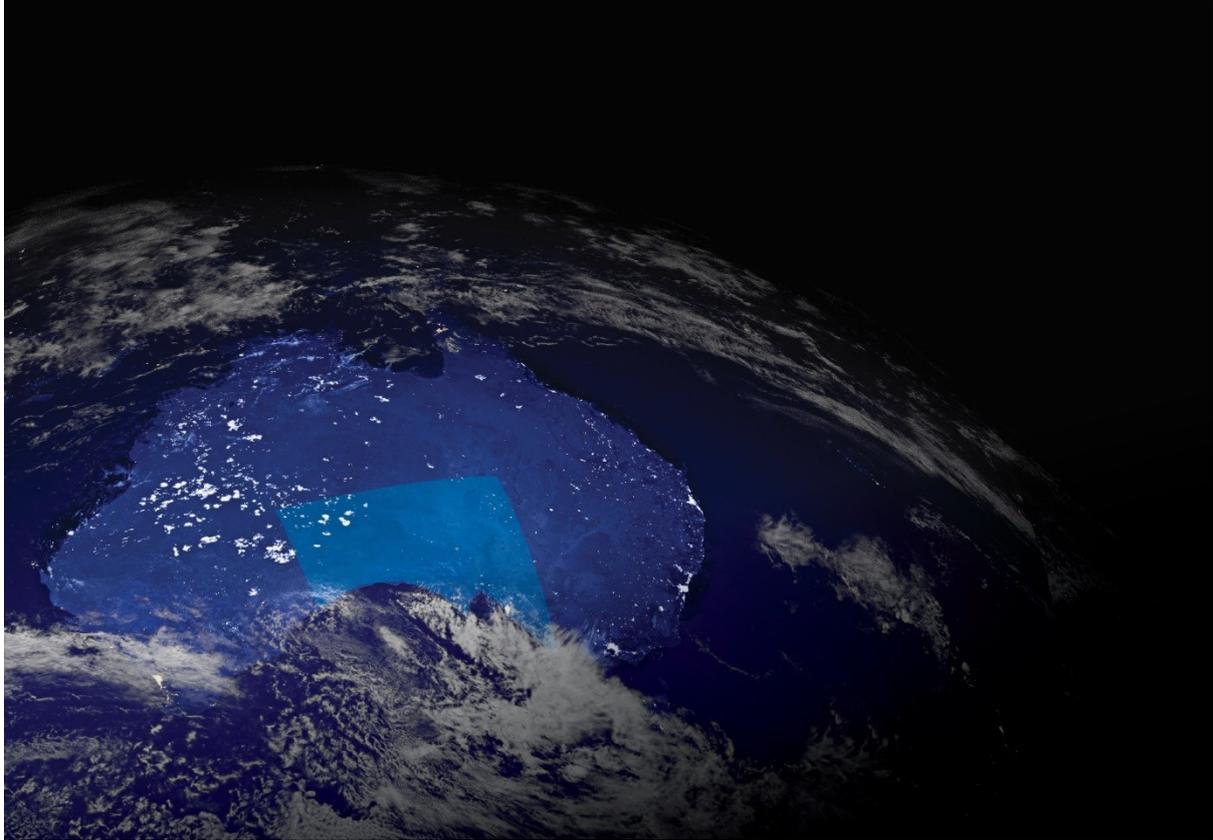


SMALL SATELLITES

Economic Trends



Giovanni Facchinetti

Intern – Defence SA – Space Industry and R&D Collaborations
Master's candidate – Università Commerciale Luigi Bocconi, Milano

Supervisors:

Nicola Sasanelli AM

Director – Space Industry and R&D Collaborations
Defence SA
Government of South Australia

Michael Davis

Chair
SIAA – Space Industry Association of Australia
www.spaceindustry.com.au

Giovanni Cucinella

Director, General
IMT – Ingegneria Marketing Tecnologia
www.imtsrl.it

December 2016

*“Quod Invenias Explorans Spatium
Progressus Est Humanitatis”*

- Human Progress is in Space Exploration

Hon Jay Weatherill
- Premier of South Australia

Disclaimer

While every effort has been made to ensure the accuracy of the information contained in this report, the conclusions and the recommendations included in it constitute the opinions of the authors and should not be taken as representative of the views of Defence SA and the South Australian Government.

No warranty, express or implied is made regarding the accuracy, adequacy, completeness, reliability or usefulness of the whole or any part of the information contained in this document. You should seek your own independent expert advice and make your own enquiries and satisfy yourself of all aspects of the information contained in this document. Any use or reliance on any of information contained in this document is at your own risk in all things. The Government of South Australia and its servants and its agents disclaim all liability and responsibility (including for negligence) for any direct or indirect loss or damage which may be suffered by any person through using or relying on any of the information contained in this document. Any liability of the Government of South Australia, its servants or its agents in any way connected with the information contained in this document, whether or not such liability results from or involves negligence, will not exceed \$100.00.

Acknowledgements

This report is the arrival point of a three-month research activity performed at Defence SA, and it has been made possible by a number of people whom I will always be deeply grateful to.

First of all, I devote my absolute gratitude to Ms. Katrina Bisanju for her outstanding review efforts and the never-ending patience demonstrated. Thank you also for all the teachings, advice, sparks and the time spent together.

Many thanks to the wonderful Defence SA team: thanks to Fiona for letting me partake in the Tour DeFence, an experience that I will never forget; thanks to Peter and David for all the insights on the authentic South Australian lifestyle as well as the constant kindness; thanks to Malcolm for making cricket less obscure; thanks to Susie for making every day starting much better; thanks to Rita, Jess, Reg, Rob and every single person in this amazing team. It's so rare to find such a warm environment at work. I hope to catch up with you again, somewhere in time.

I want to express special gratitude to my supervisors Mr. Michael Davis and Mr. Giovanni Cucinella, for the invaluable help provided and their kind words spent towards my work.

I would like to express my highest gratitude to my main supervisor, Mr. Nicola Sasanelli, for making this experience possible and for all the lessons learned inside and outside the office. Many thanks also to his wonderful family, which hospitality made me feel undoubtedly at home, again.

A special mention goes to Matteo Paone, the previous Bocconi candidate that kindly helped me in many ways with my stay.

I couldn't also avoid to mention all the extraordinary people I met in Adelaide and with whom I spent unforgettable moments: thank you Mim and Federico, Australia has been astonishing especially because of you; thanks to Vincenzo and Cristian, for all the beautiful Sunday mornings at your amazing radio show; thank you Fiona, Peter, Puja, Sukhmani, Saleem, Harry, Rochelle, Dario, Daniela and all the special people I met here. I enjoyed every single moment with you. I wish you all the best.

Last but not least, I would like to destine my most sincere thanks to Valentina and my parents Monica and Maurizio, whose love and support are priceless.

Table of Contents

EXECUTIVE SUMMARY	3
INTRODUCTION.....	4
1. THE WORLD OF SATELLITES	5
1.1 Brief history of satellites	5
1.2 Technology underneath	6
1.3 Space industry overview	9
1.4 Main segments and value chain	10
1.5 Financial considerations	12
1.5.1 Satellite services	16
1.5.2 Satellite Manufacturing.....	17
1.5.3 Launch Industry.....	19
1.5.4 Ground Equipment	20
1.6 Space commercialization and “NewSpace” emergence.....	20
2. THE SMALL SATELLITES	25
2.1 Recent history and actual landscape.....	25
2.2 Nano / Microsatellite Market and forecast	29
2.2.1 Launch facts	29
2.2.2 Launch market.....	30
2.2.3 Trends	32
2.2.4 Future developments	33
2.2.5 Risk – space debris	38
3. KEY PLAYERS	41
3.1 Earth observation.....	42
3.1.1 Planet.	42
3.1.2 Digital Globe.....	44
3.1.3 Terra Bella.....	47
3.1.4 BlackSky Global	48
3.1.5 Satellogic.....	50
3.1.6 OmniEarth	51
3.1.7 Hera Systems.....	53
3.1.8 Astro Digital	54
3.1.9 Spire Global.....	55
3.1.10 GeoOptics	57
3.1.11 PlanetiQ.....	58
3.1.12 XpressSAR.....	59
3.1.13 Iceye.....	61
3.1.14 Dhruva Space.....	62
3.1.15 Spacequest	63

3.2	Communication	64
3.2.1	O3B Networks	64
3.2.2	Fleet Space Technologies	65
3.2.3	Myriota.....	66
3.3	Multi-purpose.....	68
3.3.1	Clyde Space	68
3.3.2	GomSpace	70
3.3.3	Inovor Technologies	71
3.3.4	NanoAvionics	72
3.3.5	ISIS (Innovative Solutions In Space)	74
3.3.6	Pumpkin Space Systems	75
3.3.7	Surrey Satellite Technology	76
3.3.8	SpaceDev.....	78
3.3.9	Tyvak Nano-Satellite Systems	79
3.3.10	Blue Origin.....	80
3.4	Launch.....	81
3.4.1	Virgin Galactic	81
3.4.2	SpaceX.....	82
3.4.3	Rocket Lab	83
3.4.4	Spaceflight Industries	84
3.5	Deployment.....	85
3.5.1	NanoRacks.....	85
	CONCLUSIONS.....	87
	BIBLIOGRAPHY.....	92

Executive summary

This report provides an analysis and evaluation of the current state of small satellite technology and how it is becoming the dominant driver of the global space industry growth.

Global space industry revenues topped USD 323 billion in 2015, with 76 per cent comprised of commercial space products and services, and commercial infrastructure. The space industry has also grown by almost 10 per cent between 1998 and 2015 – much more than global GDP growth over the same period of time. In this context, the satellite industry has proven to be the dominant driver of growth, accounting for more than 62 per cent of space industry revenues in 2015, the majority of which was generated by satellite services such as telecommunications, Earth-observation, science and national security applications. In the years 2009 to 2015 satellite applications were dominated by technology (47 per cent), whereas projected trends show that as from 2016, Earth-observation will take the lead with 73 per cent of the applications market.

The average number of satellites launched globally per year increased by 36 per cent in the years 2011 – 2015 over the previous five years, with a number of total operating satellites reaching 1,381 in 2015 as compared to 986 in 2011. This report draws attention to the rise of the new wave of companies, characterised by different and innovative business models. The paradigm of traditional satellite companies - large, less cost-effective, backed by huge government investment is declining, leaving room to small-medium size companies, often spun-off from universities to grow and prosper. This phenomenon widely termed “NewSpace”.

Small satellites are expected to take a relevant stake of the projected industry growth: 28 nano/micro satellites were launched into orbit in 2008, increasing to 141 in 2014, whereas more than 3,000 are expected to be launched between 2016 and 2022. Of particular interest is the rapid adoption of the CubeSat standard of small satellite which is the first globally and academically recognised standard for small satellites with specific weight and volume requirements.

To analyse and provide a deep understanding of the NewSpace phenomenon, the report features a detailed list of 33 different companies that are directly involved in the small satellite frame, sorted into five different groups according to their business focus: Earth observation, communication, multi-purpose, launch and deployment.

The Australian government has begun to show an appreciation of the industry’s potential and is fostering a positive environment to enhance its growth and international competitiveness. This is particularly evident in the state of South Australia which in 2016 published the *Space Innovation and Growth Strategy: Action Plan 2016-2020*, the first space strategy of any Australian jurisdiction. In line with international best practice, strong emphasis has been placed on the educational system in developing the industry. Between 2014 and 2016, four satellites were developed in Australia all with the involvement of universities, and three as part of the worldwide QB50 project, a network of 50 CubeSats built by universities teams from all around the world.

An environmental scan of the main players in the NewSpace satellite market is included in the report, and features three successful South Australian companies Fleet Technologies, Inovor Technologies and Myriota, which are driving the Australian innovation in this landscape.

Introduction

Global space industry revenues has grown significantly in recent years. Between 1998 and 2015, the space-sector growth accounted for three times the annual global GDP growth rate. No doubt that the future for the space industry will be amazing and part of future success depends on small satellites. In 2008 were launched 28 nano-micro satellites (ranging 1-50 kg), increasing to 141 in 2014. It is projected that 3000 nano-micro satellites will be launched between 2016 and 2022.

This report is intended to provide insights about the disrupting technology of small satellites and their economic impact on the entire space industry as a whole. Small satellites has proven to be an incredible promising technology, representing a real point of discontinuity with a traditional satellite industry that was led by big, often government-backed companies focused on large, reliable and dramatically complex satellites. The space industry landscape is thus rapidly changing, with the rise of a large group of new ventures with distinctive features and new business model, characterising the so-called NewSpace sector.

Chapter 1 constitutes a conceptual basis of the satellite industry, providing a brief history of satellites from the dawn of space age to nowadays and examining the standard technology required to build a satellite and to run a successful satellite mission. The space value chain is examined, highlighting the various stages of this complex economic sector. A view about actual market conditions is also given, for the entire space industry and then focusing particularly on satellites as well, pointing out the different economic activities that configure the satellite industry. Looking at future developments and trends arising from actual data available, it's important to note the emergence of entirely new business models carried out by innovative companies, pushing the satellite industry beyond its traditional financial and manufacturing boundaries.

Chapter 2 contains an in-depth analysis about the industry of small satellites. It gives an overview of recent developments and some definitions regarding this particular class of small spacecraft. The analysis goes through launch numbers, the composition of purpose applications, size trends and recent acknowledgments about the launch market, considering the future developments that can be reached by means of NewSpace technology achievements and the applications that the companies further examined will be able to accomplish. However, such disruptive economic development should be actively and carefully managed by governments, state authorities and space agencies: the space-debris phenomenon is an issue that must be addressed, if the perspective numbers of spacecraft expected to be launched are to be taken into serious consideration.

Chapter 3 constitutes the core of the paper, which stands in the analysis conducted about a consistent number of companies which act as prime actors in the NewSpace arena, with special regard to smallsat-linked ventures. The dissertation is intended to gain insights about companies' business models, their market applications and the way they intend to exploit disruptive technologies which are in continuous development.

The conclusions remark on the role of the education system as a key accelerator on which space sector growth relies on. Within such a perspective, a real positive and prolific environment has been created by the Government of South Australia, which has undoubtedly built an efficient environmental framework and put a strong emphasis on the education system, enhancing the technology spillovers from universities to the commercial enterprise cluster. South Australian-based space companies Fleet, Inovor and Myriota, are good examples of companies which have commercialized research.

1. The world of satellites

1.1 Brief history of satellites

A satellite can be referred as every artificial object which has been intentionally placed into orbit by human action. To distinguish them from natural satellites such as Moon, it's not uncommon to refer to them as artificial satellites. Artificial satellites history draws back in the 50s, as the first artificial satellite sent to space was the world acclaimed "Sputnik 1", a basketball sized spacecraft launched by the Soviet Union on October 4 1957, marking the beginning of the "Soviet Sputnik Program" and triggering the start of the Space Race between USA and Soviet Union, but the very early seed of human satellite activities could be dated back in the 40s, from which consecutive innovation and transformation patterns are retrieved.

- In the 40s few visionary people theorised satellite technology – like the acclaimed writer Arthur C. Clarke, who spoke of satellite communication possibilities.
- The realization of those visions took place in the 50s as the early experimentation of launching spacecraft to space began with Sputnik and Explorer programs.
- In the 60s large international organizations started to play their role (i.e. NASA, ESRO¹), with first men launched to space for both the US (Mercury Freedom 7 mission) and for the USSR (Vostok 1 mission). Great developments continued in satellite technology such as space probes were sent exploring other planets and first satellites sent signals across the ocean.
- The study of other planets through the use of satellites continued in the 70s and they were used more often to map the other planets in our solar system. Satellites were used mainly to find out other planets' conditions trying to retrieve life-forms on other planets (Venus and Mars mostly).
- Exploration of our galaxy continued and stretched through the 80s, as assumptions on the existence of Earth-similar planet began to rise. Numerous pictures continued being returned and the space technology pushed satellites into new dimensions, while a transition from national to individual usage and liberalization took place.
- Through the 90s satellites continue being improved. Yet space ships seem to be improving faster and taking over what these satellites have accomplished so far. Business use and satellite constellations, as well as Geostationary Earth Orbits (GEOs), were milestones of the period.
- Consistent privatization processes, as long as focus onto new technologies and the strong growth of commercial space sector are the leading trends of the 2000s and recent years.

The first satellites led the way to most of our knowledge concerning space today. Because of their success, extensive research could be done about the Solar System using the pictures and information they provided. Since 1957, more than 4000 satellites have successfully been launched: with all the technology created day after day, our knowledge of space has become very sophisticated and will continue to grow, as new business opportunities and development factors are on the rise.

¹ European Space Agency's (ESA) precursor.

1.2 Technology underneath

From the early beginning of space industry, satellites has proven to be a vital resource in a very wide range of activities, and they have evolved by time embracing new development as well as economic sectors, which the main are:

- Weather information: satellites are the first reliable mean to predict meteorological conditions and provide thus a fundamental resource for many activities, from commercial flights to agriculture industry.
- Climate research: it is becoming more and more important to understand the evolution of climate as the mankind is facing strong changes in atmospherical events, as well as understand the real effects of human activities on the environment. Satellites provide useful air measurements and analysis on an hourly basis for this purpose.
- Television, telephones, multimedia communication have dramatically taken advantage of satellite transmission capabilities, and they are a relevant drivers of commercial space growth.
- Data distribution: another essential space industry growth driver, is living an explosive development as the New Data paradigm is taking place.
- Transportation and logistics, navigation, safety security and rescue.

There are also more sectors that are specifically taking advantage of small satellites development:

- Space research
- Earth remote sensing
- Early warning and disaster management

Before analysing in depth the technology embedded in satellites, it could be useful to summarize what a satellite needs to be made capable, or the main elements of a successful satellite mission. The main pivotal element around which everything else develop and take place are the mission objectives²: every launch is conceived with a list of achievements that the satellite has to reach, during its useful life cycle. These objectives can vary significantly between different missions, as we have already seen the great heterogeneity involved in the utilization of this particular unmanned spacecraft, but are always present and affect indirectly every activity. So the mission objectives start to take shape in someone's mind, which can be identified as the "user". These objectives become more defined in the boundaries of a mission concept, which includes every kind of technical, logistic, and economic aspects of a hypothetical satellite launch. Then the satellite needs a launch element to be driven into orbit, and as we has already seen it could happen in many ways, as a primary payload (especially for traditional, expensive, heavy-weight satellites or with emerging dedicated rockets for small satellites) or as a secondary payload taking advantage of hitchhiking. The satellite then reaches the designated orbit, and it can work as a stand-alone spacecraft or in association with many other (in this case, this constitutes what is technically known as a "swarm" or "constellation"). In this way, the satellite or the group of satellites need the structures to send, receive and process the data they gather: that's why satellite missions require ground stations

² Brieß, K 2016, 'The rise of small satellites', Technische Universität Berlin, MOOC@TU9, viewed in October 2016, http://mooc.tu9.de/cms/wp-content/uploads/2014/09/Rise_of_small_satellites.pdf

to operate. These ground stations are connected with mission control and mission operations centers, which can be very far; they process raw data received from satellites travelling in orbits, and generate, archive and distribute information to the ultimate customers.

A typical satellite consists of a number of vital subsystems, and of a payload carried for the ultimate mission purpose. A “subsystem” is a group of single components (or parts) that are organized in working units (equipment). The usual subsystems that make a satellite (and a small satellite, with no difference) working can be summarized as follows³:

1. Structure and mechanisms: they carry the payload and keep all the other subsystems (and equipment) together. They are often the heaviest spacecraft hardware, so they affect a number of challenges like launch loads (and costs, which can be real killers for satellite missions), material stability in vacuum and direct sunlight radiation, resistance to vibrations and shocks. Within smallsats, minimalism regarding to this specific subsystem is crucial, as they must keep the lowest weight and the smallest dimensions.
2. Electric power subsystem: every satellite needs energy, so it needs a power subsystem to generate, control, store and distribute electrical current along every working component. This way, an Electric power subsystem is often divided in four smaller parts, like a power source (solar arrays), a power storage device (battery), a power control station, and a power distribution structure. Everything needs to be balanced, especially regarding overall weight as it's been said for the outer structure. The electrical components must also be qualified for vacuum and solar radiation operations.
3. Thermal control subsystem: as a satellite's core is frequently made of integrated electronic processors (the “thinking brain”), it needs to keep an adequate working temperature for all the units in some allowed ranges. Engineers have then to take into account the very different kind of solar exposition that a satellite usually faces, as all equipment is exposed to the longest direct sunlight during the day and on the other side is completely in darkness when behind Earth's shadow.
4. Attitude control subsystem: this subsystem is aimed to direct the satellite into desired directions and stabilize the satellite attitude.
5. On-board data handling system: it controls the handling and the storage of satellite's health data and all the data generated by the (eventual) payload.
6. Communication subsystem: to assure the ground-satellite communication in both up-link and down-link directions. Usually it consist of one or more receivers that can be deployed and oriented. Reliability is a primary issue within this specific subsystem, as it's the ultimate connection between the mission control center and the satellite in orbit.
7. Payload: not always present, the payload is aimed to perform the mission objectives. For instance, a high-resolution camera constitutes the normal payload of an Earth imagery satellite.
8. Propulsion subsystem: the engine of a satellite, to perform orbit maneuvers and potentially change orbit's altitude or trajectory. It can be used to send the satellite into

³ Brieß, K 2016, 'The rise of small satellites', Technische Universität Berlin, MOOC@TU9, viewed in October 2016, http://mooc.tu9.de/cms/wp-content/uploads/2014/09/Rise_of_small_satellites.pdf

a re-entering orbit or to transfer broken spacecraft into what is known as “graveyard orbits”, in order to avoid collisions with other spacecraft.

The majority of small satellites launched recently (and expected to be launched in the immediate future), along with the majority of spacecraft under development, are CubeSat-Class spacecraft⁴. The introduction of a dedicated orbital deployer, specifically the P-POD (Poly Picosat Orbital Deployer) has made easier and more frequent for CubeSats to reach orbit as secondary payloads. The P-POD system is capable of holding three 1U CubeSats or relative combinations, and it can be regarded as a good example of technology and science collaboration between governments, universities and private industry, especially through NASA’s CubeSat Launch Initiative (CLI). Another significant system for launching smallsats in orbit via secondary payloads is the EELV Secondary Payload Adapter (ESPA), which can hold up to 6 moderate sized spacecraft as secondary payloads on a host rocket.

CubeSats are on the rise particularly because of their short time-to-orbit, as a typical CubeSat project can move from idea to launch within 18-24 months, with a cost of USD 1 million or even lesser. The CubeSat standard involves not only the structural dimensioning of a satellite but also testing requirements and waiver processes. The development and approval processes for a smallsat or a CubeSat are not less stringent than the ones required for traditional large satellites: in the end, reducing dimensions makes everything less demanding, as all the development process is tailored to this small platform. Moreover, the CubeSat standard is relatively open with payloads and components that the satellite would carry and utilize. Most CubeSats are made of COTS (commercial off the shelf) products, helping drastically to lower costs, but it does not pose any restriction to any more sophisticated instrument to be carried, as this standard is more and more required for military and more complex civil purposes due to commercial development.

The growing interest in small satellites can be brought back to:

- Increasing awareness among the public about the great potential value of on-demand access to geospatial information
- Lowering of minimum price required to enter space
- Lowering of cost per kilogram of hardware manufactured
- Earth-imaging-payloads are more sophisticated and less heavy in weight
- Technology advancements in other sectors which can be leveraged into satellite sector

All these facts are likely to show the great technology potential for a number of subjects, including:

- Education institutions, universities alike: the affordable costs and comfortable size are opening a new world of possibilities for research purposes and all STEM faculties overall.
- Business commercial opportunities for the huge amount of data that small satellites are proving to be capable to provide
- Interest by government institutions; on the military and defense side, small satellites can achieve tactical communication, imagery for war faring and technology development while on the government-backed research side geospace and

⁴ Brieß, K 2016, ‘The rise of small satellites’, Technische Universität Berlin, MOOC@TU9, viewed in October 2016, http://mooc.tu9.de/cms/wp-content/uploads/2014/09/Rise_of_small_satellites.pdf

atmospheric research, earth technology and science, heliophysics, interplanetary missions.

1.3 Space industry overview

Space economy can be viewed as the full range of activities and the use of resources that create value to human beings by means of exploring, researching, understanding, managing, and utilizing space. A definition of global space economy is given by the OECD Space Forum⁵, and it includes:

- core space industry's activities like space manufacturing and satellite operations
- other consumer activities derived over the years from R&D activities.

It therefore includes all public and private factors involved in developing, providing and using space-related, space-derived products, services and the scientific knowledge developing from research about space.

The global space industry is undergoing a period of change, as can be seen by a variety of changes among its operations. For example, efforts in reusing launch vehicles are now having some success, and more efficient launch vehicles are being designed and developed, in order to lower launch costs and make them more efficient. Moreover, small satellites are experiencing a strong growth in numbers, as the industry is ordering and manufacturing vast constellations of satellites for Earth observation and telecommunications. Large satellites, on the other hand, are taking advantage of more efficient propulsion systems, helping to increase their usable lifespan. Space technology is changing traditional ways of monitoring infrastructure and providing services. The global demand for space data and applications is driving many of the recent investments in space. These and other innovations now taking place show clearly the main evolution patterns of the industry. Space is becoming more affordable and consequently more accessible to a very broad set of public agencies, industries, and individuals.

The space sector is distinguished from the majority of the broad economic landscape, as it shows at least three main distinguishing features:

- the use of cutting edge technologies
- longer terms for project development
- longer and highly uncertain return on investments

Access to space is costly, as it entails technical risks and space services require large users markets to be profitable. Despite this, an increasing number of private entities are currently engaged in space activities, and it is gradually operating a shift in the traditional space economy establishment. In fact, the commercial space sector constitutes a prominent part of the global space industry generating 76% of the global space revenue and having showed an upward growth trend in recent years. On the other hand, defence-purpose space activities remain relevant as many space technologies have both civil and military applications - e.g. weather forecasting can be used for early warning threats detection. The defence industry has historically played a pivotal role [in the space sector] since the genesis of the Space Age,

⁵ OECD 2014, *The Space Economy at a Glance 2014*, OECD Publishing, viewed in October 2016, <http://dx.doi.org/10.1787/9789264217294-en>

acting as a platform for political and military confrontation between USA and USSR in the 1960's.

Governments are still nowadays important customers of space products and services, providing investing flows in a wide range of activities due to the value of space for strategic and political reasons. Public expenditure represents a relevant source of financing for space projects, because the particular features of the space sector (such as its complexity and economic risks) might sometimes discourage private investment. In the first instance, governments might focus on results other than profitability, while a private firm will primarily pursue an efficient, cost-effective business model aiming to exploitation of a lucrative segment of the market for profit.

1.4 Main segments and value chain

As has been noted, the space industry is a quite complex economic cluster. The OECD summarizes its main characteristics and then defines three main segments that compose space economy⁶:

- manufacturing
- services from satellite operators
- consumer-side services

The space manufacturing value chain includes a number of players that stretch between “primes” manufacturers, dedicated to design and assembling of spacecraft systems; “tier-1” manufacturers which design, assembly and manufacture the major subsystems that compose spacecraft (such as satellite structures, propulsion subsystems and payloads); “tier-2” manufacturers that put together the equipment which will subsequently be assembled in major subsystems by tier-1s and, at last, “tier-3” and “tier-4” firms that produce specific components and materials for all the other manufacturers.

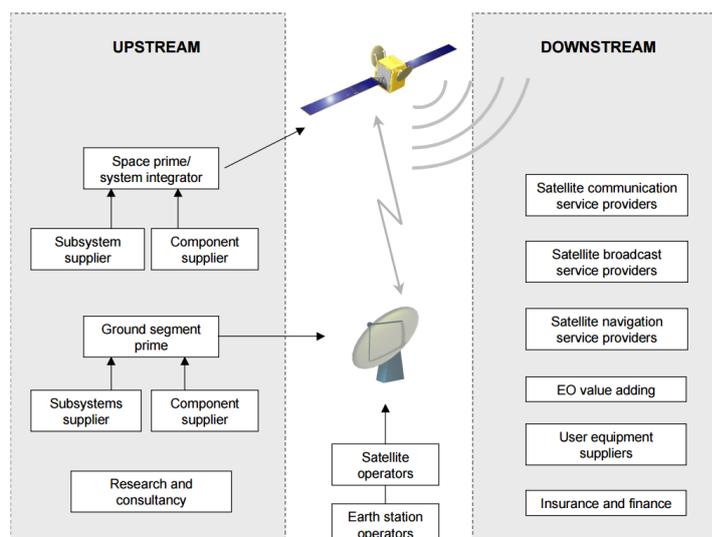


Figure 1: The Space Value Chain (Source: UK Space Agency, 2012)

⁶ OECD 2014, *The Space Economy at a Glance 2014*, OECD Publishing, viewed in October 2016, <http://dx.doi.org/10.1787/9789264217294-en>

Satellite operators own and operate satellites, providing all satellite-related activities as telecommunications, radio services and remote sensing.

Consumer services are made by players usually outside the space community, which need satellite capacity for some of their operations, for example direct-to-home satellite television, satellite navigation and value-added services.

Moving more deeply to understand the industry, it's relevant to give first of all a definition of value chain, as it consists of a range of different activities, from design until distribution to the final customer, in which all industry firms get involved in order to create a product from the very early concept to the market and then its final use, i.e. in customer's hands. Value is added in each step of the chain, from the top until the very bottom, as every player must gain some profit to survive in the competitive environment. As a complex sector, many different activities, inputs and processes contribute to shaping the global space value chain. To apply the same business terms that the economic literature considers regarding several other industries, the production process could be split into two main stages, which activities as a whole constitute the overall space value chain⁷:

- *Upstream* side, where companies and organizations are involved in space exploration and sending objects into space; this stage is devoted to the provision of space technology.
- *Downstream* side, where companies exploits the technology developed by upstream actors in a range of different applications. Downstream firms provide commercial space-related services and products to the final costumers (that are normally unrelated to space). These companies are not normally not part of the traditional space industry nor are they connected to it. Rather, they bundle space signals and data to build in their own products that typically concern location based services, satellite communication, satellite television and geospatial products. The latter is probably the industry's fastest-growing sector of recent years.

The satellite communications, Earth observation and PNT market plays a relevant role in the commercial space products and services sector, with firms known as satellite operators. They lease out the transmission capacity of their property satellites to public and private entity clients. This specific sector can be divided in two main segments:

- FSS – Fixed Satellite Services – in which satellite communications are delivered by means of stationary ground receivers
- MSS – Mobile Satellite Services – in which satellite communications are delivered by means of mobile broadcasting and receiving instruments, such as satellite telephones or in-flight communications.

A relatively small but relevant sub-sector of satellite-related activities is made of Earth observation and PNT services which appears to be on the rise on recent years, as it provides a broad range of activities in many heterogeneous fields like defence and natural resources.

⁷ Space Safety Magazine, *Space Economy: an Overview*, viewed in October 2016, <http://www.spacesafetymagazine.com/space-on-earth/space-economy/>

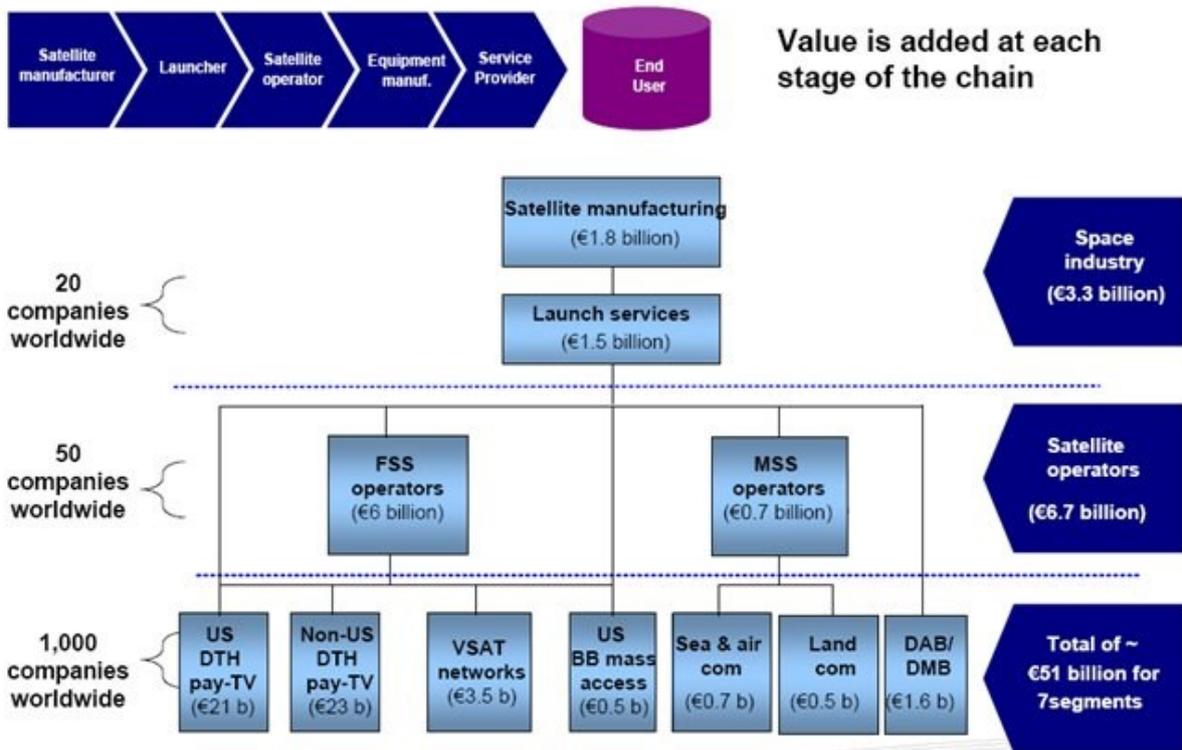


Figure 2: Breakdown of the Space Value Chain: the satellite industry example (Source: ESOA, n.d.)

1.5 Financial considerations

From 1973 to 1998 global space revenue grew at an annual rate of 6.3% from USD 15 billion to USD 68.8 billion. This growth rate is approximately double GDP growth, which for that same period had a compound annual growth rate of 2.96%.

In 2015 space revenue was about USD 323 billion, growing at a compound annual rate of 9.52% over the 17 year period from 1998 to 2015. Over that same period, world GDP grew at an annual rate of 2.87% while the space sector economy grew at more than three times that rate.

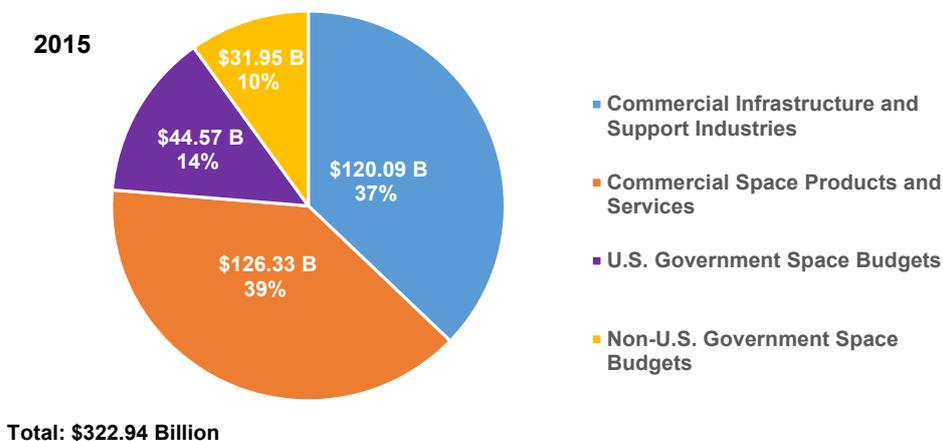


Figure 3: The Global Space Activity (Source: The Space Foundation, 2016)

The commercial space sector represents more than three-quarters of all global economic space activity. The largest portion is constituted by commercial space products and services - including telecommunications, broadcasting, and Earth observation – that grew by 3.7% to reach USD 126.33 billion⁸ in 2015 (from which starting year). Commercial infrastructure and support industries, including the manufacture of spacecraft, in-space platforms, and ground equipment, as well as launch services, independent research and development and insurance were worth USD 120.88 billion⁹ in 2015, with a slight 5.2% decrease – showing the fact that downstream activities remain relevant.

Global government spending declined by 4.8% in 2015, as it USD 76.52 billion¹⁰ (from which starting year). Government spending accounted for 24% of the global space economy, remaining unchanged from 2014. The U.S. government spending saw a 3.2% increase from 2014 on defence and non-defence space efforts, while non-U.S. government space investment declined by 14.2% in dollar terms (primarily due to exchange rates). In real terms, however, most space involved/space capable countries increased their budgets for space activities. In fact, governments and companies around the world continue investing in new space infrastructure. At least 19 countries have, are developing, or are planning to host spaceports for orbital or suborbital launches.

There were 86 orbital launches attempted around the world in 2015¹¹, the third highest number of launches in two decades. Year 2015 also saw the most significant development of the recent launch industry, with two U.S. companies successfully landing rockets returning from space – i.e. SpaceX and Blue Origin. Although no landed rocket has been proven to fly again, those companies put a lot of their trust in cutting operational costs by reusing the rockets, as rockets' reusability could really become a disruptive innovation to lower the cost of launching payloads to space, although the effective success potential has yet to be verified.

The number of large spacecraft sent to orbit remains steady, and interest in small satellites continues to grow. Nano and small satellites constituted 48% of the 262 spacecraft¹² launched in 2015, although coming with a small mass of 10 kilograms (22 pounds) or less each (they constituted less than 1% of the total mass sent to orbit in 2015).

Regarding the workforce, space technology's progressive integration into all aspects of life may lead to the creation of jobs that are not traditionally space-related like programmers, computer scientists, and "big data" analysts.

The space industry is regarded as one of the most relevant engines of economic growth, as it embeds a large variety of application fields for space technologies that imply in cascade lots of spill-overs among other industries that are not traditionally associated with space.

Benefits from the use and the development of space assets include qualitative aspects as strategic advances and better decision making procedures (huge opportunities given by Earth observation technologies for preventing natural disasters), as well as cost efficiencies.

⁸ The Space Foundation 2016, *The Space Report 2016 overview*, The Space Foundation, viewed in October 2016,

http://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf

⁹ Ibid.

¹⁰ Ibid.

¹¹ Ibid.

¹² Ibid.

As of December 31st 2015, there were 1.381 operational satellites, serving different functions¹³:

- Commercial Communications – 37%
- Civil/Military Communications – 14%
- Earth Observation Services (remote sensing) – 14%
- Research and Development – 12%
- Military Surveillance – 8%
- Navigation – 7%
- Scientific – 5%
- Meteorology – 3%

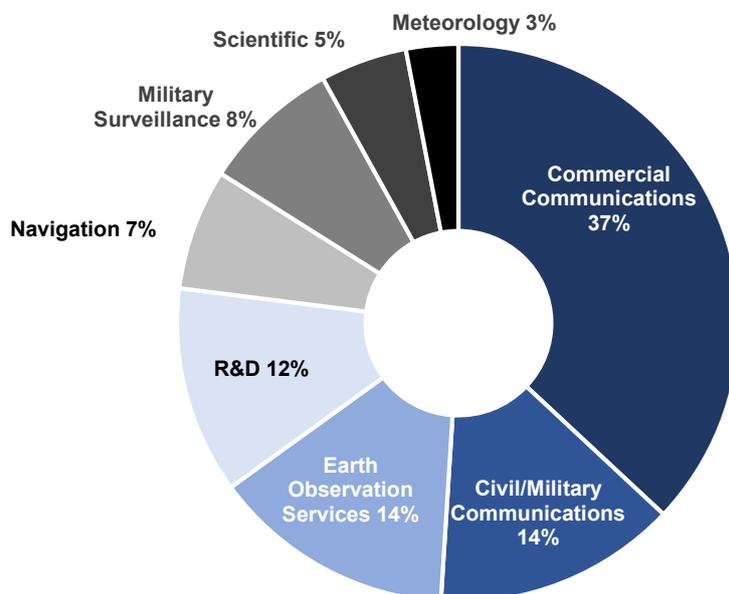


Figure 4: Operational Satellites by Function 2015 (Source: Satellite Industry Association, 2016)

The number of operational satellites, as detected at the end of 2015, has marked a 39% increase over 5 years, compared to 986 operational satellites reported in 2011¹⁴. This notable increase is connected to a number of reasons: the average number of satellites launched per year in the 2011-2015 time range has increased of 36% over the previous 5 years-period, with small and very small satellites as main contributors to this growth, particularly regarding LEO deployments; moreover the average operational lifespan of certain satellite types, such as GEO communications satellites is expanding. There are now 59 countries with operators represented by at least one satellite, even if some are part of regional consortia.¹⁵

¹³ The TAURI Group 2016, 'State of the Satellite Industry Report', Satellite Industry Association, viewed in November 2016, <http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf>

¹⁴ Ibid.

¹⁵ Ibid.

The satellite industry's global revenues reported for 2015 were USD 208.3 billion¹⁶ – 62% of Space Industry as a whole - marking a 3% growth from 2014, slightly above the world economy growth rate of 2.4%. This means that over a ten-year period of time, the global satellite industry nearly doubled, if we look at 2006 when revenues were USD 106 billion, even if the industry's growth appears to be slowing down. The average yearly market share of United States is around 43% of global industry, still underlining the pivotal role of the country in the development of space economy.

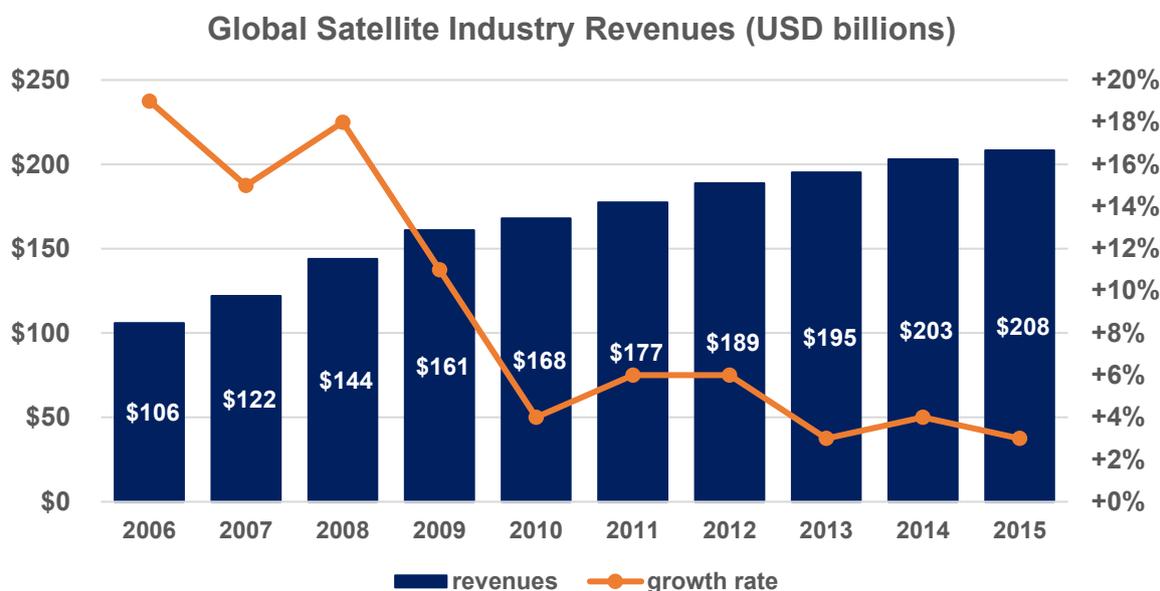


Figure 5: Global Satellite Industry Revenues (Source: Satellite Industry Association, 2016)

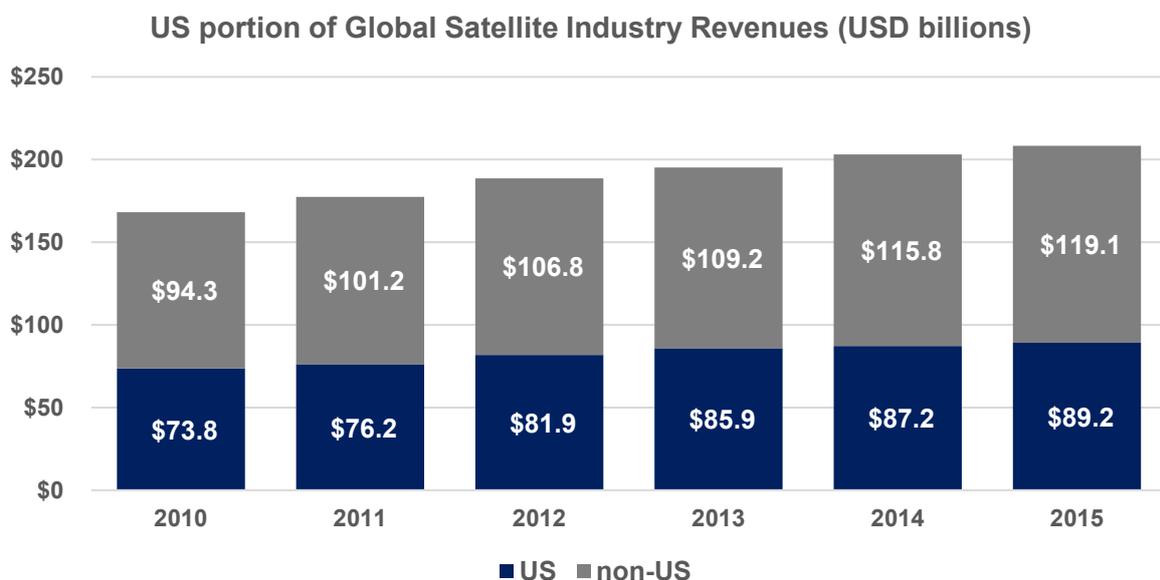


Figure 6: US portion of Global Satellite Industry Revenues (Source: Satellite Industry Association, 2016)

¹⁶ The TAURI Group 2016, 'State of the Satellite Industry Report', Satellite Industry Association, viewed in November 2016, <http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf>

Satellite Industry can be divided in **four** main activity¹⁷ segments that are summaries in the below table.

Table 1: Satellite Industry main activities

Segment	2010	2010 (%)	2015	2015 (%)	growth on 2014
Satellite Services	USD 101.3 billion	60%	USD 127.4 billion (mainly satellite TV services)	61%	+4%
Satellite Manufacturing	USD 10.7 billion	6%	USD 16.6 billion (communications sats represent 42%, military surveillance sats account for 36%. Cubesats represent 49% of total launches while less than 1% of value, mostly used for commercial Earth observation)	8%	+4%
Launch Industry	USD 4.4 billion	3%	USD 5.4 billion (launch orders: 45% US, 48% Europe, 3% Russia and 3% other)	3%	-9%
Ground Equipment	USD 51.6 billion	31%	USD 58.9 billion (mainly Satellite Navigation Equipment – GNSS)	28%	+1%
Global	USD 168.0 billion		USD 208.3 billion		

Source: author's elaboration on State of the Satellite Industry Report 2016

1.5.1 Satellite services

It is the largest Satellite Industry's segment, with USD 127.4 billion revenues reported in 2015¹⁸, marking a growth of 4% on 2014. It is furtherly divided in 4 sub-segments: consumer services (the key driver, representing 82% of Satellite Services' revenues), fixed satellite services, mobile satellite services and Earth observation services. The consumer services sub-segment, consisting of satellite television, radio, and broadband has been the most prominent segment of the whole satellite industry. Satellite TV services accounted for 77% of all satellite services revenues and 94% of consumer services revenues in 2015. The main growth driver is in emerging markets, while in the US are premium services. Earth observation services revenues has seen a growth of 10% over 2014, driven by established remote sensing companies plus new entrants deploying new small satellites. Once a small sector, dominated by a few large-satellites operators – typically founded and financed by the space industry, with governments as main customers – it is undergoing a period of transformation, with new competitors on the rise. These new entrants are the typical smallsat firms, backed by the tech sector and tech-oriented venture capitalists, developing smaller and simpler satellites, in order to take advantage of a growing customer base. Investments in Earth observation activities are driven by the rising interest for business intelligence products made available by satellite imagery. 2015 has been a record year with investment in start-up space ventures cumulating USD 2.3 billion, with several Earth observation companies earning large venture capital funds. A detailed review of these and other NewSpace companies will follow on chapter 2.

¹⁷ The TAURI Group 2016, 'State of the Satellite Industry Report', Satellite Industry Association, viewed in November 2016, <http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf>

¹⁸ Ibid.

Global Satellite Services Revenues (USD billions)

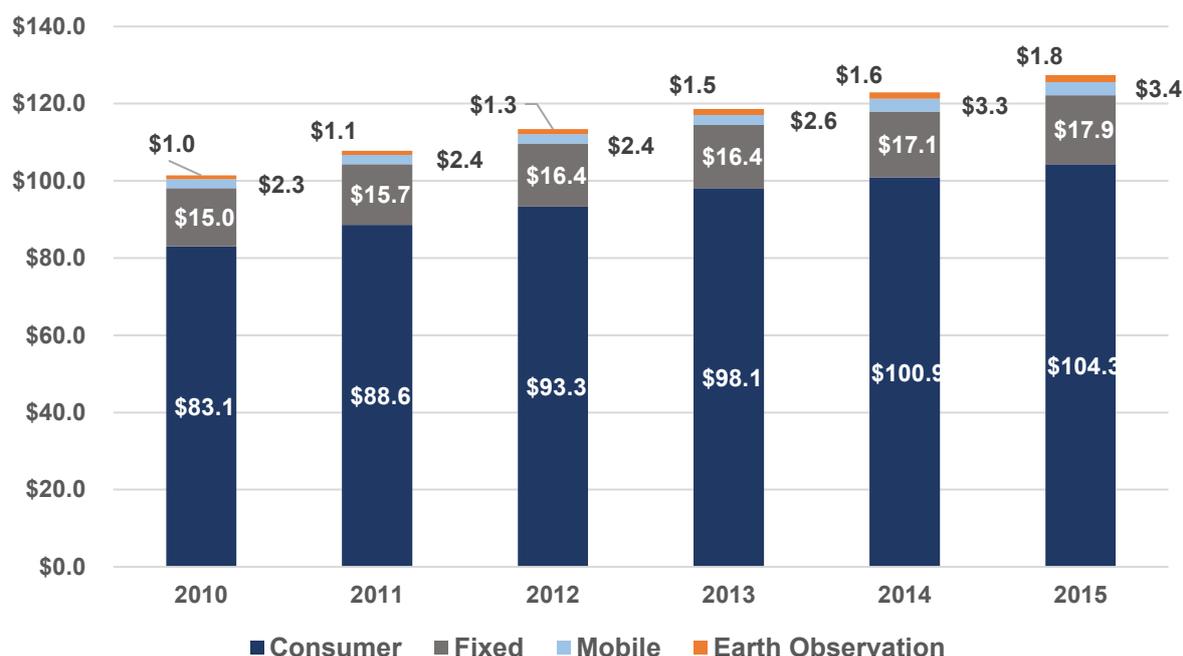


Figure 7: Global Satellite Services Revenues (Source: Satellite Industry Association, 2016)

1.5.2 Satellite Manufacturing

Worldwide revenues accounted USD 16.6 billion in 2015¹⁹, making Satellite Manufacturing the third segment in the Satellite Industry. Last year saw the launch of 202 satellites, keeping the same level of the previous year. The 49% of these launches were for 108 CubeSats launched, mostly for Earth observation purposes, even if CubeSats represented less than 1% of total manufacturing revenues. Communications satellites were 42% of revenues, while military surveillance satellites accounted for 36%. It is important to note that 89 of the 119 US-built satellites manufactured and launched in 2015 were CubeSats: in fact, US companies built 64% of the total number of satellites manufactured in 2015 and earned 60% of relative revenues. These findings reveal a continuing interest in building low-cost small satellites. In particular, CubeSats are a very strong valued standard in use for academic, government and commercial purposes due to its standardized deployment mechanisms. Of the 108 CubeSats launched in 2015, 61 were sent to orbit by the International Space Station (56%), and 61 CubeSats have been launched for Earth observation activities – the majority built and operated by Planet. The total expense to build all the CubeSats since 2005 is estimated less than USD 100 million. Commercial firms are studying the deployment of constellations using customized small satellites, and this will be a distinctive growing driver for future revenues.

¹⁹ The TAURI Group 2016, 'State of the Satellite Industry Report', Satellite Industry Association, viewed in November 2016, <http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf>

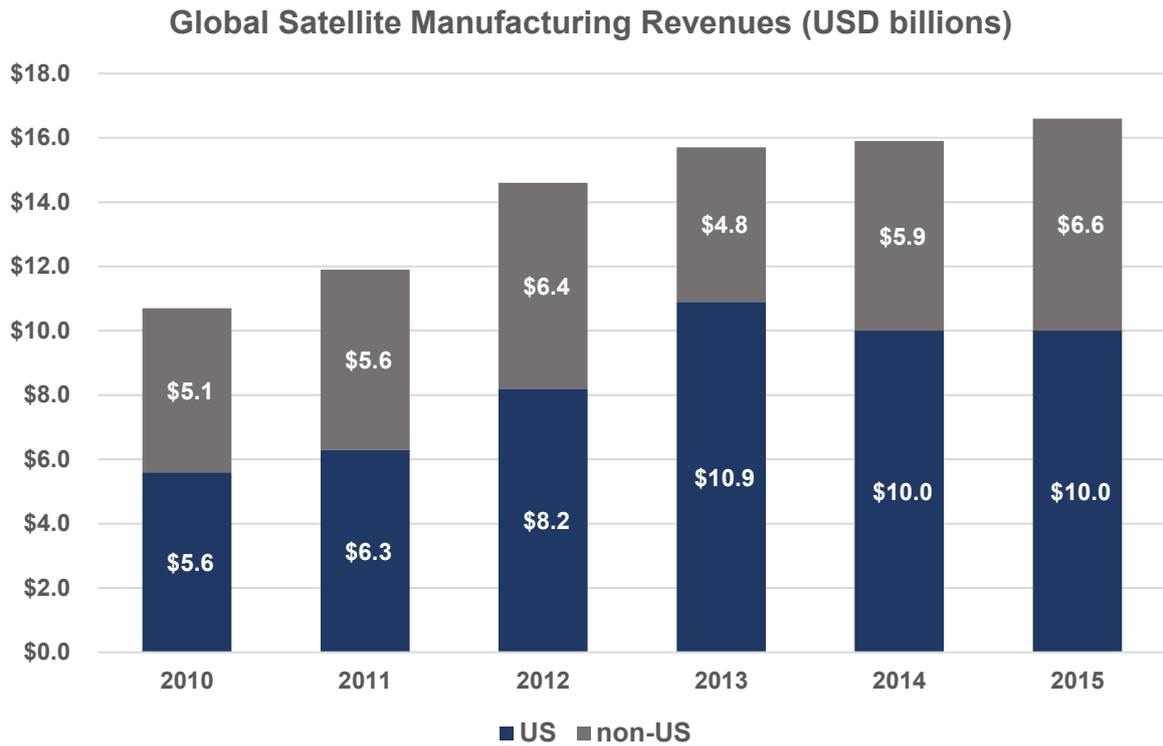


Figure 8: Satellite Manufacturing Revenues (Source: Satellite Industry Association, 2016)

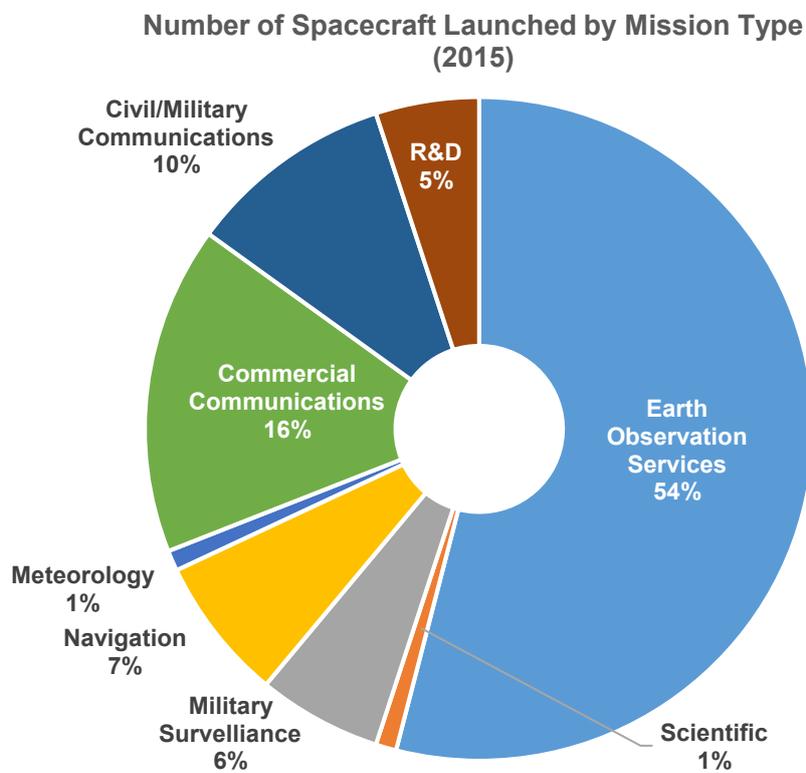


Figure 9: Number of Spacecraft Launched by Mission Type, 2015 (Source: Satellite Industry Association, 2016)

1.5.3 Launch Industry

The smallest industry's sector, it totaled USD 5.4 billion in 2015 from commercially-procured satellite launches²⁰, marking a decrease of 9% over 2014. In fact, 65 launches were commercially procured in 2015 falling from 73 launches in 2014. It is mainly due by the delays with US and Russian launches, while other providers in Europe, China and India saw an increase of satellite launches. Government customers are still the main driver, and the US had the largest share of commercially-procured launch revenues among global launch revenues. Launch orders are increasing on the other side, with 33 launch orders placed in 2015 against 22 in 2014. A notable trend in the launch industry is the development of very small launch vehicles: there are at least 17 very small launch vehicles under development all around the world, with a carrying capacity of maximum 500 kilograms – making those vehicles suitable for Low Earth Orbit purposes. The aim of these spacecraft is to answer a growing demand of dedicated vehicles for smallsat launches, but the price per kilogram launched is still relatively high if compared to larger vehicles.

Satellite Launch Industry Revenues (USD billions)

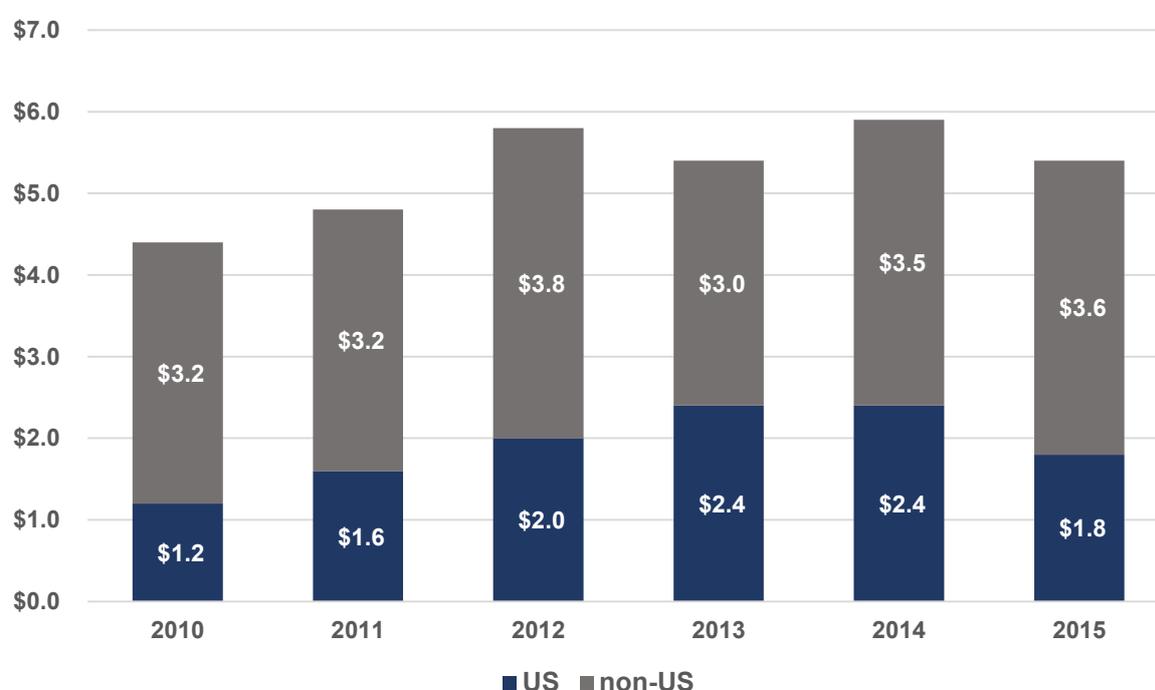


Figure 10: Satellite Launch Industry Revenues (Source: Satellite Industry Association, 2016)

Table 2: Notable launch vehicles

	Alpha	Electron	LauncherOne	Lynx Mark III	SOAR
Company	Firefly Space Systems	Rocket Lab	Virgin Galactic	XCOR Aerospace	Swiss Space Systems
LEO capacity	400 kg	150 kg	400 kg	10 kg	250 kg
First flight	2017	2016	2017	2018	2017
Price	USD 8M	USD 4.9M	USD 10M	USD 545K	USD 10.5M
Price/kg	USD 20,000	USD 32,667	USD 25,000	USD 54,500	USD 42,000

Source: Satellite Industry Association (2016)

²⁰ The TAURI Group 2016, 'State of the Satellite Industry Report', Satellite Industry Association, viewed in November 2016, <http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf>

1.5.4 Ground Equipment

The second largest satellite-related sector, it saw a slight 1% growth over 2014²¹, split among network equipment, consumer equipment like Satellite Navigation Services (GNSS) and other non-GNSS equipment like Satellite TV, radio, broadband and mobile. Network equipment saw the strongest growth accounting a plus 3% over 2014, while consumer equipment for satellite navigation (GNSS) remains the half of all Ground Equipment revenues, with the same level of 2014.

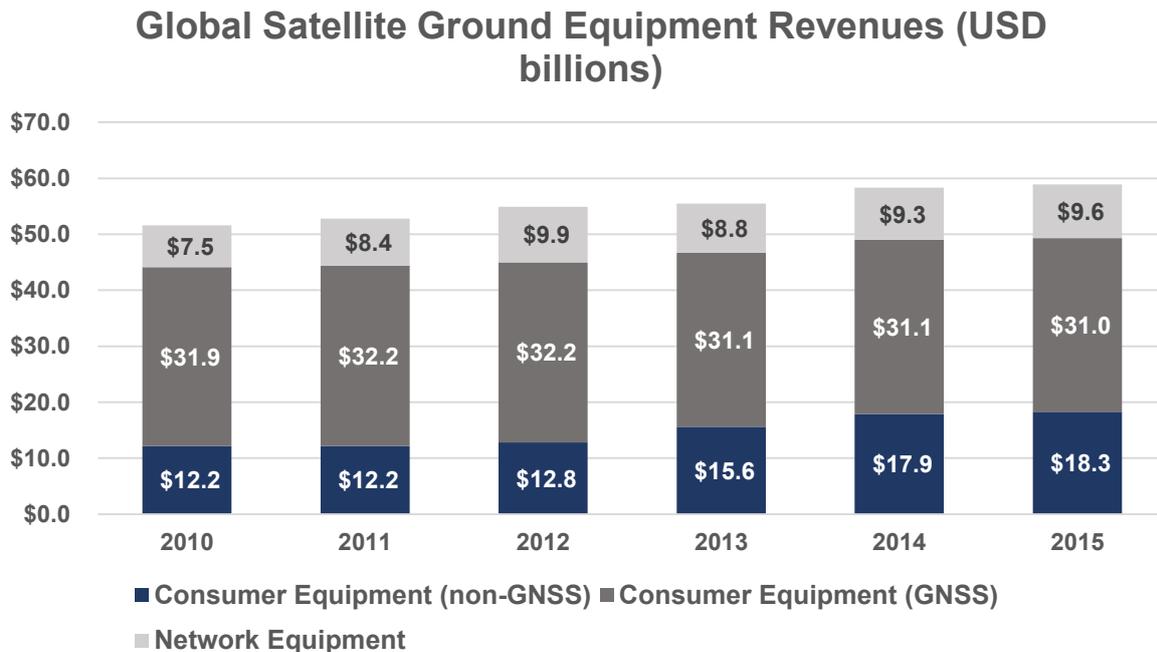


Figure 11: Global Satellite Ground Equipment Revenues (Source: Satellite Industry Association, 2016)

1.6 Space commercialization and “NewSpace” emergence

Recent years have seen a couple of great evolution patterns affecting the broad space industry, in addition to a long-term trend of globalization that regards space economy as a whole: space commercialization and the emergence of “NewSpace”. While during the 80s there was only a bunch of states engaged in the space industry, nowadays more countries and private corporates across a wide range of sectors are acting in space related activities.

We can refer to the commercial use of space as the provision of goods or services capable of generating a commercial value by using equipment that is sent into Earth orbit or outer space²². Some examples of commercial use of space include satellite navigation, satellite television and commercial satellite imagery. Operators of such services typically contract the manufacturing of satellites and their launch to private or public companies, which form an integral part of the space economy. On the other hand, space tourism could also be

²¹ The TAURI Group 2016, ‘State of the Satellite Industry Report’, Satellite Industry Association, viewed in November 2016, <http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf>

²² Equals Three Communications & Booz Allen Hamilton 2002, *Commercial Market Outreach Plan for the International Space Station*, NASA headquarters, <http://www.hq.nasa.gov/office/hqlibrary/documents/o49797051.pdf>

considered as an area of future growth, as business start-ups are making lots of effort to reduce the costs and risks of human spaceflight. Commercial development of space could be dated back to the Reagan administration, when National Space Policy set space commerce primarily as a milestone for the US. This policy then remarked strongly NASA's commitment to promote space commerce. In response to this directive NASA established the Centers for Commercial Development of Space (later renamed the Commercial Space Centers) and built a headquarters office aimed at overseeing every commercial activity ranging from technology transfer to commercial manufacturing in space. During the 1980s, NASA policy focused on opening up free access to space, and envisioned Space Shuttle and other space platforms for eventual product manufacturing in space. In 1986 the Space Shuttle Challenger deadly accident tragically proved the risks associated with space travel and space commerce. Space Shuttle programs thus experienced a sudden stop, and commercialization efforts slowed considerably. US presidency tried then to reinvigorate space programs, aiming specifically at commercialization of space. President Clinton's space directive placed space activities again at the center of national economic policy in 1996, as it defined a series of mechanisms and agreements by which companies could obtain space flight opportunities aimed at furthering commercial ventures. Today, NASA's efforts to provide commercial space-based opportunities is stronger as ever, offering a range of forms to private companies in order to settle partnership agreements. Private firms such as Virgin Galactic, SpaceX and Blue Origin are then more and more involved in a variety of space-related commercial activities like space hardware development and manufacturing, launch and support of unmanned space activity (e.g. satellite systems), conduct of scientific research.²³

The second relevant evolution pattern, starting from the beginning of 21st century, is the emergence of a new business sector, which has been called alternatively "Alt.space", "Entrepreneurial Space" or "NewSpace". These three labels have been used to describe economic approaches to space development that significantly diverge from NASA and mainstream space industry. The first person to coin the term "NewSpace" was Rick Tumlinson, a co-founder of the Space Frontier Foundation, and it defined it as

*"people, businesses and organizations working to open the space frontier to human settlement through economic development."*²⁴

It becomes clear then that *NewSpace* is a compound term that indicates a movement, made by a group of new ventures (including their people) that configure a developing private space industry – referring directly to its strong private connotation. Specifically, these ventures aim to provide low-cost access to space exploiting recent technology innovations and advocating manned and non-manned spaceflight. The emergence of this new innovative sector has been made possible by the path built with space commercialization process started 30-40 years ago. In general, the main characteristics of *NewSpace* firms are²⁵:

- **Low cost focus.** *NewSpace* companies are strictly focused on minimizing every cluster of cost – both relating hardware and software – that arises with production process. This feature is the most relevant distinctive trait of *NewSpace* ventures, as it involves across-the-board every single element of the companies themselves. The main way they try to achieve this thin cost structure is pushing on economies of scale: they try to pursue markets with higher usage than traditional ones like space

²³ Equals Three Communications & Booz Allen Hamilton 2002, *Commercial Market Outreach Plan for the International Space Station*, NASA headquarters, <http://www.hq.nasa.gov/office/hqlibrary/documents/o49797051.pdf>

²⁴ Hobbyspace n.d., *NewSpace, the alternative route to space*, Hobbyspace, viewed in October 2016, <http://www.hobbyspace.com/NewSpace/>

²⁵ Ibid.

transportation and space tourisms, which growing prospects are encouraging them to operate.

- **Future payoffs of cost reduction.** NewSpace companies are trying to set a strategy aimed to bet on cost reduction in order to create bigger markets and payoffs in the future. This comes from their belief that markets will grow in the immediate future, while traditional space companies don't rely on this prospects at all because they tend to believe that lower costs would just reduce their own revenues, as they regard space market as saturated. A deep diversity between the two perspectives is clearly assessable.
- **Incremental development.** NewSpace follow the model of recent high-tech firms such as personal computers, mobile phones and microprocessors, as their goal is to build a limited-capability initial system that could generate profit and then pay for the incremental development necessary to go through next steps. The main advantage is the fact that as markets expand, cash flows allow the young ventures to improve their product development lines and then to expand furtherly.
- **Consumer markets.** As it's been said with space commercialization, NewSpace firms target consumer markets like space tourism or commercial satellite broadcast. Space commercial growth constitutes a fundamental mean to achieve economies of scale.
- **Focus on operations.** NewSpace companies are extremely focused on operational costs instead of overall performance. They accept a certain failure risk in order to achieve an absolute cost control. Some kind of performance could be sacrificed to implement cost reduction, reliability and low maintenance costs.
- **Innovation.** The use of new technologies is available thanks to cutting-edge electronic innovations: these companies make large use of COTS (i.e. Commercial on the Shelf) materials combined to build robust space launch systems or satellites. This is another crucial mean of cost reduction.
- **Small dimensions.** As they are focused on lowering cost structures, NewSpace companies frequently are established and operate through lean, agile structures minimizing bureaucracy and overhead costs.

Strong focus on cost reduction and to hold a real control of cost structure is a fundamental character that involves every NewSpace actor. It represents a point of discontinuity with the past – the mainstream space industry – because before the advent of NewSpace ventures, there has never been such cost reduction pressure. A large, traditional and heavy communication satellite, for example, can cost some hundred million dollars, and could stay active for a decade. The giant launching and manufacturing costs are usually covered in 2 to 3 years by the generous service fees; from then nearly all revenues become profits. It shows clearly why a strong push for lower cost is the missing point among traditional satellite and space industry in general. This is the reason why traditional space firms focused completely on reliability and performance, without regarding the rise of high fixed costs. Another relevant issue that made cost reduction easier has been the steep change of NASA approach to contracts: while in the past contracts were offered on a “cost-plus” basis, meaning that all the costs would have been covered by US Space Agency granting then a profit above them, now it's getting more and more frequent for companies to award “fixed-prices” contracts. The fixed-price approach allows NASA to pay out its supply by reaching specified, incremental milestones: instead of subsidizing private space companies, this approach grants substantial budget savings for the Agency and poses a great stress on efficiency among commercial

space players, with the consequence that NewSpace firms are thus more incentivized to seek private equity and venture capital funding (and this is one great similarity with high-tech Silicon Valley companies).

There are three main regimes in which NewSpace companies operate:

- **Suborbital regime:** where spacecraft reach space at 100 km altitude or higher but without the necessary speed to go into orbit (e.g. 7.7 km/s at 300 km). This regime is suitable especially for space tourism companies like Richard Branson's Virgin Galactic, microgravity experiments and point-to-point earth travelling.
- **Orbital regime:** where spacecraft are able to reach different orbit types:

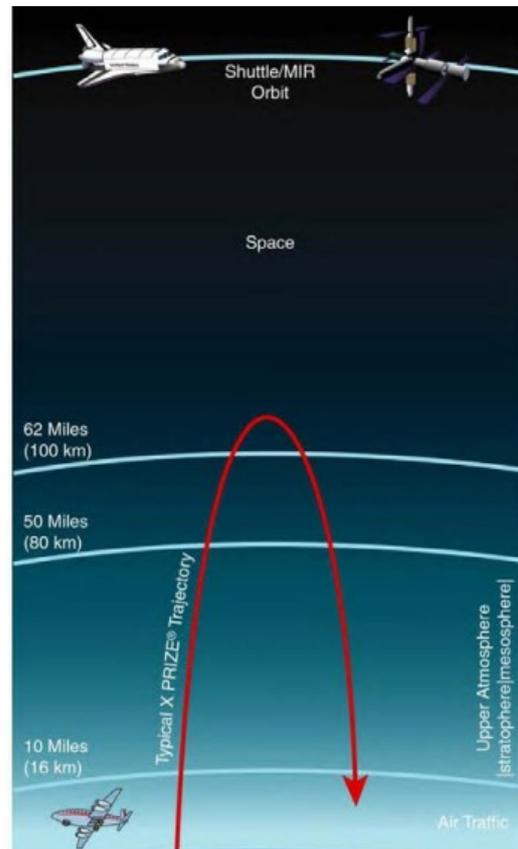


Figure 12: Suborbital regime layers (Source: <http://www.spacefuture.com>)

- HEO (High Earth Orbit): geocentric orbits above the altitude of geosynchronous orbit (35,786 km)²⁶
- GSO (Geosynchronous Earth Orbit) and GEO (Geostationary Earth Orbit): orbits around Earth matching Earth's sidereal rotation period. Both geosynchronous and geostationary orbits have a semi-major axis of 42,164 km (26,199 mi). All geostationary orbits are also geosynchronous, but not all geosynchronous orbits are geostationary. A geostationary orbit stays exactly above the equator, whereas a geosynchronous orbit may swing north and south to cover more of the Earth's surface. Both complete one full orbit of Earth per sidereal day (relative to the stars, not the Sun)²⁷.
- MEO (Medium Earth Orbit): geocentric orbits ranging in altitude from 2,000 km (1,240 miles) to just below geosynchronous orbit at 35,786 kilometers (22,236 mi). Also known as an intermediate circular orbit.²⁸
- LEO (Low Earth Orbit): geocentric orbits with altitudes from 160 to 2,000 km.²⁹

They all are suitable for satellites, but small satellites are focused mainly on LEOs as they require low launch capabilities. These orbit types are also a development field for space

²⁶ *Orbit: Definition. Ancillary description writer's guide* 2013, NASA Global Change Master Directory, viewed in October 2016, <http://gcmd.nasa.gov/add/ancillaryguide/platforms/orbit.html>

²⁷ Vallado, DA 2007, *Fundamentals of astrodynamics and applications*, Microcosm Press, Hawthorne, CA, p. 31.

²⁸ *Orbit: Definition. Ancillary description writer's guide* 2013, NASA Global Change Master Directory, viewed in October 2016, <http://gcmd.nasa.gov/add/ancillaryguide/platforms/orbit.html>

²⁹ *NASA Safety Standard 1740.14, Guidelines and Assessment Procedures for Limiting Orbital Debris* 1995, NASA, Office of Safety and Mission Assurance, pp. 37-38

tourism industry (for example visiting the International Space Station), research applications like developing new materials, earth imaging.

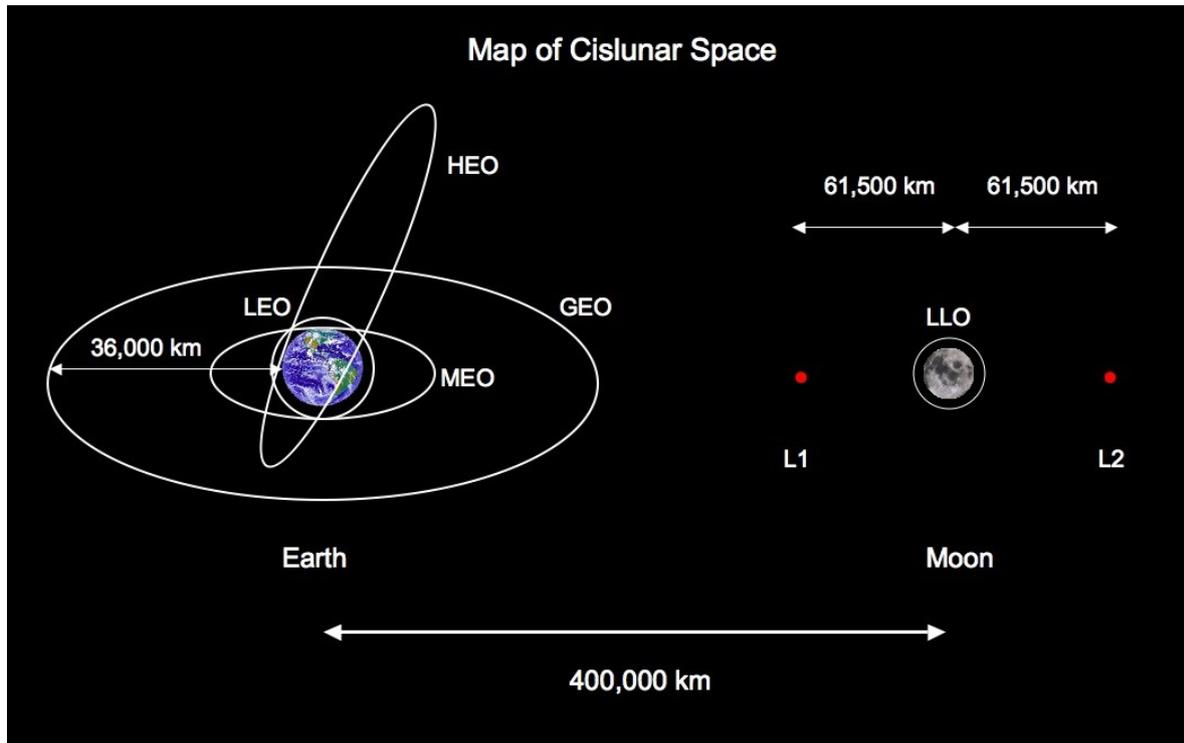


Figure 13: Map of typical Earth orbit regimes (Source: <http://www.spudislunarresources.com>)

- Deep Space regime:** a broad concept including Lagrange points, Moon, Asteroids, Mars and beyond. It involves potential development in the future space tourism industry, in particular regarding Mars human landing. It could lead also to interesting space research fields like long-term human travelling in space and launching small satellites from ISS (particularly taking advantage of CubeSat standard and P-POD launcher). Deep Space could lead also to satellite servicing development, allowing refueling, fixing and upgrading.



Figure 14: Example of Deep Space mission (Source: <http://www.jpl.nasa.gov/missions/deep-space-1-ds1/>)

2. The small satellites

2.1 Recent history and actual landscape

As this report focuses on nanosatellites - a particular segment in the broad satellite space technology, represented by a specific market with its own dynamics and features – a suitable classification is worthwhile provided.

Classifying satellites involves sorting them by mass, as given by the standard practices around the world. Small satellites in particular, also known as “smallsats”, are satellites low in mass and size, normally under 500 kg. While all satellites with a mass lower than 500 kg can be referred to as small satellites, different types are sorted basing on mass:

- Femto-satellites: from 10 g to 100 g
- Pico-satellites: lower than 1 kg
- Nano-satellites: from 1 kg to 10 kg
- Micro-satellites: from 10 kg to 100 kg
- Small-satellites: from 100 kg to 500 kg
- Traditional satellites: higher than 500 kg

The term “small satellite” sometimes “minisatellite”, often refers to objects with a wet mass (fuel included) under 500 kg, and this is increasingly the official reference.

“Microsatellite” or “microsat” is the unofficial nomenclature for all artificial satellites with a wet mass between 10 and 100 kg, but as long as it is not an official classification, there could be great variances in mass considered.

Many satellite spacecraft are based upon the “CubeSat” standard, which has been developed jointly by California Polytechnic State University and Stanford University back in 1999 to promote and develop the skills to design, manufacture, and test of small satellites intended for low Earth orbit (LEO) that could perform a number of scientific research functions and explore new space technologies. It thus refers to satellites made of multiple cube modules spanning 10 cm per side: each unit (often called “U”) has then a volume of exactly one liter. Consequently, each unit has a mass not exceeding 1.33 kg but usually very close to 1 kg.

All the small satellite items mentioned above have a distinctive feature: their relatively small volume allows space operators to deliver them into space as cargo, and then deployed by larger spacecraft as for instance the International Space Station orbiting Earth. This alternative method to reach orbit and space deployment represents a potentially disruptive characteristic in terms of costs, making it much simpler to deliver objects in space.

As this report is focused on small satellites, it is worth to look at history trends to gain some industry insights. The concept of small satellites is hardly new: Sputnik I, the very first satellite sent on space weighed just 83 kilograms, while the first American one, Explorer 1, weighed under 14 kilograms. It’s clear that at the time satellites were small primarily because of reduced launch vehicle capabilities. As launch vehicles became more capable, satellites grew larger as developers sought to make them more capable. This caused the rise of larger and heavier spacecraft launches and the lesser interest in tiny spacecraft, but they eventually experienced a resurgence starting from late 80s. Last 50 years of small satellites history could be summed

up in decades as follows, with the end of the 80s decade as a great divide between a first pioneering period with relatively small numbers and a recent renaissance with high growth potentials:

- **60s, boom and bust** - the industry experienced a rapid increase in the early 60s as the Space Age unfolded; as it's showed in figure 3, microsatellites launch rates grew rapidly from late 50s, eventually reaching a peak around 1965. A large number of small satellites were sent to space to obtain space environment data, flight test various technologies, and provide operational communication. Figure 3 shows separately *Strela* launch rates and *non-Strela* microsatellites yearly launch rates, as *Strela* (Russian for arrow) was a spacecraft designed to provide medium-range, store-and-forward communications using low Earth orbit (LEO). Around 3 nanosatellites were launched per year during the first decade of space exploration, as long as almost no picosatellites were launched in this period (figures 4 and 5). In the latter decade half small satellite launches started to decrease as they were essentially replaced by heavier ones thanks to the advent of more capable launch vehicles.
- **70s, Soviet Microsatellites dominance** – *Strela-1M* constellation's deployment (with over 300 spacecraft launched) kept high microsatellite launch rates during this period, while *non-Strela* spacecraft continue decreasing its launches. Western small satellite launch rates continue to decline as satellites grew in size with more powerful vehicles. Nano and Pico satellites entered their "dead-zone" as their launch rate fell to zero, at the beginning of the heavy-weight satellites era.
- **80s, "small satellite doldrums"** - the Soviet Union was actively launching military communications microsatellites, while the rest of the world was experiencing a dearth of new small satellites. No nano nor pico satellites were launched in the decade, confirming their path through the "dead-zone" started in the previous one. Apart from Soviet's military activity, western micro satellites numbers continue their decrease, as they eventually hit the bottom between 1977 and 1987: this period has been named "the small satellite doldrums"³⁰ to indicate the evidence of a stagnation in the small spacecraft industry. It is interesting to note that this "doldrums" did not seem to impact experimental and educational spacecraft launched by the Radio Amateur Satellite Corporation (AMSAT). AMSAT members did not want, or could not afford, communications capabilities provided by large satellites.
- **90s, small satellite resurgence** – "doldrums" ended in 1987, when two pivotal small satellite conferences were held that year:
 - Naval Postgraduate School in Monterey, California (USA) meeting, sponsored by the American Institute of Aeronautics and Astronautics (AIAA) and the Defense Advanced Research Agency (DARPA)
 - Utah State University Conference on Small Satellites that saw a large academic participation.
 - In the meanwhile, the rise of microprocessors and microelectronics gave small satellites new capabilities. Plus ESA offered standardized secondary payload capability on Ariane launch vehicles: this way new flight opportunities become available. This lead to the establishment of large LEO commercial communications constellations like Iridium and ORBCOMM. The ORBCOMM system was based on

³⁰ Janson, S 2011, *25 years of Small Satellites. The Aerospace Corporation*, viewed in October 2016, <http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1117&context=smallsat>

microsatellites and required the launch of 34 spacecraft between 1995 and 2000. Moreover, when the former Soviet Union collapsed in 1991 and approached free market economics, converted intercontinental ballistic missiles (ICBMs) became available to the world-wide community as low-cost launch vehicles. As the “doldrums” ended, launch numbers of small and nanosatellites began to recover, even if picosatellites remained still absent.

- **2000s, getting smaller** – a number of technological advancements made it possible to put more capable payloads onto smaller satellites. Among the key technical advances there are improvements in microprocessors, solar cells, batteries, and microelectromechanical systems (MEMS) that give smallsats capabilities previously possible only with larger spacecraft. Another relevant innovation that has helped small satellite development has been the Internet, allowing for improved collaboration on development efforts and even easier control of spacecraft through Internet-connected ground stations. Perhaps the major innovation that has supported the growth of the smallsat field has rather been the CubeSat program. Developed by California Polytechnic State University and Stanford University, it set a new satellite standard as a CubeSat is 10 centimeters on a side and weighs about 1 kilogram. CubeSats initially found interest among universities in part as a means to give students engineering experience with spacecraft for a tiny fraction of the cost of a larger spacecraft, particularly when coupled with secondary, or rideshare, payload launch opportunities. As it can be seen from figures 4-5, the CubeSat program definitely ignited nano and picosatellites resurgence from the beginning of 21st century, as from that point they have been populating the LEO.

This renaissance has been made possible by a set of technology drivers that have thrusted the satellite industry for the last 25 years. The advent of microelectronics saw the development of microprocessors, making gigabytes stored on a fingernail. “Moore’s Law” was proven to be successful as transistor density has been doubling every 2-2.5 years since 40 years ago and it is said it may last for more 10 years, making it possible to produce high- performance smart sensors and distributed processors systems. Inexpensive and multi-mega pixels imagery is now affordable, addressing Earth imagery purposes. The development of Micro-Electro-Mechanical Systems (MEMS) also boosted nanosatellites’ technology, as rate gyros, accelerometers and microbolometers can now be set together. Solar cells reached higher efficiency levels, as today’s solar cells are significantly more efficient than those available 25 years ago: fewer cells are required per unit power. In addition, cell voltages have increased so that a single cell can drive spacecraft circuits. Moreover, The CubeSat standard adoption led to a containerized delivery of satellites, with orbital deployers providing physical containment of secondary satellites and less risk for primary, heavy satellites. The CubeSat paradigm has then improved small satellite access to space: initial cost was around \$40K for a 1 unit CubeSat - a cost universities could afford. Many international launch options now exist, and that way small satellite missions are getting more diverse and launch rates are rising up: small satellites are deployed for space biology experiments, tracking ships, monitoring stellar magnitudes, inspecting other vehicles, space weather measurements, etc. It’s also interesting to notice that more nanosatellites are being launched than microsatellites.

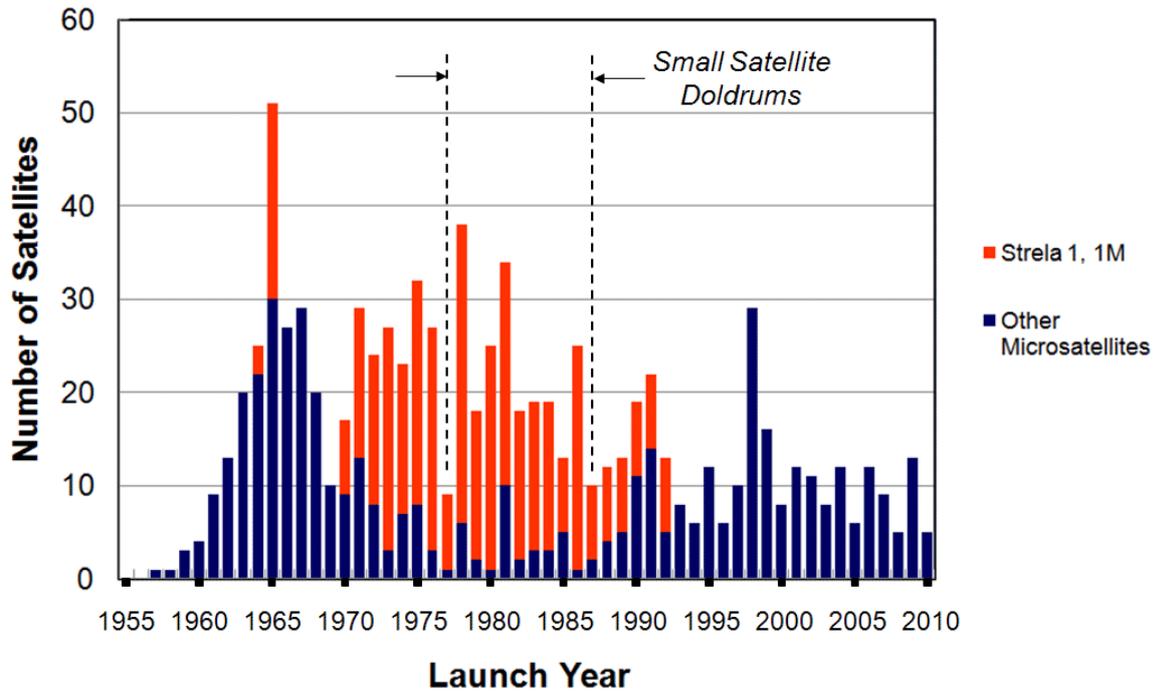


Figure 15: Microsatellites (10-100 kg) launches per year (Source: Siegfried W. Janson, 2011)

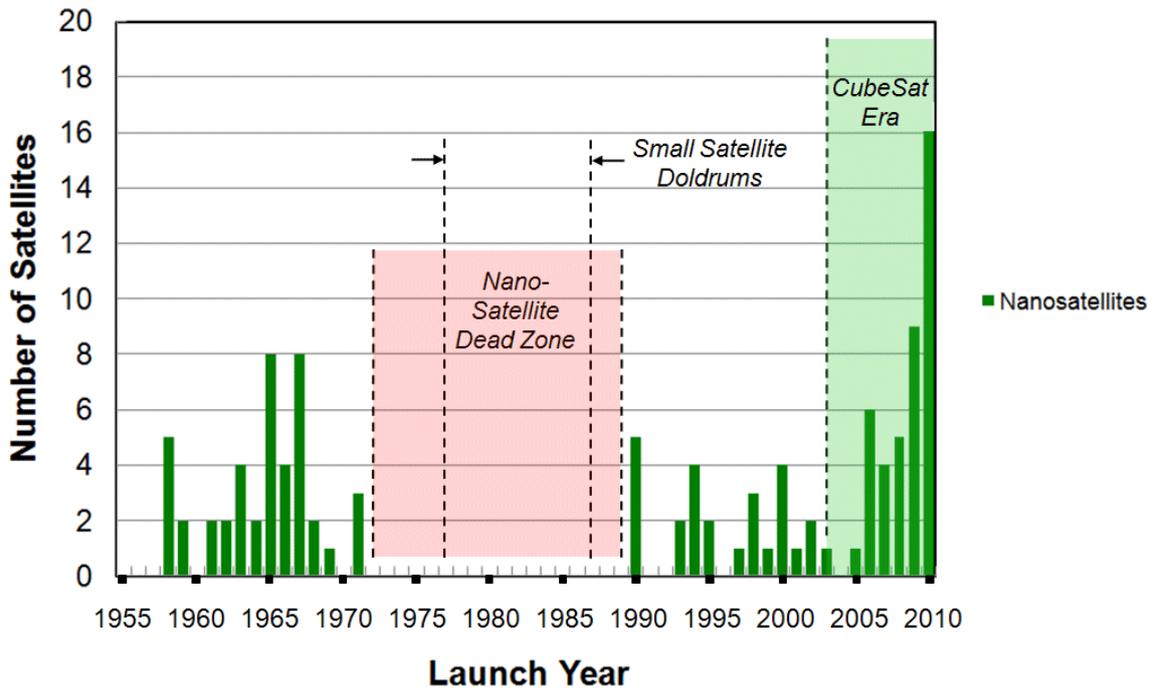


Figure 16: Nanosatellites (1-10 kg) launches per year (Source: Siegfried W. Janson, 2011)

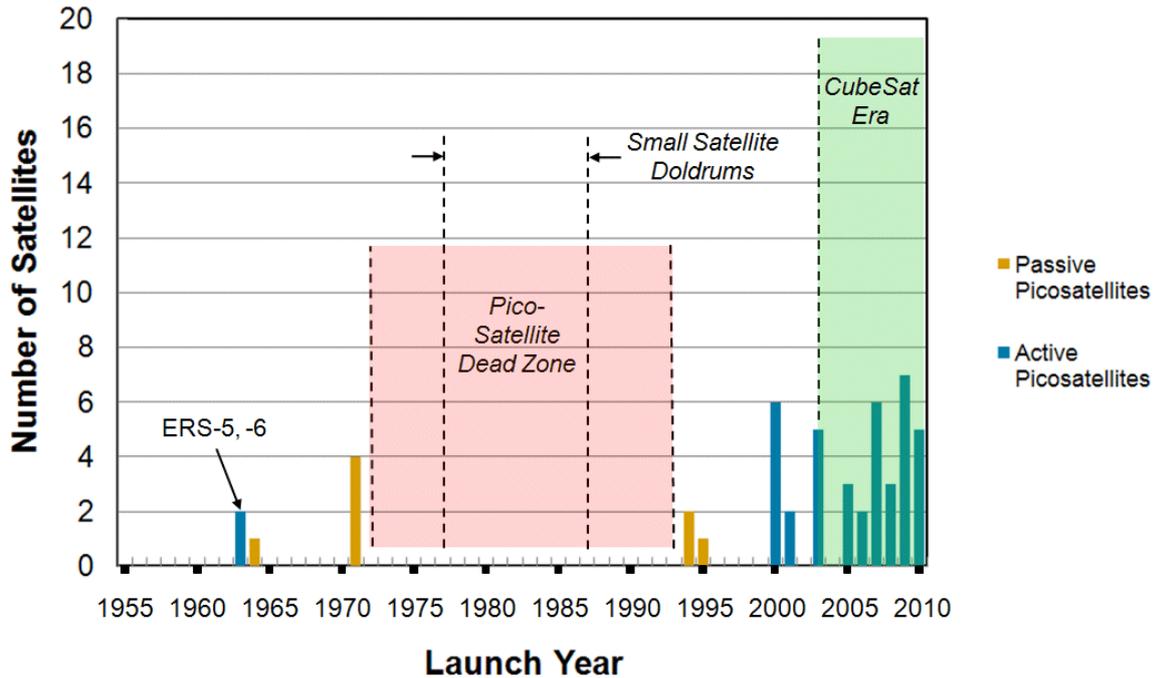


Figure 17: Picosatellites (<1 kg) launches per year (Source: Siegfried W. Janson, 2011)

2.2 Nano / Microsatellite Market and forecast

2.2.1 Launch facts

Launch history has reported a number of 128 small satellites in 2015³¹, representing a decrease of 17% if compared to previous year. Such low number was substantially due to launch issues, causing a higher 2016 forecast in terms of nano/microsatellites backlog (official estimates expected a number of launches between 163 and 212 in 2015)³² and affecting the pace of small spacecraft's growth:

- Failed launches of Antares in late 2014, Falcon 9 and Super Strypi in 2015, causing the loss of 51 small satellites with their respective primary payloads.
- The delay of SHERPA's first flight – a large payload nano/microsatellite adapter - expected to deploy around 87 satellites.

Despite those negative events, the industry continued its development on constellations of satellites for communication and imagery purposes. The most relevant projects included³³:

- Planet's attempt to launch 50 (perhaps more) additional CubeSats, continuing to build their constellation and expressing interest in swarms.

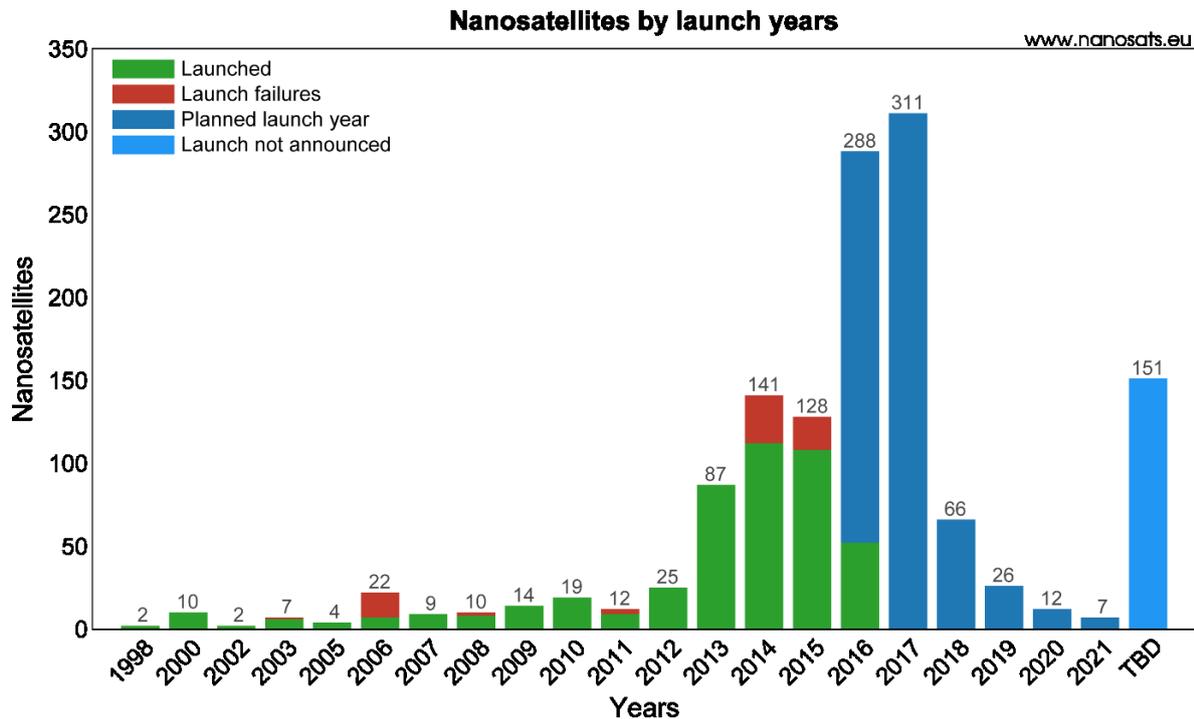
³¹ Doncaster, B, Shulman, J 2016, 'Nano/microsatellite market forecast', SpaceWorks Enterprises Inc., viewed in November 2016,

http://spaceworksforecast.com/docs/SpaceWorks_Nano_Microsatellite_Market_Forecast_2016.pdf

³² Ibid.

³³ Ibid.

- Spire’s announcement about a 100-satellites constellation expected to be launched in 2017, after a USD 40 million successful financing round from venture capitalists.



Note! At this time QB50 and SHERPA are still scheduled to launch in 2016 among many others.

Figure 18: Nanosatellites by launch years (Source: <http://www.nanosats.eu/>)

With regard to developers’ future plans and programs, several projections indicate that a number of 3.000 nano/microsatellites will be expected to require a launch between 2016 and 2022; there are thus many indicators of sustained growth in this sector among publically announced launch intentions, market researches and other qualitative/quantitative assessments.

2.2.2 Launch market

Historically, the vast majority of launch opportunities for small satellites has been provided by piggybacking as secondary payloads on medium and heavy-lift launch vehicles. Currently, in fact, most nano/microsatellite are taking advantage of these opportunities to get into orbit. The trend is likely to change, by the way, as many dedicated small-vehicle launchers are in development among a number of new players, building a new market in order to meet the growing demand of small spacecraft launches. Specifically, 2015 has been an eventful year for small launch vehicles development³⁴:

- Super Strypi experienced a failure shortly after liftoff while in its very first attempt to carry a load of 12 small satellites to orbit
- Rocket Labs announced an inaugural launch, expected to take place in last months of 2016

³⁴ Doncaster, B, Shulman, J 2016, ‘Nano/microsatellite market forecast’, SpaceWorks Enterprises Inc., viewed in November 2016, http://spaceworksforecast.com/docs/SpaceWorks_Nano_Microsatellite_Market_Forecast_2016.pdf

- DARPA cancelled the ALASA project
- Espace Dynamics ceased operations at the end of 2015 due to lack of funding

At present, it is then increasingly evident that launch market for small satellites consists of two main groups of players which compete against each other: a group of small vehicle, dedicated launchers and another group of more traditional launchers through bigger, heavier vehicles providing ridesharing opportunities. There are still no clear winners, but by now it is clear that the smallsats industry has strongly manifested a need for small, dedicated launch vehicles: the market is then projected to grow consistently in the near future.

Below some examples of ridesharing and small vehicles options:

Table 3: Rideshare providers

Rideshare Provider	LEO Payload (kg)	Stated IOC ³⁵ Date	Target Price	Launch	Configuration
Spaceflight Launch Services	165	2013	\$35K / kg ³⁶		Rideshare broker for numerous launch vehicles
Spaceflight SHERPA	1200	2016	<i>n/a</i>		Purposed designed payload adapter with propulsion for orbital maneuvers
Nanoracks	4-8	2013	\$60K / kg ³⁷		ISS deployment with resupply mission launch rideshare

Source: Doncaster, B., Shulman, J. (2016)

Table 4: Small vehicle launch providers

Dedicated Launch System	LEO Payload (kg)	Stated IOC ³⁵ Date	Target Price	Launch	Rocket Configuration
Electron	165	2016	\$30K / kg		Ground-launched, two-stage
LauncherOne	225	2017	\$45K / kg		Air-launched, expendable
SOAR	250	2017	\$44K / kg		Fully-reusable, spaceplane
Super Strypi	300	2015	\$54K / kg		Ground-launched, three-stage, solid
M-OV	363-454	<i>n/a</i>	<i>n/a</i>		Ground-launched, hybrid
Alpha	400	2016	\$21K / kg		Ground-launched, two-stage
Bloostar	90	2017	<i>n/a</i>		Ship-launched, balloon mean
GOLauncher 2	44	2018	\$57K / kg		Air-launched, solid and liquid

Source: Doncaster, B., Shulman, J. (2016)

³⁵ "Initial Operational Capability".

³⁶ For a 50 kg payload.

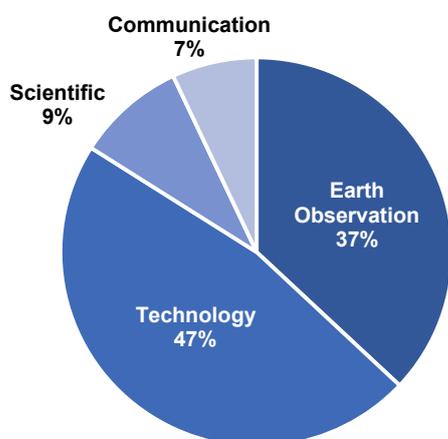
³⁷ Commercial pricing.

As the satellite industry grows steeply by the years, there are some geopolitical issues becoming increasingly relevant. For instance, U.S.-based launch vehicles have not been able to address satellites from China and Russian Federation, and with emerging markets rising and developing their own vehicles, they are going to face harsh competition for addressing foreign satellites. Despite the evidence indicates that more than 90% of worldwide nano/microsatellites are addressable for U.S. vehicles³⁸ (though non-addressable satellites are growing in numbers as foreign nations develop proper launch capabilities), many satellite operators are now choosing non-U.S. launch vehicles because of their competitive pricing and availability.

2.2.3 Trends

With regard to segments' trend, the commercial sector is expected to increase its relevance in the next three years, since it will represent the majority (over 70%) of all the future manufactured and launched nano/microsatellites. The vast majority of future nano/microsatellites is in fact expected to be utilized for Earth Observation purposes, highlighting this economic activity as one of the most profitable in companies' perspectives. With main commercial companies moving towards this segment, the portion of technology development and demonstration nano/microsatellites built by academic institutions will decrease consequently within next few years.

Historical (2009-2015):



Forecast (2016-2018):

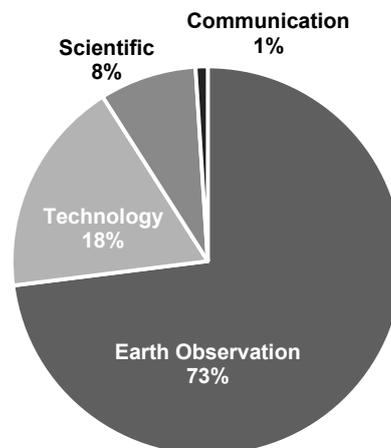


Figure 19: Nano/microsatellite purpose trends (Source: Satellite Industry Association, 2016)

The mass class of nanosatellites ranging from 1 to 3 kg has accounted for 71% of Nanosatellites number between 2009 and 2013 and it is expected to represent less than 30% of nanosatellites market in the future³⁹, even if they will be still used by academia sector.

³⁸ Doncaster, B, Shulman, J 2016, 'Nano/microsatellite market forecast', SpaceWorks Enterprises Inc., viewed in November 2016,

http://spaceworksforecast.com/docs/SpaceWorks_Nano_Microsatellite_Market_Forecast_2016.pdf

³⁹ Ibid.

The 4-6 kg mass class was represented only the 23% of Nanosatellites size portion from 2009 until 2013⁴⁰, and it's forecasted to increase: over 60% of future 1-10 kg nanosats will weight 4 to 6 kg. CubeSat standard is on the rise, as it can be noticed in figure 19: the main standard adopted at present is the 3U Cubesat, which is also expected to be successful in the future in terms of units launched and deployed.

In general, launch orders indicate that the 1-10 kg mass range will continue to be popular, marking a 40% average annual growth in terms of attempted deliveries since 2012⁴¹, attracting interest from both governments and the commercial sector, while the 11-50 kg range portion seems to remain less relevant.

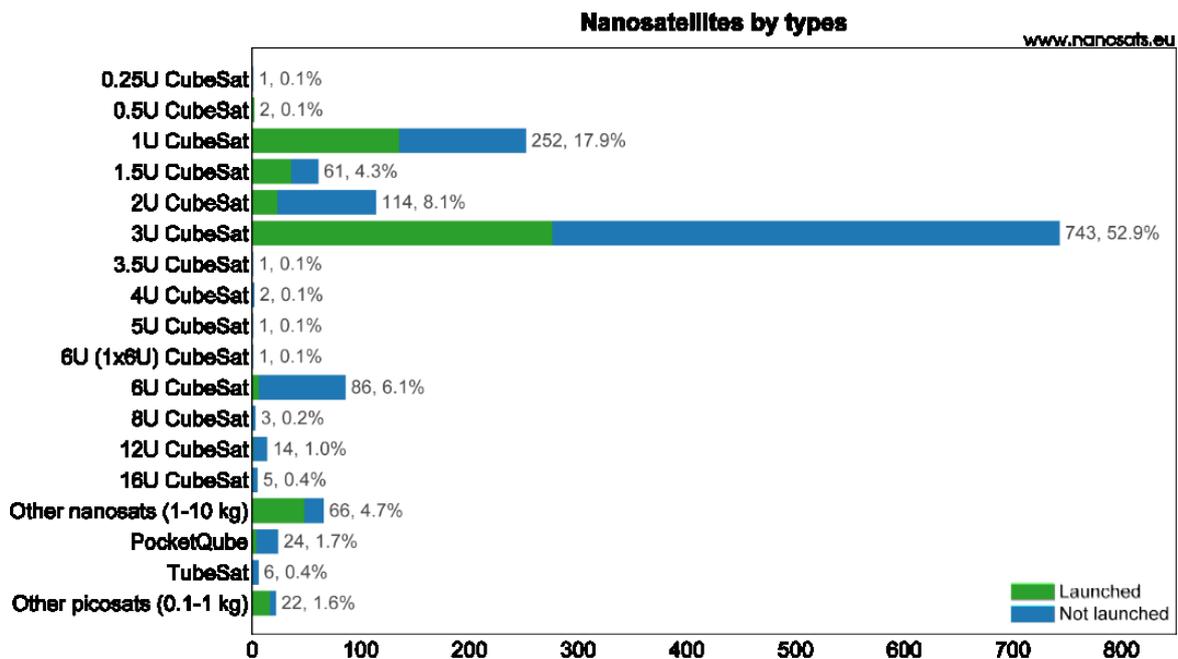


Figure 20: Nanosatellites by launch years (Source: <http://www.nanosats.eu/>)

2.2.4 Future developments

Small satellites subsystems are undergoing several seamless technology trends that can be identified. With reference to small spacecraft subsystems and auxiliary components:

- **Imaging payloads** - technology advancements have made possible to carry simple COTS sensors aboard, as long as custom and more complex multi-band sensors, thanks to their reduced dimensions. HD video capability and increasing resolution are also disrupting innovations that are affecting primarily small satellites market.
- **Power subsystems** – small, capable and thin packs of flat lithium ion polymer batteries assure power supply with a minimal weight factor. More stringent mass and volume constraints (especially for pico and femto satellites) are pushing the power storage industry above new frontiers. Future prospects see the adoption of flexible solar cells which could lead to new concepts in solar panel deployment.

⁴⁰ Doncaster, B, Shulman, J 2016, 'Nano/microsatellite market forecast', SpaceWorks Enterprises Inc., viewed in November 2016,

http://spaceworksforecast.com/docs/SpaceWorks_Nano_Microsatellite_Market_Forecast_2016.pdf

⁴¹ Ibid.

- **Altitude determination and control** – nowadays small satellites are relying on miniaturized technology without any performance degradation, even if CubeSats accuracy is still in some way worse than larger small satellites. There are some technology gaps to be filled in the next future, like the development of a thrust technology for satellites that weigh less than 100 kg.
- **Propulsion** – as small satellites are pushing down the spacecraft standard sizes, some embryonal propulsion systems are being tested like cold gas thrusters, solid rocket motors, and pulsed plasma thrusters. Within 5 years, presumably mature chemical and electric propulsion systems for smallsats will come.
- **Structures, materials and mechanisms** – size matters, as CubeSat rely on a common defined modular standard, while micro and mini satellites show still a high level of customization. Nanosats are becoming increasingly standard, though. 3-D printing represents the main and most likely disruptive technology. It could lead to smaller, more reliable, and standardized design of every mechanism that makes a satellite work.
- **Communications** – the current state of the art sees smallsats using Very High Frequency (VHF), Ultra High Frequency (UHF), X-band and IR/visible transmission technologies. The main trend is to increase signal frequency and thus transfer speeds. Cubesats data rates are still lower than bigger small satellites, as they operate in the order of Kbps. Forthcoming innovations are the development of laser communication techniques and high-gain deployable antennas.
- **Ground systems** – currently a point of weakness for the smallsat development, it represent a hard fixed cost issue that must be addressed. Today's missions rely on legacy systems from the traditional space age, and distributed individual mission systems around the globe. The industry is moving towards open source software packages that can enable distributed operations of small spacecraft, as long as commoditized networks to build a worldwide integrated ground control and transmission system. A technology gap must also be addressed, as ground systems must able to manage in an automatic way swarms of satellites' operations.
- **Launch** – small satellites reach orbits as secondary payloads, taking advantage of adapters (CubeSats and ESPA standards made it possible). Ridesharing have some issues though, because prime launches are often incompatible with specific small sats' orbits (usually much lower than traditional satellites' ones), as their reduced size makes difficult to implement capable propulsion systems able to change their orbit-regime. Nonetheless small launch vehicles are making dedicated launches for smallsats possible (and affordable), as long as large CubeSat deployers like the P-POD that deploys spacecraft from the ISS (with the advantage of being located directly in LEO).

Traditional satellite architectures are made of extremely capable and single satellites collecting data and measurements during their useful-life orbit cycle, and the conventional approach to space missions is costly. The main reason for these high cost levels is the strong focus on reliability, since expectations for performance are extremely high. That way, the traditional approach reveals itself as risk adverse, with high tradeoffs in terms of costs. Scientific, military or commercial missions, though, could require simultaneous (or near-simultaneous) measurements at distributed locations, which are proven to be very difficult and expensive due to the nature of traditional satellites and the way their networks operate. One example of useful satellite network is the Global Positioning System (GPS) by the use of very sophisticated platforms controlled by a wide range of space operators. With no doubt the high

cost of this complex systems is worth the benefits, as every large spacecraft carries multiple payloads and is able to perform various functions while orbiting. The advent of small satellites, is making possible to accomplish space missions where the key value driver is the ability to gather high fidelity measurements over a global area and in short periods of time. An alternative approach to quality-focused missions is developing: instead of paying for the absolute performance of a single spacecraft⁴², it's been proving worth to spread the responsibility for mission achievements across many low cost spacecraft (for example manufactured with respect to the CubeSat standard). With this new approach, a set of small satellites would be sent to orbit acting as a unique system, and still performing good: from a risk adverse traditional approach the industry is moving towards a risk tolerant approach. The concept of small satellites constellations is being introduced and tested: it comes to create an "ad-hoc", distributed network of smallsats, which are able to interact and act as a whole. Within such concept, a typical network architecture would consist of two different types of spacecraft⁴³:

- **"CCsat" (Communication & Computation satellite)** – the communication and computational network hub. Providing computing power and conveying space-to-ground data transmission, it's the ultimate neural center of the entire network, or constellation (also known as "swarm"). It is responsible for receiving data from all other constellation nodes, manipulating the aggregate data to downlink towards the ground, interacting with other "CCsat" nodes active in different orbits, taking care of all the subordinated "DSsats".
- **"DSsat" (Distributed Sensor satellite)** – ad-hoc sensor nodes performing missions based on their payload. The "DSsat" platform would be designed to carry any type of integrated payload. They are responsible of all the measurements thanks to their integrated payloads, configuring gathered data into broadcast packets and sending them to "CCsats", interacting with other "DSsats", conducting basic housekeeping activity. Normally "DSsats" are not meant to communicate with ground.

By this, each central network node can collect real-time data from all the peripheral nodes, allowing simultaneous measurements for a range of applications (e.g. weather forecasting).

⁴² Saylor, W, Smaagard, K, Nordby, N & Barnhart, D 2007, 'New scientific capabilities enabled by autonomous constellations of smallsats', *Small satellite conference*, viewed in November 2016, <http://digitalcommons.usu.edu/smallsat/2007/all2007/14/>

⁴³ Ibid.

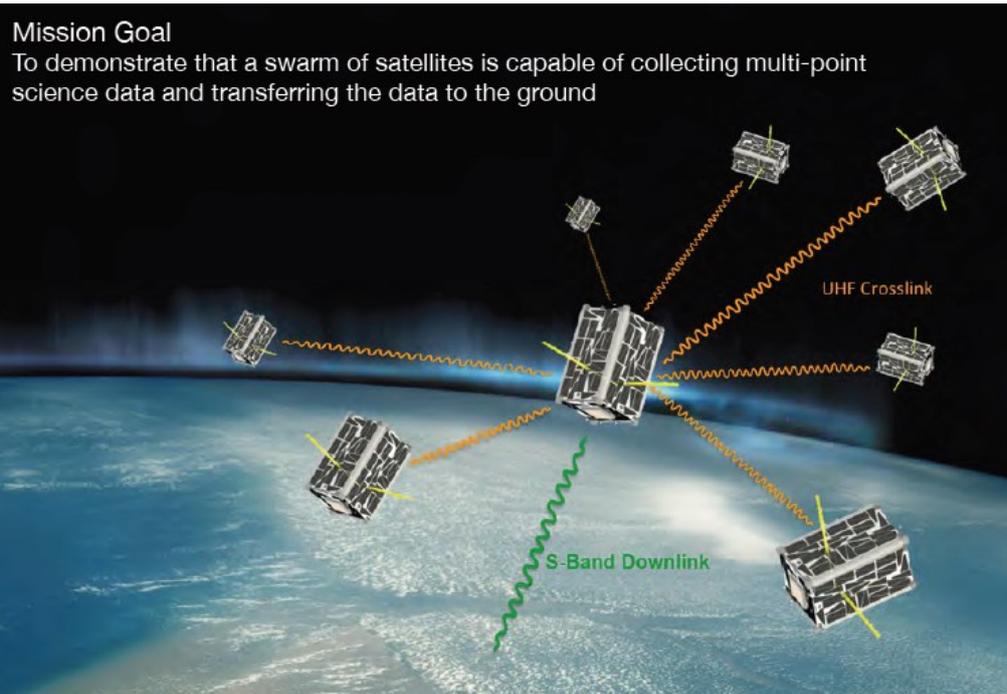


Figure 21: typical satellite swarm architecture

This particular architecture gives rise to three main capabilities:

- Ground ultimate users are immediately updated.
- Rapid collection of space disperse data measurements, at high levels of accuracy.
- The versatility of ad hoc wireless networks can be exploited for many different missions in space.

A significant demonstration of small satellites networks has been promoted by NASA's Small Spacecraft Technology Program (SSPT), with the EDSN project⁴⁴ (Edison Demonstration of SmallSat Networks). The mission goal were to demonstrate the capabilities of a swarm of small, inexpensive small satellites and the sustainability as a platform for distribute, multipoint, time synchronous measuring systems in Low Earth Orbit regimes. The mission has proved that multiple-spacecraft-networks enable risk mitigation through redundancy and function decentralization. Although EDSN project launch failure caused the loss of all the 8 test cubesats, there have been several successful constellation missions, for example Planet's Flock satellites or Skybox Imaging Earth observation constellation.

⁴⁴ Cockrell J, Alena, R, Mayer, D, Sanchez, H, Luzod, T, Yost, B & Klumpar, D 2012, 'EDSN: a large swarm of advanced yet very affordable, COTS-based nanosats that enable multipoint physics and open source apps, 26th Annual AIAA/USU Conference on Small Satellites, viewed in November 2016, <http://digitalcommons.usu.edu/smallsat/2012/all2012/89/>

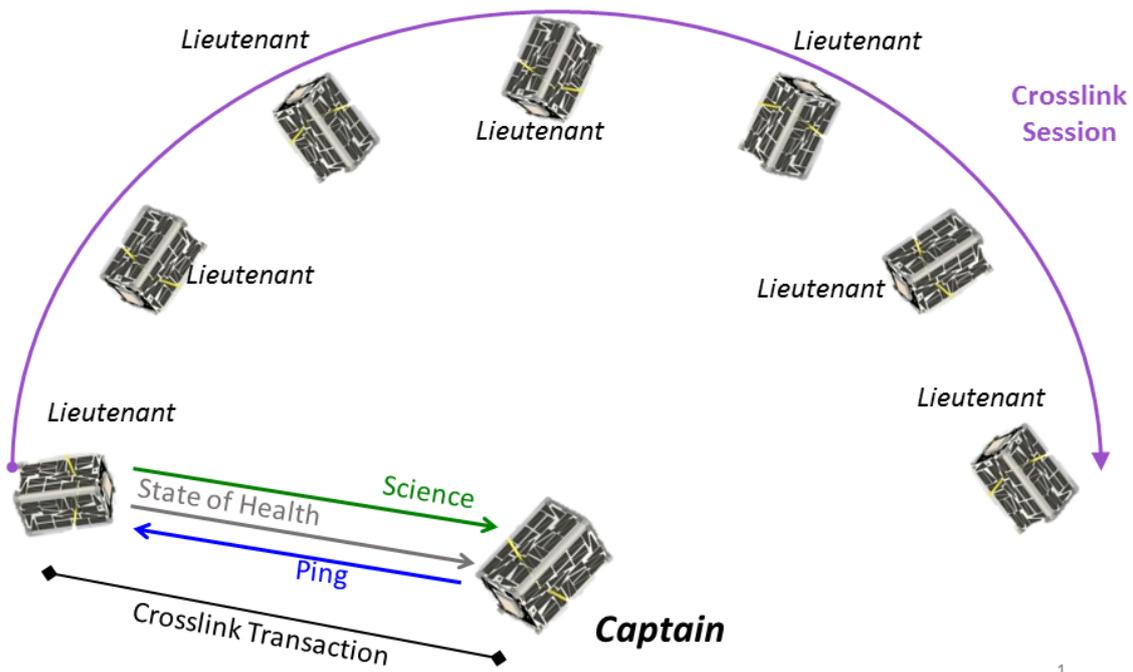


Figure 22: EDSN architecture (source: NASA)

The launch and deployment of multiple satellites has some issues associated, that essentially are:

- The deployment sequence
- The swarm geometry design

Small satellites have mass and volume constraints, so they are not often capable to carry a developed and powerful propulsion system to maneuver reaching desired orbits. In addition, compatibility requirement in order to be deployed by standardized systems as P-POD (CubeSats-only), is furtherly setting a limit. Scaling up the dimensions can jeopardize cost-effectiveness, as well as the lack of sufficiently small or inexpensive launch vehicles, so the deployment sequence (often as a secondary payload – the so called “piggybacking”) is critical both for maintaining an adequate satellite lifespan and for achieve the correct swarm geometry. In particular, the current launch paradigm as secondary payloads constitutes a limit to be successfully deployed into the correct orbit. Recent advancements in developing dedicated small launch vehicles are addressing those issues but critical orbit deployment remains a problem. In order to achieve cost-effective deployment of smallsats constellations, two particular deployment strategies have been proposed, both consisting of launching a complete multi-plane constellation on a single vehicle with on-orbit distribution⁴⁵:

- **Nodal precession:** a constellation deployment method using natural orbital perturbations to separate orbital planes, also known as “indirect plane separation”. This method takes advantage of differential rate of nodal precession due to the non-spherical geopotential of the Earth, allowing plane separations to be achieved without out-of-plane maneuvering. Multiple satellites deployment can be furtherly facilitated by carrying payloads on vehicles each equipped with a centralized propulsion system.

⁴⁵ Crisp, N, Smith, K & Hollingsworth, P 2015, Launch and deployment of distributed small satellite systems, *Acta Astronautica*, vol. 114, no. September-October 2015, pp. 65-78, <http://www.sciencedirect.com/science/article/pii/S009457651500171X>

This method of deployment has been demonstrated by the FORMOSAT-3/COSMIC mission launched in 2006, but requires a long time for the constellation deployment.

- **Earth-Moon Lagrange point (EML-1):** satellites are carried by vehicles all together launched to reach EML-1 location, before returning to Earth in the desired orbit.

2.2.5 Risk – space debris

During the last decade, as small satellite technology advanced and costs plunged, many spacecraft reached space. Moreover, more than 2.600 small satellites are expected to be launched to Low Earth Orbit by 2023⁴⁶, as for instance NASA issued contracts for small satellite launches to several companies, like for example Virgin Galactic and Firefly Space Systems. These increasing numbers conduct to the main issue that is related to small spacecraft: the risk of worsening the space junk problem. This orbiting debris consists of dead satellites and other derelict spacecraft like upper stages of launch vehicles, solid rocket motor effluents, flecks of paint, fragments from explosions or collisions, and this debris is a growing concern especially for the International Space Station, as the risk of colliding with dead objects is more and more increasing. Most of the cited debris stands in Low Earth Orbit, but Medium and Geosynchronous orbits are affected too. The required density of debris material for the initiation of the so-called “Kessler Syndrome”⁴⁷ - a cascading chain reaction of collisions leading to uncontrollable growth of further debris - may be close to be reached⁴⁸. All the NewSpace industry - and smallsats operators particularly – have then to take into consideration some debris mitigation action. There are a couple of self-mitigating aspect that in some way could scale down the problem:

- Low orbits - it causes satellite to have a shorter life-cycle due to space drag.
- Small dimensions – making this peculiar spacecraft easy to burn when falling down the atmosphere, so they usually burn-up before reaching ground.

⁴⁶ Machi, V 2016, ‘Small satellites: obvious benefits but also concerns’, *National Defense Magazine*, viewed in November 2016, <http://www.nationaldefensemagazine.org/archive/2016/september/Pages/SmallSatellitesObviousBenefitsButAlsoConcerns.aspx>

⁴⁷ Kessler, DJ & Cour-Palais, BG 1978, ‘Collision frequency of artificial satellites: the creation of a debris belt’, *Journal of geophysical research*, vol. 43, no. A6, <http://webpages.charter.net/dkessler/files/Collision%20Frequency.pdf>

⁴⁸ Anzaldúa, A 2014, ‘Orbital debris: resource ladder to the stars’, *The Space Review*, viewed in October 2016, <http://www.thespacereview.com/article/2457/1>

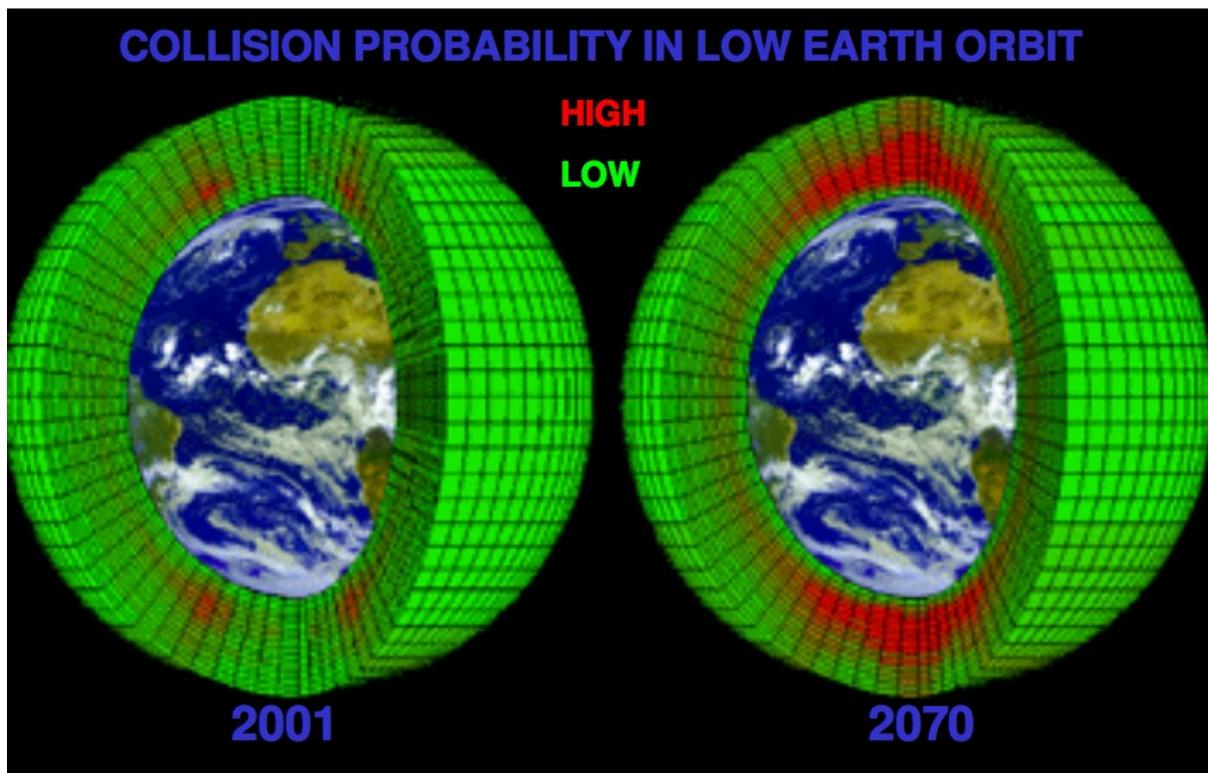


Figure 23: Probability of collision in LEO (Source: UKSA, UNOOSA)

For example, the European Space Agency (ESA) has already started testing techniques to catch space debris such as using a giant high-tech fishing net. Another option would be commercial space debris salvage operations, where companies could collect space trash for a fee - but international space law doesn't allow for that at the moment, and changing it would require a fair amount of time and discussion. There could be serious issues if a functioning satellite instead of a dysfunctional satellite is removed, and the need for global understanding and consent emerges. One of the main regulatory issues for CubeSats is that most current rules don't recognize their class as different from other satellites, whether on the issue of debris and de-orbiting or other legal hurdles such as licensing and insurance⁴⁹.

A framework of innovation management is thus needed to exploit the potential advantages offered by the small satellite solutions, keeping the maintenance of science quality as the foremost issue. This will require a science-driven approach to small satellite missions, as well as development and implementation of strategies to maintain dynamic continuity between sensors on successive satellites. Such science-driven approach will be challenging and in contrast against a traditional technology-driven approach. An overall strategy for Earth observation is needed to serve as the benchmark against which to evaluate new missions, especially if research and operational observing systems move toward a constellation approach⁵⁰.

The use of smallsats on either stand-alone or constellation basis will require management to rethink how it assesses and manages risk. Compared to large missions, management will need to tolerate higher levels of risk and develop a more flexible response to failure. The

⁴⁹ Turk, V 2015, 'We need to clear up space debris to make way for the small satellite boom, *Motherboard*, viewed in November 2016, <http://motherboard.vice.com/read/we-need-to-clear-up-space-debris-to-make-way-for-the-small-satellite-boom>

⁵⁰ Space Studies Board 2000, 'The role of small satellites in NASA and NOAA Earth observation programs', *National Academy Press*, Washington D.C., viewed in November 2016, http://docs.lib.noaa.gov/noaa_documents/NOAA_related_docs/small_satellites_nasa_noaa_2000.pdf

management of small satellite programs also needs to adopt a more streamlined and less hierarchical approach than is typical for larger missions, as for example it would be advantageous if interactions between contractor and government emphasize insight rather than oversight. Finally, smaller product development teams may lower costs, but this should be achieved by improving processes and increasing risk tolerance – not being achieved by increasing pressure on the team⁵¹.

The Earth science community is going to adjust to these new approaches. Sampling strategies must be placed on an equal footing with the drive to improve sensor quality, and the community must be willing to streamline its proposal development and review procedures⁵².

⁵¹ Space Studies Board 2000, 'The role of small satellites in NASA and NOAA Earth observation programs', *National Academy Press*, Washington D.C., viewed in November 2016, http://docs.lib.noaa.gov/noaa_documents/NOAA_related_docs/small_satellites_nasa_noaa_2000.pdf

⁵² Ibid.

3. Key Players

In this paragraph examples of prominent key players in the NewSpace industry - especially involving small satellites - are presented, as listed in the table below:

Table 5: NewSpace key players

Company name	Foundation	Location	Employees class	Application
Planet.	2010	USA	201-500	EO-Optical
Digital Globe	1993	USA	1001-5000	EO-Optical
Terra Bella	2009	USA	51-200	EO-Optical and video
Blacksky Global	2013	USA	11-50	EO-Optical
Satelloptic	2010	Argentina	unknown	EO-Optical
OmniEarth	2014	USA	11-50	EO-Optical
Hera Systems	2013	USA	11-50	EO-Optical
Astro Digital	2015	USA	11-50	EO-Optical and radar
Spire Global	2012	UK	51-200	EO-Radio occultation
GeoOptics	2006	USA	1-10	EO-Radio occultation
PlanetIQ	2012	USA	11-50	EO-Radio occultation
XpressSAR	2014	USA	unknown	EO-Radar
Iceye	2012	Finland	11-50	EO-Radar
Dhruva Space	2012	India	1-10	EO, communication
SpaceQuest	1994	USA	1-10	EO, communication
O3B Networks	2007	Netherlands	51-200	Communication
Fleet	2015	Australia	1-10	Communication, IoT
Myriota	2015	Australia	1-10	Communication, IoT
Clyde Space	2005	UK	51-200	Multi-purpose
GomSpace	2007	Denmark	51-200	Multi-purpose
Inovor	2012	Australia	1-10	Multi-purpose
NanoAvionics	2014	Lithuania	11-50	Multi-purpose
ISIS	2006	Netherlands	51-200	Multi-purpose
Pumpkin	1995	USA	1-10	Multi-purpose
SST	1985	UK	501-1000	Multi-purpose
SpaceDev	1963	USA	1001-5000	Multi-purpose
Tyvak	2011	USA	11-50	Multi-purpose
Blue Origin	2000	USA	501-1000	Multi-purpose
Virgin Galactic	2004	USA	501-1000	Launch
SpaceX	2002	USA	1001-5000	Launch
Rocket Lab	2008	New Zealand	11-50	Launch
Spaceflight	1999	USA	51-200	Launch
Nanoracks	2009	USA	11-50	Deployment

Source: author's elaboration

3.1 Earth observation

3.1.1 Planet.



Founded in 2010 by former NASA scientists Will Marshall, Robbie Schingler and Chris Boshuizen, Planet is a San Francisco based company that designs and manufacture CubeSats for Earth Observation and analytics purposes. Formerly known as “Cosmogia, Inc.” and “Planet Labs”, its primary missions are *Dove* and *Flock*. The company acquired BlackBridge in 2015, earning its constellation of 5 satellites called RapidEye – all of them include identical sensors, and stand on the same orbital regime, aimed at Earth imagery and decision making. Planet had then 87 Dove and 5 RapidEye satellites in orbit.

The Dove-1 was a technology demonstration nanosatellite for remote sensing purposes based on 3-U CubeSat standard, and its aims were: to build a low-cost imaging satellite with non-space, COTS components, showing that a constrained 3U CubeSat could host a camera payload, demonstrate the ability to design, produce and operate satellites on short schedules and low cost. Dove-1 was authorized to collect images of the Earth and undertake an experimental circular LEO. The satellite was launched as a secondary payload exploiting an Antares vehicle. The Resolution provided by Dove-1 was at an extent to discern individual trees, with a lifetime of only 6 days⁵³. Dove-2 was a technology demonstration mission similar to Dove-1, launched as a piggyback payload on a Soyuz vehicle. The lifetime of Dove-2 was about 180 days⁵⁴. Dove-3 and Dove-4 were subsequent missions of the same kind. *Dove* CubeSats are specifically designed for Earth observation, obtained through Earth surface scanning, and sending data to ground stations. The *Doves* constituted a satellite constellation that provided complete Earth imagery at 3-5 m optical resolution⁵⁵.

The *Flock* earth observing constellation consists of 3-U CubeSats, as well. *Flock-1* and *Flock-1b* constellations consist of each 28 satellites, while *Flock-1c* features 11 CubeSats. Those satellites featured a standard RGB imaging system, but five were fitted with experimental systems working in different optical spectral bands. Each *Flock* satellite carry a telescope and a frame CCD camera. First 28 *Flock-1* satellites were launched as secondary payloads on an Antares vehicle heading to the ISS, where they were deployed by Nanoracks deployers⁵⁶.

Small satellites size and low production costs allow the firm to quick prototype new designs, avoiding potential assets lost. The images gathered by such constellation can be exploited for climate monitoring, crop yield prediction, urban planning, and disaster response.⁵⁷

While most Earth-imaging companies usually do not build their own satellites, Planet is vertically integrated, as it designs and manufactures satellites completely in-house. The aim is to iterate and compound the latest technology available into their own small satellites. The

⁵³ Dove 1 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/dove-1.htm

⁵⁴ Dove 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/dove-2.htm

⁵⁵ Dove 3, 4 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/dove-3.htm

⁵⁶ *Flock-1, -1b, -1c, -1d, -1e, -1f, -2, -2b, -2c, -2d, -2e, -2e', -2k, -2p* n.d., *Gunter's Space Page*, http://space.skyrocket.de/doc_sdat/flock-1.htm

⁵⁷ Planet. n.d., *Planet. company website*, viewed in November 2016, <https://www.planet.com>

integration makes the company capable of responding to customer needs quickly. The Mission Control team is developing a custom software to manage a whole satellite fleet: in this way it could be made possible for few people to schedule imaging windows and download the image data to 30 ground stations throughout the world. For the company, in fact, the data-pipeline is crucial, as it is built to live online, ensuring easy and intuitive web access to latest imagery and archive. The imagery is then obtained through an automated compositing of scenes into mosaics, served on scalable tile servers, building time sliced mosaics, knowing exactly when every image was captured. The image processing runs through a scalable cloud-based platform that is flexible to handle any amount of data, by means of using Amazon Web Services.

The services offered by the company comprehend⁵⁸:

- **Monitoring programs** – through satellite imagery available worldwide
- **Global Basemaps** - spatially-accurate mosaics of up-to-date high-resolution imagery, for use as a background reference layer in GIS, SDIs, consumer, and general mapping
- **Planet platform** – accessible on the web for business purposes
- **Custom imagery** – on request data purchase

And covering a range of market segments, for example⁵⁹:

- **Agriculture and farming** – monitoring programs to provide useful information to identify changes in crops and soil. It is made available through the cloud-based platform, enabling farmers to make smarter decisions, optimize inputs, increase profitability, and enhance sustainable farm practices.
- **Defence and Intelligence** – giving situational awareness for fast decision making. It allows to have a glimpse on dispersed and disconnected locations.
- **Finance and business intelligence** - Progress Tracking and Competitive Intelligence to make well-informed decisions with global situational awareness plus competitive intelligence. The use of up-to-date data allows to inform supply chain management and progress tracking.
- **Civil government** - Understanding population growth, Monitor Natural Disasters, Heighten Regional Awareness to enhance a better use of land
- **Energy and infrastructure** – to implement Regulation, Enforcement, Pipeline Monitoring, Construction, Encroachment
- **Forestry** - Forest Health Monitoring, Illegal Logging Tracking, Forestry Operations Planning

Planet has lost 26 satellite because of the explosion of an Antares vehicle, causing a relevant damage to the company. But the business model has proven to be successful to reduce risks, by spreading it among multiple launches and satellites.

To keep the growth pace and launch more satellites into orbit, the company has raised a \$95 million in a combination of equity and debt financing in 2015. The USD 70 million equity part was collected with an equity financing round led by Data Collective and other investors. In

⁵⁸ Planet. n.d., *Planet. company website*, viewed in November 2016, <https://www.planet.com>

⁵⁹ Ibid.

total, Planet has raised USD 160 million since being founded in 2010, which represents a relevant amount that the firm wants to pay off: it has clients in a number of different industries, including mapping and agriculture, but sees room to expand.

In September 2016 the company awarded a USD 20 million contract from US's National Geospatial-Intelligence Agency, giving the latter access to its global imagery archive, updated every 15 days. It has been described as an "introductory contract" by the NGA, and Planet has indicated that it would seek additional work with NGA and other government agencies⁶⁰.

3.1.2 Digital Globe



DigitalGlobe is a US commercial supplier of space imagery and geospatial content, and operator of civilian remote sensing spacecraft. The company went public on the New York Stock Exchange in 2009, raised USD 279 million and it is headquartered in Westminster, Colorado.

Once called WorldView Imaging Corporation, it was founded in 1992, the year when the Land Remote Sensing Policy Act allowed private companies to begin operations within the satellite imaging business. It was initially funded by private financing from Silicon Valley sources and corporations from US, Europe, and Japan. The company's first remote sensing satellite was capable of collecting images with a 3-meters resolution. 1995 saw company's incorporation into EarthWatch, merging with Ball Aerospace & Technologies' commercial remote sensing operations. In September 2001, EarthWatch became known as DigitalGlobe and launched Quickbird, the world's highest resolution commercial imaging satellite at the time. Between 2008 and 2009 it signed key agreements with important customers – e.g. Google, Microsoft, and Nokia - focusing on location-based services and mapping applications with access to high-resolution satellite imagery. In 2013 the company acquired GeoEye which was famous for launching IKONOS - world's first commercial sub-meter resolution imaging satellite - in 1999: it became then a global leader in Earth imagery and geospatial analysis. Digital Globe strategically acquired Spatial Energy in 2014 and gained multi-source geospatial solutions for customers operating in the energy sector. In October 2016, the company has announced that it has signed a definitive agreement to acquire privately held Radiant from Aston Capital for \$140 million in cash: Radiant provides advanced technical and analytical solutions focused on enhancing the quality and speed of decision making while reducing risk and ensuring mission success. According to a company statement, "upon completing the transaction, DigitalGlobe will strengthen its position as the leading commercial source of geospatial information and insight with the capability and scale to address the needs of the world's largest and most sophisticated customers. The combined DigitalGlobe Services business will support critical national security missions with an expanded portfolio of advanced capabilities that extend across the entire geospatial intelligence value chain". Radiant has headquarters in Chantilly, Virginia and has built a relevant relationship with the U.S. Intelligence Community, having contracts with the National Reconnaissance Office (NRO), National Geospatial-Intelligence Agency (NGA), Defense Intelligence Agency (DIA) and Special Operations Command (SOCOM).

⁶⁰ Foust, J 2016, 'White House announces small satellite initiative', *Space News*, viewed in November 2016, <http://spacenews.com/white-house-announces-small-satellite-initiative/>

Digital Globe group owns and operates a sophisticated constellation of high-resolution commercial earth imaging satellites. WorldView-1, GeoEye-1, WorldView-2, and WorldView-3 together are Digital Globe's satellites capable of collecting over one billion square kilometers of quality imagery per year and offering intraday revisits around the globe⁶¹. The company plans to put another satellite in orbit, with the WorldView-4 mission by 2016, increasing imagery resolution up to 30 cm.

Digital Globe recently formed a joint venture with TAQNIA (a firm dedicated to accelerating technology development for Saudi Arabia) and KACST (King Abdulaziz City for Science and Technology), to develop a constellation of highly capable small imaging satellites to support the needs of customers around the world. The joint venture will be responsible for developing six or more sub-meter resolution imaging satellites which are expected to be capable of collecting imagery with anticipated 80 cm resolution and to leverage DigitalGlobe's ground infrastructure. Joint venture's spacecraft are expected to launch in late 2018 or early 2019⁶². This project shows Digital Globe's strong interest for small satellites, aiming at two orders of reasons: customers' data needs, complementing the small sat capacity on top of the satellites they already have, and incrementing visits frequency. The company aims at offering a unique combination of large, complex satellites with smallsats constellations to match high and low resolution capabilities, in pursuit of market needs. TAQNIA and KACST will be responsible for building and launching the satellites, while DigitalGlobe will be responsible for ground infrastructure. TAQNIA will gain the 50% of the constellation capacity inside the KACST communication zone and it will earn a revenue share of the capacity generated by DigitalGlobe. Digital Globe will monetize the 100% of the constellation capacity outside Saudi Arabia.

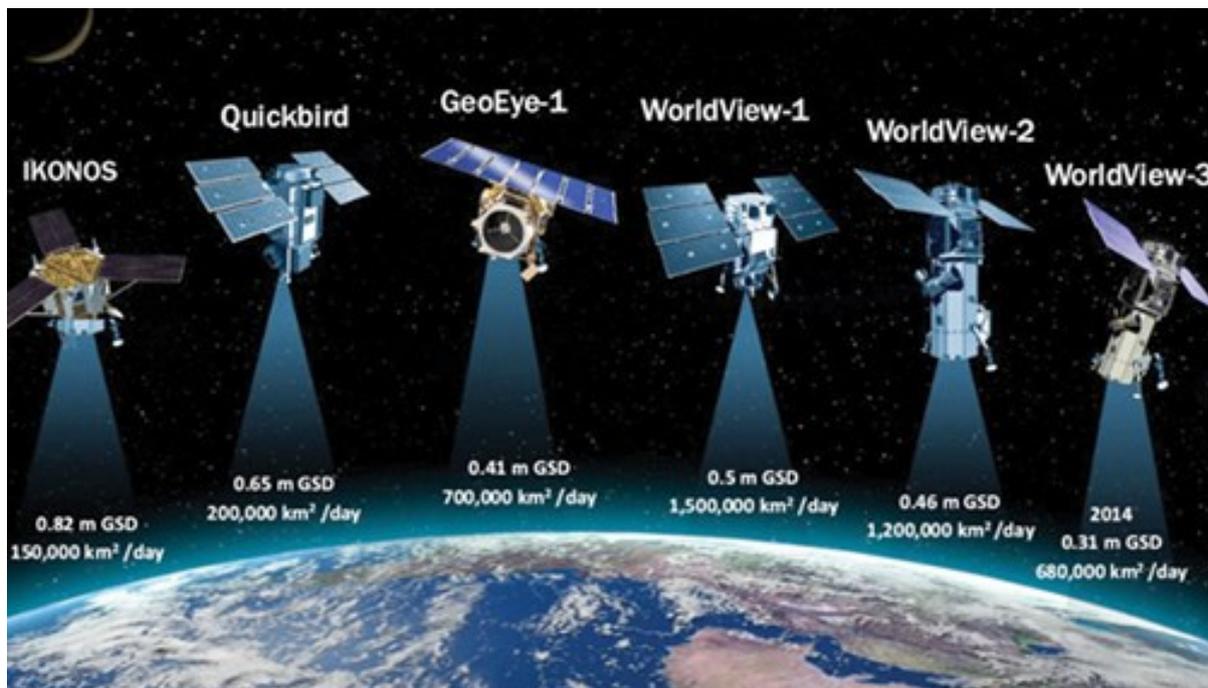


Figure 24: DigitalGlobe Satellite Constellation as of 2016 (Source: www.geospatialworld.net)

⁶¹ DigitalGlobe n.d., *DigitalGlobe company website*, viewed in November 2016, <http://www.digitalglobe.com/about/>

⁶² Magan, V 2016, 'DigitalGlobe forms joint venture to develop smallsats in Saudi Arabia', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2016/02/22/digitalglobe-forms-joint-venture-to-develop-smallsats-in-saudi-arabia/>

Digital Globe thinks that small satellites are of limited use by themselves, because of their low resolution capability. For this reason they see smallsats as complementary to other high resolution spacecraft in use, and to fill capacity gaps, as small satellite constellations would optimize their existing assets, in order to meet customer's demands⁶³. Company's traditional core-business has been about large and high performing satellites and they will keep investment going, but it intends to invest in research and development for taking advantage of small satellites potential.

The key success factors in Digital Globe's perspective are:

- **Resolution** – as it is the only company delivering 30 cm resolution imagery
- **Collection capacity** – as it collects over three million square kilometers a day
- **Haze penetration** – as technology allows to see through smoke and haze
- **Spectral diversity** – as it works with multispectral and superspectral layers
- **Revisit rate** – as high rates mean detecting changes within short periods of time
- **Locational accuracy** – as high accuracy standards help building confidence in maps
- **Historical library** – as it has a 16-year image library of global coverage
- **Cloud solutions** – as Earth imagery library is accessible through powerful cloud-based services

The firm's main market targets are:

- **Civil Government:** providing geospatial data to work more efficiently and better serve citizens, topographic mapping for improved construction of infrastructure planning, digitize parcels for accurate land use or agricultural records, mitigate disasters effect before they happen.
- **Energy industry:** making successful exploitation of new global energy sources possible, e.g. reducing time between site planning and drilling, and providing data management and analysis for oil & gas operators.
- **Location-Based Services**
- **Mining**, revealing pathfinder minerals, small outcrops, and detailed structures in remote regions
- **Defence & Intelligence**, getting a living picture of operational environments.
- **Additional Industries**, for example the marine industry and the insurance industry.

⁶³ Geospatial World 2016, 'Smallsat foray will add to DG's high-res imagery arsenal', *Geospatial World*, viewed in November 2016, <https://www.geospatialworld.net/article/smallsat-foray-will-add-to-dgs-high-res-imagery-arsenal/>

3.1.3 Terra Bella



Terra Bella (previously named Skybox Imaging) is a Google subsidiary providing commercial high-resolution Earth observation satellite imagery, high-definition video and analytics services. Founded in 2009 by Dan Berkenstock, Julian Mann, John Fenwick, and Ching-Yu Hu⁶⁴, the company's mission is "rethinking geospatial data in a bigger way"⁶⁵ that means harnessing the world's most advanced deep learning and computing resources, combining them with a vast range of geospatial and web information, to understand and reveal the real global economy drivers⁶⁶ by building satellites with "off-the-shelf" electronics that cost under \$50 million⁶⁷.

By 2012 the firm had raised a total of US\$91 million of private capital from a number of venture capital enterprises, and in 2013 it launched its first satellite, SkySat-1. In 2014 the second satellite was launched, SkySat-2 and the first images captured were released within 48 hours of launch. In 2014, it also awarded a contract to build 13 satellites based on a revised "SkySat C" design for the customer SSL. The first of these, Skysat-3 has been launched in 2016. On June 10, 2014 it announced that it had an agreement to be acquired by Google for USD 500 million.

Terra Bella's aim is to provide high-resolution satellite imagery of any place on Earth multiple times a day⁶⁸. Its plan is to innovate the satellite industry by building satellites with cheaper "off-the-shelf" electronics, relying on the CubeSat concept with optimized design using inexpensive automotive grade electronics, as well as fast commercially available processors⁶⁹. The firm is indeed actively involved in these applications:

- **Anticipating supply chain changes** - monitoring the flow of goods to measure global economic indicators. The imagery would then be valuable to help economists, supply chain managers, hedge fund traders, and logistics operators to identify inefficiencies and anticipate supply chain bottlenecks with a "from-above" unique perspective.
- **emergency and disaster relief** – providing up-to-date satellite imagery that gives critical information to emergency responders who need to assess damage and provide assistance in humanitarian and natural disasters
- **Tracking mining development** – revealing patterns in rapidly changing infrastructure and identifying areas of risk and opportunity. The huge amount of data can be used in a variety of ways, from construction companies to track development of projects of remote areas through financial analysts gathering research for investment due diligence.

Terra Bella's concept satellites are built and developed with three key characteristics:

⁶⁴ Perry, TS 2013, 'Start-up Profile: Skybox Imaging', *IEEE Spectrum*, viewed in November 2016, <http://spectrum.ieee.org/at-work/innovation/startup-profile-skybox-imaging>

⁶⁵ Terra Bella n.d., *Terra Bella company website*, viewed in November 2016, <http://terrabella.google.com/>

⁶⁶ Ibid.

⁶⁷ Truong, A 2013, 'Proof that cheaper satellites still can take incredibly detailed photos of Earth', *Fast Company*, <https://www.fastcompany.com/3023325/fast-feed/proof-that-cheaper-satellites-still-can-take-incredibly-detailed-photos-of-earth?partner>

⁶⁸ Burns, M 2012, 'Skybox Imaging raises \$70M to launch two high-res imaging microsattellites', *TechCrunch*, viewed in November 2016, <https://techcrunch.com/2012/04/17/skybox-imaging-closes-70m-in-series-c-funding-with-immediate-plans-to-launch-two-high-res-imaging-microsatellites/>

⁶⁹ Terra Bella n.d., *Terra Bella company website*, viewed in November 2016, <http://terrabella.google.com/>

- **Small size:** less than 100 kg and with dimensions not bigger than 0.6x0.6x0.8 metres
- **High speed image transfer rates**
- **Proprietary imaging chain:** <90 cm imagery resolution (Pan, RGB, NIR) and 1.1 meter video resolution at 30 frames per second from an altitude of 600 kilometers

The products developed consist then of high-resolution, small satellite platforms capable of rapid response, high-resolution imagery at a fraction of the cost of traditional imaging satellites. The breakthrough capability of the company is the ability to capture high-resolution color and near-infrared imagery (90 cm resolution) in a small package weighting less than 100 kg. In order to achieve detailed imagery, it also utilizes a two-dimensional sensor array with a proprietary image filter taking multiple frames per second. It remarkably captured the first-ever commercial high-resolution video of Earth from a satellite.

The first seven-satellite constellation has been launched, and a second generation of satellites (SkySat-3-7) includes a propulsion module to support orbit-stationing and enable improvements in resolution.

3.1.4 BlackSky Global



BlackSky Global is a start-up company with venture capital financial backing that is based in Seattle, and is using Spaceflight Services to build the satellites and hunt for launch opportunities. BlackSky does not build satellite itself but is a global intelligence platform relying on data from third-party nanosatellites, and aimed at delivering timely, relevant, and actionable information valuable to make swift and informed decisions.

The company owns a multi-source imagery catalogue that currently comes from 10 high resolution spacecraft, and they can let customers task satellites to take current images or monitor areas of interest. BlackSky delivers then geo-spatial insights about an area or topic of interest through capabilities of machine learning, predictive algorithms, and natural language processing. In that way, the firm synthesizes data from a wide array of sources including social media, news outlets, radio communications, and satellites to create a unique insightful information data set. BlackSky's business model is different from many smallsats firms analysed above, as it is focused on merging satellite imagery with real-time data. A holistic view of the situation is thus the distinctive marker of the company.

The company is planning to put together a constellation of roughly 60 satellites – with six spacecraft on orbit by the end of 2017 – providing frequent revisit rates over 95% of the Earth's human population, and revisiting the majority of spots 40 and 70 times a day. This swarm is intended to deliver colour imagery at a resolution of one meter per pixel. It has already raised capital to fund the purchase of its first six spacecraft, planned to be launched in 2016 and will pave the way for the rest of the fleet.⁷⁰ They will also have an on-board propulsion system capable of a 3 year orbital life. The satellites are meant to be built by Spaceflight Services. The first couple of satellites, BlackSky Pathfinder 1 and 2 will be launched in late 2016, as they will precede the rest of the constellation as experimental satellites while four more

⁷⁰ Henry, C 2015, 'BlackSky Global details plans for 60 satellite Earth observation constellation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2015/06/16/blacksky-global-details-plans-for-60-satellite-earth-observation-constellation/>

satellites named BlackSky Global 1 to 4 will follow in 2017. The full constellation of 60 satellites is planned for 2019 that will be replaced every three years.⁷¹ It would also be able to provide video as well at a speed of one frame per second, and the company is also planning to offer premium services. Each constellation satellite will have a mass of 50 kilograms and about the size of a mini-fridge. The company contracted a division of Spaceflight Industries known as Spaceflight Systems to build the satellites and Spaceflight Services is facilitating launches and Spaceflight Networks is one of the main third-party partners for ground stations as well. They are designed for a three-year mission life at an altitude of 450 kilometres. The satellites are designed with planned obsolescence in mind, as the lifespan of each spacecraft offers enough time to provide services and allowing the company to perform technology update to the constellation on a regular basis. The downside is that the firm will be in a continuous capital-expenditure cycle but the market seems to be changing fast enough that more and more affordable launches should be available.⁷²

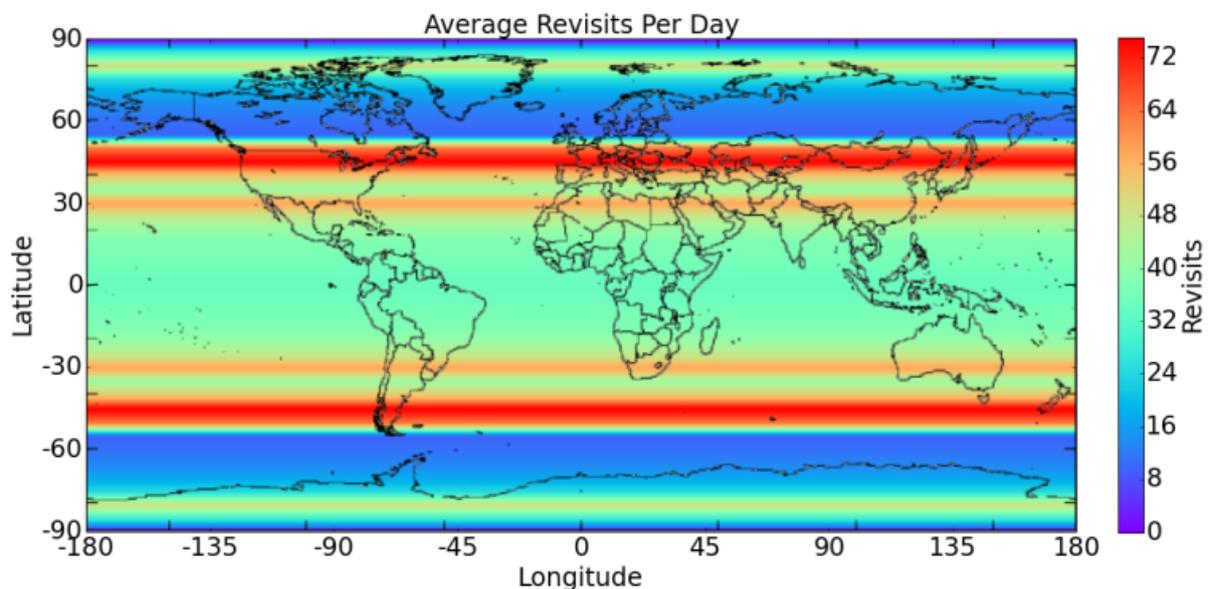


Figure 25: A color-coded map of satellite revisit rates, per region, for the full BlackSky constellation (Source: BlackSky Global)

BlackSky Global is focusing on customers playing in markets such as agriculture, forestry, government, finance, energy and more. In company's opinion, imagery providers could also be potential customers, as they could purchase pixel-capacity by leasing time on the company's satellites. BlackSky is also creating a Web-scale software platform for customers to request, receive and interact with its satellite imagery online.⁷³

⁷¹ BlackSky Global 1, 2, 3, 4 / BlackSky Pathfinder 1, 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/blacksky.htm

⁷² De Selding, PB 2015, 'BlackSky Global says it's poised to cover globe with 60 smallsats', *Space News*, viewed in November 2016, <http://spacenews.com/blacksky-global-says-its-poised-to-cover-globe-with-60-smallsats/>

⁷³ Henry, C 2015, 'BlackSky Global details plans for 60 satellite Earth observation constellation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2015/06/16/blacksky-global-details-plans-for-60-satellite-earth-observation-constellation/>

3.1.5 Satellogic

Satellogic is an Argentinian space start-up, founded by the actual CEO Emiliano Kargieman. The company is aimed to launch a network of hundreds of satellites in Low Earth Orbit, allowing customers to get high-resolution and real-time images of Earth spots. Satellogic satellites are built with newer electronics technology and come with the size of a desktop computer hard drive, and they will allow customers to be able to get images in nearly five minutes. The company has raised USD 4.5 million from the founder and undisclosed angel investors.⁷⁴

The firm plans to manufacture and deploy into orbit a constellation of around 300 Earth Observation satellites to provide real-time Earth imagery. Having already launched three prototype satellites between 2013 and 2014, Satellogic owns a manufacturing facility in Uruguay⁷⁵ enabling the potential to build several dozen satellites per year. The location was chosen because of its close proximity to the company's largest Research and Development facility in Buenos Aires, Argentina. Each satellite will approximately weight 35 kilograms, and will perform one-meter multispectral imaging. Satellogic originally planned to begin launching its satellites in 2015 but launch delays have led to stretch the timeline, and the company is pursuing launch opportunities for another 19 smallsats in 2017⁷⁶, after the original six, to accelerate the constellation deployment. The firm is closely monitoring new entrants in the growing launch market, seeking better launch opportunities, like Rocket Lab's Electron and Virgin Galactic's LauncherOne. It will require years to complete the entire constellation of smallsats but in company's plans it would allow to revisit times of around 5 minutes anywhere on the planet for one meter resolution multi-spectral imaging⁷⁷. Satellogic is also building a network of ground stations to support the large stream of data that will be generated. The company is intended to use a combination of owned ground stations and third party stations to build a network of more than 20 sites worldwide: two stations are operational up-to-date. Satellogic is also developing downstream analytics platforms to let customers access data without having to develop their own image processing capabilities.

Satellogic's focus on specific technology achievements are as follows⁷⁸:

- **Real-time imagery**, to view any point on earth more frequently reducing revisit times for from days to a matter of minutes.
- **Commercial-grade resolution**, to allow ground sampling distance of less than 2 meters which is comparable with more expensive and bigger satellites.
- **Affordable, cutting-edge technology**, through agile processes, rapid development cycles, using latest commercial components, combined with proprietary patent-pending technology.

⁷⁴ Ha, A 2014, 'Satellogic aims to launch a constellation of small imaging satellites around Earth', *Techcrunch*, viewed in November 2016, <https://techcrunch.com/2014/06/20/satellogic-launch/>

⁷⁵ Henry, C 2016, 'Satellogic on its way to launching 300 satellite constellation for Earth observation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2016/03/17/satellogic-on-its-way-to-launching-300-satellite-constellation-for-earth-observation/>

⁷⁶ Ibid.

⁷⁷ Ibid.

⁷⁸ Satellogic n.d., *Satellogic company website*, viewed in November 2016, <http://www.satellogic.com/>

- **Lightweight**, reducing weight from over a ton to less than 100 pounds.

The firm is fully concentrated to drive a consistent Big Data stream from Space, where it's generated, into a fundamental part of daily decision making for government, organizations, industries and individuals. The main applications that will be served are⁷⁹:

- **Agriculture**
- **Pipeline monitoring**
- **Critical infrastructure monitoring**
- **Disaster response**
- **Illegal logging**
- **Border patrol**
- **Port security**
- **Business intelligence**

3.1.6 OmniEarth



OmniEarth is a young company based in Arlington, Virginia, which focus is on delivering data-analytics, multispectral imagery from multiple locations on Earth and - on a daily-basis - enabling customers to view, analyze and react to change in real time.

At present, the company is selling two main products relying on satellite data⁸⁰:

- **Water Resource Management:** through Efficiency Based Analyses, which integrate usage information with satellite imagery and advanced data science techniques to provide deliverable insights. In other words, it relies on satellite imagery and powerful algorithms to create a quantitative water budget by parcel based on land cover. Customers can then access these dynamic, updated data streams through a series of cloud-based dashboards.
- **OmniParcels:** providing detection, quantification and change in a variety of parcel and property features. It is achieved with crucial capabilities granted by Artificial Intelligence and Machine Learning application to imagery and property data.

OmniEarth has agreed to collaborate with UrtheCast on its planned UrtheDaily constellation, including joint system development, the sharing of intellectual property, and combined customer-marketing activities. The constellation is expected to be capable of imaging 140 million square kilometers of the global landmass every day at 5 meters Ground Sampling Distance (GSD).⁸¹ The UrtheDaily's key market area is precision agriculture: daily revisit,

⁷⁹ Satellogic n.d., *Satellogic company website*, viewed in November 2016, <http://www.satellogic.com/>

⁸⁰ OmniEarth n.d., *OmniEarth company website*, viewed in November 2016, <http://www.omniearth.net/>

⁸¹ Henry, C 2016, 'UrtheCast and OmniEarth team up on UrtheDaily constellation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/publications/st/2016/08/02/urthecast-omniearth-team-urthedaily-constellation/>

combined with UrtheCast's scalable data distribution capabilities enabled by its cloud-based UrthePlatform, will enable growers to proactively measure and manage crop health and identify pest infestation early enough to prevent major losses.⁸²

The company is planning to deploy the constellation consisting of 18 satellites to enhance its offer to customers, through a partnership with Harris Corp., Draper Laboratory and Dynetics⁸³. Imagery data and products will be for subscribers in the agriculture, energy, natural resources, mobile services and government communities. The planned swarm will cover 100% of the Earth at least once per day, enabling operators to be aware of land changes over time. The planned satellite constellation will also provide to customers a hosted-payload solution, including launch, ground infrastructure and global coverage with a rapid revisit time. The offering consists of up to 80 kg of payload space per satellite on a highly stabilized LEO platform⁸⁴. Moreover, the spacecraft are compatible with the ESPA multi satellite launch adaptor, making them compatible with a large number of launch vehicles, and up to 5 OmniEarth satellites are planned to be launched together. The firm is partnering with Dynetics, which manufactured in the past a space platform in less than 10 months using off-the-shelf technology and agile processes at half the cost of a traditional satellite and plans to build OmniEarth spacecraft in its Alabama plant that includes a production line for small satellites⁸⁵. The satellites will be based on Dynetics' TerraSense, a high-bandwidth and maneuverable small satellite platform⁸⁶. Harris Corporation will integrate the hosted payloads using its reconfigurable, multi-mission payload platform to support marketing efforts for leveraging the available capacity for secondary missions. In 2014 OmniEarth has also signed a memorandum with Spaceflight for rideshare launch services related to its planned constellation⁸⁷. A unique feature of the OmniEarth satellites will be their data storage and downlink capability, as they will feature a communications downlink of more than 1.2 gigabytes per second and the ability to store 1 terabyte of data onboard.⁸⁸

So the main products to be delivered by the company can be summed up in this way⁸⁹:

- **Imagery:** from either high-orbiting satellites or low-flying drones, integrating a wide variety of products and having established relationships with a number of satellite imagery providers, as well as with smaller aerial imagery firms.
- **Resource Management:** from understanding water consumption to gaining insight into forests' health.

⁸² Henry, C 2016, 'UrtheCast and OmniEarth team up on UrtheDaily constellation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/publications/st/2016/08/02/urthecast-omniearth-team-urthedaily-constellation/>

⁸³ OmniEarth 1, ..., 18 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/omniearth.htm

⁸⁴ Henry, C 2016, 'UrtheCast and OmniEarth team up on UrtheDaily constellation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/publications/st/2016/08/02/urthecast-omniearth-team-urthedaily-constellation/>

⁸⁵ Miguel-Lago, M 2014, 'OmniEarth team announces \$250M small-sat imagery venture', *European Association of Remote Sensing Companies*, viewed in November 2016, [https://earscc-portal.eu/display/EOSTAN/2014/05/21/OmniEarth+Team+Announces+\\$250M+Small-sat+Imagery+Venture](https://earscc-portal.eu/display/EOSTAN/2014/05/21/OmniEarth+Team+Announces+$250M+Small-sat+Imagery+Venture)

⁸⁶ Henry, C 2016, 'UrtheCast and OmniEarth team up on UrtheDaily constellation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/publications/st/2016/08/02/urthecast-omniearth-team-urthedaily-constellation/>

⁸⁷ Ibid.

⁸⁸ Miguel-Lago, M 2014, 'OmniEarth team announces \$250M small-sat imagery venture', *European Association of Remote Sensing Companies*, viewed in November 2016, [https://earscc-portal.eu/display/EOSTAN/2014/05/21/OmniEarth+Team+Announces+\\$250M+Small-sat+Imagery+Venture](https://earscc-portal.eu/display/EOSTAN/2014/05/21/OmniEarth+Team+Announces+$250M+Small-sat+Imagery+Venture)

⁸⁹ OmniEarth n.d., *OmniEarth company website*, viewed in November 2016, <http://www.omniearth.net/>

- **Precision Agriculture:** from planting, fertilizing and harvesting to predicting yield information for farmers, insurers and commodity traders
- **Asset Monitoring:** providing subscription-based monitoring of pipelines and other fixed assets, with change-detection algorithms identifying differences in and around physical structures.
- **Hosted Payload** on its brand-new satellite constellation to be deployed.

3.1.7 Hera Systems



Hera Systems is a satellite information and analytics company that collects Earth images and is aimed to enable commercial and government organizations to monitor change and make smart decisions⁹⁰. An initial constellation will be launched and deployed in late 2016, consisting of nine 1-meter resolution satellites that will deliver fresh, daily imagery and video of Earth, as well as intelligent analytics and derived information products, made available on demand through a user interface. That constellation will be expanded according to market growth, reaching 48 satellites in order to provide near-hourly updates⁹¹. Moreover, future-generation systems will feature ultra-high resolution imaging capabilities and other advanced technologies. Founded in 2013 in San Jose, California, during its first two years it has focused on refining spacecraft design and capabilities, and the basic architecture for its secure data cloud and supporting web services for the next planned development. Hera Systems completed its Series A round of investment funding, with Firsthand Technology Value Fund as the lead investor in 2015, allowing the development of a mockup satellite demonstration about technology, components for the construction of the initial satellites, and initial commitments to launch opportunities⁹². The firm is seeking to continue the development of systems and software, including rounding out the initial satellite constellation, supporting operations including a ground station network, and systems development through a next financing round.

The company's products for enterprises will be available in a "self-service" configuration via a proprietary application, called GeoSnap™, which is supported on a variety of platforms (including mobile devices, smart phones and tablets), customized according to customers' specific technical data needs⁹³. The entire satellite system, as well as the availability and functionality of the satellites, will be scalable following customers' needs evolution. Hera Systems' products will enable government and commercial enterprise customers to better monitor changes and events affecting Earth's surface and emerging situations that influence the environment, the economy and our nation's security, in order to help making smarter decisions.

The base infrastructure to achieve their goals is the 1-meter resolution imaging microsatellite built on a 12U CubeSat, coming with a weight of 22 kg. The company intends to take

⁹⁰ Hera Systems n.d., *Hera Systems company website*, viewed in November 2016, <http://www.herasys.com/>

⁹¹ Ibid.

⁹² Ibid.

⁹³ Ibid.

advantage of launch costs' reduction while increasing flexibility, transferring the benefits to customers⁹⁴.

The company sees itself as one of the industry's most aggressive, simplest pricing for high-resolution satellite imagery and video. The competitive offer includes per-square-kilometer pricing as low as \$1 for archived one-meter resolution imagery, \$2 for freshly tasked one-meter imagery orders, and \$3 for 50-centimeter resolution products. The company's competitive pricing and simplified ordering process reduce and eliminate the obstacles that have typically put such imagery products out of reach for customers and made the budgeting process cumbersome⁹⁵.

3.1.8 Astro Digital



Astro Digital is a US start-up that owns and operates different satellites with Earth-imagery purposes. The company is aimed to enable so called “big-data” analytics from space, by: monitoring Earth from space with open data with a constellation of multi-spectral satellites, and software for imagery analysis and distribution. The imagery from their constellations runs directly into the Astro Digital's pipeline where it's live processed and accessible via API endpoints⁹⁶.

The main industries served are:

- **Agriculture**, allowing to understand the current stage of crop growth, comparing it to previous weeks and producing Yield Estimates based on growth rates.
- **Disaster management**, to monitor the progression of flood waters and wildfire, capture snapshots of tornado and earthquake damage; assess impact or hurricane winds and storm surge.
- **Forest management**, to get images of large areas at high frequency in order to monitor variations in forest vigor, identify regions damaged by weather or disease, delineate boundaries between forest and protected habitats, and identify potential illegal activity.
- **Urban development**, to map urban landscapes, detect changes to infrastructure, analyze population density, perform selection analysis for proposed development areas, and monitor environmental impact of regional developments.
- **Business intelligence**, to analyze and track global economy, as its imagery for instance shows the rapid construction of infrastructure, captures frequent shots of open pit mines and resource stockpiles, compares historical data to current conditions.

To address these diverse span of economic activities, the firm takes advantage of different satellite systems:

⁹⁴ Hera Systems n.d., *Hera Systems company website*, viewed in November 2016, <http://www.herasys.com/>

⁹⁵ *Hera Systems unveils groundbreaking \$1 pricing for satellite imagery* 2016, Hera Systems press release, viewed in November 2016, <http://www.spaceref.com/news/viewpr.html?pid=47866>

⁹⁶ Astro Digital n.d., *Astro Digital company website*, viewed in November 2016, <https://astrodigital.com/>

- **Landmapper-HD:** a constellation of 20 satellites imaging all agricultural land, globally every 3-4 days, capturing high resolution daily shots of Earth areas. With a 2.5 meters resolution, the spacecraft weighs 20kg and is about the size of a small microwave.
- **Landmapper-BC,** a constellation of 10 satellites that complement the HD sensor constellation of Landmapper-HD. It captures images of the world at 22 meters resolution, and the spacecraft weighs 10kg.

The company also takes advantage of open data, mainly from two different satellite systems: Landsat-8 (a US Geological Survey traditional and high-weighted satellite, used from drought monitoring to regional planning, from forest management to geological mapping, has diverse spectral bands) and the Sentinel program (Sentinel-2 consists of 2 identical satellites with multi-spectral coverage tuned for agriculture and forest monitoring, natural disaster management, soil and water cover sensing, and climate change monitoring; it is a free and open data source where the satellites are operated by the European Space Agency as part of the Copernicus Program).

3.1.9 Spire Global



Spire Global is a US private company specializing in data gathered from a network of small satellites, successfully deploying twelve Earth observation CubeSats into Low Earth orbit.

Spire was founded in 2012 with its first office opened in San Francisco, eventually opening further offices in Scotland and Singapore.⁹⁷ In that year the company moved into Lemnos Labs – a hardware start-up incubator - in San Francisco. Formerly known as Nanosatisfi, it raised USD 1M in funding from angel and venture capital investors in 2013, and won the best “Demo Pit” at the Launch Conference, when ArduSat - a crowd-funded satellite, successfully launched in 2013, with its name explaining the electronics technology on which they were based (Arduino)⁹⁸ - was presented to the public by Peter Platzer, one of the founders. ArduSat satellites were delivered to customers in the same year: ArduSat-1 and ArduSat-X were the world's first crowdfunded satellites to reach orbit. They re-entered the atmosphere the following year, when ArduSat-2 was launched and the next generation Lemur-1 was delivered. Released in Low-Earth-Orbit, this satellite set the way for Spire's complete constellation by providing a test bed for both satellite and ground station features. The company then changed its name from Nanosatisfi to Spire and announced the raise of a USD 25M financing, one of the largest in Silicon Valley history so far. In 2015 Spire presented its first weather product, a collection of weather data via an upcoming constellation providing accurate temperature, pressure, and humidity profiles on the entire Earth. Spire remarkably launched from the Satish Dhawan Space Center on India's east coast its first four LEMUR-2 spacecraft, as the first ever commercial US satellites that has been launched from an Indian base. In 2016 the firm reached a production pace up to two satellites per week (working on up to eight at once), and in September NOAA awarded the first ever commercial weather contract to Spire, in which the company is intended to provide GPS-RO data from its constellation of satellites.

The company believes that the world is suffering a worldwide lack of data, and that's why Spire was established to provide a vastly different approach to data collection and analysis.

⁹⁷ Spire n.d., *Spire company website*, viewed in November 2016, <https://spire.com/>

⁹⁸ ArduSat 1, X n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/ardusat-1.htm

The firm's satellites scratch the surface seeking what's possible for data collection, fusion, and analysis. Spire satellites are manufactured with respect of CubeSat standard, using minimally adapted consumer electronics to reduce costs. They are then placed in LEO and are scheduled to be retired and replaced every two years. In September 2015, Spire became the first CubeSat operator based in the US to launch from India⁹⁹.

The project undergoing development by the company are:

- **ArduSat-1, ArduSat-X:** two 1U CubeSats, their mission was to act as a platform on which students and space enthusiasts could design and make their own space - based Arduino experiments. They has been built as a crowd-funded project by Spire, and primary payloads were banks of Arduino processors with some embedded code programmed by students and other enthusiasts. The Arduino processors sampled data from the satellites' imaging payload which consisted of a 1.3 megapixel optical CMOS camera module, photolux sensor, IR temperature, PCB temperature, 3-axis magnetometer, Geiger counter, 6-DOF IMU, and MEMS gyros, for a total weight of less than 1 kg for each satellite. Launched and deployed in 2013, ArduSat-1 and ArduSat-X re-entered atmosphere in 2014¹⁰⁰.
- **ArduSat-2:** a 2U CubeSat, acted as a platform on which students and space enthusiasts may design and make their own space - based Arduino experiments, in the same way of ArduSat-1 and ArduSat-X, and it has been built as a crowd-funded project as well. ArduSat-2 is an improved version of the ArduSat-1 satellite and weighted around 2 kg. Launched and deployed in 2014, it didn't give any signal back to Earth, so re-entered the atmosphere in the same year¹⁰¹.
- **Lemur-1:** a low-Earth 3U CubeSat, its primary mission aim is a technology demonstration of several science payloads carried by a 3U standard unit and in addition to technology demonstration purpose carries two Earth-observation payloads. Its primary Earth-observation payload is an electro-optical imaging system, operating in the visible band with a ground resolution of approximately 5 m. Its secondary payload is a low-resolution IR imaging system, with an approximate ground resolution of 1 km. It has been deployed from the Italian UniSat 6 and it serves as a prototype for a larger constellation of more than 50 satellites. Its weight is around 4 kg.¹⁰²
- **Lemur-2:** it is an initial constellation of 3U LEO CubeSats weighting around 4 kg. They carry two payloads for meteorology and ship traffic tracking - STRATOS imaging payload and the SENSE-AIS payload. SENSE payload enables tracking ships worldwide by receiving their AIS signals. The constellation receives GPS satellite signals - which are impacted as they pass through Earth's atmosphere. Through a GPS radio occultation process, it measures the change in GPS signal readings to identify very precise profiles for temperature, pressure, and humidity



⁹⁹ De Selding, PB 2015, 'PSLV rocket launches India's 1st astronomy satellite, 4 Spire Cubesats', *Space News*, viewed in November 2016, <http://spacenews.com/pslv-rocket-launches-indias-1st-astronomy-satellite/>

¹⁰⁰ ArduSat 1, X n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/ardusat-1.htm

¹⁰¹ ArduSat 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/ardusat-2.htm

¹⁰² Lemur 1 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/lemur-1.htm

on Earth. The first four Lemur-2 satellites were launched in 2015. The second batch was launched to the ISS, with five satellites deployed from a NanoRacks deployer in 2016. The third batch of four satellites was launched also on a NanoRacks NRCSD-E deployer on the Cygnus cargo craft after the departure from the ISS. The total number of Lemur-2 satellites that will be still launched is currently unknown, but the entire constellation will be around 100.¹⁰³

The main products on which the company is focused at present are:

- **SENSE™**: a data stream designed for full maritime awareness relying on ship-tracking capabilities. Consistent data covering all of Earth's oceans leads for instance to decreased search time and improved rescue efficiency for Coast Guard officers, greater security for ships' crews against modern day pirates, improved quality of life for local fisherman whose livelihood is stolen by illegal or unreported fishing activity, higher levels of confidence in decision-making by those whose operations rely upon a truly global supply chain. Spire provides a frequently refreshed global ship tracking data. The signal from AIS transponders that ships have onboard (required to be onboard by International Maritime Law) becomes blocked by the curvature of the Earth. SENSE satellites, operating in Low Earth Orbit, are able to capture and relay critical information from every ship and deliver it to the decision makers.¹⁰⁴ Standard AIS data are simply the beginning of SENSE, yet fusing AIS and weather data or any other space-based and terrestrial data providers, a contextual stream of data could be built to tackle the truly complex problems that global organizations face day after day. Typical customer base may include mining companies, local governments, port operation facilities and arctic shipping companies. SENSE relies on 10 satellites in orbit, allowing a 34 minutes revisiting time.
- **STRATOS™**: a high-fidelity weather data from a constellation of commercial weather satellites. It is aimed to deliver a global weather data set with regularity, and with enough data points to remove random errors which could generate uncertainty. Recent weather models improve while the underlying data is becoming increasingly erratic, that's why forecasting models are made up of complex formulas that requires more and more kinds of weather data. In company's predictions, STRATOS will provide ten times more GPS-RO based weather data than the sum of all publicly funded weather satellites. GPS satellites (usually orbiting up to 20.000 km above Earth) made it possible to replace paper maps with mobile, digitalized maps. These same satellites are used by Spire to measure global weather patterns through the same radio-occultation process mentioned before.¹⁰⁵

3.1.10 GeoOptics



GeoOptics Inc. is a private company operating in the collection and sale of Earth Observation data, for use in operational monitoring and forecasting applications. Its products include global atmospheric temperature and pressure profiles, data about atmospheric constituents, and space weather data. The company is developing a constellation of small satellites to collect

¹⁰³ Lemur 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/lemur-2.htm

¹⁰⁴ Spire n.d., *Spire company website*, viewed in November 2016, <https://spire.com/>

¹⁰⁵ Ibid.

data about Earth's climate and environment from a Low Earth Orbit plane. The constellation will be called CICERO and the first satellite is scheduled for launch in late 2016, with more following soon¹⁰⁶.

CICERO (Community Initiative for Cellular Earth Remote Observation) is a constellation system of 24 (eventually more) LEO microsattellites intended to perform GPS and radio occultation activities of Earth's atmosphere and surface remote sensing by GNSS reflection¹⁰⁷. GPS-RO satellites can provide some of the most accurate weather and climate data available, offering significantly more impact per measurement than traditional weather instruments.

The system is aimed to deliver critical data on the state of the earth to scientists and decision makers worldwide. Products delivered will consist of¹⁰⁸:

- high-accuracy profiles of atmospheric pressure, temperature, and moisture
- 3D maps of the electron distribution in the ionosphere
- a variety of ocean and ice properties.

Its most relevant applications will be¹⁰⁹:

- **weather forecasting**
- **climate research**
- **space weather monitoring**

The initial operational constellation (CICERO-I) will consist of six LEO satellites - weighting around 115 kg - operating in multiple orbit planes with a broad global coverage, and it is expected to be fully operational at the end of 2016¹¹⁰. Regarding company's plans, the constellation will be expanded to 12 satellites in 2017 and to 24 satellites in 2018 and for the upcoming launches, GeoOptics has signed an agreement with Virgin Galactic to operate its LauncherOne rocket. The company is also involved in a partnership with NASA's Space Technology Mission Directorate, to develop the nanosatellites' capabilities beyond their current state to detect changes of the Earth's gravitational field that represent the flow of water around the world, in oceans, lakes and rivers, snow and ice packs and under the Earth's surface¹¹¹.

3.1.11 PlanetiQ



PlanetiQ was founded in 2012 by Chris McCormick to create a commercial constellation of satellites specifically focused on real-time, high-quality weather, climate and space weather data. It is planning to launch a constellation of microsattellites in 2017 equipped with a GPS radio occultation sensor called "Pyxis" — a device able to regularly ping the lowest layers of

¹⁰⁶ CICERO n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/cicero.htm

¹⁰⁷ Ibid.

¹⁰⁸ Ibid.

¹⁰⁹ Ibid.

¹¹⁰ Ibid.

¹¹¹ GeoOptics n.d., *GeoOptics company website*, viewed in November 2016, <http://www.geooptics.com/partners/>

Earth's atmosphere where severe weather action takes place¹¹². The PlanetiQ constellation is intended to collect over 30,000 soundings per day, fairly distributed around the globe. Future developments planned for a following group of satellites include an active temperature, ozone and moisture microwave spectrometer and a next-generation microwave radiometer. The group's driving focus is to gather critical data for enhanced weather forecasting, space weather prediction and climate analytics. The company's aim is to beat the traditional model for government-funded environmental satellite programs, characterized by aging and less-modern spacecraft, and more and more subject to tight budgets and schedule slips¹¹³.

The constellation will consist of 12 6U CubeSat satellites built by Blue Canyon Technologies – a firm located in Boulder, Colorado - each carrying a Global Positioning System radio occultation payload. They also will comprehend an on-board propulsion weighing less than 20 kilograms, and will operate in orbits of 750 to 800 kilometers at an inclination of 72°. PlanetiQ had to eliminate the real-time data relay system in at least the first six satellites, because of the small CubeSat standard scale. Instead, the satellites will use a network of ground stations, which should delay the receipt of data by no more than 90 minutes. An initial set of 12 satellites is planned to be deployed by 2017, expanding to 18 satellites by 2020¹¹⁴.

The company intends remarkably to establish a non-profit organization, called "The PlanetiQ Foundation", that would provide global observations with no cost to research and education users. This unprecedented supply of atmospheric and ionospheric data will¹¹⁵:

- establish a **long-term climate record** based on GPS Radio Occultation
- **enhance climate monitoring**, climate change detection, and testing of climate models
- **Advance research in weather forecasting** and space weather monitoring and prediction
- Encourage research to improve the **impact of GPS Radio Occultation** data on forecasts
- **Empower faculty and students** with high-quality data and support research on additional uses for the data

The Foundation board will set the standards for granting data to the research community and review applications, and will help guide future innovations in sensor design and data products based on input from research users in the academic, public and private sectors.

3.1.12 XpressSAR



XpressSAR is a US company licensed to operate a Synthetic Aperture Radar (SAR) system consisting of a prospect constellation of four X-Band satellites capable of gathering imagery with a resolution of 30 meters to less than 1 meter. The constellation will consist of four

¹¹² David, L 2016, 'Chris McCormick on PlanetiQ's launch plans, NOAA's commercial weather pilot', *Space News*, viewed in November 2016, <http://spacenews.com/chris-mccormick-on-planetiqs-launch-plans-noaas-commercial-weather-pilot/>

¹¹³ PlanetiQ n.d., *PlanetiQ company website*, viewed in November 2016, <http://www.planeti.com/>

¹¹⁴ PlanetiQ 1, ..., 12 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/planeti-1.htm

¹¹⁵ PlanetiQ n.d., *PlanetiQ company website*, viewed in November 2016, <http://www.planeti.com/>

identical satellites, operating in two orbit planes with a 35 degrees inclination. With a planned launch in 2020, the constellation is to provide excellent revisit performance in the cloud-persistent regions of the globe and the satellites will operate in an equatorial orbit at an altitude of 425 km, with control operated from a US-based ground control center in Miami (Florida), as well as image data transmission¹¹⁶. The system is designed to provide multiple collections per day over the selected areas in all weather conditions, and the collected imagery, especially high quality Earth images and other radar data products, are intended to be sold to private and public-sector customers as well as government agencies.

XpressSAR's system differentiates substantially with other optical imaging spacecraft that have been mentioned above, because¹¹⁷:

- It relies on **radar imaging** which penetrates clouds, haze, dust and smoke, regardless of daylight absence during the night.
- The **average revisit rate** of just a few hours: the company's purpose is to act as a watchful eye in space over any location in its coverage area, being able to monitor harbors, airfields, active volcanoes, spreading floods, oil spills, ship traffic, and other sites. Moreover, radar illumination is consistent image-to-image, so XpressSAR collections of stacks of images can be used for automated change detection enabling early alerts when something significant has occurred.
- Focus on **image quality**: the system is designed with the most advanced radar imaging technology available, based on existing radar imaging.
- Broad **coverage and flexibility**: radar imaging has not a fixed resolution and swath width; it is more flexible than optical imaging with multiple collection modes, from small-area spotlight images with resolutions under one meter, to large-area images with resolutions of 2 to 3 meters, to an ocean scan mode that can be as large as 300 km across and 2000 km long with resolutions of 10 to 30 meters.
- **Precision**: the firm's aim is to take full advantage of radar capabilities' precision. Combined with commodity GPS orbit-determination processes, radar images could be used to form images coherent with geolocation revolution.

The Synthetic Aperture Radar is a consistent imaging technique that comes with a range of capabilities: radar sensors illuminate the ground using pulses of microwave radiation, then they record the resulting echoes, measuring the time it takes for each pulse to travel from the sensor to the ground and back, as well as other characteristics of the return wave. Starting from these raw data, the SAR technique is applied to create images. It represented a breakthrough in radar imaging because it can be achieved by a small physical antenna, allowing imaging from a small platform put into orbit, perfectly compatible with small satellites low cost technology. Moreover radar's microwave pulses are coherent, as are controlled and made consistent in structure from pulse to pulse, which doesn't simply happen with random illumination of sunlight. A remarkable characteristic of SAR is that it is not dependent on the distance between the sensor and the ground. Coherence also enables processing techniques regarding the measurement of surface changes over time: for example, commercial SAR systems have been used to measure ground subsidence in oil fields at a level of a few millimeters per year. SAR imaging is also not limited by a fixed focal length like optical telescopes.

¹¹⁶ XpressSAR n.d., *XpressSAR company website*, viewed in November 2016, <http://www.xpresssar.com/>

¹¹⁷ Ibid.

3.1.13 Iceye



Iceye is a company providing a satellite-based service to give a worldwide access to near-real-time imagery from space and based on synthetic aperture radar (SAR) technology¹¹⁸. Founded in 2012 and based in Finland, it's planning to launch tens of satellites reducing response times from days to minutes, through miniaturization and industrial manufacturing to the field of radar imaging. The company focuses mainly in serving the following markets¹¹⁹:

- **Nature-related activities**, monitoring illegal fishing, oil spills, storm damage, and forest growth.
- **Agriculture**, monitoring crops growth, storm damages, pest movements and assist in efficient harvest.
- **Planetary exploration**, mapping other planets for resources and ensures exploration safety
- **Logistics**, monitoring port or storage activity, sea ice and icebergs, track pirate vessels, and view highway activity.
- **Disaster relief**, monitoring flood damage, receive real-time mapping for aid activities, and conduct maritime search and rescue activity.

The firm believes strongly that at least 76% of the globe is un-imageable with traditional optical systems at any moment¹²⁰: that's the reason why it's fully focused in exploiting all most recent development in mobile technology to squeeze radar sensors into nanosatellites, at least 20 times lighter and more than 100 times less costly than its traditional peers¹²¹. Shaping the technology around latest off-the-shelf electronics gives a real advantage in terms of low component prices and fast technology update cycle. The company's satellites are designed to operate in swarms, achieving reliability and quick access to anywhere worldwide, and it recently raised \$2.8 million in Series A funding to start with design and production¹²².

The constellation is to be deployed in two phases: the first starts with 5 to 10 satellites, which would be capable of revisits in a matter of hours, and the second constellation would be larger, 30 to 50 satellites, bringing revisit rates down under an hour, possibly to half an hour. Each satellite is expected to have a mass of less than 100kg. Iceye believes that radar technology, compared to optical Earth observation systems, enables satellites to see through weather and keep collecting when outside sunlight areas. Since its foundation, the company has secured multiple investments and customers, but it was a government grant that helped the company get started, enough to run business for half a year without further investment, even without any satellite in orbit. The very early focus was ice monitoring, as can be derived from its name, so that early customers come from this domain but the firm rapidly adapted to grow into a broader market. In addition to the \$2.8 million raised through True Ventures in Silicon Valley,

¹¹⁸ Iceye n.d., *Iceye company website*, viewed in November 2016, <http://iceye.fi/>

¹¹⁹ Ibid.

¹²⁰ Ibid.

¹²¹ Henry, C 2015, 'Iceye prepares prototype satellite for 2017 launch', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2015/12/08/iceye-prepares-prototype-satellite-for-2017-launch/>

¹²² Ibid.

Iceye received in 2015 another \$2.8 million in Research and Development funding from SME Instrument, part of the European Union's Horizon 2020 research and innovation program. Ground operations will be contracted out to young companies, providing downlink services. Iceye has seen larger funding from the U.S., but it expects that Europe will be more involved in the next few years¹²³. The satellites will be based on the S-Class bus provided by York Space Systems. The first prototype is scheduled to be launched in the second half of 2017. In 2016, ICEYE signed a partnership with Vector Space Systems to launch 21 satellite on Vector-RE1 rockets, but vehicles from other partners will also be used as well¹²⁴.

3.1.14 Dhruva Space



Dhruva Space is an Indian space firm based in Bangalore, and it is engaged in development of small satellite platforms with a vision to lead the privatization of satellite industry in India. It was established by Narayan Prasad and Sanjay Nekkanti, as they met in Europe while attending their Erasmus Mundus Space Master program in Sweden and France. After they won the French Government's EGIDE scholarship, they returned to India and started Dhruva Space in 2012. Dhruva's team has been working on student satellite projects of Indian universities and drones, as well as high-altitude scientific study balloons used by professional bodies¹²⁵. The firm's founder has said that he took inspiration from ISRO's (India Space Research Organization) Mars mission, costing less than a Hollywood Blockbuster¹²⁶. The young company is currently developing a small satellite platform with primary focus on assembly, integration, testing and operation. It signed a collaboration with Berlin Space Technologies for manufacturing miniaturized satellites in India, and is providing high altitude ballooning platform to Indian Institute of Astrophysics for experiments and observations.¹²⁷ The company has also signed an agreement with AMSAT India – an international Radio Amateur Satellite Corporation – to build HAMSAT-2, a small satellite weighting less than 30 kg and which will act as a valuable communication resource for radio amateur purposes.

Dhruva Space is using 3D printing technology, advanced CNC machines and open-source architectures to build subsystems and for final integration in the spacecraft.

The primary applications on which the company is focused are¹²⁸:

- **automatic identification of ships**

¹²³ Henry, C 2015, 'Iceye prepares prototype satellite for 2017 launch', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2015/12/08/iceye-prepares-prototype-satellite-for-2017-launch/>

¹²⁴ ICEYE n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/iceye.htm

¹²⁵ Madhumathi, DS 2015, 'Space entrepreneurs and their startups', *The Hindu*, viewed in November 2016, <http://www.thehindu.com/news/cities/bangalore/space-entrepreneurs-and-their-startups/article7830135.ece>

¹²⁶ Murali, M 2014, 'Inspired from Isro's Mars mission Dhruva Space gears up for commercial launch within two years', *The Economic Times*, viewed in November 2016, <http://economictimes.indiatimes.com/news/science/inspired-from-isros-mars-mission-dhruva-space-gears-up-for-commercial-launch-within-two-years/articleshow/45354501.cms>

¹²⁷ Dhruva Space n.d., *Dhruva Space company website*, viewed in November 2016, <http://www.dhruvaspacespace.com/>

¹²⁸ Murali, M 2014, 'Inspired from Isro's Mars mission Dhruva Space gears up for commercial launch within two years', *The Economic Times*, viewed in November 2016, <http://economictimes.indiatimes.com/news/science/inspired-from-isros-mars-mission-dhruva-space-gears-up-for-commercial-launch-within-two-years/articleshow/45354501.cms>

- **disaster management**
- **pollution monitoring**
- **national security**

3.1.15 Spacequest



SpaceQuest is a developer of microsatellites and small satellites systems, founded in 1994 and located in the US. Serving government, universities and commercial companies, the company has built and successfully launched 18 satellites over the past two decades, focusing mainly on design, development, testing and manufacture of spacecraft as well as space and ground components for operation with LEO satellites. It owns also a subsidiary – i.e. SpaceQuest Canada - to serve government and private organizations throughout the Canadian market¹²⁹.

The company offers a range of products that can be summarized as follows¹³⁰:

- **Satellite components:** for example antenna systems, radio and modems, electrical power, attitude determination, AIS payloads, Earth station equipment.
- **Satellite systems,** as the company produces satellite bus spanning from 3U CubeSats to microsatellites, featured by low cost and high performance, mean mission duration of 5 years, and an average weight of 13 kg, all customized for piggyback launch. The company also offers low-cost hosted payload opportunities on their AprizeSat series of microsatellites.
- **Satellite data services:**
 - S-AIS data: a variety of data products direct and through a host of re-sellers, including global and regional data feeds, data archives back to 2009, processed streams, and value added AIS services
 - M2M (Machine to Machine): an important aspect of asset management with application in remote control, robotics, traffic control, logistic services, supply chain management, fleet management and telemedicine. It forms the basis for a concept known as the Internet of Things. The company offers this technology through a sister company called Aprize Satellite.

The main project developed by SpaceQuest is AprizeSat, formerly known as LatinSat¹³¹. It is a constellation of small LEO satellites consisting of a planned total 64 satellites, intended to build a global communication system of data transmission and fixed and mobile asset tracking and monitoring (GMPCS). The satellites are also carrying experimental payloads. AprizeSat 3 to 10 feature an AIS (Automatic Identification System) receiver to gather position data from ships¹³². Excluding antennas, each satellite is a 20 cm cube on a side and weighing less than

¹²⁹ SpaceQuest n.d., *SpaceQuest company website*, viewed in November 2016, <http://www.spacequest.com/>

¹³⁰ Ibid.

¹³¹ LatinSat A, B, C, D / AprizeSat 1, ..., 10 / exactView 3, 4, 5, 5R, 6, 11, 12, 13 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/aprizesat-1_latinsat-1.htm

¹³² Ibid.

12 kg, containing ten radio receivers, two transmitters and up to twelve megabytes of solid-state data storage; the whole spacecraft requires only one watt of power. The proprietary spacecraft design reduced the construction and launch cost for a LEO satellite constellation: while other players have an estimated cost of USD 350 to 600 million for the construction and launch of a small LEO constellation of 24 to 48 satellites, Aprize comparable system is worth around USD 60 million (average USD 1.2 million per each satellite). This significant cost reduction was the direct result of a unique system architecture that particularly eliminated the need for an active satellite attitude control system using thrusters. The initial Aprize system was to include six communication satellites in LEO regime: as the data relay market is going to be sufficiently developed, up to 42 more satellites are to be deployed into similar orbits. These additional satellites would increase the data relay capacity, system redundancy and global coverage¹³³.

3.2 Communication

3.2.1 O3B Networks



O3b Networks is a network communications service provider founded in 2007 by pioneering high-technology entrepreneur Greg Wyler - who helped to create Africa's first commercial 3G mobile and fiber-to-the-home (FTTH) network – aimed at building and operating a medium Earth orbit satellite constellation. Its final purpose is to deliver satellite Internet services and mobile backhaul services to emerging markets, bridging the so-called “Digital Divide”. Its name stands for “(the) Other 3 Billion”, referring to the world population without broadband Internet available. Financially backed by a number of subjects like SES, Google, HSBC, and the Development Bank of Southern Africa, O3B is primarily intended to serve mobile operators and internet service providers, providing voice and data¹³⁴. It's relevant to notice that SES, one of the main world satellite operators, has by time reached the control of O3B, meaning that the traditional space sector is beginning to understand and positively seeing the growth potential of NewSpace (and small satellites)¹³⁵.

The O3b system is intended to combine the global reach of satellite with the fiber speed communication, in terms of high capacity, fiber-like latency and a bandwidth significantly lower in cost. The company's satellites will be designed, integrated and tested by Thales Alenia Space and will operate in Medium Earth Orbit (MEO) at an altitude of 8,062 km above Earth. From that altitude, the latency is reduced bringing it on par with a long haul fiber transmission. For this reason, customers would be interested in considering satellite technology for latency-sensitive applications¹³⁶.

The firm mainly provides the following solutions¹³⁷:

¹³³ *Encyclopedia Astronautica n.d.*, viewed in November 2016, <http://www.astronautix.com/a/aprizesat.html>

¹³⁴ O3B n.d., *O3B Networks company website*, viewed in November 2016, <http://www.o3bnetworks.com/>

¹³⁵ De Selding, PB 2016, 'SES exercises option to buy 100% of O3b Networks, will raise new equity', *Space News*, viewed in November 2016, <http://spacenews.com/ses-exercises-option-to-buy-100-of-o3b-networks-will-raise-new-equity/>

¹³⁶ O3B n.d., *O3B Networks company website*, viewed in November 2016, <http://www.o3bnetworks.com/>

¹³⁷ Ibid.

- **IP-trunking:** through “O3BTrunk” it provides tailored, cost effective solutions and unlimited scalable bandwidth to allow flexibility and the ability to grow with demand.
- **Mobile backhaul:** through O3BCell, a connectivity solution between cell site towers and the core mobile network. It will support 2G, 3G and 4G-LTE voice and data services offering upgrade to packet switched networks.
- **Enterprise solutions:** through O3BEnergy, it offers the speed of fiber with the flexibility of satellite delivered cost effectiveness and reliability.
- **Maritime services:** through O3BMaritime, it delivers immersive broadband experience at sea leading for guest satisfaction, enhanced crew welfare and the potential for greater IT operational efficiency for the cruise operators.
- **Government services:** through O3BGovernment, it provides flawless communications for the Government sector with secure communication solutions, global coverage to government entities, humanitarian organisations and international peace-keeping and aid agencies. Government customers would then be able to take advantage of sustainable, secure, cost-effective communication solutions, combined with global coverage and the ability to deliver mission critical applications when and where they are needed.

3.2.2 Fleet Space Technologies



Fleet is an agile space company making it faster, simpler and cheaper to connect the world’s Internet of Things (IoT) devices, connecting the IoT around the world using a massive fleet of small low-cost satellites. It provides direct, global access to a secure low-cost low- bandwidth connectivity platform ideal for machine to machine data exchange and deploying IoT sensor networks at scale. With simple device setup and management through a web interface and powerful cognitive analytics built in, the IoT is about to take a giant leap forward¹³⁸.

The company is a truly agile space technology start-up building connectivity as a service platform. Scalability and iterative development are built into its business model and infrastructure. Its core expertise is nanosatellite manufacture and deployment, satellite propulsion systems, IoT connectivity and software as a service platform development¹³⁹.

In a world where the so-called “Internet of Things” is rapidly expanding, there are approximately 5 billion devices connected to the internet and by 2020 this number is estimated to increase to 60 billion¹⁴⁰. These devices need accurate tracking and low-cost data transfer services, and especially with regard to devices operating in remote locations, connecting regularly to the internet is in many cases expensive or impossible when their region lacks satellite coverage. That’s the main reason why the company is taking advantage of existing

¹³⁸ South Australian Space Capability Directory 2016, viewed in November 2016, <http://www.defencesa.com/upload/Space%20Capability%20Directory%20FINAL.%20V.2%20as%20at%2029%20August.pdf>

¹³⁹ Ibid.

¹⁴⁰ Fleet Space Technologies n.d., *Fleet Space Technologies company website*, viewed in November 2016, <http://www.fleet.space/>

miniaturized technologies, having reduced connectivity costs by more than 1000 times and being able to manufacture a satellite in a matter of days. The firm is planning to deploy a global satellite communications network, launching multiple small, low-cost satellites in order to eliminate much of the risk associated with space. According to company statements, the main applications for which such a small data-network is suitable are:

- **oil & gas**
- **mining**
- **agriculture**
- **transport and logistics**
- **science and research**
- **environmental monitoring**
- **consumer IoT applications** and simple communications.

3.2.3 Myriota



Established in 2015, Myriota's breakthrough technology makes it incredibly easy and affordable for the world's essential industries to collect and access the critical data they need to optimize their operations.

The company was spun off from the University of South Australia in November 2015 with a \$2m investment from Canadian LEO satellite operator ExactEarth whose polar orbiting satellites will be used for the space segment of the service¹⁴¹. Fully operational commercial service is expected to begin in 2017, as first terminals are being deployed in current year.

Myriota creates small, self-contained modules to connect things to the internet via satellite at disruptively low prices using locally developed cutting edge technology, and using very simple communications waveform. All the complexity is then transferred to ground stations where all the transmissions received from thousands of devices in the field must be separated and processed¹⁴². Myriota is making the Internet of Things an economic reality for a whole new range of industries and devices¹⁴³.

In particular, the company intends to focus on a specific category of users whose needs are not being met by traditional communications technologies, like farmers, resource companies, environmental agencies, governments, defense agencies and industries¹⁴⁴. Generally speaking, all the organizations with some remote operations have a strong and growing

¹⁴¹ Corner, S 2016, 'Myriota promises satellite IoT from matchbox-sized device', *IoT Australia*, viewed in November 2016, <https://www.iotaustralia.org.au/2016/01/21/iotnewanz/myriota-promises-satellite-iot-from-matchbox-sized-device/>

¹⁴² Ibid.

¹⁴³ *South Australian Space Capability Directory* 2016, viewed in November 2016, <http://www.defencesa.com/upload/Space%20Capability%20Directory%20FINAL.%20V.2%20as%20at%2029%20August.pdf>

¹⁴⁴ Myriota n.d., *Myriota company website*, viewed in November 2016, <http://myriota.com/>

demand for remote machine-to-machine connectivity. As they normally need small amounts of data from tens of thousands of sensors, they simply cannot justify the enormous costs associated to applications where the current data-collection method might involve expensive site visits, or the occasional installation of expensive, power hungry broadband satellite solutions. This is the main reason why in contrast to always-on, broadband “big data”, there is evidence of a growing need to access high-value, small data terminals with no regards of their worldwide dispersion. Some examples of new solutions proposed by the company¹⁴⁵:

- sensor readings that when aggregated can improve operational efficiency
- extension of environmental sensing footprint
- on-line tracking and condition monitoring for remote-assets management

Myriota is thus offering a highly-scalable global service for this new category of customers. The integrated sensing systems works as follows¹⁴⁶:

- **Low power micro transmitters produce data:** a standard transmitter is a clever little module (50mm x 50mm x 25mm) with in-built antenna, GPS, motion sensor, microprocessor and battery. It can be programmed to log and transmit data to suit each application. It has a battery life lasting over 12 months for most applications and can withstand the harshest of elements.
- **Narrow Bandwidth transmission and uplink:** transmitters can send multiple small packets (20 Bytes) of data using only as much bandwidth as needed. This means not paying for more spectrum than necessary.
- **Small Satellites get data from transmitters:** all messages from transmitters are received by LEO Satellites. These small and inexpensive satellites are in polar orbit and rotate around the earth every 90 minutes at an altitude of approximately 800km, as well as being capable of receiving hundreds of thousands of individual messages at a time.
- **Downlink and Clever Signal Processing:** messages are received by satellite ground stations and processed by software hosted in the cloud. This allows the Myriota platform to scale significantly. Data is then available via standard Architecture Programming Interfaces (API).

Specific applications for Myriota’s fully integrated connectivity systems are:

- **Resource Sector Asset Monitoring:** allowing cost effective monitoring of resource sector assets regardless of location.
- **Pumping Assets:** as water pumping assets are high value assets that are often installed in remote and hard to reach, cost effective connectivity solution means framers can monitor all their irrigation assets at a fraction of existing costs.
- **Horticulture Monitoring:** as horticulture relies on large inputs and precise application of water, fertilizer and crop protection chemicals.
- **Livestock Monitoring:** making the idea of widespread livestock tacking economically feasible.

¹⁴⁵ Myriota n.d., *Myriota company website*, viewed in November 2016, <http://myriota.com/>

¹⁴⁶ Ibid.

- **Rain Measurement:** making it possible to check rainfall in any location, at any time at low prices.
- **Remote Asset Monitoring:** as the company allows connectivity at affordable prices anywhere on the globe.
- **Low Cost Asset Monitoring:** while in the past if the asset wasn't worth tens of thousands of dollars, it wasn't worth monitoring, at present companies are realising it costs more if you don't monitor these assets. Myriota's tiny transmitters include a low power GNSS module and an inertial measurement unit to support sophisticated asset tracking applications.

The initial focus will be on Australia, but the company is already attracting interest from other countries. The company is confident that it would have more than sufficient capacity on ExactEarth satellites, but it plans also to take advantage of small satellites and CubeSats in terms of future providing capacity¹⁴⁷.

3.3 Multi-purpose

3.3.1 Clyde Space



Clyde Space is small-medium firm that produces small satellites and related subsystems. Started in 2005 and based in Scotland, the company has established itself as provider for CubeSats supplying both high performance spacecraft components and complete advanced CubeSat missions. It is a privately owned company with backing from local private equity investors (Nevis Capital and Coralinn). The firm's key focus is on designing and manufacturing CubeSats, small satellites and nanosatellites. Despite its tiny dimension, Clyde Space provides all mission levels from conceptual design through development, integration, testing, launch and on-orbit operations. The corporate business consists of two main levels: assembling off-the-shelf products in subsystems and platforms and bespoke solutions which are specifically designed to customers' requirements, ranging from tailor-made subsystems to full mission design integration and test.

Clyde space offers standard platform designs aimed at a range of missions that vary from pictures taken for scientific research, ocean colour monitoring, and commercial applications like star-mapping. The company has a strong awareness of customers' needs diversity, so they choose to reject the "one-size-fits-all" approach that they view as outdated. For this reason they offer platforms that can range from 1U Cubesats up to 27U combining space qualified 'off-the-shelf' subsystems with end-to-end platforms heritage. The standard platform design for 1U and 3U spacecraft consist of off-the-shelf subsystems offering shorter development times and reduced costs. The company offers also tailor made solutions which

¹⁴⁷ Corner, S 2016, 'Myriota promises satellite IoT from matchbox-sized device', *IoT Australia*, viewed in November 2016, <https://www.iotaustralia.org.au/2016/01/21/iotnewanz/myriota-promises-satellite-iot-from-matchbox-sized-device/>

are designed to meet your specific mission requirements. In Clyde Space's view, a typical satellite project is managed through a 5-step process¹⁴⁸:

1. **Planning**: a specialist engineer reviews customer's enquiry and then calls back to discuss requirements.
2. **Kick-off**: when an agreement about the project is reached, the project itself kicks-off under the responsibility of a dedicated Project Manager.
3. **Design**: designs are developed and tailored for the project and then undergo a Critical Design Review process.
4. **Building & testing**: the project, now tangible, is verified for testing and environmentally tested using extreme conditions.
5. **Delivery**: the final product is inspected, reviewed and delivered to the final customer.

The company's main projects were¹⁴⁹:

- **UKube-1**, for the UK Space Agency - one of the most advanced nanosatellites ever built and the first satellite designed and built in Scotland, it has been jointly funded by Clyde Space and the UK Space Agency, and was also the first mission to be commissioned by the UK Space Agency since its establishment in 2010. The project is set out to demonstrate UK space technology, the capability of a CubeSat sized spacecraft, industry and university based training in spacecraft development, education and outreach in STEM subjects, payload kick-off to flight qualified spacecraft in less than 12 months. Ukube-1 is the most advanced 3U cubesat of its kind and will test several new technologies in space. Ukube-1 was essentially a technology demonstration mission.
- **SeaHawk**, for The Gordon and Betty Moore Foundation – it is part of the Sustained Ocean Colour Observation from Nanosatellites (SOCON) project, that is a collaboration between Clyde Space, the University of North Carolina Wilmington, Cloudland Instruments, and Goddard Space Flight Centre. The project is aimed at developing two 3U CubeSats to observe the biology of the ocean surface and its implications for the marine food chain, climate scientists, fisheries, coastal resource managers, and oil spill responders. The final goal is to develop a constellation of SeaHawks providing a global measurement of Ocean Color Data. The final product will take two years to complete.
- **PICASSO**, for the European Space Agency (ESA) – it is a 3U CubeSat science mission, promoted by the Belgian Institute for Space Aeronomy (BISA), to study the unexplored layers of the earth's atmosphere. The mission is also intended to serve as an ESA in-orbit-demonstrator of CubeSat technology. The project will demonstrate the capability of low-cost nanosatellites to perform remote and in-situ scientific measurements of physiochemical properties of the Earth's atmosphere (for example ozone distribution and electron density) as well as enhancing the technology readiness level of the instruments on-board.
- **OuterNet**, for UK Space Agency and Outernet Inc. - a 1U CubeSat platform, it will send emergency weather warnings, medical advice and news and entertainment information to end-users. Funded by the UK Space Agency's International

¹⁴⁸ Clyde Space n.d., *Clyde Space website*, viewed in November 2016, <https://www.clyde.space>

¹⁴⁹ Ibid.

Partnerships in Space Programme (IPSP), it will be part of a constellation of three communication satellites which is the first phase of our US partner's plan to deliver free internet content globally from a constellation of hundreds of CubeSats.

Approximately 80% of Clyde Space sales are outside of the European Union and 95% are outside the UK, setting Clyde Space as a strongly export-focused venture.¹⁵⁰

The company announced in January 2016 the creation of a US subsidiary company, Clyde Space, Inc. that will meet the rising demand for small satellites in the quickly growing American market.

3.3.2 GomSpace



GomSpace is situated in Denmark established in 2007. Its mission is to develop innovative products as components, platforms and systems, based on Nanosatellite technology. Headquartered in Aalborg, it's focused on product development, mission design and mission integration. GomSpace has exported space hardware to customers in more than 50 countries around the world. Its workforce consists of more than 50 international employees.

The firm's aim is to provide cost-effective reliable subsystems and platform solutions to the expanding nanosatellites and CubeSats markets.¹⁵¹ The company aims to provide cost-effective, reliable subsystems and platform solutions for nanosatellites and Cubesats markets, developing new products and mission concepts for nanosatellites. It holds an extensive portfolio of commercially available off the shelf subsystems and software components for nanosatellites. GomSpace takes care of design and integration phases, leaving subcontractors in Denmark carry out a large part of the production.

Company's main applications are:

- **Tracking**, in particular aircraft, ships and equipment
- **Surveillance systems**
- **Communication**, mainly satellite telephony and data connectivity
- **Internet of Things**
- **Monitoring of radio activities** for defense and security purposes

The main projects under development by the company are:

- **TeSeR**, Technology for Self-Removal of Spacecraft. Initiated in 2016, aimed to reduce the risk of spacecraft colliding with debris in space. Airbus Defence and Space was the project leader, alongside 10 European partners (including GomSpace). It is a project of a prototype for a cost-efficient and highly reliable module. The module is to ensure that future spacecraft does not present a collision risk once they reach the end of their operational lifetime or suffer failure.
- **GOMX-3**, a 3U CubeSat developed in collaboration with ESA, was launched in October 2015 and included for example a ADS-B receiver for flight tracking as a payload. The

¹⁵⁰ Clyde Space n.d., *Clyde Space website*, viewed in November 2016, <https://www.clyde.space>

¹⁵¹ GomSpace n.d., *GomSpace company website*, viewed in November 2016, <https://www.gomspace.com>

satellite is remaining in operation as a proprietary GomSpace's laboratory for in orbit testing of new software, ADCS algorithms and SDR waveforms.

- **GOMX**, an experimental 2U nano-satellite that was launched in 2013, which primary objective was to demonstrate aircraft tracking from space based on reception of ADS-B signals. This was proven successful and the satellite is still in operation, being used to characterize the radiation effects on our subsystems.
- **OPS-SAT**, a 3U CubeSats developed for the European Space Agency (ESA) and European Space Operations Center (ESOC) that is aimed to on-orbit testing and demonstration of experimental and innovative software that may be used in future ESA missions and programs. GomSpace is meant to deliver the core satellite platform for the program.
- **DOC**, or ESA Demise Observation Capsule (DOC). It consists of a capsule for measurement purposes. It is intended to measure GPS, velocity, acceleration, pressure, and temperature. It will also accommodate a camera, which will capture descent and de-orbit phase.

3.3.3 Inovor Technologies



Founded in 2012, Inovor Technologies consists of two business streams¹⁵²:

- **defence contract research and development**
- **nanosatellite technologies**

It designs and integrates small satellites, providing a full development service from customer needs to requirements, through design, build, integrate and test. Its specific capabilities are mission design, satellite guidance, navigation and control, systems engineering, structures and power management, with commercial off the shelf hardware being used where necessary¹⁵³. With regards of small satellites, the company focus is on spacecraft design and integration. Their specific capabilities include:

- **Nanosatellite integration** using in-house and COTS hardware to meet mission needs.
- **Satellite test and evaluation**, including functional and environmental tests.
- **Nanosatellite hardware manufacturing** structures, attitude determination and control modules, sensors and Star trackers.
- **Systems Engineering** from needs identification through requirements development, and on to verification and validation.
- **Mission design**, including sensor and communication coverage, thermal, power and satellite guidance, navigation and control.

¹⁵² *South Australian Space Capability Directory* 2016, viewed in November 2016, <http://www.defencesa.com/upload/Space%20Capability%20Directory%20FINAL.%20V.2%20as%20at%2029%20August.pdf>

¹⁵³ Ibid.

In addition to providing nanosatellite services, the company partnered with the University of Adelaide to develop a nanosatellite based space object detection system to detect and track space objects¹⁵⁴.

Inovor Technologies has a small team with expertise in guidance navigation and control, embedded systems and software design and development, with a balanced split between graduate level, mid-career and subject matter experts. The main areas of expertise in space systems are¹⁵⁵:

- **systems engineering and mission design**
- **spacecraft integration and test**
- **attitude determination and control – precision pointing**
- **spacecraft navigation and positioning**
- **space object detection and tracking**
- **flight/ground segment software development**
- **spacecraft structures**

Moreover, the company has two prototype space subsystems and associated Intellectual Property.

The firm is a small agile company with a capable team of specialists as well as considerable experience commercializing technology and building international collaborative teams. It has both a deep research and development culture, with the majority of the team coming from a research background, and expertise in systems engineering, which enables it to engineer quality assured products that meet user/customer needs. Inovor is geographically close to the booming Asia-Pacific region and has a less restrictive export control regime, allowing free access to this growing market¹⁵⁶.

3.3.4 NanoAvionics



Founded in 2014 by Vytenis Buzas, Linas Sargautis and Laurynas Maciulis, NanoAvionics is a Lithuania-based aerospace company. Setting itself as a smallsat and CubeSat mission integrator, it provides products and technological solutions ranging from separate electronic and mechanical subsystems, complete integral satellite platforms to mission integration services. Company supplies various customers worldwide (it is an official ESA and NASA supplier) and has already implemented several successful satellite missions. The firm is also performing intensive R&D activities, as it is currently developing green propulsion technologies

¹⁵⁴ Inovor Technologies n.d., *Inovor Technologies company website*, viewed in November 2016, <http://www.inovor.com.au>

¹⁵⁵ *South Australian Space Capability Directory* 2016, viewed in November 2016, <http://www.defencesa.com/upload/Space%20Capability%20Directory%20FINAL.%20V.2%20as%20at%2029%20August.pdf>

¹⁵⁶ Ibid.

- based on contemporary non-toxic monopropellants - that are aimed at unlocking new opportunities for small satellites and CubeSat applications and business¹⁵⁷.

The company's goal is to make smallsats affordable to a wide range of companies and organizations around the globe, addressing these factors: price, durability, reliability, integrity, lead time. The most relevant company products are:

- Plug-and-play highly integral **components and subsystems**
- Reliable and multi-functional **platforms** allowing more volume for payload on board the spacecraft
- Small satellite **propulsion technologies** based on contemporary non-toxic monopropellants

NanoAvionics has carried out four relevant projects by far, that are summarized as follows:

- **LituanicaSAT-1**: the first Lithuanian 1U CubeSat satellite launched in 2014, and which weighted around 1 kg¹⁵⁸. It was one of the first European satellites launched from the ISS in cooperation with NASA Ames center and the space logistics company NANORACKS. The mission started as a non-profit initiative of NanoAvionics founders together with Vilnius University. It later evolved into a successful national scale project involving more than 40 committed people and more than 30 partner organisations. The objectives covered a technical demonstration of the satellite's capabilities and capture of the first Lithuanian pictures from space, all successfully accomplished. The satellite de-orbited in the same year it was launched after 5 months of activity¹⁵⁹.
- **LituanicaSAT-2**: a 4 kg 3U CubeSat acting as an in-orbit technology demonstration. Actively part of an international network of 50 nanosatellites called QB50 that will be launched together in 2016 from the ISS, it is aimed to carry out long term measurements of key parameters and constituents in largely unexplored lower thermosphere and ionosphere layers. The satellites will be deployed into a circular orbit at an altitude higher than 300 km. The satellite consists of three modules: a science unit with the FIPEX (Flux- Φ -Probe Experiment) sensor for QB50, a functional unit with NanoAvionics Command and Service module and an experimental unit with the "green" propulsion system. The innovative propulsion system prototype for small satellites developed by NanoAvionics will be tested during this mission, as it is made of a state-of-art green monopropellant micro-thruster able to perform high impulse orbital maneuvering and drag compensation capabilities for a smallsat, powerful enough to perform Hohman orbital transfer, orbit shape corrections or even change of inclination¹⁶⁰. The fuel used will be a green fuel blend developed by the Swedish firm ECAPS, proving a strong collaboration efforts between different entities involved in such projects.
- **Catalytic Materials for Small Satellite Propulsion Systems (ICAT)**: together with the Lithuanian National Centre for Physical Sciences and Technology (FTMC), it is project about innovative catalytic materials for miniaturized monopropellant thruster systems which began in 2015 and will last until December, 2016. The project goal is

¹⁵⁷ NanoAvionics n.d., *NanoAvionics company website*, viewed in November 2016, <http://n-avionics.com/>

¹⁵⁸ LituanicaSAT 1 (LO 78, Lituanica-OSCAR 78) n.d., *Gunter's Space Page*, visited in November 2016, http://space.skyrocket.de/doc_sdat/lituanicasat-1.htm

¹⁵⁹ NanoAvionics n.d., *NanoAvionics company website*, viewed in November 2016, <http://n-avionics.com/>

¹⁶⁰ LituanicaSAT 2 (QB50 LT01) n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/lituanicasat-2.htm

to design and develop a novel solid state catalyst bed for nano and micro spacecraft thrusters using a prototype propulsion system¹⁶¹.

- **Chemical Propulsion System for Small Satellites (EPSS):** recognized by the European Commission as one of the most innovative ideas, its purpose is to introduce the use of a “green”, non-toxic fuel, replacing the hydrazine-based propellant used by large-scale satellite technologies and corresponds to the European Space Agency’s (ESA) and the National Aeronautics and Space Administration (NASA) Clean Space Initiative. If successful, this novel solution could bring a wide range of possibilities for cost reduction and safety while simultaneously empowering new space start-ups with affordable space propulsion systems¹⁶². It will undergo testing on the LituanicaSAT-2 project.

3.3.5 ISIS (Innovative Solutions In Space)



Established in 2006 as a spin-off from the Delfi-C3 nanosatellite project from Delft University of Technology in The Netherlands¹⁶³, ISIS is a vertically integrated small satellite company, focused on providing high value, cost effective space solutions by making use of the latest innovative technologies. As one of Europe’s leaders in the nanosatellite domain, ISIS offers contract research, innovative satellite systems and turnkey space solutions to a broad range of customers for small satellite applications. It operates from two different sites in the Netherlands (Delft) and South Africa (Somerset West). The company’s core competencies lie in the application of space systems engineering in combination with an expertise in the following technical areas: radiofrequency systems and payloads, deployable systems and hold-down and release mechanisms, attitude determination systems, and embedded systems¹⁶⁴. After making its first products sale in 2007, ISIS outgrew YES!Delft incubator building and moved to a larger accommodation, preparing for the successful launch of its first ever satellite, named Delfi-C3. In 2009 it launched 4 customer satellites and the services CubeSatShop.com, Innovative Data Services and Innovative Space Logistics, while in 2013 it launched its first satellite for ship-tracking purposes – i.e. TRITON-1. ISIS has reached a record in 2014 when it built 2 satellites in 6 months¹⁶⁵.

Company’s focus is primary on solutions involving satellite systems in the range of 1 to 30 kg, although it delivers expertise also in other domains like the general area of microsatellites, miniaturized payload systems and satellite components. ISIS’s catalog consist of 76 CubeSat parts available, and it has successfully launched 75 satellites from 5 contracted launch sites around the world.

As a vertically integrated company, ISIS’s supply offer is organized around four main businesses¹⁶⁶:

¹⁶¹ NanoAvionics n.d., *NanoAvionics company website*, viewed in November 2016, <http://n-avionics.com/>

¹⁶² Ibid.

¹⁶³ ISIS Space n.d., *ISIS Space Company website*, viewed in November 2016, <https://www.isispace.nl/>

¹⁶⁴ ISIS Space n.d., *ISIS Space LinkedIn profile*, viewed in November 2016,

<https://www.linkedin.com/company/isis---innovative-solutions-in-space-by>

¹⁶⁵ ISIS Space n.d., *ISIS Space Company website*, viewed in November 2016, <https://www.isispace.nl/>

¹⁶⁶ Ibid.

- **Satellite solutions:** providing CubeSat and nanosatellite solutions for governmental and commercial customers, delivering timely solutions tailored to customers' needs. ISIS satellite mission team is able to deliver small satellites ready for launch in 6 to 18 months.
- **Launch services:** including orbital delivery of the spacecraft through its launch services subsidiary Innovative Space Logistics (ISL) as one of the leading players in the small satellite launch business.
- **Research and Development (R&D):** mission design, flight hardware, payload development, environmental testing, training, contract research.
- **CubeSat products:** CubeSat structures, on board computer, command data handling systems, communication systems, solar panels, CubeSat control systems, attitude control systems, antennas, CubeSat deployers, CubeSat dispensers, ground stations, ground support equipment.

The most relevant mission realized so far is TRITON, with its two satellites: TRITON-1 and TRITON-2 are 3U CubeSats developed by the company with the purpose of a radio science mission which aims to test an experimental advanced AIS (Automatic Identification System) receiver. A telemetry decoding software will be made available which will allow radio amateur operators to listen to periodic downlink broadcasts containing housekeeping telemetry, payload telemetry as well as received AIS messages. The planned mission duration of the science mission is three months, with the amateur radio mission planned to continue as long as possible after the science mission finishes. The first satellite was successfully launched in 2013 while the second one has been put on hold and it is unclear, when or if the project will commence¹⁶⁷.

3.3.6 Pumpkin Space Systems



Located in San Francisco, Pumpkin provides nanosatellite components and complete CubeSats to government, commercial and educational organizations, as well as cost-effective solutions. Pumpkin Space Systems is a business unit of Pumpkin Inc. focusing on nanosatellite buses and the software that runs them. Its offer vary from sub-1U size solutions, through a family of 3U-sized CubeSats, out to 6U and 12U buses. Pumpkin Inc. was founded in 1995 in California and its first commercial product was the Salvo(TM), an event-driven, multitasking, priority-based RTOS (Real Time Operating System) with extremely limited RAM. In 2003, Pumpkin began deliveries of its CubeSat Kit, a hardware and software solution for organizations who wished to build nanosatellites that conform to the CubeSat standard. The company designed and delivered twelve 3U CubeSats to the NRO's Colony 1 Bus (C1B) program in 2013, and 2014 saw the release of Pumpkin's 6U supersymmetric general-purpose

¹⁶⁷ Triton 1, 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/triton-1.htm

nanosatellite bus, called SUPERNOVA. In 2016, the company was contracted by SpaceVR to build its first two OVERVIEW-1 CubeSats¹⁶⁸.

The main projects developed by Pumpkin are:

- **SUPERNOVA-Beta**: a picosatellite built as prototype of the SUPERNOVA 6U CubeSat bus. Supernova-Beta mission is a test flight of multiple subsystems on the SUPERNOVA 6U bus developed by the firm. The satellite was to be launched but was lost in a launch failure¹⁶⁹.
- **OVERVIEW-1**: virtual reality satellites coming with a 3U CubeSat standard and 5 kg weight to enabling users to experience space firsthand using any mobile, desktop, or virtual reality device. Pumpkin is meant to build the bus, while SpaceVR will provide internally designed VR cameras as main payload¹⁷⁰.

3.3.7 Surrey Satellite Technology



Surrey Satellite Technology is a spin-off company of the University of Surrey (UK), and that is now owned by Airbus Defence and Space. It builds, owns and operates small satellites. It started as an amateur radio satellites builder known by the UoSAT (University of Surrey SATELLITE) name or by an OSCAR (Orbital Satellite Carrying Amateur Radio) designation. SSTL cooperates with the University's Surrey Space Centre, which does research into satellite and space topics. The firm has developed a business model that covers the entire satellites' life cycle, from design and manufacturing through launch and in-orbit monitoring and maintenance¹⁷¹.

The company began remote sensing services with the launch of the Disaster Monitoring Constellation (DMC) in 2002. It has also developed a new GEO microsatellite platform aimed at the telecommunications market under the brand name SSTL-900. In 2010 and 2012 SSTL was awarded contracts to supply 22 navigation payloads for Europe's Galileo space navigation system¹⁷². In 2008 the company has also opened a US branch.

They provide the following services¹⁷³:

- in-house design, manufacture, launch and operation of small satellites
- mission solutions for remote sensing, science, navigation and telecommunications
- space training and development programs
- Design and manufacturing of remote sensing and communication payloads

¹⁶⁸ Pumpkin Space n.d., *Pumpkin Space company website*, viewed in November 2016, <http://www.pumpkinspace.com/>

¹⁶⁹ Supernova-Beta n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/supernova-beta.htm

¹⁷⁰ Overview 1 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/overview-1.htm

¹⁷¹ Surrey Satellite Technology n.d., *Surrey Satellite Technology company website*, viewed in November 2016, <https://www.sstl.co.uk/>

¹⁷² Ibid.

¹⁷³ Ibid.

- avionics suites and subsystems
- ground infrastructure
- consultancy services

The main applications for SST products can be summarized as follows¹⁷⁴:

- **Earth-observation and imaging**
- **Navigation and telecommunications**
- **Scientific research**
- **Military/ defense purposes**
- **Technology demonstration**

The company has remarkably been a pioneer in building small satellites constellations, relying on their financial viability, rapid revisit, flexibility and data continuity. Among the many project developed and under development, the most relevant ones can be summarized:

- **DMC3/TripleSat Constellation:** the company has awarded a GBP 110 million contract in 2011 with satellite imaging provider DMC International Imaging (DMCii) to provide three new design small satellites delivering 1-meter resolution imagery at high speed downlink and 45 degrees off-pointing. The three satellites are intended to form a new constellation (called DMC3). By combining the coverage from three spacecraft, the constellation will be able to revisit a given area daily that is crucial for change detection, disaster monitoring and response planning, and essential for acquiring cloud-free imagery. The satellites will be leased to the Chinese 21AT (Twenty First Century Aerospace Technology Company), which will take 100% of the capacity of the three spacecraft over an initial contract period of seven years¹⁷⁵.
- **FORMOSAT-7 Constellation:** an international collaboration between Taiwan (NSPO) and the United States (NOAA) that will use a constellation of twelve remote-sensing microsatellites to collect atmospheric data for weather prediction and for ionosphere, climate and gravity research. Surrey Satellite technology will provide the bus. The satellite have GPS, GALILEO and GLONASS tracking capability. NOAA will then procure the launch vehicles¹⁷⁶.
- **Disaster Monitoring Constellation:** an Earth observation constellation of low cost small satellites providing daily images for applications including global disaster monitoring, it is coordinated by DMC International Imaging Ltd (DMCii) for both commercial imaging programs and to provide free satellite imagery for humanitarian use in the event of major international disasters within the International Charter. The national civil protection authorities of Algeria, China, Nigeria, Turkey and UK are direct authorized users of the Charter¹⁷⁷. The DMC satellites are designed and built by Surrey

¹⁷⁴ Surrey Satellite Technology n.d., *Surrey Satellite Technology company website*, viewed in November 2016, <https://www.sstl.co.uk/>

¹⁷⁵ DMC 3 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/uk-dmc-3.htm

¹⁷⁶ FORMOSAT 7 / COSMIC-2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/formosat-7-cosmic-2.htm

¹⁷⁷ Surrey Satellite Technology n.d., *Surrey Satellite Technology company website*, viewed in November 2016, <https://www.sstl.co.uk/>

Satellite Technology and each satellite is independently owned and controlled by a DMC Consortium member.

3.3.8 SpaceDev



SpaceDev is a California-based company that became a branch of the "Space Systems Business" of Sierra Nevada Corporation, being focused on spaceflight and microsatellite work. It is working on the development of microsatellites and nanosatellites, as well as on a small expendable launch vehicle - the Streaker - and it has designed a spaceship for both sub-orbital and orbital regimes - the Dream Chaser – collaborating with NASA. The firm has been a publicly traded company prior the acquisition by Sierra Nevada Corporation which took place in 2008, at a stated price of USD 38 million¹⁷⁸.

The company's first relevant project was the so-called "Near Earth Asteroid Prospector" (NEAP), a small commercial spacecraft mission that would have landed on a Near Earth Asteroid after some rendez-vous, conducting scientific experiments. An interesting success for the company was the Cosmic Hot Interstellar Plasma Spectrometer microsatellite (CHIPSat). The company has built and conducted early orbit operations of the Low Earth Orbit (LEO) microsat, being the first player ever using only the Internet for its communications, in collaboration with University of California under NASA's University Explorer Program (UNEX). It announced a merge with Starsys Research Corporation of Boulder, Colorado in 2005, granting additional expertise about microsatellite technologies¹⁷⁹.

The firm is focused mainly on the following sectors:

- **Communication**
- **Imaging**
- **Science**
- **Technology Demonstration**

The main project developed by the time have been:

- **CHIPSat:** a University-Class Explorer (UNEX) mission funded by NASA, it is intended to carry out a sky spectroscopy, helping scientists to determine electron temperatures, ionization conditions, and cooling mechanisms of the million-degree plasma believed to fill the local interstellar bubble. Launched in 2003 and with a weight of around 60 kg, its instruments were built at the Space Science Laboratory of the University of California, Berkeley. The project has been sponsored and managed by NASA through the Explorers Program. The satellite was shut down in 2008 after operating successfully for five years¹⁸⁰.
- **Trailblazer:** a demonstration satellite weighting 84 kg with the purpose of proving a flexible, modular commercial bus design using off the shelf components, that

¹⁷⁸ Sierra Nevada Corporation n.d., *Sierra Nevada Corporation company website*, viewed in November 2016, <http://www.sncorp.com/>

¹⁷⁹ Ibid.

¹⁸⁰ Explorer: CHIPSat (UNEX 1) n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/explorer_chips.htm

unfortunately failed to reach orbit due to a launch vehicle first stage malfunction. It was to be operated by the United States Air Force and the Missile Defense Agency and was selected for launch under a so-called "jumpstart" contract to demonstrate responsiveness - as the final payload being chosen less than a month ahead of the scheduled launch date - and launched as the primary payload of a SpaceX's Falcon-1 vehicle¹⁸¹.

- **ORBCOMM:** a constellation of LEO satellites for data communications purpose, providing Machine-to-Machine (M2M) interaction, to be built for the Orbcomm company. It consists of 18 satellites with an option to scale up to 30 additional satellites to augment and upgrade the existing satellite swarm. SpaceDev is the prime contractor and has formed an integrated space team which includes Boeing's Intelligence and Security Systems (I&SS). Each satellite will weight 172 kg and will be equipped with an enhanced communications payload, so customers will be able to transmit data over the constellation at greater speeds and send larger data packets using future modems. Moreover, all satellites will be designed with Automatic Identification System (AIS) payloads to receive and report transmissions from AIS-equipped maritime vessels, targeting U.S. and international coast guards and government agencies, as well as companies engaged in security or logistics businesses for tracking shipping activities or for other navigational purposes. The total contract value for 18 satellites is around USD 117 million¹⁸².

The company is also involved in the development of the Dream Chaser Cargo System, a reusable automated cargo spaceplane designed to resupply the International Space Station with both pressurized and unpressurized cargo load.

3.3.9 Tyvak Nano-Satellite Systems



Tyvak Nano-Satellite Systems provides nanosat and CubeSat space vehicle products and services that target advanced state-of-the-art capabilities for government and commercial customers to support operationally and scientifically relevant missions.

It has been established in 2011 by Jordi Puig-Suari and Scott MacGillivray in San Luis Obispo, California, with the aim to sell miniature avionics packages for small satellites, and to increase the available volume for payloads. It has an European headquarter in Italy, near Turin¹⁸³.

The firm provides¹⁸⁴:

- a complete **integrated suite of in-house engineering** capabilities for nanosatellite missions, from design to launch, including a nanosatellite lab for engineering development and testing, and a mission operations center with roof-mounted antennas to operate satellites.

¹⁸¹ Trailblazer n.d., *Gunter's Space Page*, viewed in November 2016,

http://space.skyrocket.de/doc_sdat/trailblazer.htm

¹⁸² Orbcomm FM101, ..., FM119 (OG2) n.d., *Gunter's Space Page*, viewed in November 2016,

http://space.skyrocket.de/doc_sdat/orbcomm-2.htm

¹⁸³ Tyvak n.d., *Tyvak company website*, viewed in November 2016, <http://www.tyvak.com/>

¹⁸⁴ Ibid.

- **Nanosatellite custom platforms**, including an “Endeavour Platform” capable of satellites spanning from 3U to 12U CubeSat missions, ultra-compact small pico-satellites solutions, and a radiation protection infrastructure for all missions.
- **Consulting and Launch Integration Services**, consisting of spacecraft development and analysis, launch services, and ground operations.
- **Launch and Satellite Insurance**, providing critical coverage for small satellite missions and programs.
- **Launch Integration**, seeking U.S. and international launch opportunities that best meet customers’ mission requirements and ensure flexible launch manifesting.

The firm is notably part of the Terran Orbital Corporation, delivering advanced mission solutions with industry leading turn-times and price-points to customers¹⁸⁵.

3.3.10 Blue Origin

BLUE ORIGIN

Blue Origin is developing technologies to enable human access to space at lower cost and increased reliability. The company is currently focused on developing rocket-powered Vertical Takeoff and Vertical Landing (VTVL) vehicles for access to suborbital and orbital space¹⁸⁶.

It was set up by Amazon.com founder Jeff Bezos and it is headquartered in Kent, Washington. While initially focused on sub-orbital spaceflight, in 2014 the firm moved into orbital spaceflight technology business, as a rocket engine supplier for other companies¹⁸⁷.

Its main product is the “New Shepard”: a fully reusable vertical takeoff, vertical landing space vehicle, consisting of a pressurized capsule on the top of a booster, with the capsule being designed to separate from the booster once into space. The booster performs then an autonomously controlled rocket-powered vertical landing, after a few minutes of free fall, while the capsule lands softly under parachutes, both ready to be used again. Reusability is thus the main distinctive feature of Blue Origin’s business model: it allows to fly the system continuously lowering operational costs. The New Shepard capsule’s interior is 530 cubic feet, as it seats six astronauts and is large enough weightless floating with comfort, and it has large windows enabling tourism sightseeing purposes. The capsule has a built-in escape system, relying on a solid rocket motor that provides 70,000 lb of thrust in a two-second burn, so the capsule can quickly move away from any hazard¹⁸⁸.

The company builds also liquid rocket engines, which are designed for high performance, low recurring cost, reusability, and reliable operations, providing great control with precisely timed starts, high-power thrust for launch, deep throttling for landing, and stop and restart capabilities. All engine types are designed, developed, and manufactured at our headquarters in the USA¹⁸⁹.

With its capabilities and expertise in orbital and sub-orbital launches, the company offers payload hosting as a secondary business, apart from human spaceflight, targeting the increasing-need small satellite launch market. Their frequent flight schedule will then allow

¹⁸⁵ Terran Orbital n.d., *Terran Orbital Corporation website*, viewed in November 2016, <http://terranorbital.com/>

¹⁸⁶ Blue Origin n.d., *Blue Origin company website*, viewed in November 2016, <https://www.blueorigin.com/>

¹⁸⁷ Ibid.

¹⁸⁸ Ibid.

¹⁸⁹ Ibid.

customers to launch multiple payloads, as human flights begin. Blue Origin leaves own full rights to customers for all collected data from their proprietary platform. Payloads are installed in the capsule, using two different payload locker infrastructures: a bigger one carrying 50 pounds and a smaller one carrying 25 pounds, the payload integration is provided by NanoRacks¹⁹⁰.

3.4 Launch

3.4.1 Virgin Galactic



With its headquarters located in New Mexico, Virgin Galactic has been founded in 2004 by the multi-billionaire, world-famous Richard Branson, also founder of Virgin Group. The company is developing commercial spacecraft to provide suborbital spaceflights for space tourism, suborbital launches for space science missions, and orbital launches of small satellites - in its plans there is the aim to provide orbital human spaceflights as well¹⁹¹.

In 2004, being released from the twin-turbojet carrier plane, Branson's brand new "SpaceShipOne" passed through the outer limits of the atmosphere, followed by a second successful flight less than a week later: it marked the first time an aerospace program completed a manned mission without government sponsorship. SpaceShipOne, a high-altitude research rocket, let Branson win a USD 10 million prize from XPRIZE – for the first private organization to launch a reusable manned spacecraft that could reach suborbital space twice in two weeks. Branson then announced his intention to launch the world's first commercial space tourism venture, and with this purpose Virgin Group licensed Mojave Aerospace Venture's technology, inaugurating Virgin Galactic¹⁹².

The company is focused on developing two product lines¹⁹³:

- **Human Spaceflight**, by means of two vehicle types: "WhiteKnightTwo" and "SpaceShipTwo". The first is a custom-built, four-engine, dual-fuselage jet aircraft, designed to carry SpaceShipTwo up to an altitude of 50,000 feet for safe and efficient air launch. The latter is a reusable, winged spacecraft designed to repeatedly carry as many as eight people (including two pilots) into space.
- **Satellite Launch**, with the air-to-orbit rocket "LauncherOne". It is an orbital launch vehicle dedicated to the small satellite market, designed to be launched by a customized and equipped Boeing 747-400 as a dedicated carrier aircraft. The estimated cost per satellite launched is around USD 10 million; the system is devoted to provide a reliable small satellite launch facility, to foster nanosats and smallsats market growth, avoiding "hitchhiking" to space.

¹⁹⁰ Blue Origin n.d., *Blue Origin company website*, viewed in November 2016, <https://www.blueorigin.com/>

¹⁹¹ Virgin Galactic n.d., *Virgin Galactic company website*, viewed in November 2016, <http://www.virgingalactic.com/>

¹⁹² La Vone, M 2014, 'Virgin Galactic, a brief history', *Space Safety Magazine*, viewed in November 2016, <http://www.spacesafetymagazine.com/space-disasters/virgin-galactic/virgin-galactic-brief-history/>

¹⁹³ Virgin Galactic n.d., *Virgin Galactic company website*, viewed in November 2016, <http://www.virgingalactic.com/>

Virgin Galactic has a major partnership with Spaceport America, the first spaceport designed and constructed specifically for commercial users that had not previously been an airport or federal infrastructure of any kind, located in New Mexico as well.¹⁹⁴

3.4.2 SpaceX



SpaceX designs, manufactures and launches rockets and spacecraft. The company was founded in 2002 by Elon Musk with the aim to revolutionize space transportation, with the ultimate goal of making human life achievable on other planets. In 2010, SpaceX became the first commercial company in history to send a spacecraft into orbit and return it safely to Earth. In May 2012, SpaceX's Dragon spacecraft became the first private commercial vehicle to successfully attach to the International Space Station, previously being accomplished only by governments. In October 2012 and March 2013, Dragon again successfully delivered cargo to and from the space station in its first two official cargo resupply missions for NASA¹⁹⁵.

Headquartered in California, SpaceX is flying multiple cargo resupply missions to the International Space Station, as it signed a USD 1.6 billion contract with NASA¹⁹⁶. In 2016, NASA awarded SpaceX a second version of that contract that will cover a minimum of 6 additional flights from 2019 onward and in the near future, SpaceX will carry crew as part of NASA's Commercial Crew Program as well. SpaceX is a fast-growing provider of launch services and has over 70 future missions on its manifest, representing over \$10 billion in contracts¹⁹⁷. These include commercial satellite launches as well as NASA and other US Government missions. The company is working toward a key goal: developing reusable rockets, a feat that will transform space exploration by delivering highly reliable vehicles at radically reduced costs.

The company uses three different rockets to deliver payloads into space¹⁹⁸:

- **Falcon 9:** a two-stage rocket providing reliable and safe transport of satellites and the Dragon spacecraft into orbit. It consists of a simple two-stage configuration that minimizes the number of separation events. This vehicle made history in 2012 when it delivered the Dragon spacecraft into the rendezvous orbit with the International Space Station, making SpaceX the first commercial company ever to visit the station. The payload fairing is intended to deliver satellites to destinations in low Earth orbit (LEO), geosynchronous transfer orbit (GTO) and beyond.
- **Falcon Heavy:** one of the most powerful operational rocket in the world, it will have the ability to lift into orbit over 54 metric tons - a mass equivalent to a 737 jetliner fully-loaded with passengers, crew, luggage and fuel. The vehicle is designed to carry humans into space and for flying manned missions to the Moon or Mars. The composite payload fairing protects satellites during delivery to destinations in low Earth orbit (LEO), geosynchronous transfer orbit (GTO) and beyond.

¹⁹⁴ David, L 2007, 'Spaceport America: first looks at a new space terminal', *space.com*, viewed in November 2016, <http://www.space.com/4304-spaceport-america-space-terminal.html>

¹⁹⁵ SpaceX n.d., *SpaceX company website*, viewed in November 2016, <http://www.spacex.com/>

¹⁹⁶ Ibid.

¹⁹⁷ Ibid.

¹⁹⁸ Ibid.

- **Dragon:** a free-flying spacecraft designed to deliver both cargo and people to orbiting destinations. Dragon made history in 2012 when it became the first commercial spacecraft in history to deliver cargo to the International Space Station and safely return to Earth. Currently Dragon is carrying cargo to space, but it was designed from the beginning to carry humans. Under an agreement with NASA, SpaceX is now developing customizations that will enable Dragon to fly crew, as its first manned test flight is expected to take place in 2-3 years.

3.4.3 Rocket Lab



Rocket Lab is a recent start-up company focused on rocket launches, and with the aim to disrupt the traditional orbital launch industry through frequent, dedicated and low cost launch services to the small satellites industry. Founded in 2006 by Peter Beck and then headquartered in Los Angeles (with operations and a launch site in New Zealand), the firm is trying to offer a reliable service to deliver small satellites to LEO, at a minimum price of USD 50.000 for a single unit CubeSat.¹⁹⁹ Rocket Lab's mission is to remove commercial barriers to space, as it was founded on the belief that small payloads require dedicated launch vehicles and a flexibility not currently offered by traditional launch systems. Rocket Lab's orbital launch vehicle Electron is capable of delivering payloads of 150 kg to a 500 km Sun-synchronous orbit. The Electron test program is scheduled to run over the second half of 2016, with commercial flights commencing in 2017 at a starting price of USD 4.9 million. It is intended to enable a change in the space industry by providing affordable, high-frequency launches for the emerging small satellite market. The company is privately funded and its major investors include Khosla Ventures, K1W1, Bessemer Venture Partners and Lockheed Martin²⁰⁰.

In December 2010 it awarded a US contract from the Operationally Responsive Space Office (ORS) to study a low cost space launcher to place nanosatellites into orbit²⁰¹.

The main active project is the rocket "Electron", which is a two-stage launch vehicle which uses Rocket Lab proprietary Rutherford liquid engines on both stages. The vehicle is capable of delivering payloads of 150 kg to a 500 km orbit, with a projected launch costs of less than USD 5 million per launch. The engine uses pumps that are uniquely powered by battery-powered electric motors rather than a gas generator, and the engine parts are fabricated largely by 3D printing. The vehicle can be tailored to specific mission requirements including a range of sun-synchronous altitudes in circular or elliptical orbits at inclinations between 45 and 98 degrees, and Electron makes use of advanced carbon composites for a strong and lightweight flight structure²⁰².

¹⁹⁹ Rocket Labs n.d., *Rocket Labs company website*, viewed in November 2016, <https://www.rocketlabusa.com/>

²⁰⁰ Messier, D 2014, 'A look at Rocket Lab funding sources', *Parabolic Arc*, viewed in November 2016, <http://www.parabolicarc.com/2014/07/30/rocket-lab-funding-sources/>

²⁰¹ NZPA 2009, 'NZ set to join the space age', *Stuff.co.nz*, viewed in November 2016, <http://www.stuff.co.nz/science/2946619/NZ-set-to-join-the-space-age>

²⁰² Rocket Labs n.d., *Rocket Labs company website*, viewed in November 2016, <https://www.rocketlabusa.com/>

The company makes possible for a customer to send a 1U CubeSat payload in orbit at a starting cost of USD 50,000 that scales up to USD 180,000 for a 3U platform²⁰³.

3.4.4 Spaceflight Industries



Established in 1999 and located in Seattle, Washington, Spaceflight's mission is to revolutionize the business of spaceflight by delivering a new business model for access to space. The company provides a cost-effective suite of products and services including state-of-the-art satellite infrastructure, rideshare launch offerings, and global communications networks that enable commercial and government entities to achieve their mission goals, on time and on budget²⁰⁴.

Spaceflight targets the market through a broad diversification strategy, being active along three diverse business lines²⁰⁵:

- **Launch services:** taking advantage of partnerships with many launch providers worldwide and focusing on launch capabilities spanning from CubeSats to 2000 kg microsatellites, it provides launch opportunities to numerous orbit destinations addressing operational and budget constraints. The company has also the competencies to manage customers' missions through its experienced mission managers and to integrate different payloads including all hardware support equipment.
- **Spaceflight networks:** managing a global ground station network capable to provide connectivity for small satellites missions or constellations. Through its branch "Spaceflight Networks" it holds sparse ground stations which are optimized to minimize latency and maximize data throughput.
- **Spaceflight systems:** enabling systems for the commercial space industry. It supplies a range of spacecraft and launch system solutions including microsatellites such as the Small Agile Tactical Spacecraft for the US Army SMDC, and the Reusable Booster System Pathfinder vehicle for the USAF. The company provides also the SCOUT satellite, which is notably an imaging microsatellite capable of 1 m visible imagery, weighting around 50 kg of wet mass and compatible with either vertical or cantilever orientation as a secondary payload on a variety of launch vehicle platforms.

The company has recently announced that the imagery firm Terra Bella has signed an agreement with its launch services entity for a SpaceX launch of Terra Bella's SkySats. The mission will also transport both government and commercial microsatellites and CubeSats from different countries²⁰⁶.

²⁰³ Rocket Labs n.d., *Rocket Labs company website*, viewed in November 2016, <https://www.rocketlabusa.com/>

²⁰⁴ Spaceflight n.d., *Spaceflight company website*, viewed in November 2016, <http://www.spaceflight.com/>

²⁰⁵ Ibid.

²⁰⁶ Ibid.

3.5 Deployment

3.5.1 NanoRacks



Headquartered in Houston, Texas, and founded by Jeff Manber, NanoRacks is a firm focused on on-orbit research and especially on developing small satellite launchers. It hosts a CubeSat deployment system and equipment for experiments on the International Space Station. NanoRacks services include reviewing space payloads to ensure they meet NASA's safety and other technical requirements²⁰⁷. In July 2015, NanoRacks announced an agreement with Blue Origin to offer business development services for the New Shepard Suborbital Vehicle. It estimates a cost of USD 30-60.000 per CubeSat launched²⁰⁸.

The company's vision is about democratizing the utilization of the low-earth orbit region of space, as it is intended to provide a viable commercial pathway to the Space Station. The three distinctive concepts on which the company is focused are²⁰⁹:

- **low-cost philosophy**
- **hardware standardization**
- **deep understanding of customers' needs**

The customer base include a very broad range of subjects spanning from high schools to government space agencies and commercial firms, as the client base includes NASA, the German Space Agency, ESA, Planet Labs, Spire, biopharmaceutical firms, Urthecast, high schools and universities worldwide²¹⁰.

The main products that the company is offering the market are²¹¹:

- **Suborbital services:** through integration, payload development and customer services to Blue Origin's New Shepard space vehicle, as Nanoracks provides in-house capabilities for the New Shepard space vehicle integration, payload design and development, interfacing with Blue Origin's technical team.
- **Internal payloads:** providing an in-orbit system that provides payload opportunities on the International Space Station using the CubeSat form factor. The main solutions provided are:
 - Nanolab, the company's core payload hardware. It is a box in the CubeSat form factor, measuring 0.1 m by side. Every box has a circuit board that activates the experiment, turns it off and can be functioned for other activities. The modules are plugged into research platforms via a normal USB port, allowing data and power to flow. A single NanoLab is 1U in size; but 2U, or 4U or 2 by 4U for example can be handled too. These modules are the core of NanoRacks's philosophy: low-cost, open sourced, standardized, miniaturized

²⁰⁷ Moring, F 2014, 'Commercial Outpost: Next Steps on ISS may include private researchers', *Aviation Week*, viewed in November 2016,

http://images.spaceref.com/docs/2014/here_to_mars_Manber_Testimony_040914.pdf

²⁰⁸ Martin, G 2016, 'NewSpace: The emerging commercial space industry', viewed in November 2016,

<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160001188.pdf>

²⁰⁹ Nanoracks n.d., *Nanoracks company website*, viewed in November 2016, <http://nanoracks.com/>

²¹⁰ Ibid.

²¹¹ Ibid.

hardware that allows the customer to focus more on the research than on hardware development and functioning.

- Platform-3, a module suitable for a range of low-cost biological microgravity research opportunities in the US National Lab onboard the ISS. It accommodates a total of 3 4U payloads, and has advanced features including an internal computer with its own crew interface facility for easier payload software development.
- Centrifuge-1, which will be permanently housed on the ISS National Lab, provides microgravity experimentation opportunities for microgravity research, being able to simulate Earth, Moon and Mars gravity.
- Plate Reader-2, specifically designed for life sciences research, features a wide range of high-performance multi-mode reader capabilities, ideal for life science research.
- Microscope, a digital reflective microscope that allows on-the-ground researchers to undertake in-situ microgravity analysis on the International Space Station.
- MixStix, providing non-powered environment for fluid and biological research.
- **Smallsat deployment:** NanoRacks CubeSat Deployer (NRCSD) is a self-contained CubeSat deployer system that mechanically and electrically isolates CubeSats from the ISS, cargo resupply vehicles, and ISS crew. Compliant with NASA ISS flight safety requirements, the NRCSD is a rectangular tube that consists of anodized aluminum plates, base plate assembly, access panels, and deployer doors. Within the deployment phase, the platform is moved outside via the Kibo Module's Airlock and slide table that allows the Japanese Experimental Module Remote Manipulator System (JEMRMS) to move the deployers to the correct orientation for the satellite release and also provides command and control to the deployers. Each NRCSD is capable of holding six CubeSat Units – allowing it to launch 1U, 2U, 3U, 4U, 5U, and 6U (2×3 and 1×6) CubeSats.

The diverse supply solutions mentioned above are aimed to serve the following market applications²¹²:

- **Educational programs**, serving the education, basic research and commercial research communities. from basic student opportunities at \$15,000 to \$100,000 and up for advanced hardware.
- **Life Sciences studies**, offering commercial research opportunities for life science companies exploring the effects of gravity on cellular structures and tissue growth.
- **National security**, providing fast internal and external access to the space station facilities, taking advantage of the first deployment system of small satellites from the ISS.

²¹² Nanoracks n.d., *Nanoracks company website*, viewed in November 2016, <http://nanoracks.com/>

Conclusions

Commercial companies operating in the field of small satellites and NewSpace actors are growing and developing around well-defined geographic and culturally prolific areas, forming clusters featured by vibrant ecosystems where public sector, universities, and private firms play an active role in generating fruitful partnerships. The most important cluster for NewSpace ventures has formed in the Silicon Valley area, where a big amount of the small satellite enterprises are co-located. Some reasons could be retrieved for this particular development:

- **Technology spillovers:** the area can be regarded as the biggest high-tech hub in the world, making technology exchange possible between research institutions and private firms.
- **Proximity to venture capital firms:** these finance companies hold a relevant experience in funding high-technology, early stage companies.
- **Availability of COTS (Commercial-Off-The-Shelf) technology products:** in this area the purchase of packaged solutions, particularly regarding advanced, miniaturized electronic solutions, is crucial for the small satellite development.

The presence of a network of interconnected industries along the whole value chain is the key for innovation, as these industries provide cost-effective specialized inputs and participate in the innovation process. The level of interconnection with related and supporting industries determines the cluster's ability to generate innovation at the system level and results ultimately in widespread socioeconomic development when interconnections among different industries bring about cross-fertilization and knowledge spillovers²¹³. Moreover, technology spillovers between education institutions and private companies are fundamental to form the required ecosystem for letting startups develop and grow: many notable and talented individuals often come from universities and create their own firm to realize their innovative concept ideas, reinforcing the continuous exchange of knowledge between education centers and the commercial arena. From a financial point of view, a fundamental growth driver is certainly the presence of technology-oriented venture capital groups, which have fueled the small satellite boom and broadly the entire NewSpace industry: acting as feeders of young companies, they provide relevant capital amounts that are necessary to fund every development step and foster the creation of an entire new market. These subjects, in form of wealthy individuals or private organized firms, are less adverse to risk: their strategy is to fund high-risk ideas expecting higher returns in the future, as they also help the new-born companies giving their management experience gained with years of activity on-the-field.

Highlighting the importance of education in the development of small satellites sector, two examples are remarkable: **QB50** and the Australian firm **Quberider**.

QB50 Project

QB50 is an international network of small satellites with scientific research purposes: the mission aim is to prove the feasibility of launching a network of 50 CubeSats built by Universities from all over the world as a primary payload on a low-cost launch vehicle to perform science research in the still largely unexplored lower thermosphere – from 90 to 350

²¹³ Paone, M 2016, *Aerospace Clusters, World's Best Practice and Future Perspectives*, Defence SA, <http://www.defencesa.com/upload/capabilities/space/Intern%20-%20Paone,%20Matteo%20-%20Aerospace%20Clusters.pdf>

km altitude²¹⁴. Since space agencies are not pursuing a multi-spacecraft network for low-thermosphere measurements as the cost for a network of satellites would be extremely high and not justifiable in view of the limited orbital lifetime, a network of satellites for in-situ measurements in the lower thermosphere can be achieved by very affordable satellites, and CubeSats are a viable option.

The QB50 mission has four main objectives²¹⁵:

- Facilitating access to space, achieving a sustained and affordable access to space for small scale research space missions and planetary exploration. For this purpose, a dedicated launcher interface acting as deployment system has been specifically developed, called QuadPack. The global CubeSat community as well as launch providers and the European industry are benefitting of a technology developed within the QB50 project.
- Scientific Research, carrying out atmospheric research within the lower thermosphere, the least explored atmosphere layer. QB50 will provide measurements along several months of activity, overtaking the previous atmospheric explorers which flew in highly elliptical orbits lasting only for minutes. Three different types of science sensors, each of which is part of a science set, will be used to fulfill the objective of carrying out atmospheric research in the lower thermosphere. These science sensors include the Ion-Neutral Mass Spectrometer (INMS), the Flux- Φ -Probe Experiment and multi-Needle Langmuir Probe (m-NLP).
- In-orbit demonstration, serving as a platform for technology demonstration. A group of QB50 satellites will not accommodate science sensors, but carry their own payload²¹⁶:
 - QARMAN (QubeSat for Aerothermodynamic Research and Measurements on Ablation), with the purpose of studying the atmospheric re-entry process and the associated aerothermodynamic phenomena.
 - DelFFi, 2 identical 3U CubeSats - Delta and Phi – with the objective of demonstrating autonomous formation flying between with the use of innovative concepts and methodologies.
 - InflateSail, a 3U CubeSat built by the Surrey Space Centre whose primary objective is the flight demonstration of an inflatable sail structure.
- Education purposes, as QB50 invites universities worldwide to join the project and send a satellite to space. As a result, the involved CubeSats will be designed and built by young engineers, supervised by experienced staff at their universities and guided by the QB50 project.

The entire project will be deployed during three different launch campaigns²¹⁷ (2 satellites has already been launched with an amateur radio precursor mission, QB50p1 and QB50p2):

- 6 CubeSats will be launched on a “Dnepr Science Flight” as “QB50-DS”
- 40 CubeSats will be deployed from the ISS as “QB50-ISS”

²¹⁴ QB50 n.d., *QB50 project website*, viewed in November 2016, <https://www.qb50.eu/>

²¹⁵ Ibid.

²¹⁶ QB50 n.d., *QB50 project website*, viewed in November 2016, <https://www.qb50.eu/>

²¹⁷ Ibid.

- 2 In-Orbit Demonstration CubeSats will be launched on a second Dnepr vehicle, as “QB50-DIOD”.

Among the others - Australia is actively participating to the QB50 project, as 3 different CubeSats are developed by Australian universities²¹⁸:

- SUSat, developed by the University of Adelaide
- UNSW-EC0, developed by the University of New South Wales
- i-INSPIRE II, developed by the University of Sydney

It has also been announced that an initial series of tests of the transponder payload aboard the QB50p1 - one of two QB50 precursor spacecraft, launched in 2014 - have been successfully completed. The primary science payloads are still being extensively tested, and the transponder is intended as a long term secondary mission following the initial technology demonstration and de-risking phase²¹⁹.

Quberider

Quberider is a Sydney start-up, among the few commercial space companies located in Australia. Set up in 2015 by young space innovators Solange Cunin and Sebastian Chaoui, it has been accelerated by Telstra’s Muru-D start-up hub²²⁰, and was born with a mission to “educate and inspire” school pupils about coding and careers in IT, by using hands-on learning to engage students to use their imagination, curiosity, critical thinking and problem solving skills, enabling them to become the next generation of innovators²²¹. Students’ experiments range from testing variations in the earth’s magnetic field and Einstein’s theory of relativity to an astronaut’s exposure to radiation and the creation of music and art using data patterns. Quberider is the first Australian organization to win government approval to fly a mission to space, and it’s also the first time so many Australian high school students have been given access to the ISS. Its “#Mission2016” payload has been approved by NASA for launch to the International Space Station (ISS) on December 9th, and its payload consists of 1,000 experiments by Australian students from 60 different schools. It is based on a compact programming board with 10 sensors that records data such as temperature, UV radiation and magnetic fields for STEM experiments on the International Space Station²²².

This report has shown the strong growth that the space industry has experienced in the last decade, with small satellites becoming an extraordinarily important business. With South Australia having experienced sustained economic growth, arising as a key player in the international competitive landscape, the state has become an innovation hub: the local space industry is also on the lead in the development of a space economy for the entire nation.

As it can be seen by the diverse enterprise landscape examined in this report, commercial applications of space innovations cover a very broad field such as agriculture, energy, environmental control, telecommunications and national security. South Australia is proving significant capabilities across this wide range of segments, as the state offers a complex and

²¹⁸ QB50 n.d., *QB50 project website*, viewed in November 2016, <https://www.qb50.eu/>

²¹⁹ Ibid.

²²⁰ Nott, G 2016, ‘Australia’s commercial space program blasts off with Sydney start-up’, *Computerworld*, viewed in November 2016, <http://www.computerworld.com.au/article/605772/australia-commercial-space-program-blasts-off-sydney-start-up/>

²²¹ McDonough, R 2016, ‘Quberider set to become Australia’s first space mission’, *Medianet*, viewed in November 2016, <http://www.medianet.com.au/releases/115318/>

²²² Strom, M 2016, ‘Solange Cunin’s Quberider to send Australia’s first payload to International Space Station’, *The Sydney Morning Herald*, viewed in November 2016, <http://www.smh.com.au/technology/sci-tech/solange-cunins-quberider-to-send-australias-first-payload-to-international-space-station-20160504-gomog3.html>

vibrant ecosystem that fosters innovative companies, universities and research institutions. The state is home to around 60 players from Academia, Government and Industry, with space-related expertise and the potential to apply such expertise to the space sector.

The vibrant industrial ecosystem is backed by an excellent academic environment, hosting three local universities (University of Adelaide, University of South Australia and Flinders University) and three international universities (University College London, Carnegie Mellon University and Torrens University Australia), with relevant space research activity mainly carried out by local universities, which are equipped with state-of-the-art research infrastructure like, for instance, the University of Adelaide's wind tunnel and the Institute for Telecommunications Research (ITR) renowned for global satellite communications. In addition, the Southern Hemisphere Space Studies Program is held annually in Adelaide as a result of the partnership between the University of South Australia and the International Space University. South Australian academia is enriched by the presence of world-class research institutions such as the Defence Science and Technology Group (DSTG), a government agency that carries out cutting-edge research and development activity in the field of innovation and technology for national security purposes. The agency addresses the demand expressed by the Australian Defence Force creating a link with the supply offered by the state's research organizations and private companies. Furthermore, it is beneficial to the development of a strong space industry, setting the conditions to a sustainable growth, the presence of the Space Industry Association of Australia, which has long been carrying out remarkable advocacy activity. The association promotes the national space sector by fostering knowledge sharing among its members and assisting them in carrying out their business, as well as voicing their interests at the institutional level.

In April 2016 the South Australian Government established the office of Space Industry and R&D Collaborations at Defence SA. Its goal is to support the space economy in the State by supporting space industries, universities and research organizations which will contribute strategically to the development of many other priority sectors such as advanced manufacturing, agriculture, health care, energy, mining, technology and services, national security and education, all areas in which space applications play an important role.

The new Office was established with the goal of positioning South Australia as the national hub of space activity where high-tech industries, universities and research centers are actively involved in developing a vibrant space innovation ecosystem. The Office has developed the Space Innovation and Growth Strategy (South Australia): Action Plan 2016-2020 (the Strategy) that was launched in November 2016 during the second South Australian Space Forum. It is the first space strategy of any Australian jurisdiction, and it details the State's vision through three pillars:

- **Knowledge** - Grow South Australia's economy through space activity by increasing the awareness of the importance of space technology in our daily lives and for all citizens
- **Industry and Innovation** - Invigorate South Australia's space innovation ecosystem by strengthening technological capabilities and expertise and stimulating the commercialization of research results in the space sector. This will be advanced by a strong networking among the SA stakeholders led by industry in partnership with research organizations, universities and schools with a view to stimulate local innovation and competition.
- **International partnerships** - Engaging international cooperation with lead countries by growing a network of strategic partnerships in the space sector

Key actions from the Strategy are:

- Establishing a “National Hub of Space Industry, Research and Development” in South Australia which will be achieved through a series of biennial forums, a website and regular contact through a stakeholder communication list. The First Space Forum was in May 2016, the second was on 10 November 2016 and the third will be in 2017. More than 120 participants have been attended to each event.
- Publication and annual revision of the South Australian Space Capability Directory which identifies and maps the State’s existing expertise and capabilities in space, and promotes them at local and international level. The first Capability directory was launch in June 2016 and the second edition will launch in May 2017.
- Strengthening of international cooperation and R&D partnerships in South Australia to enhance high-quality knowledge and stimulate export and strategic partnerships. In October 2016 a Letter of Intent was signed with the Italian Space Agency to promote collaboration among companies and research organizations. They have established a dialogue with China and Japan’s space industry as well as the Japanese space agency (JAXA). An important activity in this regard is the 68th International Astronautical Congress (IAC) which will be held in Adelaide in September 2017. This represents an important opportunity to promote the local space sector on a worldwide stage. During the Congress, a bilateral roundtable co-hosted by SA Government, French Space Agency and the Brittany Aerospace Cluster is planned to promote bilateral collaboration between France and South Australian companies.
- The SA Space Council has been established with nine high-profile expert members representing research organizations, universities, private companies, government and all the most relevant stakeholders in the space sector. The Council will serve as a primary avenue for the discussion of actual trends and for identification of strategies and actions aimed to assist Defence SA in supporting space industry growth and in enhancing innovation in the SA space sector.

Due to such well-managed innovation environment, large private companies such as Airbus Defence & Space, BAE Systems, Boeing, Lockheed Martin, Raytheon, Northrop Grumman Australia and Nova Systems, as well as other world-class aerospace multinational companies have established or have shown interest in establishing their presence in the state. The presence of these operators is certainly an important factor that has fueled the creation of small and medium-sized companies that now are part of the space supply chain by providing products and services in a wide array applications. South Australia is also home to space-focused companies that underwent strong development in the last decade and which have been mentioned in this report, including Fleet, Myriota and Inovor Technologies.

A relevant source of competitive advantage for the development of a space industry in South Australia is also constituted by the state’s geographical position and commercial relations, especially regarding the proximity to the Asia-Pacific region. South Australia has become capable of addressing the increasing demand for aerospace-related products and services from Asian countries, taking advantage of the traditionally good commercial relationships with countries such as China and India.

Bibliography

- Anzaldúa, A 2014, 'Orbital debris: resource ladder to the stars', *The Space Review*, viewed in October 2016, <http://www.thespacereview.com/article/2457/1>
- ArduSat 1, X n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/ardusat-1.htm
- ArduSat 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/ardusat-2.htm
- Astro Digital n.d., *Astro Digital company website*, viewed in November 2016, <https://astrodigital.com/>
- BlackSky Global 1, 2, 3, 4 / BlackSky Pathfinder 1, 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/blacksky.htm
- Blue Origin n.d., *Blue Origin company website*, viewed in November 2016, <https://www.blueorigin.com/>
- Brieß, K 2016, 'The rise of small satellites', Technische Universität Berlin, *MOOC@TU9*, viewed in October 2016, http://mooc.tu9.de/cms/wp-content/uploads/2014/09/Rise_of_small_satellites.pdf
- Burns, M 2012, 'Skybox Imaging raises \$70M to launch two high-res imaging microsats', *TechCrunch*, viewed in November 2016, <https://techcrunch.com/2012/04/17/skybox-imaging-closes-70m-in-series-c-funding-with-immediate-plans-to-launch-two-high-res-imaging-microsatellites/>
- CICERO n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/cicero.htm
- Clyde Space n.d., *Clyde Space website*, viewed in November 2016, <https://www.clyde.space>
- Cockrell J, Alena, R, Mayer, D, Sanchez, H, Luzod, T, Yost, B & Klumpar, D 2012, 'EDSN: a large swarm of advanced yet very affordable, COTS-based nanosats that enable multipoint physics and open source apps', *26th Annual AIAA/USU Conference on Small Satellites*, viewed in November 2016, <http://digitalcommons.usu.edu/smallsat/2012/all2012/89/>
- Corner, S 2016, 'Myriota promises satellite IoT from matchbox-sized device', *IoT Australia*, viewed in November 2016, <https://www.iotaustralia.org.au/2016/01/21/iotnewanz/myriota-promises-satellite-iot-from-matchbox-sized-device/>
- Crisp, N, Smith, K & Hollingsworth, P 2015, Launch and deployment of distributed small satellite systems, *Acta Astronautica*, vol. 114, no. September-October 2015, pp. 65-78, <http://www.sciencedirect.com/science/article/pii/S009457651500171X>
- David, L 2007, 'Spaceport America: first looks at a new space terminal', *space.com*, viewed in November 2016, <http://www.space.com/4304-spaceport-america-space-terminal.html>

- David, L 2016, 'Chris McCormick on PlanetiQ's launch plans, NOAA's commercial weather pilot', *Space News*, viewed in November 2016, <http://spacenews.com/chris-mccormick-on-planetiqs-launch-plans-noaas-commercial-weather-pilot/>
- De Selding, PB 2015, 'BlackSky Global says it's poised to cover globe with 60 smallsats', *Space News*, viewed in November 2016, <http://spacenews.com/blacksky-global-says-its-poised-to-cover-globe-with-60-smallsats/>
- De Selding, PB 2015, 'PSLV rocket launches India's 1st astronomy satellite, 4 Spire Cubesats', *Space News*, viewed in November 2016, <http://spacenews.com/pslv-rocket-launches-indias-1st-astronomy-satellite/>
- De Selding, PB 2016, 'SES exercises option to buy 100% of O3b Networks, will raise new equity', *Space News*, viewed in November 2016, <http://spacenews.com/ses-exercises-option-to-buy-100-of-o3b-networks-will-raise-new-equity/>
- Dhruva Space n.d., *Dhruva Space company website*, viewed in November 2016, <http://www.dhruvaspace.com/>
- DigitalGlobe n.d., *DigitalGlobe company website*, viewed in November 2016, <http://www.digitalglobe.com/about/>
- DMC 3 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/uk-dmc-3.htm
- Doncaster, B, Shulman, J 2016, 'Nano/microsatellite market forecast', SpaceWorks Enterprises Inc., viewed in November 2016, http://spaceworksforecast.com/docs/SpaceWorks_Nano_Microsatellite_Market_Forecast_2016.pdf
- Dove 1 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/dove-1.htm
- Dove 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/dove-2.htm
- Dove 3, 4 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/dove-3.htm
- Encyclopedia Astronautica n.d.*, viewed in November 2016, <http://www.astronautix.com/a/aprizesat.html>
- Equals Three Communications & Booz Allen Hamilton 2002, *Commercial Market Outreach Plan for the International Space Station*, NASA headquarters, <http://www.hq.nasa.gov/office/hqlibrary/documents/o49797051.pdf>
- Explorer: CHIPSat (UNEX 1) n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/explorer_chips.htm
- Fleet Space Technologies n.d., *Fleet Space Technologies company website*, viewed in November 2016, <<http://www.fleet.space/>
- Flock-1, -1b, -1c, -1d, -1d', -1e, -1f, -2, -2b, -2c, -2d, -2e, -2e', -2k, -2p n.d., *Gunter's Space Page*, http://space.skyrocket.de/doc_sdat/flock-1.htm

- FORMOSAT 7 / COSMIC-2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/formosat-7-cosmic-2.htm
- Foust, J 2016, 'White House announces small satellite initiative', *Space News*, viewed in November 2016, <http://spacenews.com/white-house-announces-small-satellite-initiative/>
- GeoOptics n.d., *GeoOptics company website*, viewed in November 2016, <http://www.geooptics.com/partners/>
- Geospatial World 2016, 'Smallsat foray will add to DG's high-res imagery arsenal', *Geospatial World*, viewed in November 2016, <https://www.geospatialworld.net/article/smallsat-foray-will-add-to-dgs-high-res-imagery-arsenal/>
- GomSpace n.d., *GomSpace company website*, viewed in November 2016, <https://www.gomspace.com>
- Ha, A 2014, 'Satellogic aims to launch a constellation of small imaging satellites around Earth', *Techcrunch*, viewed in November 2016, <https://techcrunch.com/2014/06/20/satellogic-launch/>
- Henry, C 2015, 'BlackSky Global details plans for 60 satellite Earth observation constellation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2015/06/16/blacksky-global-details-plans-for-60-satellite-earth-observation-constellation/>
- Henry, C 2015, 'Iceye prepares prototype satellite for 2017 launch', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2015/12/08/iceye-prepares-prototype-satellite-for-2017-launch/>
- Henry, C 2016, 'Satellogic on its way to launching 300 satellite constellation for Earth observation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2016/03/17/satellogic-on-its-way-to-launching-300-satellite-constellation-for-earth-observation/>
- Henry, C 2016, 'UrtheCast and OmniEarth team up on UrtheDaily constellation', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/publications/st/2016/08/02/urthecast-omniearth-team-urthedaily-constellation/>
- Hera Systems n.d., *Hera Systems company website*, viewed in November 2016, <http://www.herasys.com/>
- Hera Systems unveils groundbreaking \$1 pricing for satellite imagery* 2016, Hera Systems press release, viewed in November 2016, <http://www.spaceref.com/news/viewpr.html?pid=47866>
- Hobbyspace n.d., *NewSpace, the alternative route to space*, Hobbyspace, viewed in October 2016, <http://www.hobbyspace.com/NewSpace/>
- ICEYE n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/iceye.htm
- Iceye n.d., *Iceye company website*, viewed in November 2016, <http://iceye.fi/>

- Inovor Technologies n.d., *Inovor Technologies company website*, viewed in November 2016, <http://www.inovor.com.au>
- ISIS Space n.d., *ISIS Space Company website*, viewed in November 2016, <https://www.isispace.nl/>
- ISIS Space n.d., *ISIS Space LinkedIn profile*, viewed in November 2016, <https://www.linkedin.com/company/isis---innovative-solutions-in-space-bv>
- Janson, S 2011, *25 years of Small Satellites. The Aerospace Corporation*, viewed in October 2016, <http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1117&context=smallsat>
- Kessler, DJ & Cour-Palais, BG 1978, 'Collision frequency of artificial satellites: the creation of a debris belt', *Journal of geophysical research*, vol. 43, no. A6, <http://webpages.charter.net/dkessler/files/Collision%20Frequency.pdf>
- La Vone, M 2014, 'Virgin Galactic, a brief history', *Space Safety Magazine*, viewed in November 2016, <http://www.spacesafetymagazine.com/space-disasters/virgin-galactic/virgin-galactic-brief-history/>
- LatinSat A, B, C, D / AprizeSat 1, ..., 10 / exactView 3, 4, 5, 5R, 6, 11, 12, 13 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/aprizesat-1_latinsat-1.htm
- Lemur 1 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/lemur-1.htm
- Lemur 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/lemur-2.htm
- LituanicaSAT 1 (LO 78, Lituanica-OSCAR 78) n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/lituanicasat-1.htm
- LituanicaSAT 2 (QB50 LT01) n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/lituanicasat-2.htm
- Machi, V 2016, 'Small satellites: obvious benefits but also concerns', *National Defense Magazine*, viewed in November 2016, <http://www.nationaldefensemagazine.org/archive/2016/september/Pages/SmallSatellitesObviousBenefitsButAlsoConcerns.aspx>
- Madhumathi, DS 2015, 'Space entrepreneurs and their startups', *The Hindu*, viewed in November 2016, <http://www.thehindu.com/news/cities/bangalore/space-entrepreneurs-and-their-startups/article7830135.ece>
- Magan, V 2016, 'DigitalGlobe forms joint venture to develop smallsats in Saudi Arabia', *Satellite Today*, viewed in November 2016, <http://www.satellitetoday.com/technology/2016/02/22/digitalglobe-forms-joint-venture-to-develop-smallsats-in-saudi-arabia/>
- Martin, G 2016, 'NewSpace: The emerging commercial space industry', viewed in November 2016, <http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160001188.pdf>
- McDonough, R 2016, 'Quberider set to become Australia's first space mission', *Medianet*, viewed in November 2016, <http://www.medianet.com.au/releases/115318/>

- Messier, D 2014, 'A look at Rocket Lab funding sources', *Parabolic Arc*, viewed in November 2016, <http://www.parabolicarc.com/2014/07/30/rocket-lab-funding-sources/>
- Miguel-Lago, M 2014, 'OmniEarth team announces \$250M small-sat imagery venture', *European Association of Remote Sensing Companies*, viewed in November 2016, [https://earsportal.eu/display/EOSTAN/2014/05/21/OmniEarth+Team+Announces+\\$250M+Small-sat+Imagery+Venture](https://earsportal.eu/display/EOSTAN/2014/05/21/OmniEarth+Team+Announces+$250M+Small-sat+Imagery+Venture)
- Morning, F 2014, 'Commercial Outpost: Next Steps on ISS may include private researchers', *Aviation Week*, viewed in November 2016, http://images.spaceref.com/docs/2014/here_to_mars_Manber_Testimony_040914.pdf
- Murali, M 2014, 'Inspired from Isro's Mars mission Dhruva Space gears up for commercial launch within two years', *The Economic Times*, viewed in November 2016, <http://economictimes.indiatimes.com/news/science/inspired-from-isros-mars-mission-dhruva-space-gears-up-for-commercial-launch-within-two-years/articleshow/45354501.cms>
- Myriota n.d., *Myriota company website*, viewed in November 2016, <http://myriota.com/>
- NanoAvionics n.d., *NanoAvionics company website*, viewed in November 2016, <http://n-avionics.com/>
- Nanoracks n.d., *Nanoracks company website*, viewed in November 2016, <http://nanoracks.com/>
- NASA Safety Standard 1740.14, *Guidelines and Assessment Procedures for Limiting Orbital Debris* 1995, NASA, Office of Safety and Mission Assurance, pp. 37-38
- Nott, G 2016, 'Australia's commercial space program blasts off with Sydney start-up', *Computerworld*, viewed in November 2016, <http://www.computerworld.com.au/article/605772/australia-commercial-space-program-blasts-off-sydney-start-up/>
- NZPA 2009, 'NZ set to join the space age', *Stuff.co.nz*, viewed in November 2016, <http://www.stuff.co.nz/science/2946619/NZ-set-to-join-the-space-age>
- O3B n.d., *O3B Networks company website*, viewed in November 2016, <http://www.o3bnetworks.com/>
- OECD 2014, *The Space Economy at a Glance 2014*, OECD Publishing, viewed in October 2016, <http://dx.doi.org/10.1787/9789264217294-en>
- OmniEarth 1, ..., 18 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/omniearth.htm
- OmniEarth n.d., *OmniEarth company website*, viewed in November 2016, <http://www.omniearth.net/>
- Orbcomm FM101, ..., FM119 (OG2) n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/orbcomm-2.htm
- Orbit: Definition. Ancillary description writer's guide* 2013, NASA Global Change Master Directory, viewed in October 2016, <http://gcmd.nasa.gov/add/ancillaryguide/platforms/orbit.html>

- Overview 1 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/overview-1.htm
- Paone, M 2016, *Aerospace Clusters, World's Best Practice and Future Perspectives*, Defence SA, <http://www.defencesa.com/upload/capabilities/space/Intern%20-%20Paone,%20Matteo%20-%20Aerospace%20Clusters.pdf>
- Perry, TS 2013, 'Start-up Profile: Skybox Imaging', *IEEE Spectrum*, viewed in November 2016, <http://spectrum.ieee.org/at-work/innovation/startup-profile-skybox-imaging>
- Planet. n.d., *Planet. company website*, viewed in November 2016, <https://www.planet.com>
- PlanetiQ 1, ..., 12 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/planetiq-1.htm
- PlanetiQ n.d., *PlanetiQ company website*, viewed in November 2016, <http://www.planeti.com/>
- Pumpkin Space n.d., *Pumpkin Space company website*, viewed in November 2016, <http://www.pumpkinspace.com/>
- QB50 n.d., *QB50 project website*, viewed in November 2016, <https://www.qb50.eu/>
- Rocket Labs n.d., *Rocket Labs company website*, viewed in November 2016, <https://www.rocketlabusa.com/>
- Satellogic n.d., *Satellogic company website*, viewed in November 2016, <http://www.satellogic.com/>
- Saylor, W, Smaagard, K, Nordby, N & Barnhart, D 2007, 'New scientific capabilities enabled by autonomous constellations of smallsats', *Small satellite conference*, viewed in November 2016, <http://digitalcommons.usu.edu/smallsat/2007/all2007/14/>
- Sierra Nevada Corporation n.d., *Sierra Nevada Corporation company website*, viewed in November 2016, <http://www.sncorp.com/>
- South Australian Space Capability Directory* 2016, viewed in November 2016, <http://www.defencesa.com/upload/Space%20Capability%20Directory%20FINAL.%20V.2%20as%20at%2029%20August.pdf>
- Space Safety Magazine, *Space Economy: an Overview*, viewed in October 2016, <http://www.spacesafetymagazine.com/space-on-earth/space-economy/>
- Space Studies Board 2000, 'The role of small satellites in NASA and NOAA Earth observation programs', *National Academy Press*, Washington D.C., viewed in November 2016, http://docs.lib.noaa.gov/noaa_documents/NOAA_related_docs/small_satellites_nasa_noaa_2000.pdf
- Spaceflight n.d., *Spaceflight company website*, viewed in November 2016, <http://www.spaceflight.com/>
- SpaceQuest n.d., *SpaceQuest company website*", viewed in November 2016, <http://www.spacequest.com/>
- SpaceX n.d., *SpaceX company website*, viewed in November 2016, <http://www.spacex.com/>

- Spire n.d., *Spire company website*, viewed in November 2016, <https://spire.com/>
- Strom, M 2016, 'Solange Cunin's Quberider to send Australia's first payload to International Space Station', *The Sydney Morning Herald*, viewed in November 2016, <http://www.smh.com.au/technology/sci-tech/solange-cunins-quberider-to-send-australias-first-payload-to-international-space-station-20160504-gomog3.html>
- Supernova-Beta n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/supernova-beta.htm
- Surrey Satellite Technology n.d., *Surrey Satellite Technology company website*, viewed in November 2016, <https://www.sstl.co.uk/>
- Terra Bella n.d., *Terra Bella company website*, viewed in November 2016, <http://terrabella.google.com/>
- Terran Orbital n.d., *Terran Orbital Corporation website*, viewed in November 2016, <http://terranorbital.com/>
- The Space Foundation 2016, *The Space Report 2016 overview*, The Space Foundation, viewed in October 2016, http://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf
- The TAURI Group 2016, 'State of the Satellite Industry Report', Satellite Industry Association, viewed in November 2016, <http://www.sia.org/wp-content/uploads/2016/06/SSIR16-Pdf-Copy-for-Website-Compressed.pdf>
- Trailblazer n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/trailblazer.htm
- Triton 1, 2 n.d., *Gunter's Space Page*, viewed in November 2016, http://space.skyrocket.de/doc_sdat/triton-1.htm
- Truong, A 2013, 'Proof that cheaper satellites still can take incredibly detailed photos of Earth', *Fast Company*, <https://www.fastcompany.com/3023325/fast-feed/proof-that-cheaper-satellites-still-can-take-incredibly-detailed-photos-of-earth?partner>
- Turk, V 2015, 'We need to clear up space debris to make way for the small satellite boom', *Motherboard*, viewed in November 2016, <http://motherboard.vice.com/read/we-need-to-clear-up-space-debris-to-make-way-for-the-small-satellite-boom>
- Tyvak n.d., *Tyvak company website*, viewed in November 2016, <http://www.tyvak.com/>
- Vallado, DA 2007, *Fundamentals of astrodynamics and applications*, Microcosm Press, Hawthorne, CA, p. 31.
- Virgin Galactic n.d., *Virgin Galactic company website*, viewed in November 2016, <http://www.virgingalactic.com/>
- XpressSAR n.d., *XpressSAR company website*, viewed in November 2016, <http://www.xpresssar.com/>