space for European smallsat companies (*cont.*)
A brokering and financing entity to facilitate access to space for European smallsat operators would help to advance the sector in several ways: • **acting as a brokering entity** to aggregate demand (and increase bargaining power) for all European players who want to launch a smallsat into space; • **aggregating European demand to project and leverage bargaining power with the LV providers** to the extent that this entity may even buy a whole LV if it is more cost effective (similar to buying a whole charter plane versus several tickets); • **serving as arranger or (co-)financing partner for wide-scale academic projects** such as QB50, such that sponsors (e.g. the EU, ESA) could channel their funds via this entity; • **supporting new players** by providing regulatory advice (at least to the extent that they will be guided to the respective national authority), technical help (to make the payload LV ready) and financial consultancy (e.g. for obtaining adequate insurance). Such brokers could also be supported directly by the financial mechanisms discussed in Recommendation 4, potentially allowing them to pre-fund the launch costs of their clients so that the latter can pay them gradually over time as part of the service.

Interview Quotes	
	• Europe is not supporting well the development of its own small launcher, which adds more risks to the European small satellite operators and their downstream business. • There is a strategic loss of not yet having a European launcher for small satellites; however, there is energy building for it, e.g. with the Horizon 2020 Low-Cost Space Launch prize. • Financing the launch and associated costs is a large hurdle for NewSpace companies—one could think of guarantees from the government to help cover the launch costs for start-ups, without eating up equity. • Using a co-passenger opportunity is good value for money, but the risk is that your satellite may be stranded for more than one year on the ground if the prime satellite has a technical issue of such gravity that it delays the launch.

Table 39: European space executives on access to space

6. Annexes

6.1. List of acronyms

Acronym	Description
AI	Artificial Intelligence
AMF	Additive Manufacturing Facility
B2B	Business to Business
B2C	Business to Customer
BofAML	Bank of America Merrill Lynch
CAGR	Compound Annual Growth Rate
CPU	Central Processing Unit
DIN	Deutsches Institut für Normung
EDRS	European Data Relay System
EIB	European Investment Bank
EO	Earth Observation
GSA	European Global Navigation Satellite Systems Agency
GTF	Geared Turbo Fan
GTO	Geostationary Transfer Orbit
HST	Hubble Space Telescope
ICBM	Intercontinental Ballistic Missile
ICT	Information and Communication Technology
ILS	International Launch Services
IoT	Internet of Things
ISO	International Standards Organisation
ISS	International Space Station
ITAR	International Trafficking of Arms Regulation
LCT	Laser Communication Terminals
LEO	Low Earth Orbit
LLCD	Lunar Laser Communication Demonstration
LV	Launch Vehicle
MAIT	Manufacturing, Assembly, Integration and Test
MMI	Man–Machine Interface
MSS	Mobile Satellite Services
NRO	National Reconnaissance Office
PPP	Public–Private Partnership
R&D	Research & Development
SAR	Synthetic Aperture Radar
SDI	Strategic Defense Initiative
ULA	United Launch Alliance
USAF	US Air Force
VLSI	Very-large-scale integration

6.2. Technology trends contributing to market disruption (further elaborations)

The following sections represent an add-on to the technology trend analysis provided within Sections 2.2.1–2.2.10, providing further details on the top technology trends that disrupt the space and space application market.

6.2.1. Acceleration of generation change/obsolescence

Element	Assessment
Affected market segments	1–8, strong driver for 4 (see Figure 8)
Enabling	Shorter generation cycles, better performance, reduced costs
Innovation type	Sustaining–evolutionary (see Table 7 and Table 6)
Specific financing needs	Limited (electronics can be easily sourced from multiple suppliers; as long as the access to a free and open market is guaranteed, there is no specific need to set up a dedicated financing tool)[xxiii]

Moore's Law predicts a doubling of transistor density on a VLSI chip every two to three years. This exponential growth of capability allows faster and/or smaller electronic systems, with performances and costs that outperform earlier system by orders of magnitude. A **clear example of Moore's Law is comparing a top-notch portable computer ("Osborne Executive" 1982) with the first Apple iPhone (2007)**. About 25 years of exponential growth, with probably 10 VLSI chip generations in between, have led to the following evolution of the respective features (Figure 95).[xxiv]

Feature	Osborne Executive (1982)	Apple iPhone (2007)
Weight	100	1
Volume	500	1
Clock speed	1	100
Cost	10	1

Figure 95: Comparison of two computer systems, 25 years and 10 generations apart: Osborne Executive 1982 versus Apple iPhone 2007[183]

Over time, the ever-increasing capabilities and dropping costs of electronics and microprocessors were noticed by different industrial sectors; **today there is not likely to be a single that does not employ microprocessors** to provide for telecommand and telemetry functionality or uses them to optimise chemical, physical and biological processes in order to improve efficiency, reduce the footprint of employed resources or allow new services, better flexibility, etc.

The two- to three-year-generation frequency of Moore's Law has a profound effect, as it leads to a trend of swifter generation changes in all areas where electronics play a role. A modem car model is obsolescent after six years (10–20 years ago, car models lasted for nine years or more) and so are its major components. Today, **the obsolescence of electronic components is one of the most significant issues for any long-term programme**. Locomotives, ships, aeroplanes, power plants—which may last for 30-40 years (or even longer)—all require a mid-life electronics upgrade to overcome obsolescence issues.

Space is no exception to that faster generation change/obsolescence trend. The aerospace sector features a cycle in the order of 7-10 years, which is approximately five times slower than that of the ICT sector. Currently, the very costly accessibility of space assets (e.g. space qualification or launcher cost) prohibits a general acceleration of the space generation cycle to align itself with that of the ICT sector. The maintenance activities performed at the Hubble Space Telescope (HST) and the ISS, however, have shown that space systems can be improved and upgraded, and

xxiii This may change however if a tightening of export regulations (such as ITAR) will prohibit the access to electronic devices. Such a move may happen if certain devices would be considered to be of high military and or strategic value—in this case Europe would have to set-up its own strategic devices/parts list and a dedicated financing regime will have to be set up to ensure that several European suppliers maintain this particular technology.

xxiv For simplicity reasons, the table features relative values, normed at the lowest unit per comparison feature.

electronics may be changed by systems that are better performing (and in some cases exchanged and/or augmented by **photonics**). One can therefore assume **the faster generation change/obsolescence trend will sooner or later prevail in most space market segments.** The advent of commercial activities related to in-orbit maintenance/servicing and to a more frequent and cheaper access to space already lead in that direction.

6.2.2. Advanced manufacturing technologies/3D printing

Element	Assessment
Affected market segments	1–8, game changer for 6, 7 and 8 (see Figure 8)
Enabling	Reduced complexity costs, manufacturing in space and on other celestial bodies
Innovation type	Disruptive (see Table 6 and Table 7)
Specific financing needs	Medium (R&D and bridge financing to further develop and commercialise space-qualified printers)

Whether it is space, aviation, automotive, software or any other sort of industry, according to Stephen Wilson and Andrei Perumal, "**Complexity costs are the single biggest determinant of your company's cost competitiveness.**"[184] As stated in their book and depicted in Figure 96, complexity costs are different from any others, as they follow a geometric growth; complexity costs do not just rise in proportion to the amount of complexity in the business, whether product, process, or organisational complexity; they rise exponentially with greater levels of complexity. This geometric nature of complexity cost growth separates it from other forms of cost.

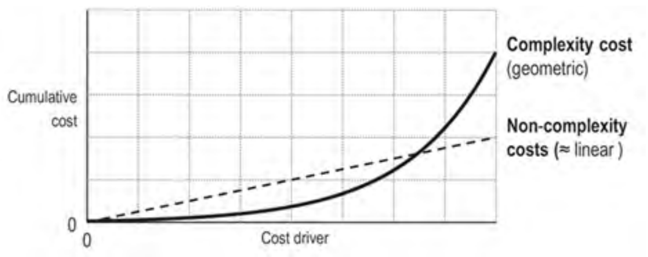


Figure 96: Complexity Costs rise exponentially[185]

Complexity costs, all non-value-adding, are driven by the overall number of items—the overall level of complexity. While complexity is simply the number of things, complexity costs are the non-value-adding costs associated with having a number of things. Consequently, **reducing the complexity of a product** (Space Shuttle, A380, a rocket engine such as the SSME or the F-1) **is key to reducing its cost.** In addition, this strategy will also **increase the reliability and maintainability of the product.** All these items are of great importance for any system, and even greater importance for systems that need to be commercially competitive.[186]

Clever mechanical designs and the transfer of functionality from hardware to software are good measures to reduce the complexity of technical systems. The advent of **advanced manufacturing technologies/3D printing has provided engineers with a powerful tool to reduce complexity** even further as one can now design and manufacture complex systems in one piece without the need to combine and fasten elements together. NASA experiments on board the ISS have proven that 3D printing in space works.

"Made in Space", a start-up based at the NASA Ames Research Center in California, has installed a second 3D printer on the ISS; its Additive Manufacturing Facility (AMF) is the **first commercial 3D printer in space** (Figure 97). Brought to the ISS in 2016, the AMF is already printing orders for commercial customers, including the first 3D-printed advertisement in space, a crowdsourced sculpture and projects for educational programmes, such as Enterprise in Space.[187]

Once 3D printing (in space and on Earth) has been developed to such an extent that all sorts of material can be utilised (metals, plastics, ceramics, etc.), it will change the way we build and repair items in remote areas; instead of shipping spare parts to a remote place (like space), we will rely on a 3D printer to manufacture the required element out of locally available resources. The possibilities seem endless; visions and concepts connected to 3D printing in space entail the construction of space probes, stations and space ships. The Reconstituting Asteroids into Mechanical Automata (RAMA) architecture goes one step further, aiming to turn asteroids into basic spacecraft capable of moving themselves to useful locations in space (Figure 98).

Figure 97: The AMF installed on board the ISS[188]

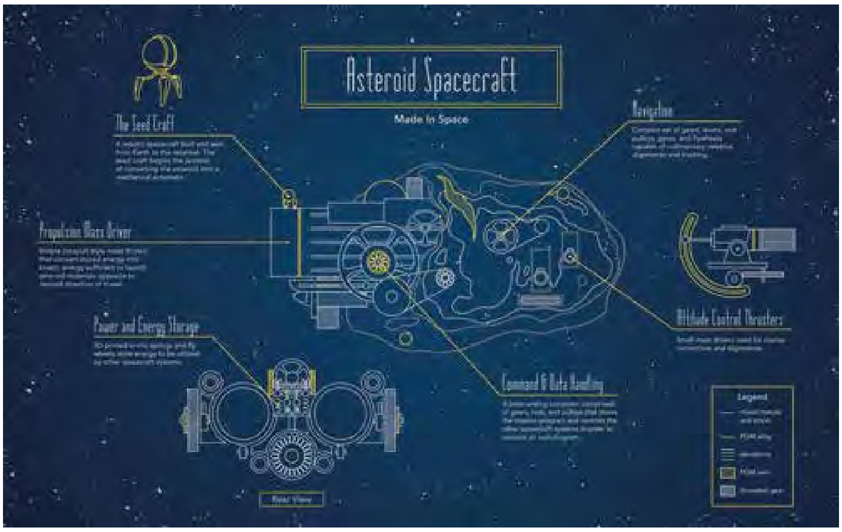


Figure 98: Artist's concept of an asteroid spacecraft created by the RAMA architecture[189]

6.2.3. Micro- and nanoelectronics/advanced telemetry and telecommand

Element	Assessment
Affected market segments	1–8, game changer for 4 (see Figure 8)
Enabling	Holistic observation, control of processes, health monitoring, predictive maintenance
Innovation type	Disruptive for the IoT element of it (see Table 6)
Specific financing needs	Limited (electronics can be easily sourced from multiple suppliers)

Moore's Law has a profound effect on everything that uses electronic systems. CPUs, microprocessors and computer systems are directly affected, whereas sensors far exceed these systems in number and have seen drastic improvements under Moore's Law. Such improvements relate to both performance increases and the miniaturisation of components. Today, a **suite of sensors are available to observe a plethora of processes, providing a wealth of data that can be used for health monitoring and predictive maintenance of systems.** Table 40 provides an overview of sensors currently used in the automotive and transport sector.

The trend of recording more and more system data and transmitting it online to the system provider's data storage centre (telemetry), where it will be analysed and processed in real time so corrective measures can be devised and transferred to the system concerned (telecommand), is not in itself disruptive, as telemetry and telecommand have always played an integral part in every space mission. What is disruptive, however, is the fact that **the inter-connectivity concerns more and more sectors and acquires an ever-increasing amount of data from more and more sensors, ultimately providing new, holistic views on systems and processes to users and operators.**

Typical sensors used in the automotive and transport industry		
Air flow meter	Knock sensor	Tire-pressure monitoring sensor
Air–fuel ratio meter	MAP sensor	Torque sensor
AFR sensor	Mass flow sensor	Transmission fluid temperature sensor
Blind spot monitor	Oxygen sensor	Turbine speed sensor
Crankshaft position sensor	Parking sensors	Variable reluctance sensor
Defect detector	Radar gun	Vehicle speed sensor
Engine coolant temperature sensor	Speedometer	Water sensor
Hall effect sensor	Speed sensor	Wheel speed sensor
	Throttle position sensor	

Table 40: Typical sensors used in the automotive and transport sector[190]

A look at the aircraft industry reveals the number of sensors integrated into modern aircraft. The Airbus A350 has almost 6000 sensors across the entire plane, and generates 2.5 TB of data per day, while the newer model—expected to take to the skies in 2020—will capture more than three times that amount: the A380-1000, the supersized airliner that can carry up to 1000 passengers, will be equipped with 10 000 sensors in each wing.[191] This aircraft is only one part of the data explosion equation; the engines form another—very dominant—one. Pratt & Whitney's GTF engine is a perfect aviation big data role model (see Figure 99). **Equipped with 5000 sensors, it generates up to 10 GB of data per second. A single twin-engine aircraft with an average 12-hour flight time can therefore produce up to 844 TB of data** (in comparison, at the end of 2014, it was estimated that Facebook accumulated around 600 TB of data per day), but with an order book of more than 7000 GTF engines Pratt could potentially download zettabytes of data once all their engines are in the field.[192]

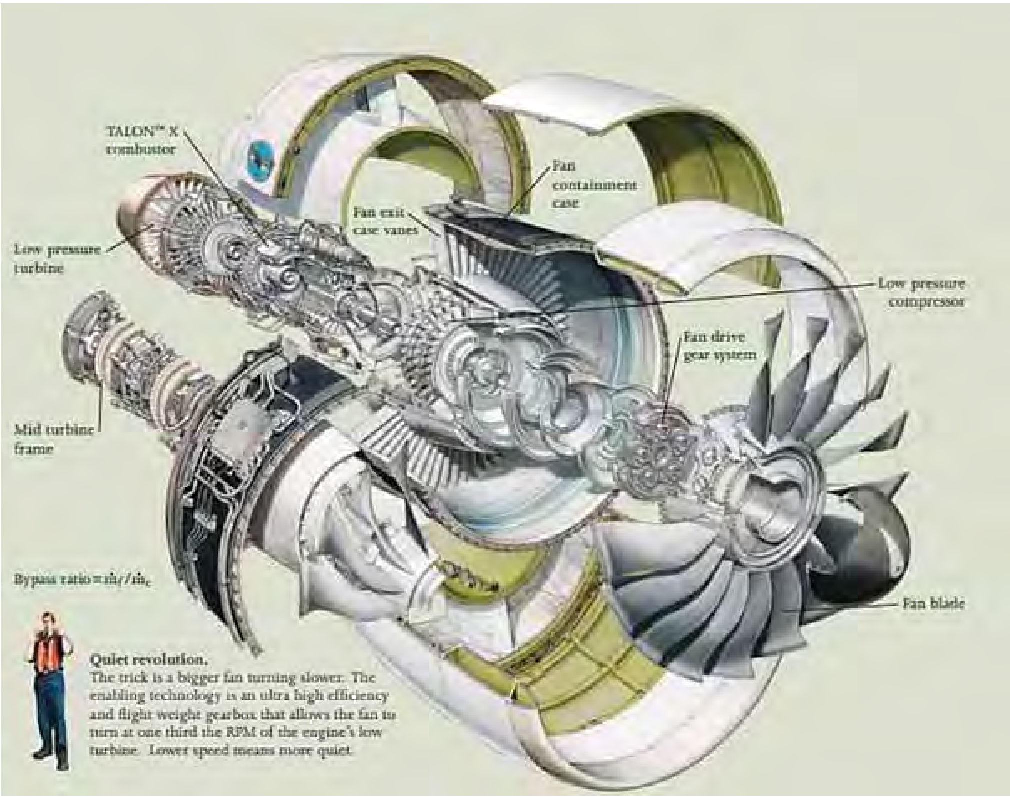


Figure 99: Pratt & Whitney's GTF engine, using a planetary reduction gear to reduce the speed of the fan, will power the new A320neo[193]

The drivers for this sensor and data inflation are health monitoring and predictive maintenance techniques. The latter are designed to help determine the condition of in-service equipment in order to predict when maintenance should be performed. This approach promises cost savings over routine or time-based preventive maintenance, because tasks are performed only when warranted. Bearing all this in mind, it is no surprise that the aircraft sensors market in 2016 was valued at USD 1.59 billion and is projected to reach USD 2.25 billion by 2022, at a CAGR of 6.01 % from 2017 to 2022. **One can expect more and more sectors to embark on using advanced telemetry and telecommand algorithms.**

6.2.4. Agile development and industrial standard implementation

Element	Assessment
Affected market segments	1–8, high impact on 2, 4, 6 and 8 (see Figure 8)
Enabling	Flexible designs, minimum viable product strategies, staggered rollout sequences
Innovation type	Sustaining–Revolutionary (see Table 6 and **Table 7**)
Specific financing needs	Limited (it is more business philosophy than classical engineering)

Agile Development is an approach from the IT sector that has recently seen its introduction into space along with the NewSpace trend.[194] It is based on agile software development, an umbrella term for a set of methods and practices based on the values and principles expressed in the Agile Manifesto. It represents an approach to software development under which **requirements and solutions evolve** through the collaborative effort of self-organising cross-functional teams, their customer(s)/end users(s)[195] and advocates, adaptive planning, evolutionary development, early delivery and continuous improvement. It encourages rapid and flexible response to change.[196]

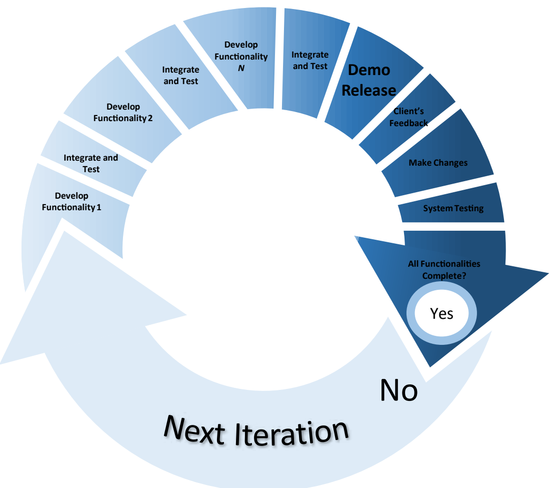


Figure 100: Agile development cycle[197]

Figure 100 outlines the agile (software) development approach. It is **an iterative and cyclic improvement process that offers a minimum viable product early in the process, which can be used to test out markets, raise interest and test certain aspects** with respect to customer satisfaction. Acknowledging that this process does not produce a fully fledged product in the first cycle, typical buzzwords associated with agile development are "pilots", "releases" and "patches"—all words in common use from the computer, software and mobile phone industry.

Agile development is in **stark contrast to the classical space project management**, which features a series of well-defined project phases and reviews (see Figure 101).

Traditional space companies follow a structured **project management approach (European Cooperation for Space Standardization), which has been devised to minimise failures and risks**. It calls upon an early selection of the mission's target and Objectives, and performs a well-orchestrated process in down-selecting systems, payload and operational activities to ensure mission success. Numerous reviews serve as review and decision points, allowing a thorough assessment of the selected systems and technologies. Lessons learned from other missions are thus able to be considered, thereby avoiding making the same mistakes twice.

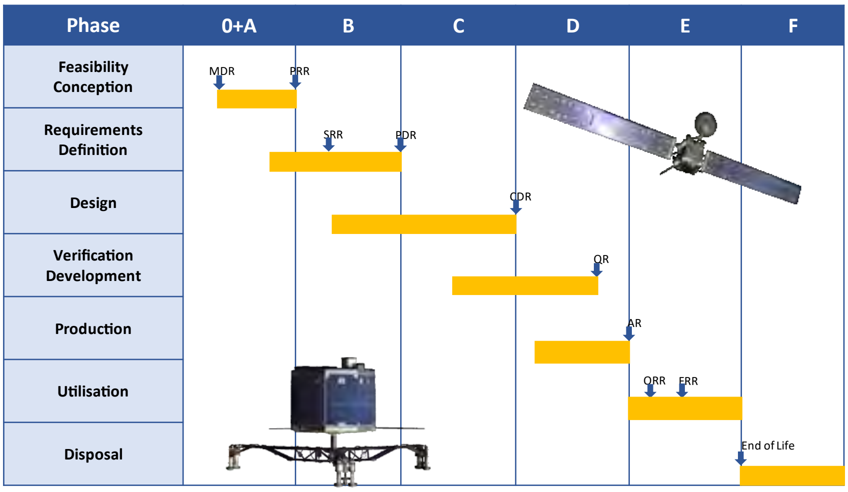


Figure 101: ECSS project management phases, typical of classical missions such as Rosetta/Philae[198]

Due to the **constant down selection** (also called "freezing of options"), **the process does not inherit any spirit of agility**. Changes can be made, but the later they happen in the process, the costlier and more complex they become. A specific milestone in this respect is the start of Phase C. When the project passes this critical step, the only agile element that remains is the on-board software, and even then the software can only move within strict boundaries.

Missions such as Rosetta/Philae, Cassini/Huygens and SOHO showcase the benefits of using the ECSS project management approach. **Owing to the "first-of" nature of these missions (that ventured into the unknown), quality and performance were imperative and hence traded for cost.** As these missions travelled for several years through the solar system, they had to be ruggedised to reach their destination and to perform their mission Objectives.

While there will always be a necessity to plan, design and manufacture space missions to such high standards, **the increased commercialisation of space has triggered a different design philosophy, showcased by NewSpace**. This focuses on the rollout of demand-driven, commercially set up and (mostly) privately financed space missions, serving B2C or B2B models. As these missions are often operating in the LEO, where the environment is well known and less harsh than deep space, the systems employed can often make use of commercially available systems that readily fulfil the specific environmental requirements. Today's industrial standards published by ISO, DIN, etc., call for electronic components to survive high g-loads and shocks, have strict requirements on the electromagnetic compatibility of equipment and look carefully into the safety of power storage systems. In addition, computer, tablet and mobile phone producers are forced by the market to minimise mass, volume and power consumption while providing the highest possible processing power, to allow a suite of apps and programmes to operate flawlessly.

With the advent of cheap electronics that can readily survive a rocket launch (the g-forces when a mobile phone hits the ground, are higher than the shocks happening during a rocket launch) and are powerful yet small, lightweight and power-economical enough, the race is on to design space systems by making use of industrial standards and Agilent design. **Space systems such as the EO constellation of Planet, the IoT/M2M constellation of Orbcomm and the ADS-B/AIS-Radio Occultation constellation of Spire are proponents of this NewSpace design and business philosophy**, where market proximity rates higher than perfect quality.[199]

6.2.5. Artificial intelligence/man–machine interface

Element	Assessment
Affected market segments	1–8, high impact on 3, 4 and 8 (see Figure 8)
Enabling	Autonomous operations, better management of on-board resources, higher performance, easier and faster data interaction with computer systems
Innovation type	Sustaining–revolutionary for weak AI/disruptive for strong AI (see Table 6)
Specific financing needs	Medium to high (R&D and strategic investments to build up a whole industry sector)

Figure 102 summarises the key items of AI. Defined in 1956 at the Dartmouth Conference, two flavours emerged: strong and weak. While strong AI is connected to an "appropriately programmed computer with the right inputs and outputs [which] would thereby have a mind in exactly the same sense human beings have minds",[200] **the weak version is something that we already see today in the form of a machine with narrow intelligence**, designed to solve a specific task, such as optimisation of processes or time series analysis.

AI (Dartmouth College, 1956)

- Four types of intelligence: Visual/Verbal/Physical/Rational
- Strong AI: Creation of an intelligence
- Weak AI: Simulation of intelligent behaviour

Artificial neuronal networks are a specific branch of AI
Learning aptitude!

Applied for:

- Early-warning systems
- Optimisation
- Time series analyses
- Picture processing and pattern recognition
- AI modules in games and simulations

Figure 102: Snapshot on artificial intelligence—strong and weak[201]

Apple's Siri is a good example of a combination of a narrow intelligence augmented with a novel man–machine interface (MMI). While Siri improves the data input and output, and hence enables an easier and faster data interaction with computer systems, it still operates within a limited predefined range; there are no genuine intelligence, no self-awareness and no life despite Siri being a sophisticated example of weak AI. In contrast, HAL 9000[xxv] features a similar MMI to Siri, but is a master example of strong AI—but of course HAL is pure science fiction.[xxvi]

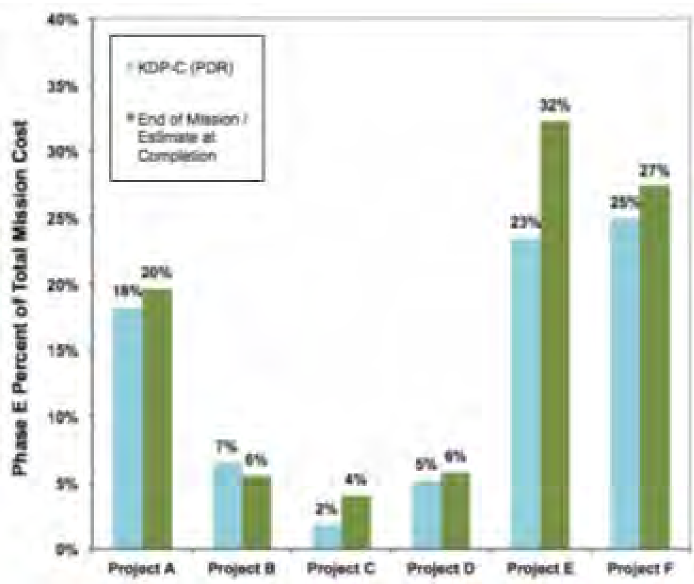


Figure 103: Assessment of operations costs of selected space projects[202]

While it may take decades until humanity has mastered strong AI, the appearance of **weak AI to solve particular issues for space missions is not too far away**. As stated within Section 2.2.4, the capability of modern software for performance and its adaptability enable the use of imperfect hardware. High-performance computers allow the

xxv The on-board computer of the spaceship "Discovery" in the sci-fi movies "2001" and "2010".

xxvi Critics state that it is good that strong AI has not advanced yet, as it may pose a huge risk to the survival of humanity.

usage of AI algorithms with inherently stronger autonomy. **Bearing in mind that operational costs can range from 4 % to 32 % (see Figure 103), two-digit savings in satellite operations cost might be possible**. These savings can be accrued by using a specialised AI implanted on board the satellite, which will, for example, optimise the satellite's trajectory to better satisfy requirements related to optimal observation of targets on the ground, the avoidance of space debris and the establishment of good communication links to the ground or with other space systems while trying to minimise the need of propulsive manoeuvres and fuel consumption. The extent to which deep learning algorithms can be used for these tasks remains to be seen.

6.2.6. Change detection and data fusion

Element	Assessment
Affected market segments	1–8, game changer for 3, 5 and 8 (see Figure 8)
Enabling	Cost-effective observation and analysis of specific points of interest; correlation of images and time sequences with other data (from ground and other sources)
Innovation type	Sustaining–revolutionary (see Table 6 and Table 7)
Specific financing needs	Medium to high—it is not so much a technology topic but more a matter of whether Europe wants to have its own player(s) that can provide this service, which is highly relevant for security

A mix of high-resolution observations of the order of tens of centimetres and observations of the order of 2.5 m–5 m are preferred for "**change detection**" approaches employed by military users to swiftly assess whether a particular place of interest has seen improvement, degradation or other changes. While the high-resolution satellite will observe the areas of interest once every few days or weeks, a **fleet of low resolution satellites will provide a very frequent and wide coverage, making it easy to detect any changes**. If these exceed a certain threshold and hence require the observer to take a closer look, a **higher resolution satellite is tasked to make an up-to-date observation of the area of interest** and the complete change detection observation cycle starts again (see Figure 104).

26 November 2012 | 10 November 2017

Figure 104: Long-term changes within a Chinese naval base, as seen from space[203]

Figure 104 provides for an example of the change detection process, with two satellite images depicting the same Chinese naval base with a time difference of approximately five years. Change detection algorithms are usually not run for such a long time differences. In our example, however, the time difference helps to show the changes in the base: trees have grown higher, some buildings have been renovated, others demolished and some newly built. Above all, different vessels dock at the ports. All **these data are highly relevant for military users as they allows users to assess the readiness and capabilities** of this specific actor.

While it is clear that specific satellites are needed to provide the high-resolution images, **a constellation of cost-effective CubeSats are sufficient to provide the delta frames, complementing the change algorithm**. Planet's business model is built exactly on this CubeSat-constellation approach.[xxvii] Given the relevance of these data for military and security users, it is imperative that there are several players openly providing the delta frame data. If such an open commercial setting cannot be ensured, we should think of setting up one or preferably two of our own players—this, however, is a more strategic decision than a classical commercial one.

xxvii In a personal discussion with M. Safyan, Director of Launch and Regulatory Affairs at Planet Labs in March 2015, he confirmed that 50 % of Planet Labs' business is based on providing this change detection observation for national security users.

With computers becoming more and more powerful and accessible with every new generation (cloud computing), the processing power of intensive data algorithms such as change detection and data fusion, becomes more feasible. The combination of in situ and/or ground-based data with space-borne data can provide interesting insights. Establishing the correlation is not always easy as there are a near infinite number of possibilities of combining data. The advent of new algorithms, based on weak AI (see Section 2.2.5), will certainly help to more quickly identify those fusion algorithms that feature stronger correlations.

6.2.7. Digital transformation and convergence

Element	Assessment
Affected market segments	1–8, game changer for 4 (see Figure 8)
Enabling	Data archiving, search within and comparison of data sets, lower entry hurdles to data processing, manipulation and visualisation
Innovation type	Disruptive, as showcased by global information storage capacity (see Table 6)
Specific financing needs	Limited to medium (electronics can be easily sourced from multiple suppliers; the development of specific software may not be easily outsourced and requires skilled personnel)

Digital transformation, as well as several other trends that we see in electronics and communication and which form the ICT revolution is based on Moore's Law. Although Moore's Law itself is not disruptive, the digital transformation is, as can be seen by the exponential growth in the global information storage capacity, representing the world's technological capacity to store, communicate and compute Information (see Figure 105).

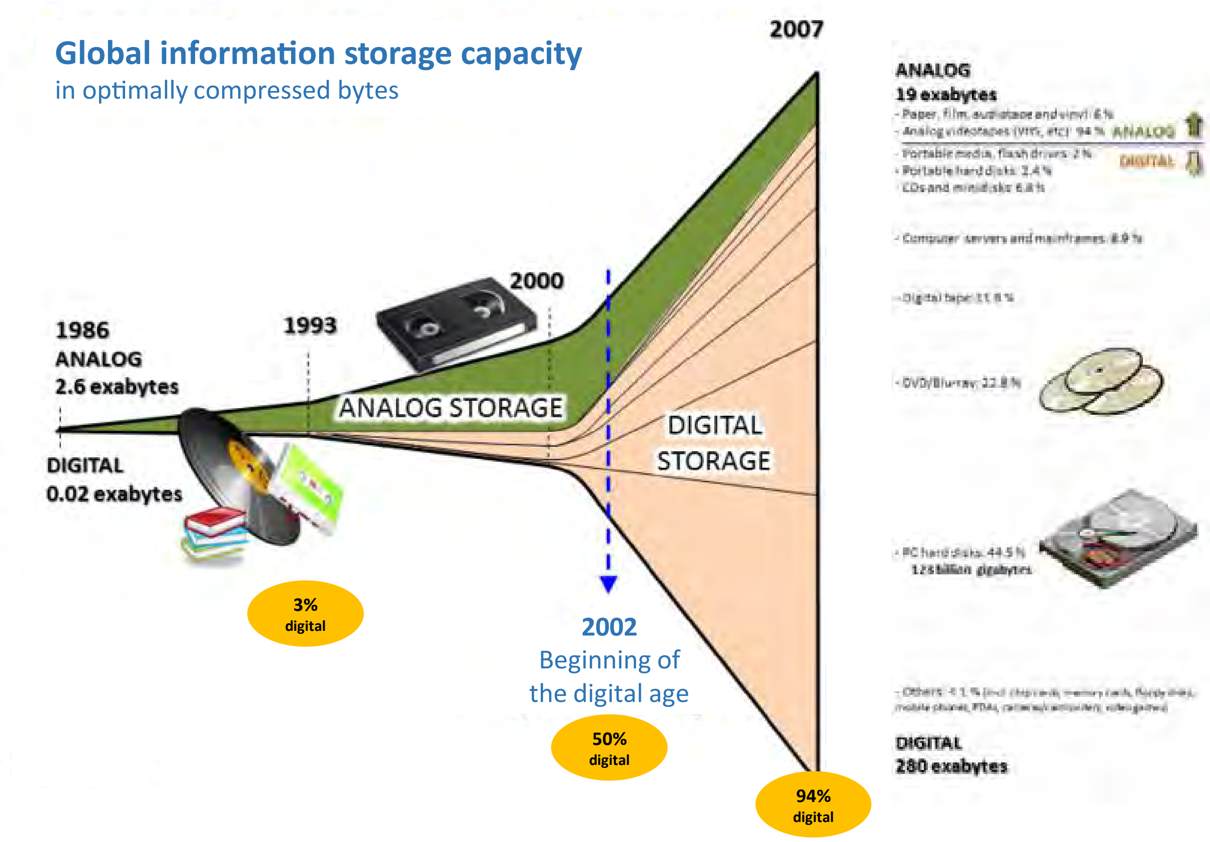


Figure 105: The onset of the "digital age"[204]

The growth in **storage capacity goes hand-in-hand with the growth in data generation**—some key data are presented in Figure 105 (see also Table 41, which provides some perspective on the numbers involved).

When CERN started its Large Hadron Collider in 2008, the yearly data amount stored for later analysis was 20 PB. With the recent upgrades in particle detectors and experiments, the yearly data generation in the year 2022 is forecasted to increase by a factor of 10 (, hence 200 PB per year).

Besides making it easier to search for data and compare and cross-correlate data sets, digital transformation is a key element in what has been described as technological convergence. Several definitions for the term **convergence** exist, but in essence they all describe it as **a trend or process describing the evolution of technology services and industry structures in a such way that several different technological systems sometimes evolve towards performing similar tasks.**

Data users	2017	2020
Data generation and processing	• Daily data generation per human: 600–700 MB • Worldwide data generation: 2.5 EB per day • Google adds 1 PB each day to its digital storage pool • Facebook processes 4 PB of data every day	• Daily data generation per human: 1.5 GB
Internet of Things	• 28.4 billion interconnected devices • 5.5 million devices are installed every day	• 50.1 billion interconnected devices • IoT devices will generate 1.6 ZB of data
Health data	• 150 EB of data are already stored • Daily hospital data storage need: 3 TB on average	• ZB and YB data storage requirement are expected for 2020 • 2025: the sequencing of genome data of more than 1 billion people will have been done—this requires a storage capacity of 2–40 EB
Science	• WorldView 4 Satellite generates 19.5 TB per day and 7 PB per year • Radio telescope "Square Kilometre Array" produces more than 1 EB of data per day	

Table 41: Data generation, processing and storage needs—in 2017 and in 2020[205]

Different flavours of convergence exist, such as **digital convergence**, which aims to pull four industries (information technologies, telecommunication, consumer electronics and entertainment) into one conglomerate. Digital convergence is a fact, as is **media convergence**, the interlinking of computing and other information technologies, media content, media companies and communication networks. By 2014, another convergence, the NBIC—**Nanotechnology, Biotechnology, Information technology and Cognitive science convergence**—had emerged. This may lead to an improvement in human performance, but it may also make us obsolete.[206] So far, humanity has seemed able to master information technology and, to a certain extent, cognitive science. As far as the capabilities of bio- and nanotechnology are concerned, humanity is still in its infancy. Once humanity has mastered bio- and nanotechnology, it remains to be seen what humans will do with them, as these technologies provide us with the capability to (mis)use it.

As far as space is concerned, digital transformation and convergence have a profound effect on the way data is generated, stored, processed, analysed and presented. Powerful computers allow the emulation of tasks by software for which one had to obtain specific—and costly—hardware some years ago (e.g. Software Defined Radio (SDR) that can nowadays emulate GNSS signals). Although the software may be very specialised and costly, requiring skilled personnel to develop it, it is certainly cheaper and more adaptable than any hardware solution. With computers becoming so powerful and versatile they are able to fully utilise the trend of convergence, they can nowadays handle tasks that were so specific their processing requires special tools and equipment. **Digital transformation and convergence significantly lower the entry hurdles**, as all the hardware and experts needed to operate computers can nowadays be substituted—at least to a certain extent—by skilled personnel, who resort to software-based methodologies to perform the tasks in question.

6.2.8. Evolved expendable/reusable launcher systems

Element	Assessment
Affected market segments	1–8, game changer for 1, 6, 7 and 8 (see Figure 8)
Enabling	Cheaper and hence more frequent access to space, enlargement of the space market, new business models in space
Innovation type	Disruptive, as it will extend humanity's sphere of influence beyond LEO and into space (at least the near solar system) (see Table 6)
Specific financing needs	Medium to high (building a rocket calls requires high upfront investment, dedicated safety analysis, a competitive launch platform, etc.—synergies with advanced materials (e.g. carbon fibre), which withstand higher temperature, high density power systems, improved control algorithms can reduce rocket and launch costs significantly)

Spaceflight is (still) expensive. **The cost to send 1 kg of mass into low Earth orbit (LEO) is typically rated at USD 10 000–20 000.** Even though miniaturisation has helped to reduce some of the costs, satellites and spacecraft used to weigh hundreds to thousands of kilograms and hence the launch into space became a major cost item. For several decades, satellite communications was the only sector that could commercially afford launch prices, which would amount to around USD 115 million. This amount had to be paid to obtain a dedicated launch into geostationary transfer orbit (GTO) by a Russian Proton-M rocket. As one can see in Figure 106, launch prices fluctuated considerably over time, as the number of satellites to be launched into geostationary orbit (GEO) varied between 12 and 28 per year.

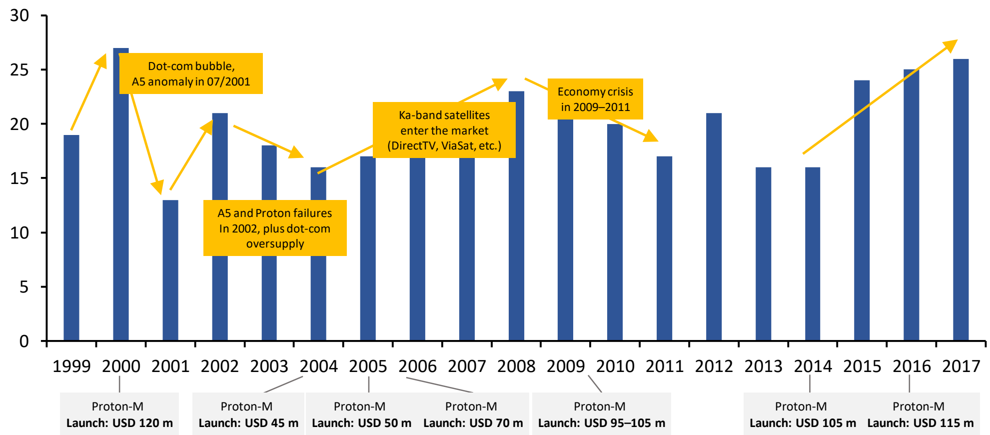


Figure 106: Price fluctuations between 2000 and 2017 for a dedicated Proton-M launch[207]

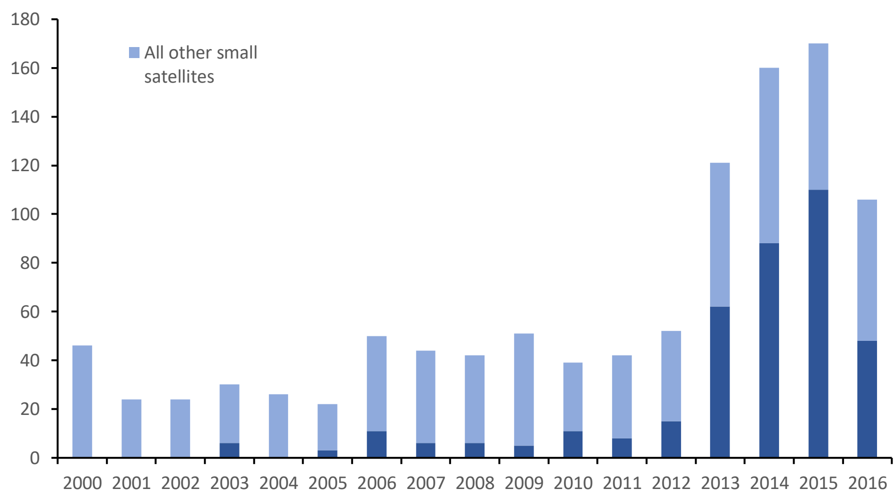


Figure 107: Number of small satellites (≤600 kg), launched between 2000 and 2016[208]

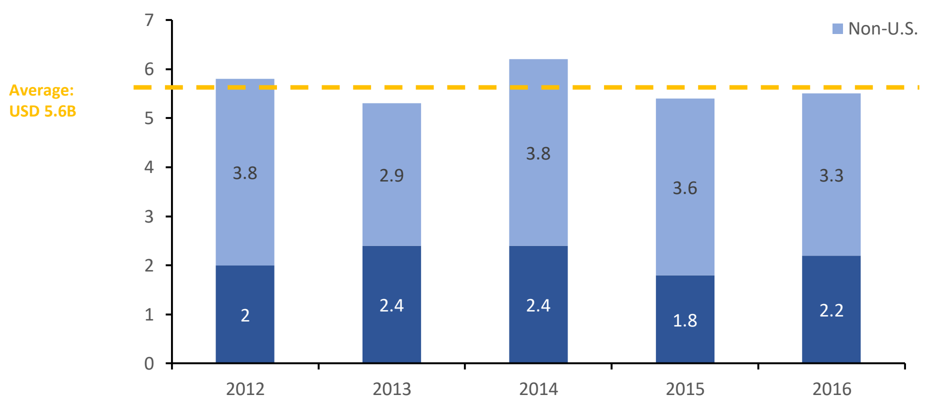
The advent of small satellites and CubeSats offering good performance with a mass in the tens of kilograms and hence at a fraction of those cost of a classical big space mission has changed the ecosystem considerably (Figure 107).

With increased demand, rocket launch start-ups such as SpaceX, Rocket Lab, Vector Space Systems, Blue Origin and Virgin Galactic/The Spaceship Company **moved into the launch sector**, aiming to compete with Arianespace, ILS, ULA and others. While SpaceX, Blue Origin and Virgin Galactic/The Spaceship Company aim to create synergies with their space tourism activities, Rocket Lab, Vector Space Systems and others focus entirely on the Micro Launcher segment, which deliberately provides launch services for the very small satellites with masses of a few hundred kilograms (Figure 108).

	Electron	LauncherOne	Vector H	Vector R	ARION2
Company	Rocket Lab	Virgin Galactic	Vector Space Systems	Vector Space Systems	PLD Space
LEO Capacity (kg)	150	400	100	60	150
First Flight	2016	2017	2019	2018	2021
Price	USD 4.9 million	USD 10 million	USD 3 million	USD 1.5 million	USD 4.5–5.25 million
Price/kg	USD 32 667	USD 25 000	USD 30 000	USD 25 000	USD 30 000–35 000

Figure 108: Micro Launch Vehicles with announced investment[209]

Optimised for this specific part of the launch service market segment, **Rocket Lab et al offer dedicated launch capabilities, but at a price tag of the order of USD 25 000 per kilogram or more—much more expensive than the USD 10 000 per kilogram launch cost benchmark**. Similar to the economy of scale, rockets become more cost effective the bigger they are—a rocket that can launch twice the payload mass will not be twice as expensive as operational costs, while engineering costs will not scale 1:1.



Total [bn USD]	5.8	5.4	5.9	5.4	5.5
Growth Rate	21%	–7%	9%	–9%	2%

Figure 109: Satellite launch industry revenues between 2012 and 2016[210]

While a small satellite will be able to afford a specific launch price of USD 25 000 per kilogram or more, the operator of a 5000 kg telecoms satellite will certainly take a closer look if the launch provider asks for USD 5000, USD 100 000 or USD 200 000 per kilogram. Price is therefore an important factor, and **SpaceX, aiming to compete with Arianespace, the market leader with a typical market share of more than 50 % (see Figure 109), had tried to obtain a significant market share by offering a launch discount of 40 %**. As important as launch costs are, they are, however, not the only selling argument in a market segment that is becoming more and more competitive.

A recent report by Goldman Sachs[211] compared an Ariane 5 launch with a Falcon 9 launch, stating that **the Ariane 5 is more expensive (USD 18 700/kg versus USD 11 300/kg), but simultaneously provides a much higher probability of mission success (96 % versus 91 % success rate)**. Ariane 5 has been accident-free since 2002, with 77 consecutive successful launches, while SpaceX has suffered two failures in the past two years.

Prior generation		Next generation		Change
Rocket	USD/kg to LEO	Rocket	USD/kg to LEO	%
Proton	4.565	Angara A5	4.167	–9 %
Ariane 5	8.476	Ariane 6	4.762	–44 %
Falcon 9*	4.654	Falcon 9 FT*	2.719	–42 %
N/A	N/A	Falcon Heavy*	1.654	N/A
H-IIA/B	6.818	H3	5.000	–27 %
GSLV	9.400	LVM3	7.500	–20 %
Saturn V	22.857	SLS	3.268	–86 %
Atlas V/Delta IV	11.093	Vulcan	6.378	–43 %

Figure 110: Dropping specific launch costs for the next generation of launchers[212]

Figure 111: A lunar base with a mass driver (the long structure that goes toward the horizon)[213]

While this 5 % difference does not look striking at first, it makes a huge difference when one wants to insure the satellite. A satellite placed in geostationary orbit can be worth hundreds of millions of dollars, making the difference between a 90 % and a 100 % launch success rate substantial. According to industry sources, **the cost of insuring an Ariane 5 is one third that of a Russian Proton launcher**. The Proton rocket has suffered five failures in six years, including an accident in 2015 that destroyed a MexSat payload insured for approximately USD 390 million. Assuming insurance rates of about 5 % for an Ariane 5, a 3× insurance rate for the Proton launcher would essentially add nearly USD 40 million to the Proton's price relative to Ariane, without factoring in lost revenue. SpaceX's failed launches would imply that they are likely to see higher insurance rates as well.

As the competition unfolds due to new entrants, launch prices drop. The next generation of launchers is expected to feature launch prices well below the USD 10 000/kg threshold. Based on data from institutions such as the FAA and NASA, Goldman Sachs assumes an average price drop of 38 % (Figure 110).

It remains to be seen if specific launch costs of presumed USD 1654 per kilogram for SpaceX' Falcon Heavy are sufficiently low to allow the rollout of space-based solar power (Figure 112) systems, lunar bases (Figure 111), asteroid mining concepts (Figure 98 and Figure 112) and a crewed mission to Mars.

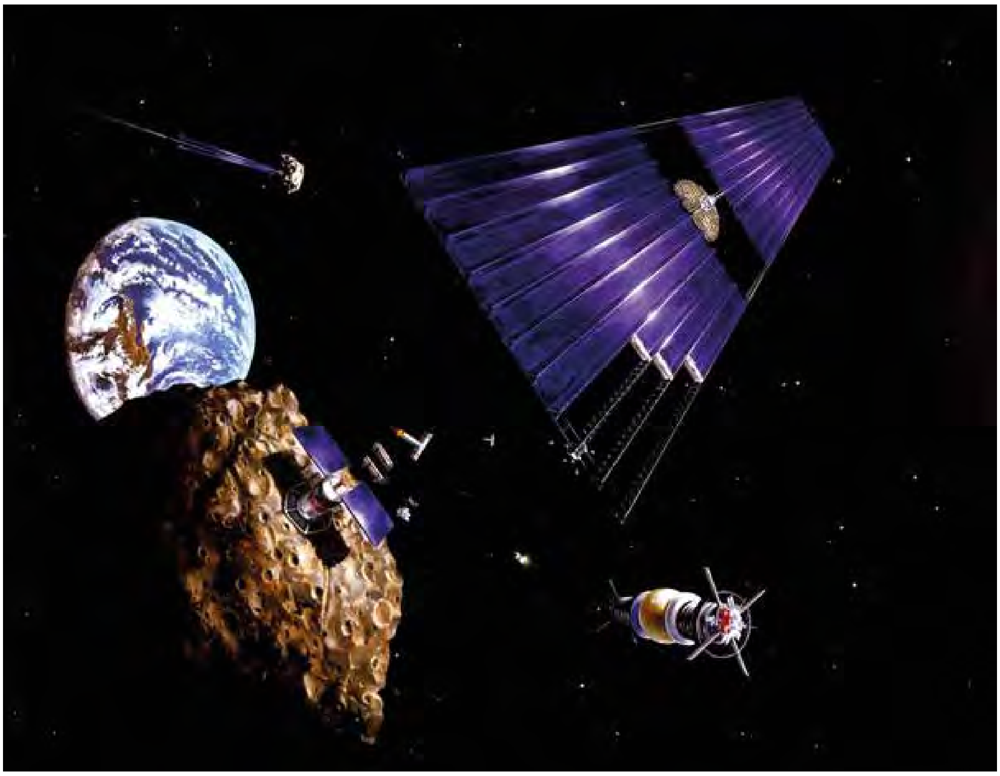


Figure 112: A NASA concept of a solar power satellite built from a mined asteroid[214]

6.2.9. Miniaturisation and nanotechnology

Element	Assessment
Affected market segments	1–8, nanotechnology is a game changer for everything (see Figure 8)
Enabling	Cheaper and smaller systems; stiffer and best performing structures; self-repairing and -replicating systems
Innovation type	Sustaining–evolutionary for miniaturisation (see **Table 7** and Table 6) and disruptive for nanotechnology
Specific financing needs	Limited to high (miniaturisation is mostly thriving on Moore's Law and some advances in new materials, while nanotechnology does still require a considerable amount of R&D to develop the "universal assembler", miniature Power Control and Distribution Unit (PCDU), nanoscale energy storage systems, nanoscale control systems and computers, etc.)

There are those who say that miniaturisation gave the US the leading edge in the space race. If one compares the size and mass of Explorer 1, the first satellite by the United States (13.9 kg, 205 cm length, 16 cm in diameter), with Sputnik 1 of the USSR (83.6 kg, a sphere with a diameter of 58 cm) and bears in mind that Sputnik 2 (a circular cone 2 m in diameter with a height of 4 m and a mass of 508.3 kg), launched less than a month after Sputnik 1 with the very same R-7 rocket, the Russian rockets were certainly more powerful than the US ones. **The only way the United States could compensate this launcher performance gap before stronger rockets became available to them was to miniaturise their satellite sub/systems to the utmost.** This gave a lot of impetus to the development of modern electronics and led to the replacement of tubes by transistors, having a profound effect on integrated circuits (IC), microprocessors and VLSI electronics, with their continued evolutionary development being governed by Moore's Law.

Although nanotechnology may seem a mere extension of miniaturisation—since it takes miniaturisation to the atomic level—this statement could not be further from the truth. **Nanotechnology entails a profound change in how we will interact with nature, as it allows us to directly manipulate matter at the atomic level** (Figure 113).

Nanotechnology (Greek νάννος = dwarf) is the direct manipulation of matter at atomic scales (< 100 nm)

- Origin: "There Is Plenty of Room at the Bottom", R. Feynman lecture, 1959
- Popularised by Eric Drexler
- Application areas:
  - ✓ Medicine (arteriosclerosis and cancer treatment, immune system, implants)
  - ✓ Computers and Robotics (computers on nano basis; nano robots/Nanites)
  - ✓ Materials (nanotubes, defect-free structures, quantum dots)
  - ✓ Process technology (self-organisation und reproduction, recycling)

Figure 113: Nanotechnology—origin and potential applications

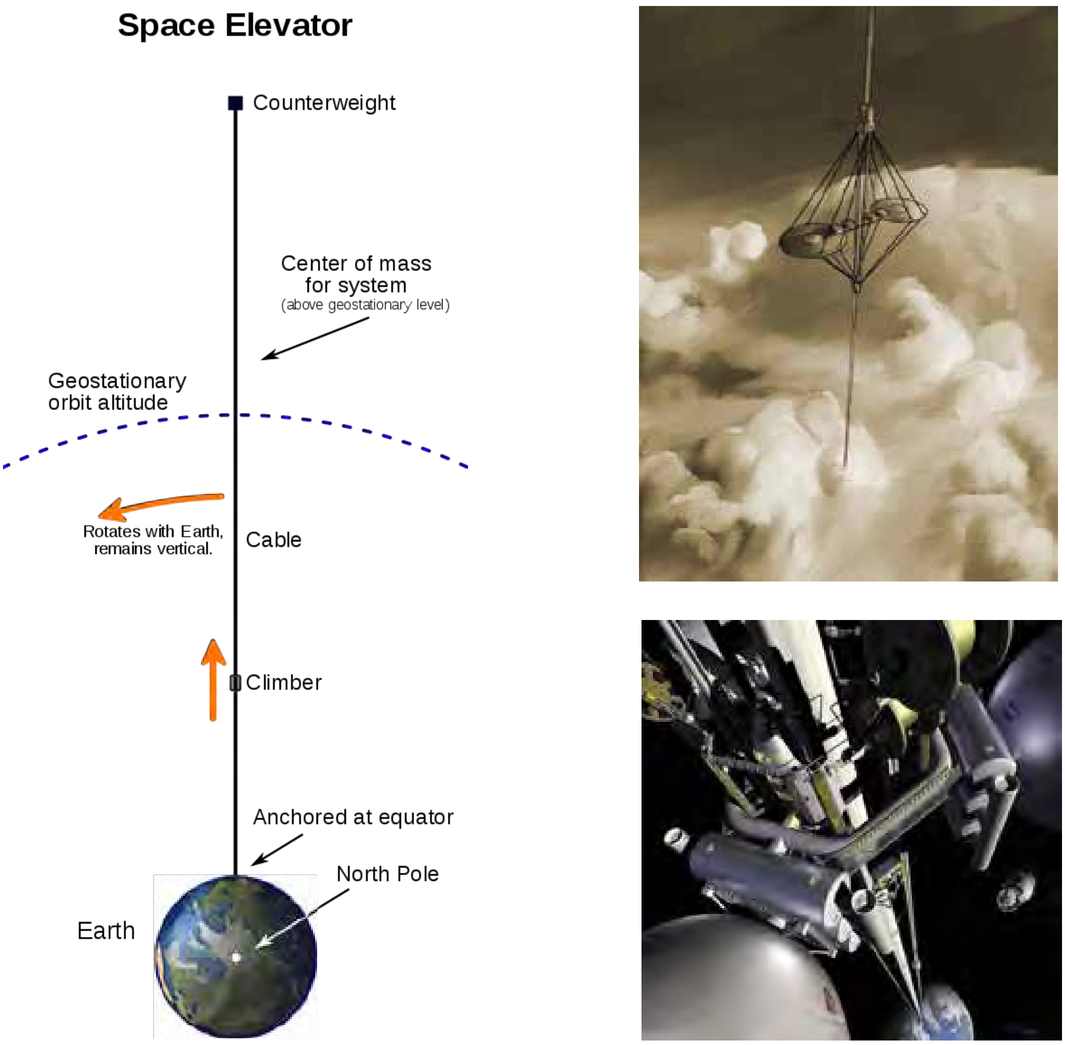


Figure 114: A space elevator concept using a tether made out of e.g. carbon nanotubes[215]

Figure 113 outlines some of the potential applications, which range from medicine, computers and robotics to materials and process technology. Space will benefit in numerous ways from nanotechnology. **Nanomedicine** will support the immune system such that it will augment the natural repair mechanism to the extent that astronauts will be able to survive radiation doses far beyond levels at which health risks start to emerge today. **Nano-based computers and robotics** will allow faster and more robust computer and robot systems, supporting swarm intelligence and behaviour. The most profound effect, however, will come from **nanomaterials** (e.g. carbon nanotubes and -balls, graphenes), providing failure free structures with superior material strength characteristics to such an extent that it may be possible to build a space elevator ranging from the Earth's surface to geostationary orbit at 36 000 km altitude and beyond (Figure 114). In this respect, nanotechnology takes the promises of **advanced materials** (like superalloys such as gamma-titanium-aluminide or metal–ceramic matrices, carbon fibre reinforced plastics (CFRP), as well as combinations of CFRP and other resin materials with metals, etc.) further, to unprecedented levels.

While the aforementioned items are individually already disruptive, the last item is especially disruptive. **Process technology** will be the ultimate game changer, as it will enable self-organisation and reproduction, as well as perfect recycling. Figure 115 shows how a nanoproduction facility would work.

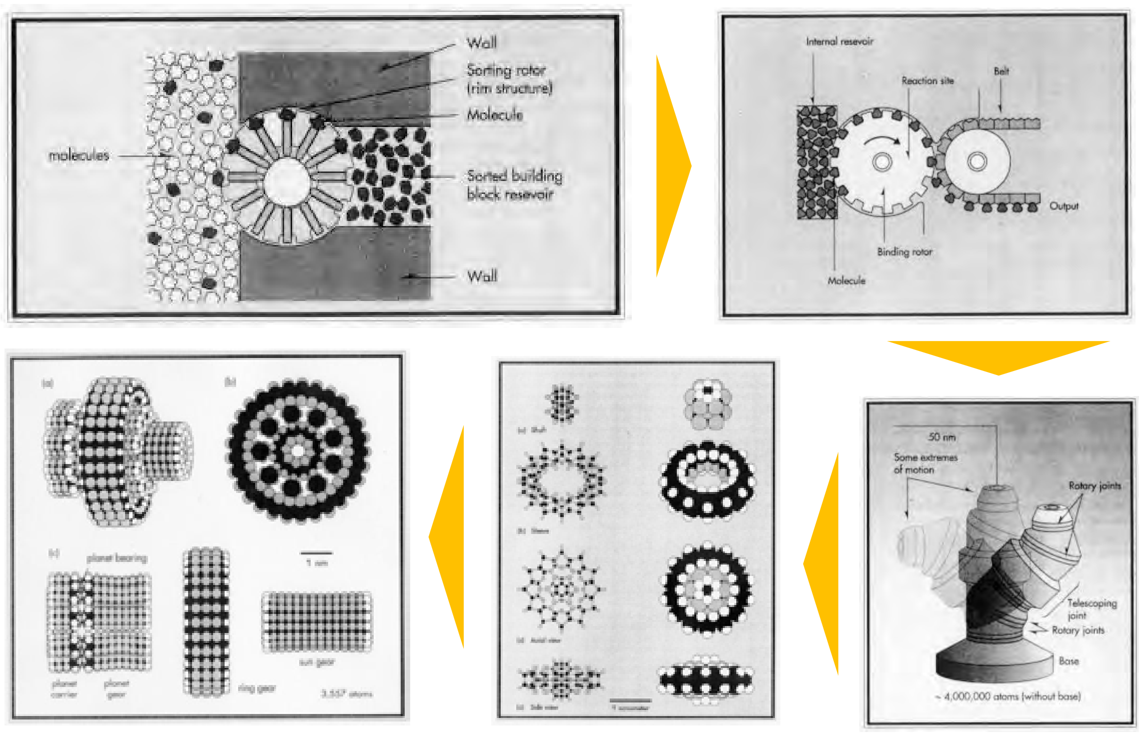


Figure 115: Schematic of a production of a molecular planetary gear with a single atom[216]

Similar to the "Industry 4.0" approach, a production based on nanotechnology will be able to fully customise the production of specific elements, systems and units. Unlike an Industry 4.0 facility, however, **the nanotechnology factory will not use radio frequency identification tags to align and integrate preassembled parts, but rather rely on a universal assembler** (the lower right image in Figure 115) to properly assemble all parts.

Starting with an **atomic/molecular extractor** (upper left image in Figure 115), working similarly to an enzyme in our body, the right atoms/molecules are picked from a material reservoir (it may be some pool of scrap material that needs to be recycled), stored and transported by **nano-conveyors** (upper right image in Figure 115) to the universal assembler, which will then place the atoms in the designated form and shape (lower middle image in Figure 115) such that at the end a planetary gear has been produced at the atomic level.

To a certain extent this may sound like science fiction, but **nature is using the very same principles of nanotechnology in most of its biological processes** (e.g. when replicating DNA); instead of a universal assembler, however, nature relies on enzymes to modify substrates into products that can be used by the metabolism. Enzymes, however, are all proteins, so they are sensitive to high temperatures: above 40°C they start to break down. The human body contains around

3000 unique enzymes, each speeding up the reaction for one specific protein product; the optimum temperature for the enzyme-related processes to take place is 37°C—the normal core temperature of our body.[217] What sounds like science fiction, is state-of-the-art in every biological system and what we call life. Nanotechnology is to some extent the technical analogue to life and naturally, **industrial biotechnology** has therefore a very strong overlap with it.

Once nanotechnology has been mastered (hence, when we are able to construct the first universal assembler, along with its control and power system), the ultimate disruption will unfold, in that a **nanotechnology system will be able to replicate itself, thereby breaking once and for all the vicious circle of advanced systems having surmounting complexity costs** (Figure 96). With the help of nanotechnology, complex systems can be built at miniscule cost, as such systems build themselves in an autonomous way—it would be like a car that assembles itself within a factory.

6.2.10. Optical and ubiquitous communications

Element	Assessment
Affected market segments	1–8, high impact on 5, 6 and 8; however, space is more an enabler than a benefactor (see Figure 8)
Enabling	Ubiquitous communication; M2M data exchange; holistic insights into events ongoing worldwide
Innovation type	Disruptive, as it is at the root of mobile Internet (see Table 6)
Specific financing needs	Medium to high (R&D and bridge financing need to be provided to further develop and commercialise space-based optical communication systems)

Already trialled (e.g. with SILEX between Artemis and SPOT 4), space optical communication is a necessary extension to cope with the data generation and transportation demands of the future (see Table 41 and Figure 105). In addition, the radio frequency (RF) spectrum is already overcrowded, not leaving too much space for new services that demand bandwidth for data transmission (Figure 116).

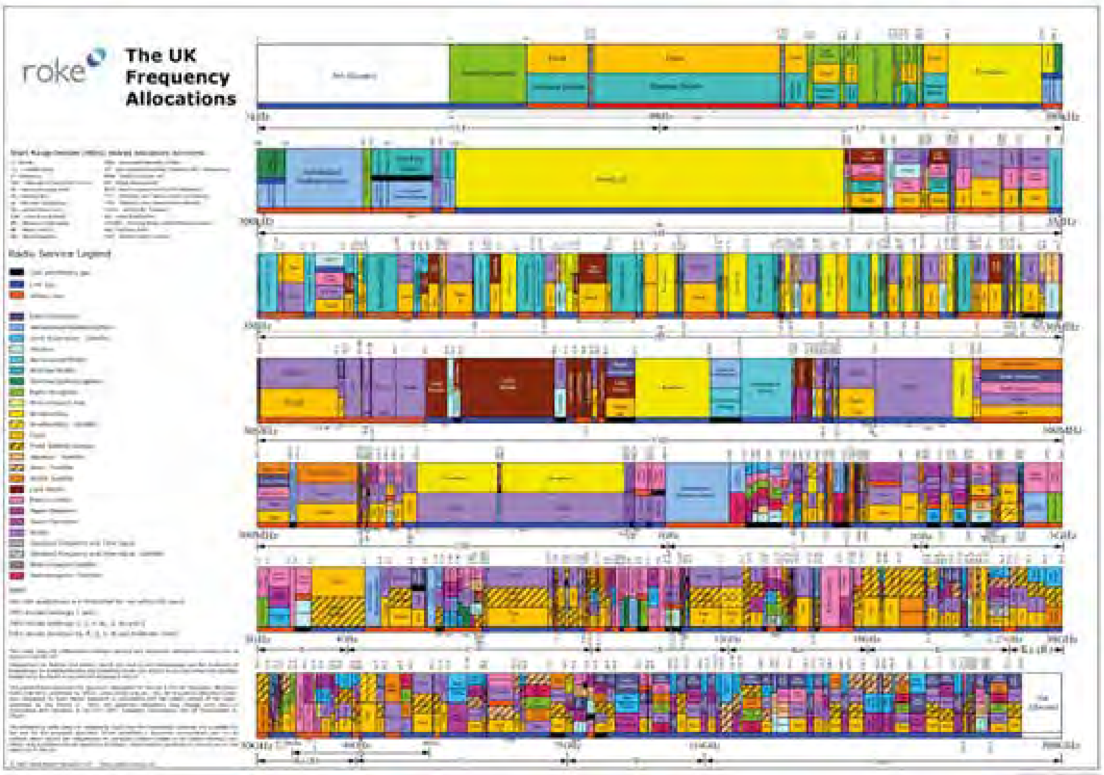


Figure 116: Radio frequency spectrum of the United Kingdom[218]

While **NASA, ESA (EDRS, Figure 117) and JAXA (Japanese Data Relay System) have set up space optical systems, R&D efforts are still ongoing, standards are yet not entirely harmonised (e.g. used wavelengths of 1550nm and 1064nm) and a network of ground stations is yet to be built**. Consequently, it will take a while until commercially available systems are entering the market.

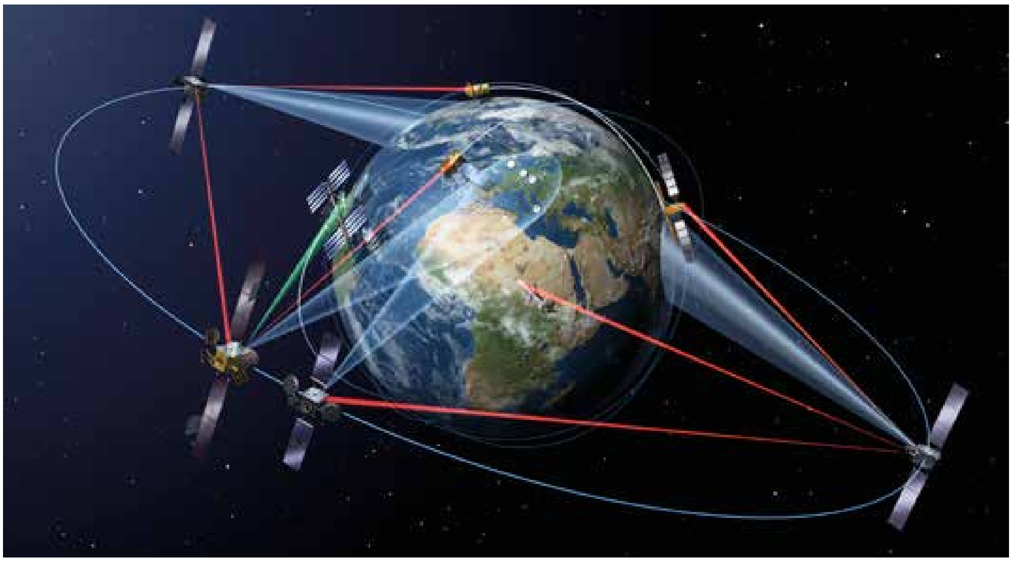


Figure 117: Schematic of the European Data Relay System (EDRS)[219]

The advantages of optical communications are manifold. When NASA conducted its **Lunar Laser Communication Demonstration (LLCD) in 2013, data was returned from the moon at a ground-breaking record of 622 megabits per second (Mbps)**, which is equivalent of streaming more than 30 HDTV channels simultaneously.[220] Consequently, space optical communications play a key role in NASA's future plans for crewed missions to deep space using the Orion spacecraft.

ESA's EDRS is already operational. EDRS-A has been in orbit since 2016 and EDRS-C will follow in 2018. EDRS-D is in the planning stage. The Copernicus Sentinels 1 and 2 series use a laser communications terminal (LCT) working at 1064 nm offering a data rate of 1.8 gigabits per second (Gbps) over a distance of 80 000 km.[221]

The follow-up to EDRS, dubbed **GlobeNet, is poised to start in 2023**. It is an EDRS evolution, featuring multiple LCTs on board EDRS-D. Phase B has started, with investment coming from Airbus D&S. GlobeNet will provide data relay services to the Pacific Rim. Ground segments are to be installed in Australia and Japan to allow a global quasi-real-time service such that Sentinel data taken over the Pacific will be delivered to Europe via a GEO–GEO link.

Given the advantages of space optical communications, a **data relay will enable** the following applications:

- space network technology for all kind of constellations or backbone capabilities;
- space–air communications (aeroplanes, uncrewed aerial vehicles);
- LEO–ground communications (e.g. for SAR or security applications);
- GEO–ground (high-throughput satellites, feeder links);
- vision of "all optical satellite" (on-board photonics and laser com);
- quantum technologies/quantum key distribution systems.

As a commercial market is yet to emerge, it is key to enable an environment in which ventures related to space-based communications systems can flourish. These ventures are likely to perform their activities in NewSpace mode, and hence with a business model building upon the following pillars:

- space is ***not a destination***;
- space is an ***enabler*** for a variety of business verticals;
- space accelerates and expands business verticals by providing ***new, disruptive ways of doing business*** that are ***faster, cheaper and better***.

Under this mantra, **governments may catalyse and accelerate space-related businesses**. Space-based infrastructure projects (such as Galileo) **can serve as precursors for space-related applications.**[222] **The globalisation of data access by installing and operating:**

- one or two **ubiquitous communication constellations** and
- the data stream truncating function by means of an **optical communications links system**

will be key to allow global **autonomy applications and services**. This will trigger the advent of a suite of **novel commercial apps and services**.

6.3. Case study: the convergence of commercial EO and space reconnaissance

6.3.1. Introduction

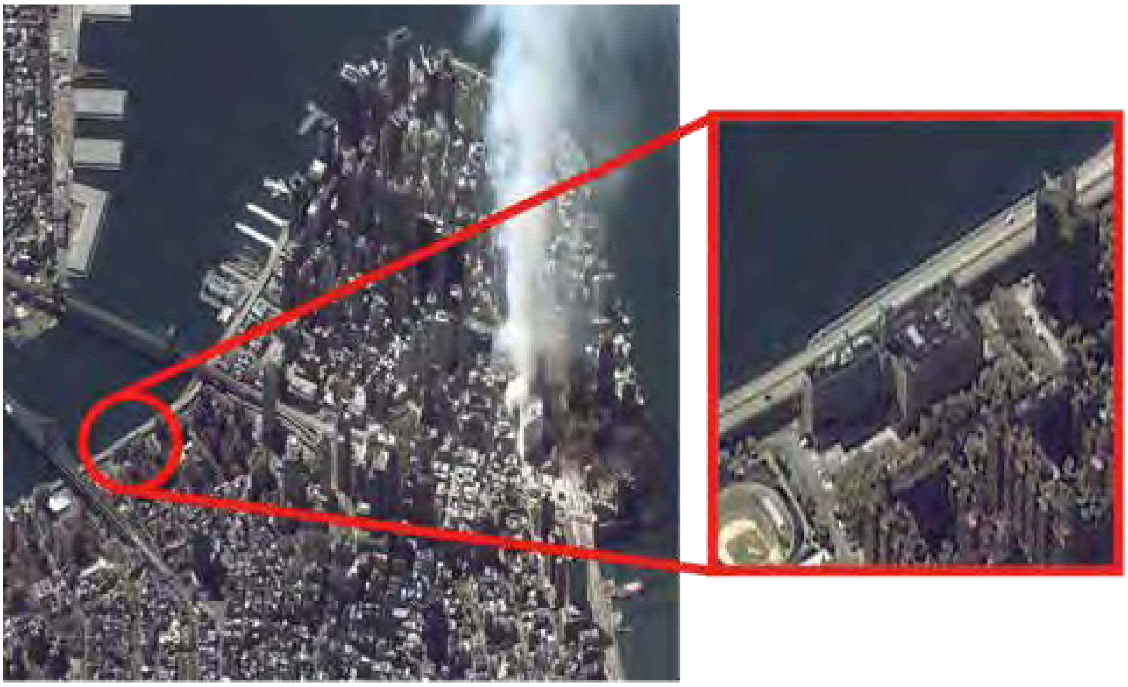


Figure 118: Downtown Manhattan as seen by the IKONOS satellite on 12 September 2001[223]

The power of Earth imagery became obvious to the general public for the first time on 11 September 2001. Due to the terror attacks on the World Trade Center and other sites, all aeroplanes were banned from the US skies for several days. Consequently, it was up to Earth observation (EO) satellites such as IKONOS to provide exclusive images of "Ground Zero", as depicted in Figure 118. Launched two years earlier and operated by DigitalGlobe, IKONOS was the first of its kind: a commercial EO satellite providing images in four visual bands with a resolution as high as one metre, demonstrated on the right-hand side of Figure 118, where a close-up clearly shows cars driving along the highway on the waterfront.

6.3.2. From science and Earth observation to "Battleground Space"

Earth Observation was one of the early applications of spaceflight. When the first rockets were launched into space after World War II, science and reconnaissance were the main drivers. **Over time, space has seen an ever increasing military utilisation** showcased by purposes such as:

- navigation (GPS);
- space reconnaissance (especially observation of foreign intercontinental ballistic missiles (ICBMs));

- control of own ICBMs and long-range guided missiles (performed by US/USSR);
- communication;
- the strategic defense initiative (SDI).

The SDI was a proposed missile defence system intended to protect the United States from an attack by ballistic strategic nuclear weapons (ICBMs and submarine-launched ballistic missiles (SLBMs)). Announced by US President Ronald Reagan on 23 March 1983, efforts to develop SDI systems continued through the 1980s up to 1993, when political support for SDI collapsed due to the end of the Cold War.[224]

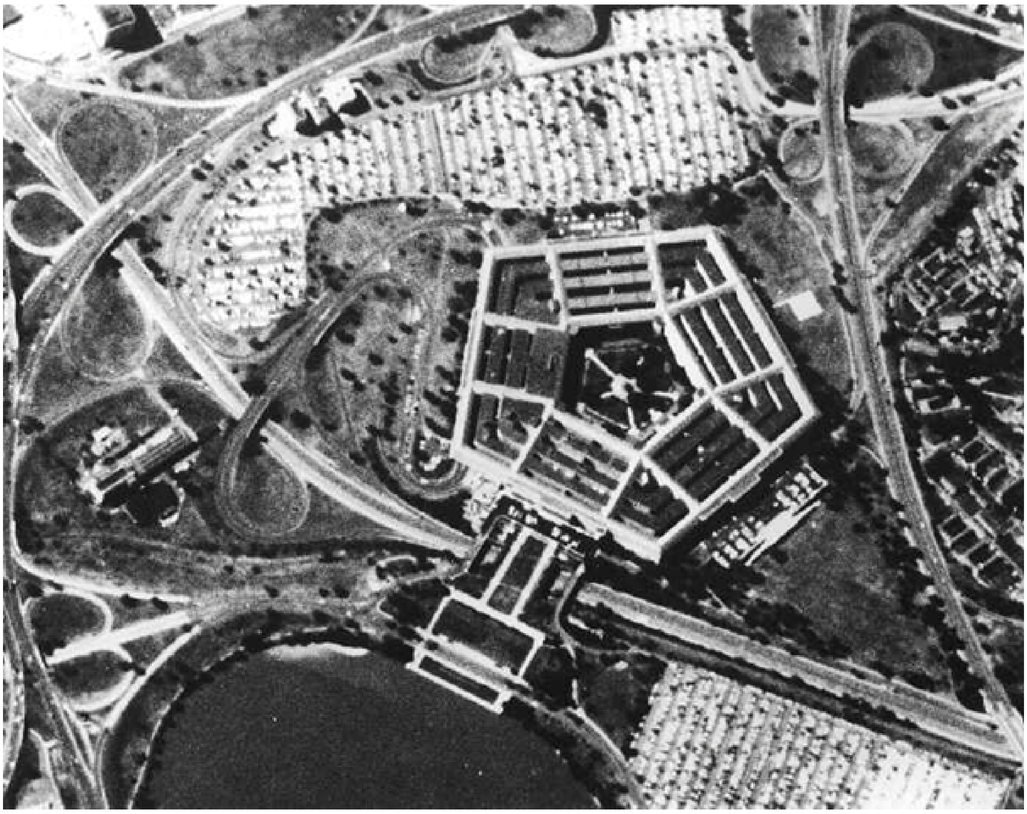


Figure 119: Image of the Pentagon, made by a Corona Spy Satellite on 25 September 1967[225]

While SDI never became operational, the militarisation of space continued. In 1985, the US set up the United States Space Command (USSPACECOM) to oversee US space activities. **Space assets gave the coalition in Operation Desert Storm (1990–1991) a decisive edge, and later operations in the Balkans, Southwest Asia, Afghanistan and Iraq relied heavily on space-based command and control, communications, surveillance and intelligence, navigation and weather systems.** In 1992, a new single command responsible for all strategic nuclear forces was formed: the United States Strategic Command (USSTRATCOM). The new command's principal mission was to deter military attacks, especially nuclear attacks, on the United States and its allies, and to employ nuclear forces if deterrence failed. Both commands were finally merged in 2002, leading to the creation of USSTRATCOM, which is still active today;[226] its mission has enlarged to employ tailored nuclear, cyber, space, global strike, joint electronic warfare, missile defence and intelligence capabilities to deter aggression, decisively respond if deterrence fails, assure allies, shape adversary behaviour, defeat terror and define the force of the future.[227]

Figure 120 depicts **the seal of USSTRATCOM**, with the history and legacy of strategic and space operations being represented. One of the many symbols in it is **the globe as viewed from space, symbolising the Earth as the origin and control point for all space vehicles and representing the command's span of operations**. The various emblem colours represent the joint character and rigour of the command: in particular, the blue command designation band represents the command's air-based and responsive ballistic missile force, agile bomber assets, aerial refuelling, reconnaissance aircraft and airborne command platforms.[228]

Figure 120: Seal of the United States Strategic Command[229]

6.3.3. Air and space reconnaissance in the Cold War

While **reconnaissance had always played an important role in times of conflict, the end of World War II and the start of the Cold War gave it a clear primary role, fuelled by the two buzz words "bomber gap" and "missile gap"**. Both Cold War terms were used in the US in the 1950s and 1960s for the perceived superiority of the number and power of the USSR's bombers and missiles in comparison with the systems available to the US. Sparked by ICBM tests performed by the Soviets in August 1957 and the successful launch of Sputnik I in October 1957, the United States began to believe that the Soviet Union possessed superior missile capabilities that directly threatened the US mainland. Moreover, US military and intelligence agencies projected that the Soviet Union would be likely to improve its missile technology significantly, as well as increase its numbers of nuclear missiles relative to those of the United States. The Gaither Report, issued in November 1957, gave a comparative analysis of the state of US and Soviet nuclear forces and presented policy proposals. It argued that US nuclear strategy could no longer be built around its superior strategic bomber force and its destructive capacity, because those could be neutralised by a preventive surprise missile attack.[230]

Figure 121: USAF Lockheed U-2 Dragon Lady[231]

Quantifying the bomber and missile gap was the task of the hour and efforts were made to obtain reconnaissance data of the presumed large numbers of bombers and missiles hiding behind the Iron Curtain. The tool of choice to obtain such information was the U-2, a US high-altitude reconnaissance aircraft, built by the Lockheed Skunk Works, which saw its introduction into service in 1957. With a range of more than 6000 nautical miles, a service ceiling of nearly 85,000 ft (25.9 km) and an endurance of 12 hours, the U-2 was believed to be out of range for Soviet radar, interceptors and incoming missiles.[232]

The **shooting down of a U-2 on 1 May 1960** proved that this assumption was wrong, when Francis Gary Powers performed a deep-penetration Soviet overflight crossing the USSR on a planned route starting in Peshawar, Pakistan and ending in Bodø, Norway.

The CIA designation for this 24th deep-penetration Soviet overflight was Operation GRAND SLAM, and what looked like a successful mission for the first four and a half hours into the flight turned out to be a disaster when **the Soviets fired three SA-2 missiles at the spy plane over Sverdlovsk**. One of these detonated behind the aircraft at 70,500 feet and made the U-2 crash in the USSR. The pilot survived the crash and got captured; the U-2 was not entirely destroyed, allowing the Soviets to identify much of its equipment. A public trial starting in August 1960 was set up to disgrace the US and saw Powers being sentenced to three years in prison. He got finally exchanged for Rudolf Abel on 10 February 1962[233]—a first-ever spy exchange, which has been nicely covered in the recent movie "Bridge of Spies" featuring Tom Hanks.

While the shooting down of Powers' U-2 did not halt the use of the U-2 as a reconnaissance aircraft,[xxviii] **it nonetheless accelerated the satellite reconnaissance programmes, notably Project Corona, a US strategic reconnaissance satellite programme** that had already started in June 1959.

6.3.4. Corona: the first US spy satellite

The Corona programme was a series of US strategic reconnaissance satellites produced and operated by the Central Intelligence Agency (CIA) Directorate of Science & Technology with substantial assistance from the US Air Force (USAF). The Corona satellites were used for photographic surveillance of the USSR, the People's Republic of China and other areas between 18 August 1959 and 25 May 1972.[234]

As is typical for secret programmes, several other names have been used for Corona, such as Discoverer and Samos. Bearing in mind that Corona is only the first US spy satellite system in a long series of follow-up programmes, several names have emerged for the different US spy satellite systems, such as Argon, Lanyard, Gambit. This plethora of names should make it more difficult to track and sort the different systems. Luckily, however, there is a common element to all these programmes: the main imaging payload, which is designated "Keyhole" or "KH". Looking for KH will therefore relatively easily provide a listing of US spy satellite systems. **In the case of Corona the camera systems in use were KH-1 to KH-4, as well as KH-4A and KH-4B**.

When Corona was launched, charge-coupled device (CCD) systems were still futuristic science fiction; the state-of-the-art camera system relied on chemical film that had to be stored, moved forward on a reel, exposed image-by-image and finally processed in a chemical laboratory. Consequently, **a Corona mission was complex**, as depicted in the picture sequence in Figure 122.

A typical Corona mission lasted for 19 days. Launched by a THORAD-AGENA booster, the satellite was delivered in a 186 km x 280 km polar orbit to perform its reconnaissance objectives. While early satellites had a mass of 780 kg, later generations, such as the KH-4B depicted in the middle right image of Figure 122, were as heavy as 2000 kg. Since the system relied on chemical film, a complicated film transport mechanism had to be used to store and process the photographs. In the end **the system was required to handle up to 4900 m of film for each of the two cameras, giving a total of 9800 m of film carried on board.**[235] Once the film had been exhausted, the final part of the mission sequence was initiated, cumulating in a very particular and spectacular feature of every Corona mission: the recovery of the descending Corona capsule by an aircraft, depicted in the lower right-hand corner of Figure 122.

xxviii The current model, the U-2S, received its most recent technical upgrade in 2012. Recently, U-2s have taken part in post–Cold War conflicts in Afghanistan and Iraq and supported several multinational NATO operations. The potential retirement of the U-2 is on hold until 2019 (according to Breaking Defense (2015) Air Force, Riding Budget Boost, Warns on Sequester U-2 Is BACK! https://breakingdefense.com/2015/02/air-force-riding-budget-boost-warns-on-sequester-u-2-is-back/; accessed on 9 January 2018).

The aircraft to perform this specific task was a US Air Force C-119; typically, the capsule was captured at an altitude slightly lower than 5000 m.

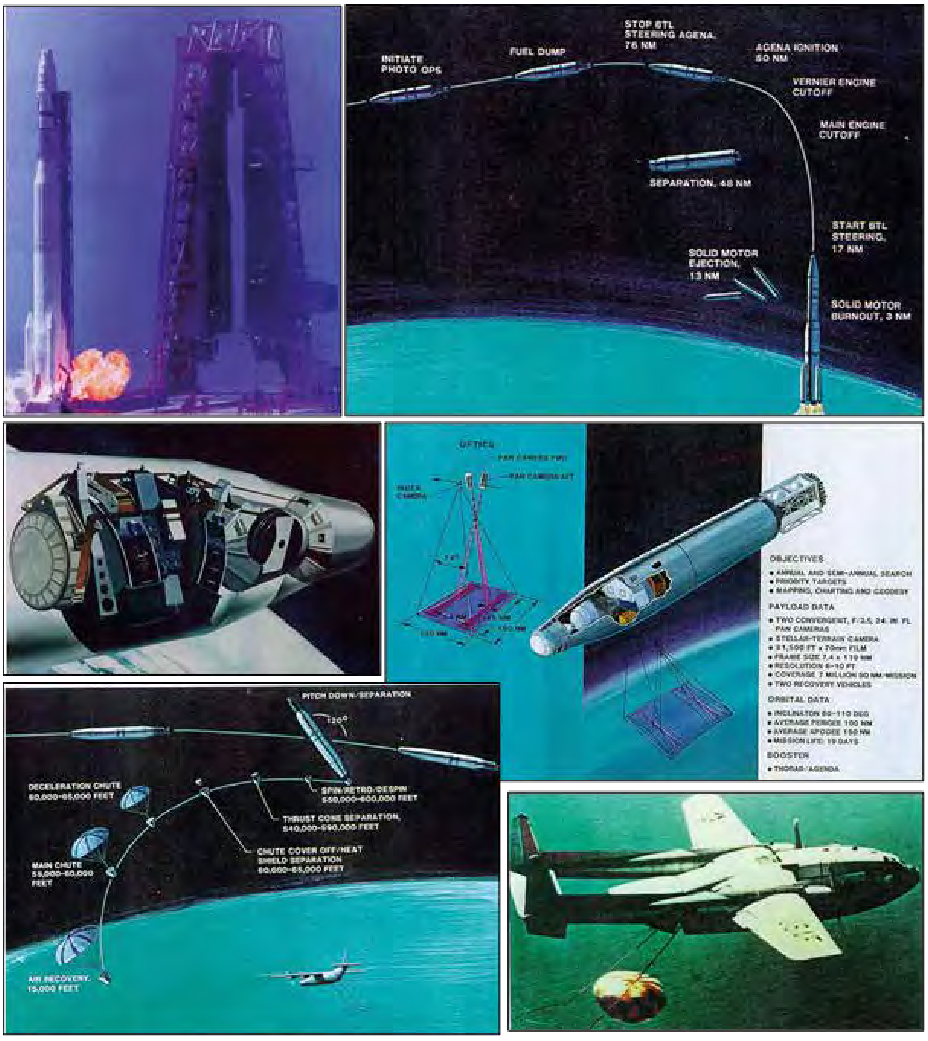


Figure 122: A typical sequence of a Corona reconnaissance mission[236]

Although they were very complex, **102 out of the 145 missions were very successful. In total 860 000 photographs were shot, 39 000 film canisters used and the land area covered amounted to nearly 2 billion square kilometres**. The resolution of the black and white images was astounding: 1.5–1.8 m were feasible: a typical photograph from the Corona programme is shown in Figure 119.

6.3.5. Argon, Lanyard, Gambit, etc.: Corona's offspring

If anyone was sceptical that spy satellites could deliver, the success of the Corona programme would have proved them otherwise. After Corona, spy satellites became the accepted tool of choice for the reconnaissance demands of the US Air Force, Army, CIA, NRO and others. **Consequently, spy satellite activities increased, culminating in several generations of reconnaissance satellites, each more performant than another.** Starting in 1962 with the 1274 kg KH-5 Argon, a programme lasting from 1962 to 1964 and encompassing 12 missions, of which 6 were successful, and finishing with the nearly 20 metric ton KH-12 Improved Crystal, which saw its first mission in 1990, ever bigger and heavier systems have been launched into orbit (see Figure 123 and Figure 124).

KH-11 Kennan (Figure 124) shows a striking resemblance to the Hubble Space Telescope (HST), depicted on the left-hand side of Figure 125. But while the HST is a unique piece of space hardware, its sister system KH-11 features a complete constellation of satellites to provide a continuous observation of the Earth (rightmost image in Figure 125).

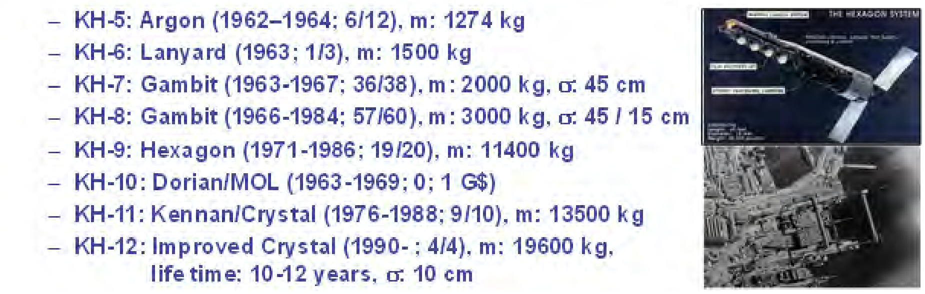


Figure 123: A list of US spy satellite programmes along with an image depicting KH-9 Hexagon, the last system, which relied on chemical film, and a computer-enhanced CCD-based KH-11 photograph showing the general layout of the Nikolaiev 444 shipyard in the Black Sea, with a Kiev-class aircraft carrier under construction[237]

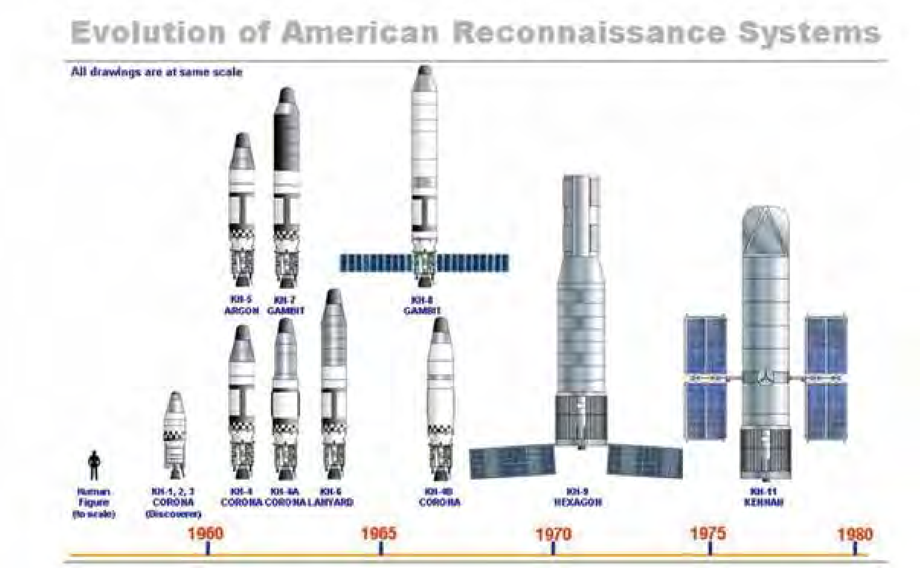


Figure 124: Size comparison of US spy satellite systems[238]

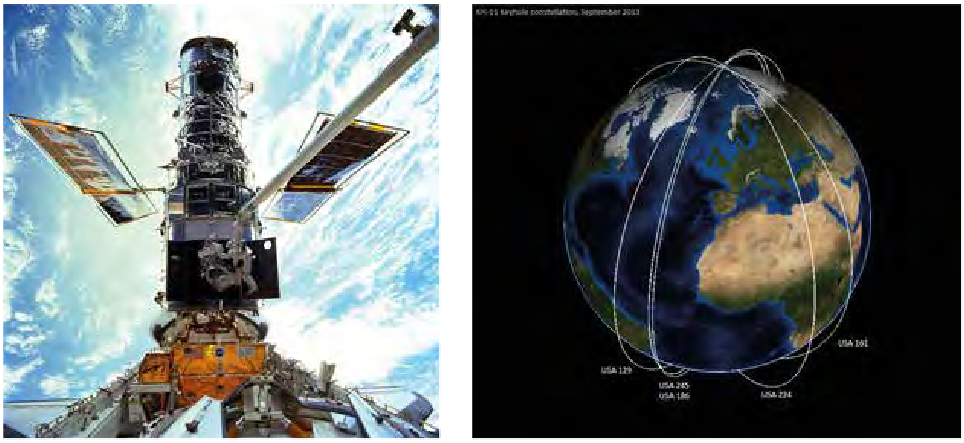


Figure 125: astronauts Steven L. Smith, and John M. Grunsfeld at work on the Hubble Space Telescope during Servicing Mission 3A[239] (left). KH-11 Satellite Constellation as of September 2013[240] (right).

The latest generation of optical US spy satellites such as KH-11 and KH-12 have resolutions higher than 10 cm. These optical systems are complemented by radar-based systems, with a somewhat limited resolution of 1 m, due to the wavelength difference between visible light and microwaves as well as volume and mass limits when it comes to launching large mirrors and/or microwave antennas (see Figure 130). This limited resolution, however, is largely offset by the radar satellites' observational capabilities at night and when a particular patch of land or sea is hidden beneath clouds. In addition, radar satellites enable different applications from optical satellites, and hence can largely complement humanity's picture of planet Earth.

Figure 126 **shows how the same object will appear in space-based reconnaissance sensors with different capabilities in terms of spatial resolution**. Bearing in mind that a radar satellite will in general feature a lower resolution than an optical satellite, the left image patch of Figure 126 may be attributed to the observation domain of radar satellites, while the right image patch of Figure 126 represents the capabilities of optical satellites. One could say that the bottom right image in the right patch represents the best observational capabilities of a modern radar satellite or of a first-generation commercial optical satellite, such as IKONOS, while the left upper image in the right patch showcases the capabilities of the KH-11 and KH-12 satellite systems.

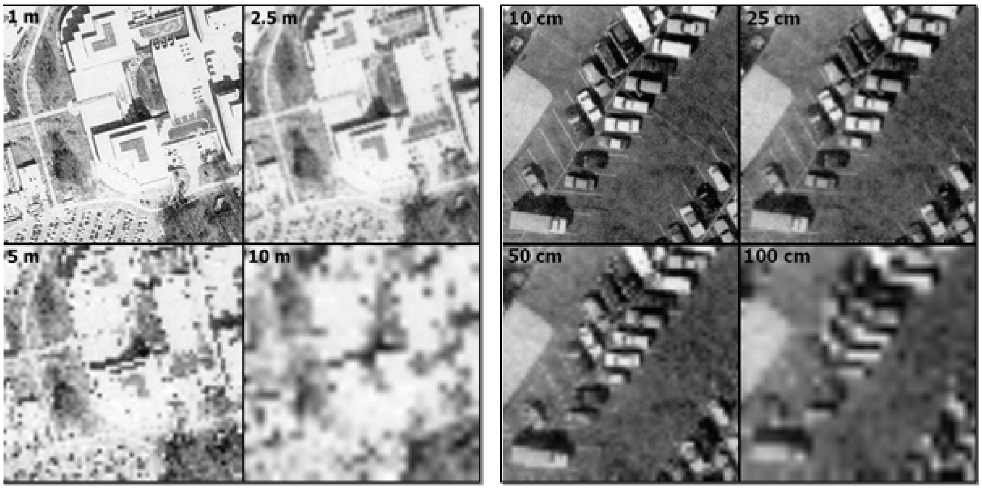


Figure 126: How the same area of interest will look differently when observed by satellites with different capabilities in terms of spatial resolution

Today it is not only the United States that uses EO satellites: Russia, China, Japan, India, EU countries and numerous others are reliant on the continuous view on Earth. The reasons range from pure commercial and civilian purposes to 100 % military objectives, with a floating dual-use area in between. And while modern peace-loving societies often tend to condemn everything related to military use, they should not forget that in recent decades it has mostly been the spy satellites that have tracked military movements, were instrumental in assessing the "bomber gap" and provided insights into the planning by the Cold War adversaries. In the end, **one may even argue that it was due to information from the spy satellites that the Cold War remained cold and never turned into a hot war**.

6.3.6. Public–private partnerships for space reconnaissance projects

Triggered by the success of spy satellites, **the security dimension of space increased over time**. Today, space is used for navigation, Earth reconnaissance (especially relating to ICBMs), control of own ICBMs and long-range guided missiles, communications, early warning and more. However, times have changed; the Cold War is history and so is the threat of nuclear annihilation and the confrontation of West versus East, which provided the incentive to run large space programmes such as Apollo—using space as an arena to show one's scientific, technological, economic and even societal strength to the adversary.

Still, national security remains a primary objective of many countries and EO has proven its worth for other application beyond reconnaissance, such as urban planning, environmental monitoring and protection and tracking applications. **Dual-use is the buzzword of the hour.** Europe's Copernicus programme is a master showcase for a dual-use EO programme, while GeoEye serves as a great example of an EO satellite built in a PPP fashion (see Figure 127).

Launched in 2008, **GeoEye-1 is a pioneer of the most recent EO satellite generation, serving the interests of both civilian and military users**. It features a very high resolution of 0.41 m and can perform observations on several bands and at wide angles.

Figure 127: Key features of the GeoEye-1 satellite[241]

While resolution is always a key specification of every EO satellite, one particular difference between the typical commercial/civilian user and the military user is the maximum time that it may take until an acquired image is made available to the user and how quickly a specific area of interest can be revisited. Time is of the essence—particularly for the military user. In a military campaign one wants to know as quickly as possible what adversaries (and your own assets) are doing, how a campaign is progressing and how things are developing ("**change detection**"). Therefore, image transmission and processing need to be fast, and several satellites are needed to be able to provide a frequent observation of the area of interest. Consequently, companies such as the Satellite Image Corporation have not only one satellite like GeoEye-1 in their portfolio but several, with the latest (WorldView-4) offering a resolution of 0.31 m (close to the upper right image in the right patch of Figure 126).[242]

As the applications and services in the space and security domain have increased, so has the number of players. Today, EO is one of the most vibrant application domains in space, serving both civilian and military users, often at the same time (see Figure 128).

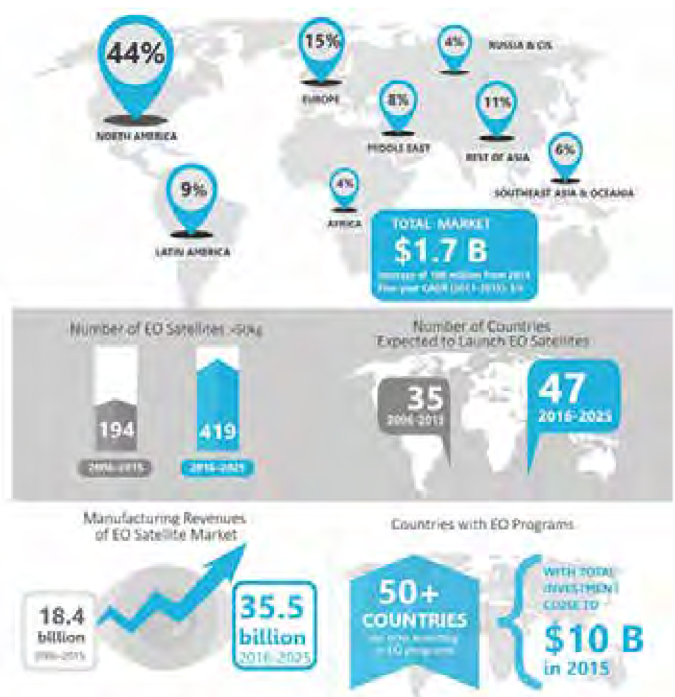


Figure 128: Current and forecasted commercial data demand in the Earth observation market for different regions[243]

6.3.7. Small is beautiful? Smallsats and Earth observation

As picturesque as a high-resolution image of a particular place on Earth may be, several applications and services (e.g. harvest forecasting, deforestation monitoring, EO data collection for insurance purposes and urban planning) do not demand EO data in the centimetre range. For such applications, resolutions of the order of 2.5–5 metres are sufficient (see Figure 126, left patch of images). In addition, these resolutions are also those of choice for "**change detection**" approaches employed by military users (see the discussion on resolution in the previous subsection)—best realised by a mix of very few high-resolution satellites and a large constellation of low-resolution satellites. **While the high-resolution satellite will observe the areas of interest once every few days or weeks, a fleet of low-resolution satellites will provide a very frequent and wide coverage, making it easy to detect any changes. If these exceed a certain threshold and hence require the observer to take a closer look, a higher resolution satellite is tasked to make an up-to-date observation of the area of interest and the complete change detection observation cycle starts again.**

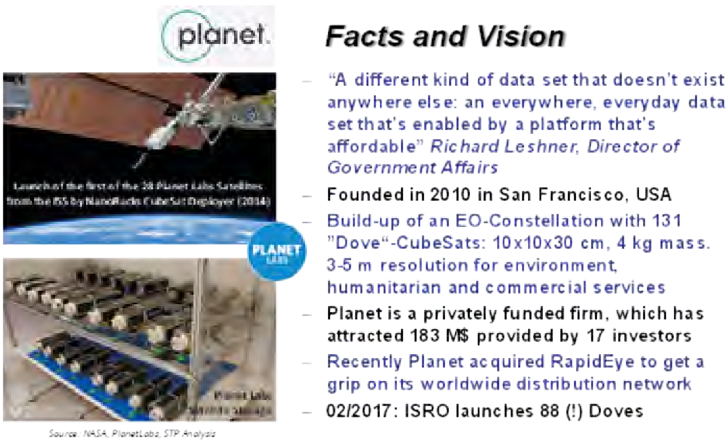


Figure 129: Planet's CubeSat Earth observation constellation between facts and vision

The whole procedure is similar to the optical compression algorithm employed in DVDs or Blu-rays, where the requirement of having 25 frames per second while reducing the data to be stored to the greatest extent has sparked the idea of using key and delta frames. While the key frame represents a full picture and hence takes a huge amount of storage data, the delta frames in between contain only the data set of changes with respect to the key frame (e.g. the moving mouth when two people are standing still in front of a static background while talking with each other). Most of the compression algorithms (e.g. the Moving Picture Experts Group MPEG software) use one key frame every five to ten seconds and hence save a lot of storage capacity.[244] Obviously the similarity to change detection is that the key frame is like the high-resolution satellite image, while the delta frames can be likened to the low-resolution and frequent satellite observations. Under this picture **a company such as Planet, with its 3–5 m resolution nano-satellite EO constellation, provides the delta frame functionality within the change detection algorithm** (Figure 129).

What sounds like an easy task is, however, quite difficult. Nano satellites such as **CubeSats** are very small: the smallest unit—1U—is as "big" as 10 cm × 10 cm × 10 cm and allows a maximum mass of 1.33 kg per unit. Combining multiple units (e.g. 2U, 3U, 6U) is possible. Trying to include a telescope in such a small volume is an arduous task, but one absolutely necessary in order to obtain a 3–5 m resolution. In the case of Planet, this meant that a 3U CubeSat had to be designed in such a way that it was virtually built around the telescope. **The physics behind the optical capabilities of an EO satellite is discussed in Figure 130, which demonstrates the difficulties in achieving a spatial resolution of the order of a few centimetres.**

Obviously, **the aperture of the optical sensor as well as the distance to the object are key to achieving really high resolution**. The formula for sigma in Figure 130 explains how satellites such as KH-11 can achieve high-end reconnaissance features; only by being placed in a low Earth orbit and using a mirror with a diameter of 2.34 m is it able to achieve a spatial resolution of a few centimetres.

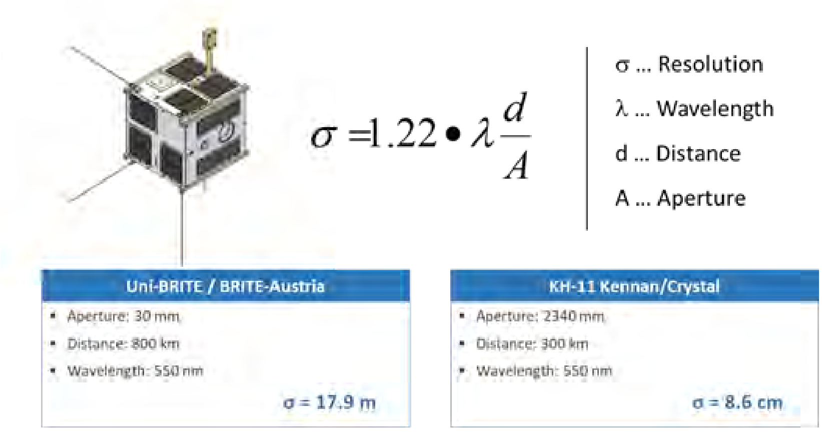


Figure 130: The physics driving the optical resolution that can be achieved by an Earth observation satellite

Acknowledging that the HST is in essence merely a KH-11 looking in the other direction, we can use the same methodology for an astronomical nano satellite, such as the Uni-BRITE/BRITE-Austria, which is part of a constellation to measure brightness variations of very bright stars, as can be found within the constellation of Orion. What if we follow the KH-11/HST swap and turn Uni-BRITE/BRITE-Austria around, using its optical telescope to observe the Earth? What kind of resolution would we achieve? The left-hand side of Figure 130 provides the answer—as **the aperture of the telescope is limited to 30 mm and the distance is 800 km the resolution is mediocre: 18 m is what can be achieved with such a system.**

It is exactly this balance of low cost versus limitation in resolution and high cost versus superior spatial resolution that drives the rollout of EO/space reconnaissance constellations to support the change detection methodology employed by the military forces. **The convergence of the commercial and the civilian and military EO world allows new business models and is fuelled by technology trends, thriving on spillovers, agile developments and the digital transformation.**. In the end, these changes within the ecosystem permit a plethora of new and established players to compete in the EO domain, offering services based on different satellite systems.

6.4. Technology readiness levels

The following definitions of technology readiness levels (TRLs) are used in Horizon 2020:[xxix]

- TRL 1—basic principles observed;
- TRL 2—technology concept formulated;
- TRL 3—experimental proof of concept;
- TRL 4—technology validated in the laboratory;
- TRL 5—technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies);
- TRL 6—technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies);
- TRL 7—system prototype demonstration in operational environment;
- TRL 8—system complete and qualified;
- TRL 9—actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies) or in space.

xxix Extract from Part 19 - Commission Decision C(2014)4995.

6.5. Identified space portfolio companies of European venture capitalists

Investor	Portfolio Companies
ACT Venture Capital	Ferfics Front End Office, Farran Technology, Arralis, Pilot Protonics
ATOMICO	Mapillary, Ontruck, Lilium, Orbital Systems, Hailo
BayBG	Tiramizoo, Cargoguard, NavVis
Bayern Kapital	Terraloupe, Coredinate, Parcel Lab
Caixa Capital	Zero2Infinity, Fever, PLD Space, D-Orbit, Eat Tasty
Calibrate Management	Kisan Hub
Capricorn Venture Partners	Sensolus
Comoventure	D-Orbit, Leaf Space
Coparion	Libify, Vimcar, Parcel Lab, Reactive Robotics
Dendera	Orbital Systems
DB Digital Ventures	Connected Signals, Talixo, What 3 Words
Digital+ Partners	NavVis
EarlyBird Venture Capital	CartoDB, Movinga, Obilet
Force Over Mass	Zencargo, Hummingbird Technologies, What 3 Words
Hambro Perks	What 3 Words
Heliad	Libify
Hessen Kapital	Mapcase
High-Tech Grunderfonds	Orbex, Cevotec, Reactive Robotics, Locr, Enercast, IQ Evolution, Synapticon, Park Tag, Blickfeld, Coredinate
Investiere	Astrocast, Planet Intus, Insolight, Arviem, Nezasa, Lunchgate
Invium Partners AB	GOMSpace
IQ Capital	Oxford Space Systems, Kisan Hub, Focal Point Positioning
JamJar Investments	Home Run, What 3 Words
Kernel Capital	Eblana Photonics, Arralis, S3 Semiconductors, Alpha Wireless, ACRA Control
Key Capital	Leaf Space, Cabeo, Le Cesarine
Kibo Ventures	Minube, iContainers, CartoDB
Kima Ventures	Thrust Me, Spot Angels, Zenly
Life Line Ventures	Iceye, Maplet
Longwall Ventures	Oxford Space Systems
MIG AG	NavVis
Mustard Seed	Rapido, What 3 Words
Notion Capital	Five AI, Kisan Hub, Localz, Shutl
OHB Venture Capital GmbH	Astrofactum, Blue Horizon
Practica Capital	Nano Avionics, PlacelLive, Trafi
Quest for Growth	Sensolus
Red Seed Ventures	Leaf Space
Red Stone	Talixo, What 3 Words
Rosengard Invest	Orbital Systems
Seraphim Capital	Spire, Iceye, Nightingale, Transrobotics, Altitude Angel
Shell Technology Ventures	Tiramizoo
Stena	Orbital Systems
Target Partners	NavVis
Tengelmann Ventures	Intranav Quantics, Blickfeld
TGFS (Technologiegründerfonds Sachsen)	Naventik, Mapcase
TT Venture	D-Orbit
Ventures One	Geospatial Insight
Vitamina K	CartoDB
Vito One	Building Radar, Homeday, CrateDB

6.6. List of export credit agencies

Country	Agency	Hyperlink to website
Australia	Export Finance and Insurance Corporation (EFIC)	http://www.efic.gov.au/
Austria	Oesterreichische Kontrollbank AG (OeKB)	http://www.oekb.at
Belgium	Credendo	https://www.credendo.com/
Canada	Export Development Canada (EDC)	http://www.edc.ca
Czech Republic	Export Guarantee and Insurance Corporation (EGAP)	http://www.egap.cz
	Czech Export Bank	http://www.ceb.cz
Denmark	Eksport Kredit Fonden (EKF)	http://www.ekf.dk
Estonia	KredEx	http://kredex.ee/en/
Finland	Finnvera	http://www.finnvera.fi
	Finnish Export Credit Ltd (FEC)	http://www.fec.fi
France	Bpifrance Assurance Export	http://www.bpifrance.fr/Qui-sommes-nous/Nos-metiers/International2/Assurance-Export
Germany	Euler Hermes Aktiengesellschaft	https://www.agaportal.de/en
Greece	Export Credit Insurance Organisation (ECIO)	http://www.ecio.gr
Hungary	Hungarian Export Credit Insurance Ltd and Hungarian Export-Import Bank plc (EXIM)	http://www.exim.hu/en/
Israel	The Israel Export Insurance Corp. Ltd (ASHRA)	http://www.ashra.gov.il/eng
Italy	Servizi Assicurativi del Commercio Estero (SACE)	http://www.sace.it/GruppoSACE/content/it/index.html
Japan	Nippon Export and Investment Insurance (NEXI)	http://nexi.go.jp
	Japan Bank for International Cooperation (JBIC)	http://www.jbic.go.jp
Korea	Korea Trade Insurance Corporation (K-SURE)	https://www.ksure.or.kr/en/index.do
	The Export-Import Bank of Korea (KEXIM)	http://www.koreaexim.go.kr
Latvia	Latvian Guarantee Agency (LVA)	https://www.altum.lv/en/
Luxembourg	Office du Ducroire (ODL)	http://www.ducroire.lu
Mexico	Banco National de Comercio Exterior	http://www.bancomext.gob.mx
Netherlands	Atradius	http://atradius.com/nl/en/dutchstatebusiness/index.jsp
New Zealand	Export Credit Office (ECO)	http://www.nzeco.govt.nz
Norway	Export Credit Norway	http://www.eksportkreditt.no/en-GB/
	Garantiinstituttet for eksportkreditt (GIEK)	http://www.giek.no
Poland	Korporacja Ubezpieczén Kredytów Eksportowych (KUKE)	http://www.kuke.com.pl
Portugal	Companhia de Seguro de Créditos	http://www.cosec.pt
Slovak Republic	Export-Import Bank of the Slovak Republic (Eximbanka SR)	http://www.eximbanka.sk
Slovenia	Slovenska izvozna in razvojna banka, d.d. (SID)	http://www.sid.si/home
Spain	Compañía Española de Seguros de Crédito a la Exportación (CESCE)	http://www.cesce.es
Sweden	Exportkreditnämnden (EKN)	http://www.ekn.se
	AB Svensk Exportkredit (SEK)	http://www.sek.se/en
Switzerland	Swiss Export Risk Insurance (SERV)	http://www.serv-ch.com
Turkey	Export Credit Bank of Turkey (Türk Eximbank)	http://www.eximbank.gov.tr
United Kingdom	UK Export Finance	http://www.ukexportfinance.gov.uk
United States	Export-Import Bank of the United States (Ex-Im Bank)	http://www.exim.gov

Table 42: Listing of the official export credit agencies involved in the Export Credit Group (ECG) work[245]

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