Cosmonautics

The development of space-related technologies
in terms of patent activity

Europäisches Patentamt
European Patent Office
Office européen des brevets

ESPI
European Space Policy Institute

in co-operation with

esa

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Table 1:

Abbreviations

AOCS	Attitude and orbit control system
AT&R	Automation, telepresence and robotics
CAGR	Compound annual growth rate
CASC	China Aerospace Science and Technology Corporation
COTS (products)	Commercial off-the-shelf (products)
CPC	Cooperative Patent Classification[1]
B64G	Cooperative Patent Classification code for cosmonautics; vehicles or equipment[2]
EPO	European Patent Office
EPO38+	The contracting states to the European Patent Convention plus the extension states and the validation states
ESA	European Space Agency
ESPI	European Space Policy Institute
FDIR	Fault-detection, fault-isolation and recovery techniques
GEO	Geosynchronous equatorial orbit
GNC	Guidance, navigation and control
IADC	Inter-Agency Space Debris Coordination Committee
ICT	Information and communications technology
IPC	International Patent Classification[3]
LEO	Low Earth orbit
NASA	National Aeronautics and Space Administration
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
R&D	Research and development
THD	Technology Harmonisation Dossier, a series of documents developed by ESA to achieve better-co-ordinated R&D activities among all actors in the European space sector
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
WIPO	World Intellectual Property Organization

[1] https://www.cooperativepatentclassification.org/cpcSchemeAndDefinitions/table
[2] https://www.uspto.gov/web/patents/classification/cpc/html/cpc-B64G.html
[3] https://www.wipo.int/classifications/ipc/en

Table 2:

Glossary

Classification	A category in which particular types of invention are indexed.
ESA Technology Tree	Provides a classification of all technological expertise currently available in ESA for space activities and guidance on who from ESA is responsible for specific technology areas.[4]
Espacenet	Free online service from the EPO for searching patents and patent applications. Includes more than 120 million documents.
Invention	Practical embodiment which involves, requires or produces a technical effect.
Jurisdiction	A country or countries (territory) for which a patent may be granted by the corresponding intellectual property office.
Patent application	Document summarising, describing and defining the scope of an invention.
Patent family	A set of patents covering the same invention but filed at different patent offices. The family size refers to the patents included in a patent family.
Priority filing	The first-filed patent application of a family. Priority year/date, the year/date in which a first filing is filed.

[4] https://www.esa.int/About_Us/ESA_Publications/STM-277_ESA_Technology_Tree

Executive summary

Global space activity has intensified and diversified considerably over the past decade. Technological innovations are driving down the cost of access to and use of space and are enabling new missions and applications; increasingly new players and countries are becoming engaged in space; and private capital flows into the space sector are gradually growing. The space sector of today is an ever more commercially viable domain of human activity and encompasses a diverse set of public and private actors across all continents, who engage in a variety of upstream and downstream activities.

This study analyses the current dynamism of the space sector through the prism of patent filing statistics, given that patents, as a form of legal protection of technological inventions, make it possible to examine various innovation-related sectorial characteristics (regional representation, technology, player type, etc.).

A pilot effort of the European Patent Office and the European Space Policy Institute with support from the European Space Agency, this study addresses in particular the domain of cosmonautics, which is defined for the purpose of this study in line with B64G[5] of the Cooperative Patent Classification and further mapped onto the associated eight technology domains and 41 subdomains of the ESA Technology Tree.

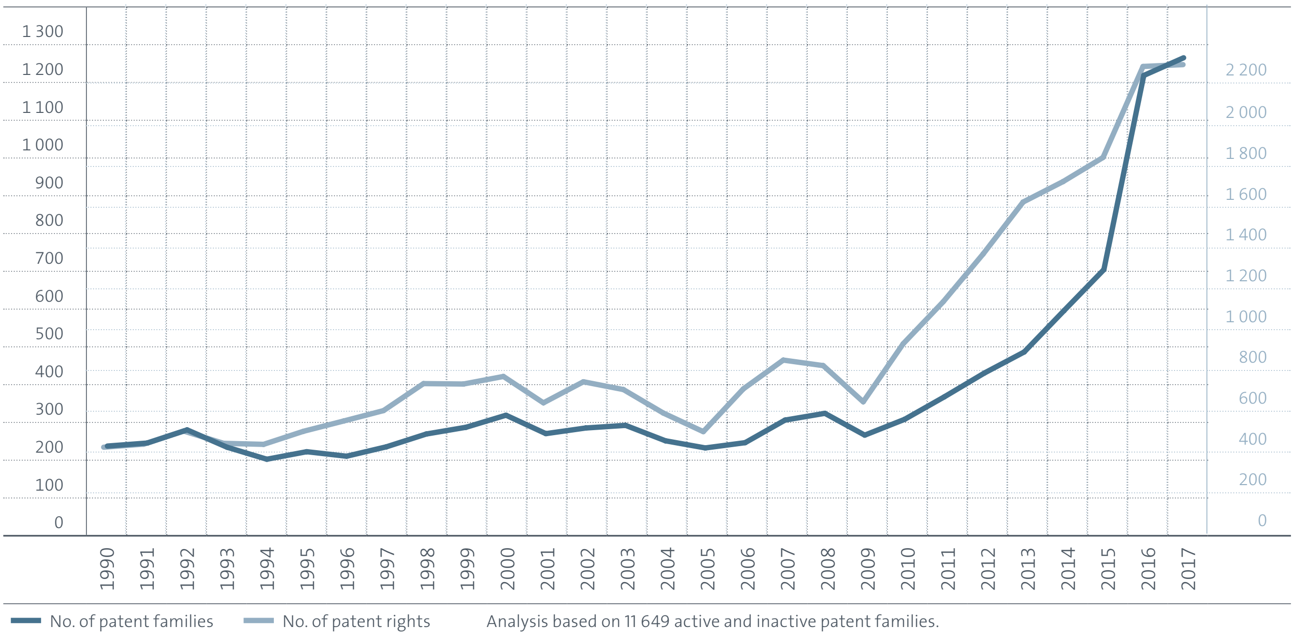
The number of patent families (inventions) in cosmonautics has grown significantly over the past decade, from about 300 to about 1200. The number of yearly space launches has multiplied to about 500 in recent years, providing evidence of the expansion of the space sector. In addition, increasing patent filing activity both in Europe and worldwide may be interpreted as an indicator of a maturing market in cosmonautics, as contributing players seek to protect their intellectual assets. These trends are observed in many other mature technologies.

Another noticeable observation explaining the increase in the number of patent applications in the past five years is filing activities originating from China, with a share of over 50% of all patent families in 2018. This is to some extent due to changes in Chinese patent policy, which greatly incentivise domestic actors to seek patent protection at an unusually high rate compared with the rest of world. This is visible in other technological and industrial sectors too. Nevertheless, the overall increase is still apparent even if the filing activity of Chinese players is not taken into consideration.

This study examines the available data, identifying close to 12 000 patent families meeting the criteria. The analytical assessment of the dataset, accompanied by desktop research on patent policy issues and space sector developments, covers overall trends, subtechnologies, country statistics and the players involved.

Figure 1:

Cosmonautics – overview of worldwide patent developments



Analysis based on 11 649 active and inactive patent families.

[5] https://www.uspto.gov/web/patents/classification/cpc/html/cpc-B64G.html. Launch systems and related technologies remain outside the scope of this study.

Overall, the study yields the following key findings:

— **Technology trends**
All eight of the examined technology domains of the ESA Technology Tree bear witness to a growing number of patent filings. The three largest technology domains, in terms of the number of patent families identified, are spacecraft electrical power, space system control and propulsion. Through a high-level assessment of technologies protected by selected patents, the study shows some technology development, such as innovations in battery technologies or increasing application types and operational uses of robotics and automation. In addition, the space debris domain is becoming a new prospective domain of inventions, invigorated by today's magnified space safety and sustainability issues. However, to provide greater insight and substantiate the deduction of technology trends in cosmonautics, further detailed analysis should focus on specific domains and their respective patent families.

— **Worldwide view**
There has been a steep worldwide increase in patenting activity in the past decade, with a distinct growth in Chinese patent filings, which for now are still filed mostly domestically. US actors lead the overall 30-year statistics from 1990 to 2020, followed by other established space-faring nations, such as China, Russia, Japan, France and Germany. There is also a visible dynamic in patent ownership. Some companies previously engaged in cosmonautics are no longer present in recent data due to their exit from the market or mergers and acquisitions. On the other hand, patent filing data highlights that there are new emerging players entering the cosmonautics field. These are either dedicated new space companies or companies from outside the space sector, which suggests a growing rate of spin-in. Statistics for academia and government actors show strong activity by Chinese institutions, but also by US, Korean, Russian, French and German ones.

— **European view**
European activity in cosmonautics appears to be rather centralised, with the main innovators in Europe generally having their place of business either in Germany or in France. Other notable countries with active players are the UK, Italy, Sweden, Spain, the Netherlands and Switzerland. Europe is an important market for foreign entities, as the data shows notable patent filing activity in Europe by US actors (32%), but also by Japanese, Korean, Russian and Canadian companies. Recent years have also seen a growth in patent filings through the EPO procedure, which facilitates the validation of patents in European Patent Organisation member states. In comparison to the worldwide view, patent filing statistics in Europe display a higher percentage of patents owned by companies (84%) and a higher ratio of patent applications to patent families.

1. Introduction

Innovation and commercialisation driving growth in the space sector[6]

The global space sector has been undergoing a structural, impactful and long-lasting transformation in the 21st century. The steep increase in the number of entities – both public and private – capable of conducting space activities has contributed to its evolution from a rather exclusive club of developed countries to a much more democratised and increasingly commercially viable domain of human activity, in which there is an increased number of diverse space actors around the world.

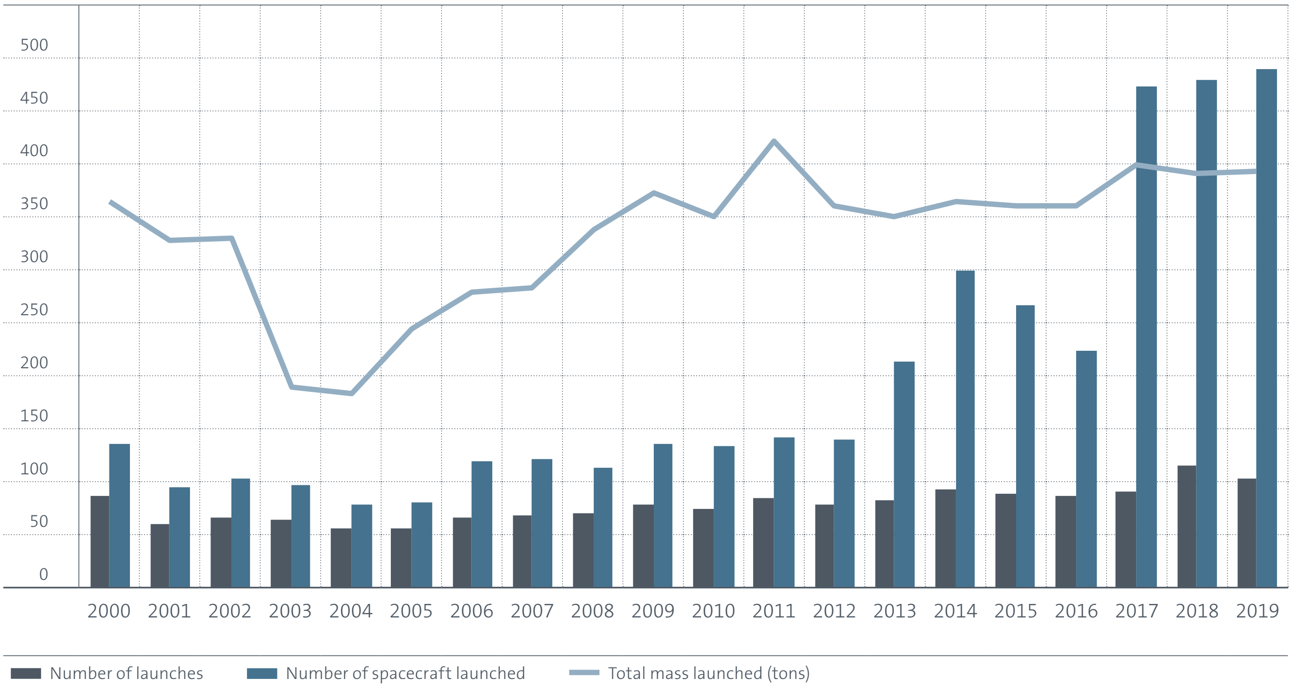
In this context, global space activity has experienced massive growth since 2013. More than 470 spacecraft were launched every year in the period 2017 to 2019, while only 110 spacecraft were launched on average per year between 2000 and 2013. As a direct result of this upsurge, the number of operating satellites has doubled in less than a decade. A major underlying factor is the increased utilisation of small and very small spacecraft, particularly CubeSats, with a mass of less than 10 kg. In future, constellations of small satellites (<500 kg) are expected to be the cornerstone of the massive growth in activity projected over the next few years.

Recent years have seen the emergence of a considerable number of new space-faring nations (i.e. countries that have developed access to space capabilities, or even have launched their first satellites). Public investment continues to represent the bulk of funding in space activities. National governments invest in space activities via procurement and grants to public agencies, research institutes, universities and the private sector in order to support a variety of objectives. While governments continue to represent the main source of funding for space, over the past few years private funding has also grown tremendously, “with unprecedented private capital flows in the space sector from angel and venture capital investments”[7].

Together with public and private investments in space activities, commercial revenues have also seen perceptible growth.

Figure 2:

Evolution of space activity since 2000 (Source: ESPI database)

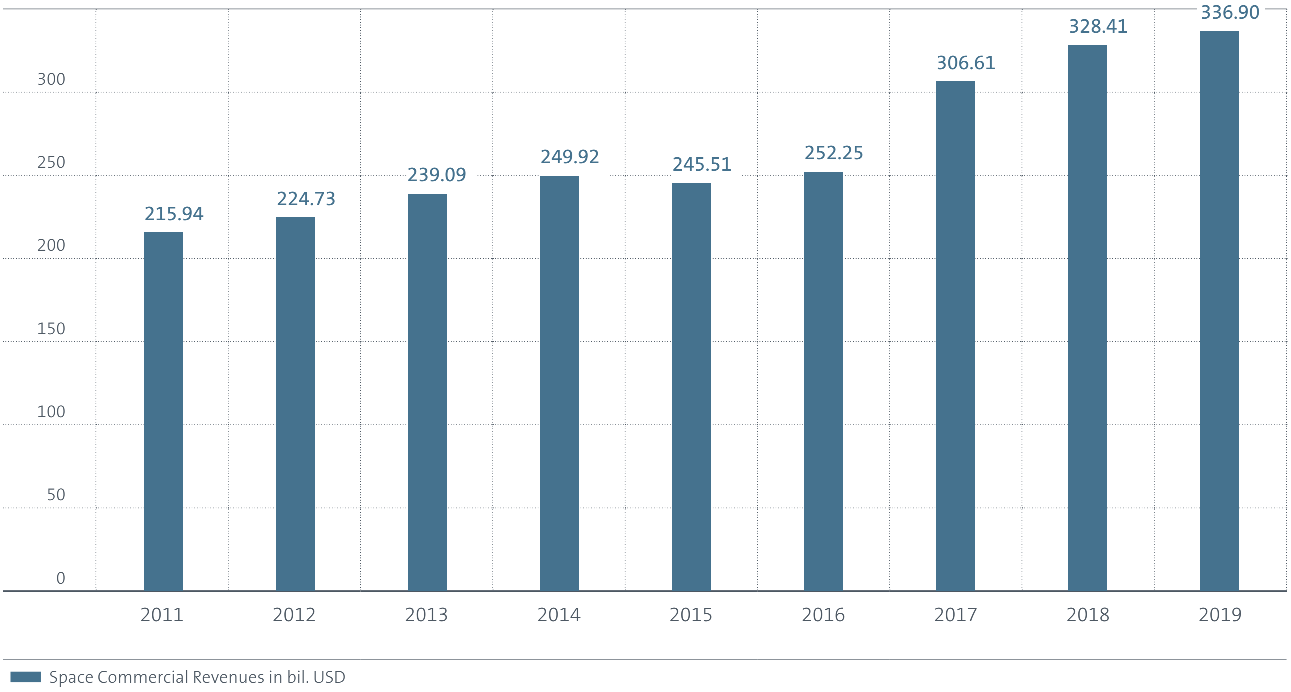


[6] This section was compiled using extracts from six recent ESPI studies, all available at www.espi.or.at:
— Executive Summary: The Rise of Private Actors in the Space Sector (published in July 2018)
— The Evolution of the Role of Space Agencies (published in October 2019)
— Towards a European Approach to Space Traffic Management (published in January 2020)
— ESPI Yearbook 2019 (published in May 2020)
— Space Venture Europe 2019: Entrepreneurship and Private Investment in the European Space Sector (published in July 2020)
— European Space Strategy in a Global Context (to be published in late 2020)

[7] https://www.oecd.org/innovation/the-space-economy-in-figures-c5996201-en.htm

Figure 3:

Commercial revenues in the space sector in billions of US dollars (Source: The Space Report)[8]



Private investment in the space sector has also experienced rapid growth to reach USD 5.7 billion in 2019, stimulated by rising interest from financial markets in new business opportunities offered by innovation and commercialisation in the sector. In this context, a significant number of companies have recently entered or emerged in the space sector, including non-space companies such as large ICT firms and new space companies or start-ups leveraging private and/or public funding to launch innovative business models and address new space markets.

The space sector is also impacted by multiple industrial and technological trends spanning across the space value chain – from production to operation and service provision to application. These trends include innovative industrial approaches with announcements and initial developments of ambitious projects based on new processes and disruptive market solutions offering, for example, integrated services, lower prices, reduced lead times, lower complexity or higher performance among other value proposition features.

The space sector is making major steps towards the globalisation, diversification, commercialisation and intensification of its activities. Various interrelated trends are at play, leading the space sector towards a more business- and innovation-oriented scenario, often referred to as New Space. In this new ecosystem, private actors are playing a more prominent role, including in public programmes, and are eager to pursue new innovation and commercialisation opportunities. The current dynamic also offers an interesting opportunity for public actors to consider more ambitious partnerships with industry and to better share costs and risks with the private sector. Fostering the emergence of more business-oriented leadership in the space sector is nowadays a dominant consideration for governments, which are increasingly eager to explore new approaches and take advantage of new possibilities for space programmes.

These trends are not expected to stop in the near future.

Patent filing statistics, an indicator of innovation and commercialisation

Patents are exclusive rights that can only be granted for technologies that are novel, inventive and industrially applicable. High-quality patents are assets which can help attract investment, secure licensing deals and provide market exclusivity. Inventors pay annual fees to maintain those patents that are of commercial value to them to protect their inventions from being openly used by others, including competitors. A patent can be maintained for a maximum of 20 years.

In exchange for these exclusive rights, all patent applications are published, revealing the technical details of the inven-

[8] Commercial revenues exclude public spending in the sector.

tions in them. Patent databases therefore contain a wealth of technical information, much of which cannot be found in any other source and which anyone can use for their own research purposes. The EPO's free Espacenet database contains more than 120 million documents from over 100 countries, and comes with a machine translation tool in 32 languages.

Patent filing statistics provide interesting indicators to measure and examine innovation, commercialisation and knowledge transfer trends in a sector. The protection of intellectual property is very well documented in national and international databases and registers, which track bibliographic and legal-event data on patent applications. Dedicated exploitations of such patent databases and registers to extract and examine patent data for different space technology fields can reveal new insights into trends in the sector and support informed decision-making processes.

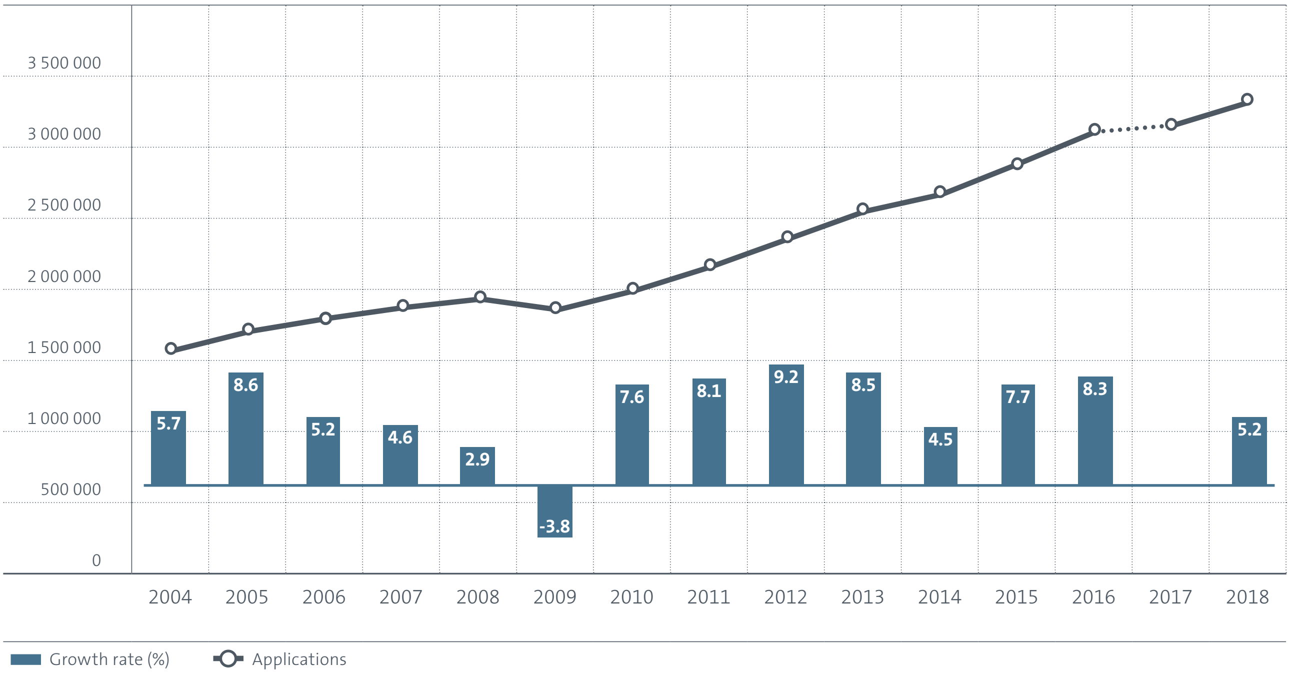
Patents provide means of observing technology trends, innovating actors and jurisdictional policies. This data can be combined with further public information such as national budgets for R&D and specific market studies. Although the individual patent strategies of inventors, companies or other entities might mean that not every invention is disclosed, the overall statistical analysis provides enough information to substantiate manifold deductions. The importance of patents is also evident from their limited lifetime and renewal fees, which are usually only considered worthwhile if a market opportunity, technology monopoly or business case is deemed likely.

On a global scale, patent filing activity has been steadily growing in recent years, providing evidence of a continuous globalisation of the world economy and also indicating which fields of technology are currently the most innovative. According to WIPO data, overall there were 3.3 million patent applications worldwide in 2018, up 5.2% on the previous year. This was the ninth straight yearly increase.[9]

Asia has continued to outpace other regions in filing activity for patents,[10] driven largely by the activity of Chinese players, while the USA has maintained its primacy in patent applications filed in export markets.[11] Europe accounts for over half of the top 20 countries of origin,[12] and computer technology, electrical machinery, digital communication, measurement technology and medical technology have been the most frequently featured technologies in patent applications.[13]

Figure 4:

Growth of patent filing activity worldwide. Source: WIPO Statistics Report, Aug. 2019



[9] https://www.wipo.int/pressroom/en/articles/2019/article_0012.html

[10] The increase in patent filing does not automatically mean new patent rights – patent filings initiate an evaluation process which may or may not lead to the granting of a patent right. Nevertheless, patents granted are also on the rise – the estimated number of patents in force was 8.5 million in 2008 and reached 13.7 million in 2017 (https://www.iam-media.com/law-policy/global-patent-market-10-charts).

[11] Ibid.

[12] https://www.iam-media.com/law-policy/global-patent-market-10-charts

[13] Ibid.

1.1 Objective of the study

By virtue of their respective missions and activities, the European Space Agency (ESA), the European Patent Office (EPO) and the European Space Policy Institute (ESPI) share a common interest in the study of patent filing statistics to improve understanding of trends affecting the space sector.

In 2019, the ESA Technology Transfer and Patent Office, which is responsible for patenting in ESA, and the EPO, which examines European patent applications, initiated a pilot study to examine patent filing statistics over the last 30 years in cosmonautics[14] and to assess the relevance of such data to the identification of trends in the space sector. ESPI joined the pilot study in 2020 to provide independent expertise and support data analysis.

The primary objective of this study, which is based on co-operation between the EPO and ESPI, with contributions by ESA, is to examine the evolution of patent filings in the world and in Europe in order to identify major trends in selected space technology fields. For this purpose, the study uses various resources, including EPO patent databases and registers; ESPI studies and databases; the ESA Technology Tree and harmonisation dossiers; and the institutions' respective expertise and know-how.

1.2 Methodology

The information, data and analysis provided in this study are based on a dedicated exploitation of EPO patent databases and registers covering patent filings in cosmonautics since 1990. The study focuses on the evolution of the European patent landscape (patent filing activity in Europe by any actor and patent filing activity by European players), but also puts this landscape into perspective by looking at global trends.

For the purpose of the analysis, various indicators are examined and referred to using patent terminology: patent rights, patent families, filing year, priority year, authority of applicant, inventor and so on.

The creation of the structured dataset for analysis was undertaken at the EPO. To retrieve the dataset, EPO patent examiners analysed and identified 41 technology subdomains in eight technology domains of the cosmonautics part of the ESA Technology Tree, ESA STM-277, 2nd edition.[17] Their searches concentrated on the "core" of cosmonautics as well as closely associated technologies.

These technology domains were mapped onto the Cooperative Patent Classification (CPC), and specifically B64G, which classifies patents for vehicles, equipment or the like which are specially adapted for cosmonautics. This subclass does not cover vehicles and equipment applicable to both cosmonautics and aeronautics, which are covered by the appropriate aeronautical subclasses of class B64. This mapping resulted in the following eight space technology domains that are analysed in this study.

EPO / ESPI

Europäisches Patentamt
European Patent Office
Office européen des brevets

The European Patent Office examines European patent applications, enabling inventors, researchers and companies from around the world to obtain protection for their inventions in up to 44 countries. The EPO is the executive arm of the European Patent Organisation, an international organisation with 38 member states. The EPO's activities and budget are overseen by the Organisation's Administrative Council, which consists of representatives of the member states.[15]

ESPI
European Space Policy Institute

The European Space Policy Institute provides decision-makers with an informed view on mid- to long-term issues relevant to Europe's space activities. It provides recommendations, policy options and forward vision as to how Europe's engagement in space can bring maximum benefit to society. In this context, ESPI acts as an independent platform for developing positions and strategies.[16]

ESA

esa

The European Space Agency is an intergovernmental organisation with 22 member states. It is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. By co-ordinating the financial and intellectual resources of its members, it can undertake programmes and activities far beyond the scope of any single European country.

[14] According to the Cooperative Patent Classification, patents in the field of cosmonautics (B64G) relate to all transport outside the Earth's atmosphere, including satellites and interplanetary and interstellar travel.

[15] https://www.epo.org/about-us/at-a-glance.html

[16] https://espi.or.at/about-us/who-we-are

[17] Newest version (V4.0): https://esamultimedia.esa.int/multimedia/publications/STM-277/STM-277.pdf

Table 3:

Technology domain overview

Spacecraft electrical power	Power system architecture, photovoltaic generator technology, fuel cell technology, nuclear and thermo-electric power generator technologies, electro-chemical technologies for energy storage, mechanical technology for energy storage
Space system control	AOCS/GNC architecture, autonomy and FDIR, GNC technologies for entry, descent and landing, high accuracy pointing technologies, GNC technologies for cruise, rendezvous and docking of capture, AOCS/GNC optical sensors, AOCS/GNC inertial and magnetic sensors, AOCS/GNC inertial and magnetic actuators
Space debris	Ground-based radar measurements of debris and meteorites, ground-based optical measurements of debris and meteorites, in situ radar and optical measurements of debris and meteorites
Automation, telepresence and robotics	Planetary, exploration, orbital systems, manipulation systems, mobility systems
Mechanisms	Non-explosive release technologies
Propulsion	Liquid propulsion systems, solid propulsion systems, air-breathing and hybrid propulsion systems, electrostatic systems, electrothermal systems, electromagnetic systems, solar thermal propulsion systems, nuclear propulsion systems, solar sailing propulsion systems, tethered propulsion systems, new concepts, ground support equipment
Structures	Advanced tank design and verification technologies, landing attenuation technologies, habitation primary and secondary structure technologies, extravehicular activity suits, mechanical aspects
Thermal	Ablative systems, coatings and insulations, radiators

By using mainly the CPC B64G classification together with appropriate keywords, the EPO experts set up 41 search strings to be searched in professional patent databases. The results of the 41 patent searches were combined into one major dataset. While the aim of the analysis was to have a dataset corresponding highly precisely to the ESA's Technology Tree and describing the field of cosmonautics in a detailed manner, the EPO searchers used only CPC classifications to define the searches of the subdomains.

Overall, these 41 searches were translated and searched in the patent databases PatentSight by LexisNexis and Orbit Intelligence by Questel, and combined again in PatentSight, which resulted in a total of 11 649 patent families with a priority date of 1990 or later (date of search: November 2019). The results are presented in chapter 2.

1.3 Territory of the analysis

Throughout this study, "Europe" and EPO38+ refer to the territory comprising the 38 contracting states to the European Patent Convention (EPC) and the associated extension and validation states, i.e. those states which recognise patent applications filed at the EPO. We also consider "Europe" to comprise the 38 individual EPC states for the purposes of national patent filings in those states.

The Patent Cooperation Treaty (PCT) is an international treaty administered by the World Intellectual Property Organization (WIPO).[18] Applicants seeking worldwide patent protection may use the services of the EPO under the PCT. PCT applications may be filed, searched and examined at the EPO. This study counts only those PCT applications which have been processed by the EPO,[19] which are known as "Euro-PCT applications". Applications where the EPO was not the filing, searching or examining authority are not included.

As in any patent analysis there is a balance between recall (retrieving all relevant documents) and precision (excluding all irrelevant documents). When dealing with large datasets, as in this study, it is impossible to achieve 100% recall and 100% precision simultaneously despite the analyst's best efforts. Therefore, it is likely that some perhaps unexpected inclusions in and omissions from the overall cosmonautics field will occur. However, the data cleaning procedure applied has reduced the extent of these, such that the statistical significance of the results is not compromised. Further details regarding the analytical approach are provided in downloadable digital supplementary information; in annex.

18 https://www.wipo.int/pct/en

19 https://www.epo.org/applying/international.html

Figure 5:

Geographical coverage of European patents as of November 2019[20]

■ Member states (38)

- Albania
- Austria
- Belgium
- Bulgaria
- Croatia
- Cyprus
- Czech Republic
- Denmark
- Estonia
- Finland
- France
- Germany
- Greece
- Hungary
- Iceland
- Ireland
- Italy
- Latvia
- Liechtenstein
- Lithuania
- Luxembourg
- Malta
- Monaco
- Netherlands
- North Macedonia
- Norway
- Poland
- Portugal
- Romania
- San Marino
- Serbia
- Slovakia
- Slovenia
- Spain
- Sweden
- Switzerland
- Turkey
- United Kingdom

■ Extension states (2)

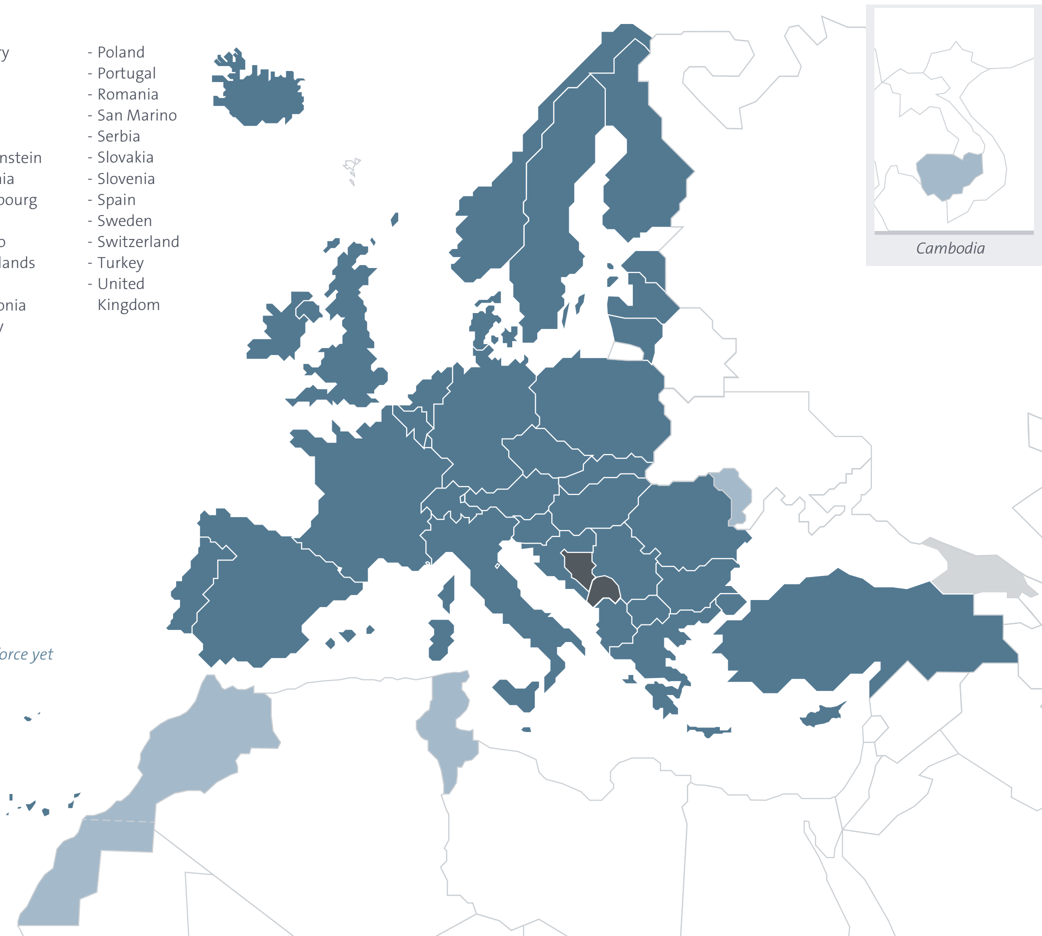
- Bosnia and Herzegovina
- Montenegro

■ Valididation states (4)
Agreement in force

- Cambodia
- Republic of Moldova
- Morocco
- Tunisia

■ Future valididation states (1)
Agreement signed but not in force yet

- Georgia



Patent filing statistics in cosmonautics are impacted by multiple factors including:

— **Patent-related factors** that pertain to different patent filing policies, processes and regulations between countries or to different IP protection strategies between inventors
— **Sector-related factors** that relate to the development of innovation and commercialisation trends in the specific technology domain

For the purpose of this study, additional steps were taken to identify, understand and isolate patent-related factors in order to focus on sector-related trends. However, the impact of patent-related factors is discussed whenever relevant.

[20] http://documents.epo.org/projects/babylon/eponet.nsf/0/8C003885190F73D2C1257EEE002E4EBB/$File/EPO-coverage_of_european_patents_map_as_of_1.11.2019_en.png

2. Analysis, results and discussion

To investigate the patent landscape, the retrieved dataset as a whole was examined with regard to overall trends, technology domains, country statistics and owner types. Throughout the analysis, major observations and remarks are highlighted. When deemed appropriate, the analysts have derived additional conclusions from the dataset. Each section provides a bottom line that is aimed at providing conclusions on the basis of the findings from a European perspective. We consider the terms “patent families” and “patent rights” to be equivalent and interchangeable.

2.1 Overall trends

Global space activity has experienced massive growth since 2013. Globally, the intensity of patent filings in cosmonautics has also been growing dramatically over the past decade, a trend observed for many other technologies. Figure 6 and Figure 7 display the overall trend in terms of the number of patent applications and number of patent rights worldwide and in Europe over the past 30 years.

Figure 6:

Cosmonautics – worldwide patent filing developments

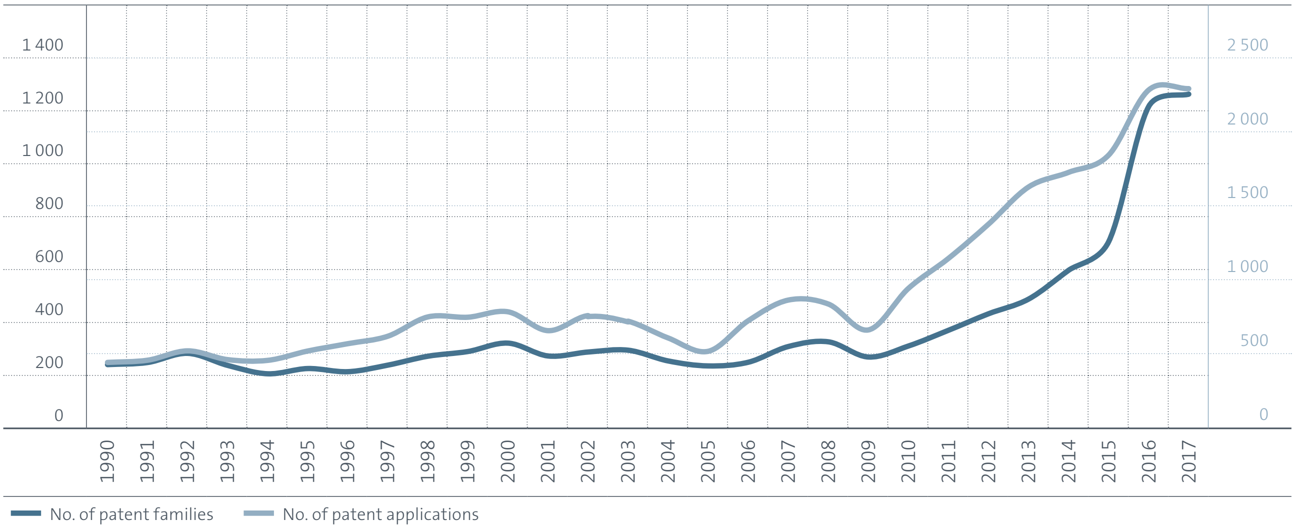


Figure 7:

Cosmonautics – developments in patents filed in the EPO 38+, not limited to appl. from Europe

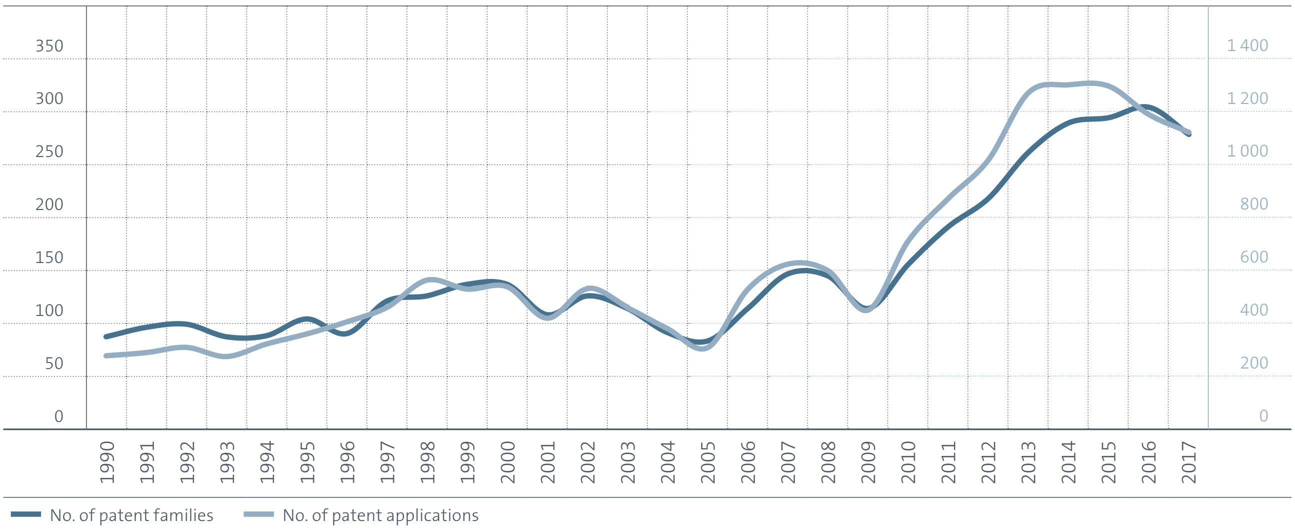


Figure 6 and Figure 7 show an increase in the number of patent applications and patent rights from 1900 up to the present. A steep decrease is evident from 2015 onwards. This decrease could potentially raise concerns of a decrease in R&D in cosmonautics. The present study is based on the analysis of patent publications – invariably published patent applications. Data from the last two years is necessarily incomplete because of the delay between patent filings and patent publications – a minimum of 18 months. The data-gathering for the present study was concluded at the end of 2019. Further major observations and additional analysis are summarised in the following table.

Table 4:

Observations for overall trends

Observations	Additional and explanatory remarks
The overall trends for cosmonautics patent filings worldwide and in Europe appear similar.	Comparable overall trends suggest that European developments mirror worldwide developments. Of the almost 12 000 patent families assessed, Figure 7 focuses on families (inventions) in the EPO38+ states. It covers 4 100 families, which constitutes more than one third of the total worldwide figure.
Both European and worldwide patent filing trends over the past 30 years can be broken down into: — a linear-like increasing trend from 1990 to 2000 — an unstable, overall stagnating trend from 2000 to 2010 — a steep increase in patent filings since 2011 There were three noticeable decreases in patent filings between 2000 and 2010, both worldwide and in Europe.	The first decade of the 21st century was a rather turbulent period bringing an end to two decades of growth, and featured distinctive periods with downward trends in terms of patent filings. The reasons for this are complex, but it can be noted that downward trends correlate to global periods of recession and to decreasing trends in many nations› space R&D budgets between 2000 and 2005.[21] The increase from 2011 can be correlated with increasing activity in the space market in general.
While the recent dramatic increase in patent filings from 2011 onwards is visible both worldwide and in Europe, the rate of this increase is notably higher worldwide: — 13.27% CAGR in 2010-2016 worldwide — 7.11% CAGR in 2010-2016 in Europe	The higher rate of the recent increase in cosmonautics patent filings worldwide might suggest a slower rate of cosmonautics-related innovation in Europe. A likely explanation for the steep worldwide increase could be the recent and unparalleled growth of Chinese patenting activity, which, however, is mostly domestic – Chinese actors pursue patent protection more actively in China and do not engage in comparable activities in foreign markets. Further remarks regarding Chinese patent activity are set out in section 2.2.
The ratio of patent applications to patent rights is distinctly higher in the European patent filing statistics.	The most probable explanation for the difference in this ratio between the worldwide and European statistics is the particular approach of Chinese players. Only a small fraction of patent filings originating in China (roughly 5%) are filed outside China. This means that more than 2 100 inventions with just a single patent right (in China) are included in the worldwide dataset (11 649 patent families) but not in the European one (4 249 patent families). The European statistics thus display a higher ratio of patent applications to patent rights. Further remarks regarding Chinese patent activity are set out in section 2.2.

Bottom line for Europe:

— Having undergone a turbulent, overall stagnating period in the first decade of the 21st century, cosmonautics has since experienced significant growth in patenting activity, with a noticeable upsurge in the last five years.
— The intensity of patent activity in cosmonautics has been growing dramatically recently, and Europe has been a part of this overall trend.
— For Europe's space industry, the overall trend indicates that the European space market has matured accordingly and is perceived as relevant.
— Lastly, while the European statistics show on average a higher number of patent rights per patent family, this relates to the interests of actors seeking patent protection in opting for protection in multiple European countries.

[21] OECD (2007) The Space Economy at a Glance 2007, OECD Publishing, Paris, https://doi.org/10.1787/9789264040847-en

2.2 Country statistics

The filtering and analysis of patent data by country provides a better picture of national activity in cosmonautics. In addition, patent analysis by country can indicate national patent and market policies. It could be combined with further information – national R&D budgets and industry development – to provide an in-depth analysis of a country of interest. However, the findings presented here are concerned with more general observations which are applicable worldwide or in the EPO38+.

The pie charts below show the distribution of filings by the inventor's country of origin. The data provides a snapshot of countries' activity on the worldwide stage. It also provides an idea of the nations that regard the European market as having business potential and capable competitors in cosmonautics.

Of the 11 649 patent families in the overall dataset, 4 246 are applicable to filings in Europe. The main observations and additional analysis are provided in Table 5.

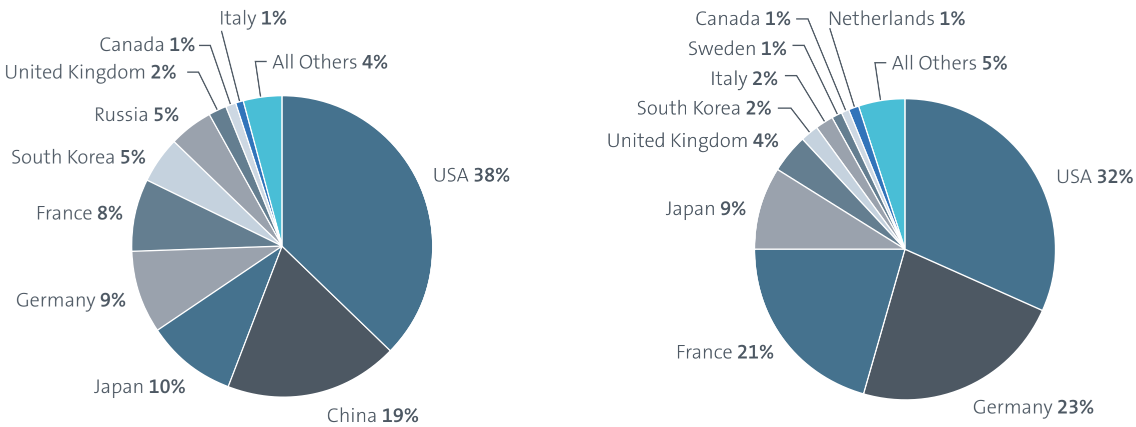
Table 5:

Observations for national filing activity

Observations	Additional and explanatory remarks
Most patenting activity worldwide over the past 30 years comes from US actors.	The USA has long been the most prominent actor in the global space sector with the highest annual public space budget – its civil portion tops USD 20 billion – and a thriving ecosystem of private space industry serving public needs or providing commercially viable services on the open market, either in the USA or abroad.
Of the European actors, German and French entities are clearly the most active in terms of cosmonautics patents.	The cosmonautics patent filing statistics in Europe remain unsurprising – the two European countries with the highest space budgets are also those making up the majority of Europe-based patent filings in cosmonautics. Cosmonautics patent filings appear to occur to a significantly lesser extent in other major European space-faring countries, such as Italy and Spain.
The EPO38+ data also provides evidence of significant US patenting activity in Europe. Chinese actors, by contrast, do not file a noticeable amount of cosmonautics patent applications in Europe.	These figures relating to US and Chinese activity in Europe seem to show different patent-related strategies of US and Chinese actors when it comes to Europe. The significant presence of US actors in European patent filings suggests that European markets are highly valuable for US space entities.

Figure 8:

Filing activity by inventor's country of origin, worldwide vs EPO38+



Additional remarks for China

This study consistently shows that Chinese entities have a presence in worldwide filings, and in some fields their activity is exceptionally high.

The Chinese government adopted intensive innovation support policies over the decades up to the day of the study. There are considerable and growing numbers of patent and related IP applications filed at the China National Intellectual Property Administration (CNIPA).[22] These patent applications cover all of the patentable technologies under the International Patent Classification (IPC), and consequently contribute a huge number of Chinese patent applications to the prior art. The “China phenomenon” is therefore observed in all patent landscape studies, and not just those in space technology. However, the vast majority of patent applications at CNIPA are national filings with no other international family members.

This can be seen in the number of cosmonautics patent applications worldwide, as shown in Figure 9.
For cosmonautics, the number of patent families filed in and only in China has been steadily increasing since 2011, and has recently been doing so at a very high rate. They accounted for more than 50% of all families in 2018. However, only approximately 5% of patent families originating in China are also protected in other jurisdictions.

Figure 9:

Number of patent applications worldwide, 2008-2017

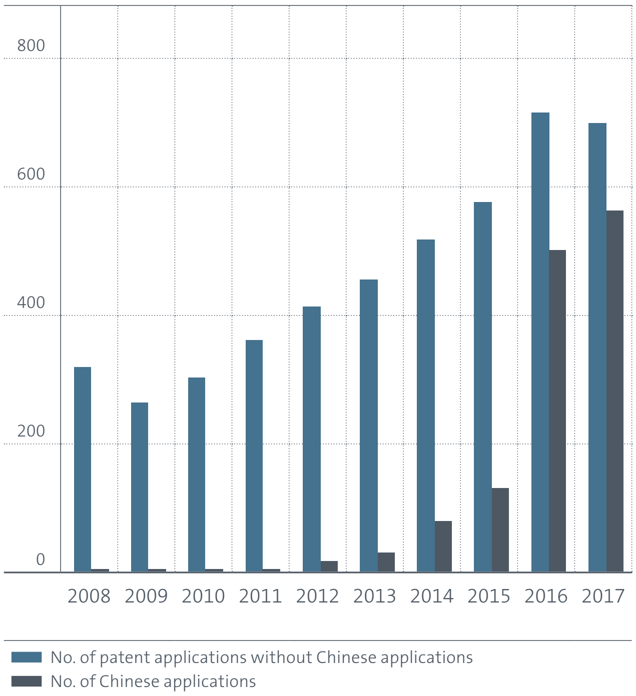
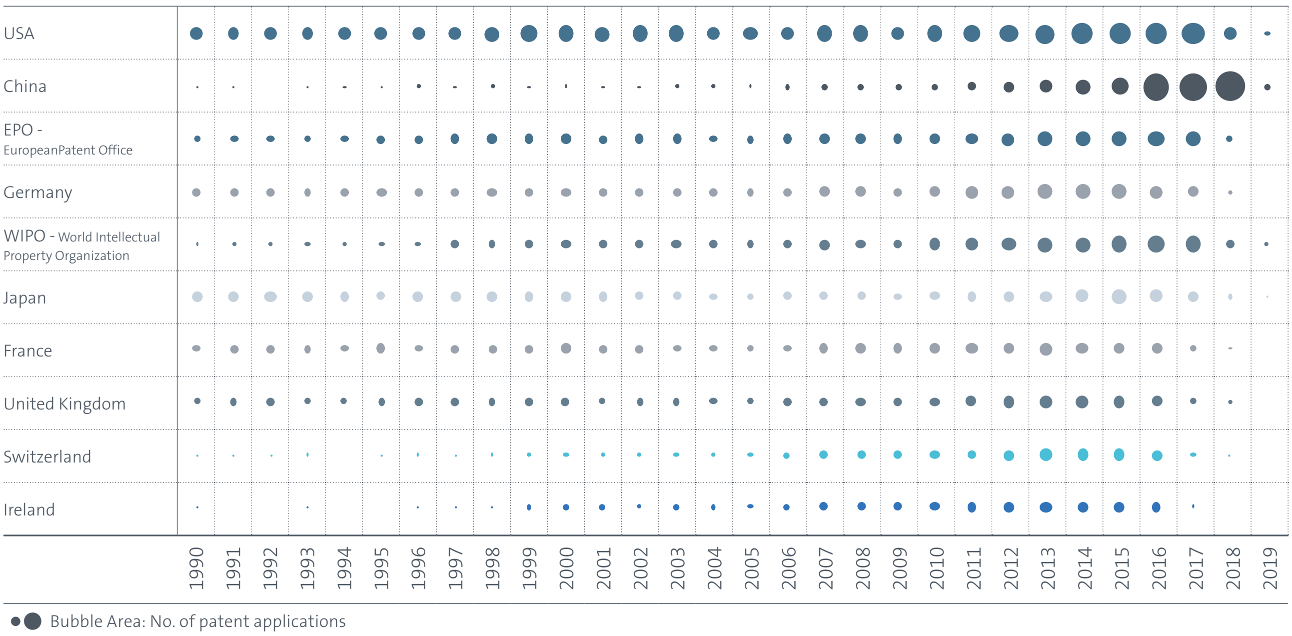


Figure 10:

Cosmonautics – worldwide filing development by patent authority



[22] https://chinapower.csis.org/patents/

Figure 11:

Cosmonautics – development of filings at European authorities

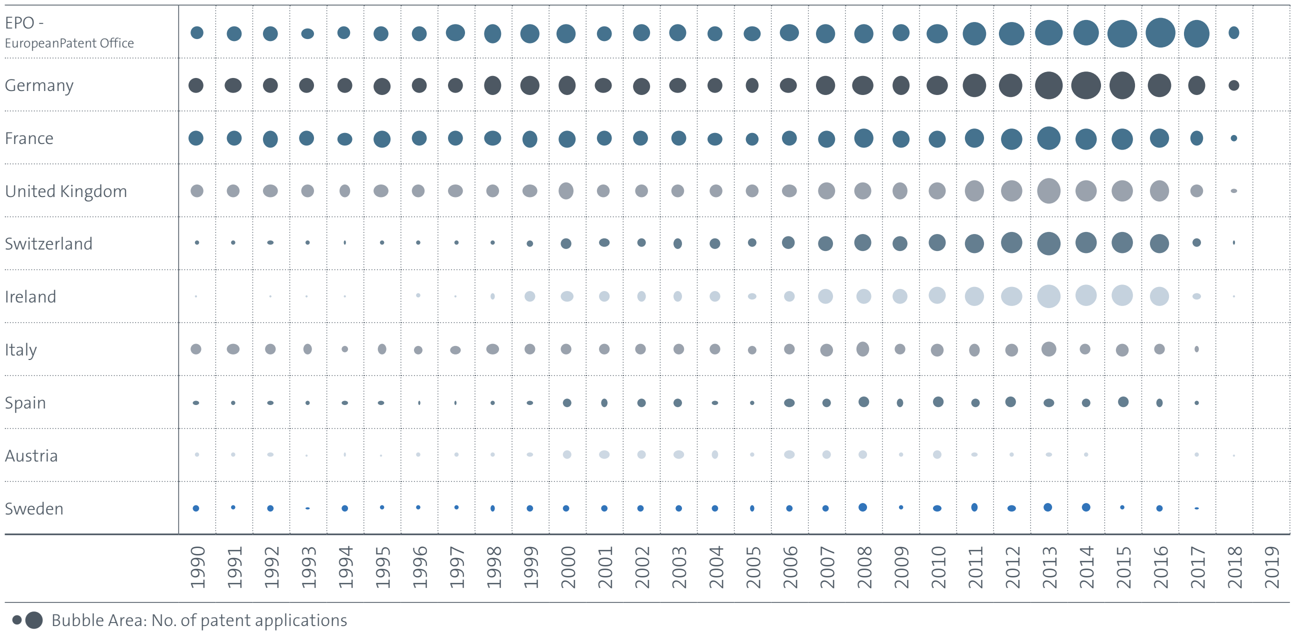
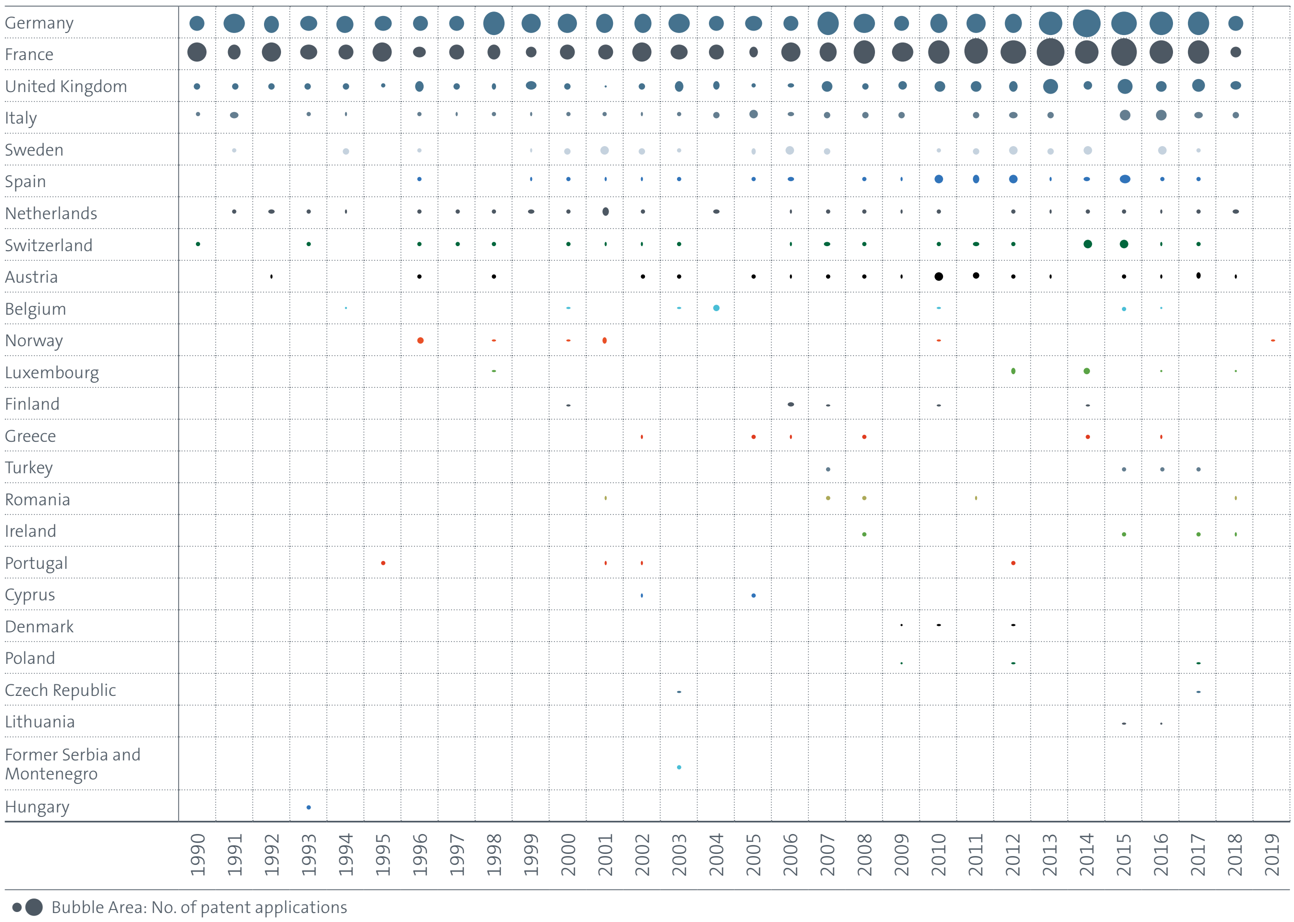


Figure 12:

Cosmonautics – development of filings from EPO38+ by country of applicant



Major observations and additional analysis

Table 6:

Observations for national filing developments

Observations	Additional and explanatory remarks
There has been a steep increase in Chinese patenting activity recently, and in annual statistics the number of patent filings by Chinese actors has surpassed US patent filings.	The recent dramatic increase in patent filings by China has made it number 2 in total patent filings in cosmonautics. The steep increase in patent filings originating in China is not an isolated trend for cosmonautics or the space sector at large, but visible in other technology fields too. In 2018, according to WIPO, China accounted for nearly half of global patent filings with a record 1.54 million applications. Most were in telecommunications and computer technology.
The number of EPO and WIPO patent filings has also grown recently, though not as steeply as patenting activity in China.	The growth of patent filing activity with international authorities suggests the growing importance that actors place on transnational patent protection and facilitated nationalisation of patents.
Patenting activity from the EPO38+ is produced almost exclusively by the 22 ESA member states, with only one visible exception: Turkey. Turkey is 15th overall in the filings from the EPO38+.	This observation underscores the position of ESA in the European space sector; ESA remains an exclusive club of European nations spurring innovation and development in cosmonautics.
The figures on filings worldwide and in the EPO38+ show rather high positions for Switzerland and Ireland, which are countries not particularly known for a robust space sector. In data on filings from the EPO38+, the position of Switzerland and Ireland is not comparably significant.	The most likely explanation for the prominent position of Switzerland and Ireland is that they are parties to the London Agreement,[23] which obviates the need for translations following the grant of a European patent when these countries are designated. This reduced barrier facilitates designations of London Agreement states.
Besides US patenting activity in the EPO38+, Japanese, South Korean, Canadian and Russian actors are also strongly represented.	The efforts to protect cosmonautics inventions in Europe by actors from these countries presumably mean that European space markets are highly relevant targets for non-European entities. Japan displays higher patenting activity in Europe than the UK or Italy.
In the data on filings by the EPO38+, comparing the patenting activity of German and French actors highlights a relatively larger patent family sizes for France.	This finding suggests a more internationally oriented filing approach on the part of French actors. Reasons for this might be a higher number of joint applications as well as specific patent policies.

Bottom line for Europe:

— Chinese actors have greatly contributed to the recent growth in patent filing activity worldwide, but their filings are still for the most part made solely in China. This has consequences for European actors seeking to enter the market in China.
— Different actors pursue different approaches to filing in Europe – for example US, Japanese and Korean actors often seek patent protection in Europe, whereas Russian actors are not so visible in the statistics and Chinese actors are almost absent.
— Patent filings via WIPO and the EPO have grown lately, demonstrating the continuing globalisation of the sector and the importance of these international organisations in facilitating the nationalisation of patents in foreign jurisdictions.

[23] Belgium, France, Germany, Ireland, Luxembourg, Liechtenstein, Monaco, Switzerland and the United Kingdom.

2.3 Technology breakdown

Figure 13 and Figure 14 show 30 years of cosmonautics patent filing statistics worldwide and in Europe, broken down according to the following eight technology domains of the ESA Technology Tree:

— Propulsion
— Structures
— Space system control
— Mechanisms
— Spacecraft electrical power
— Thermal
— Automation, telepresence and robotics
— Space debris

In the context of the B64G cosmonautics classification, these domains represent most of the essential technologies for controlling and operating a spacecraft during its mission in the space environment. The ESA's Technology Tree consists of more than 25 domains covering the complete technical know-how for space technology development available at ESA.

Figure 13:

Development of technology domains, worldwide

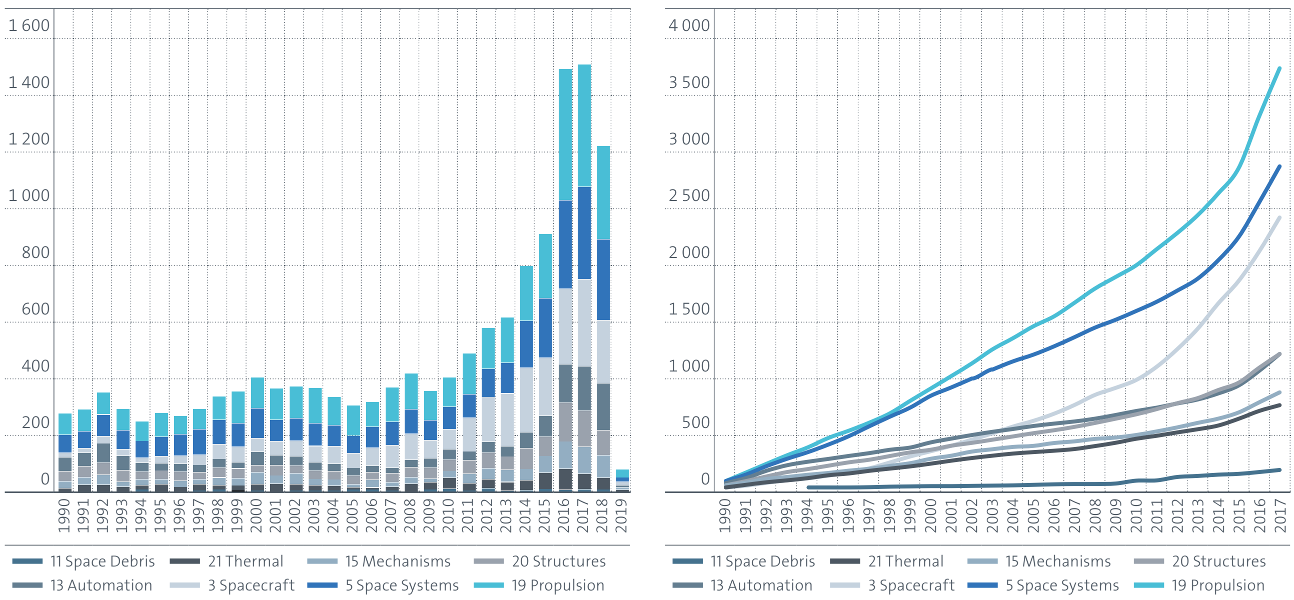
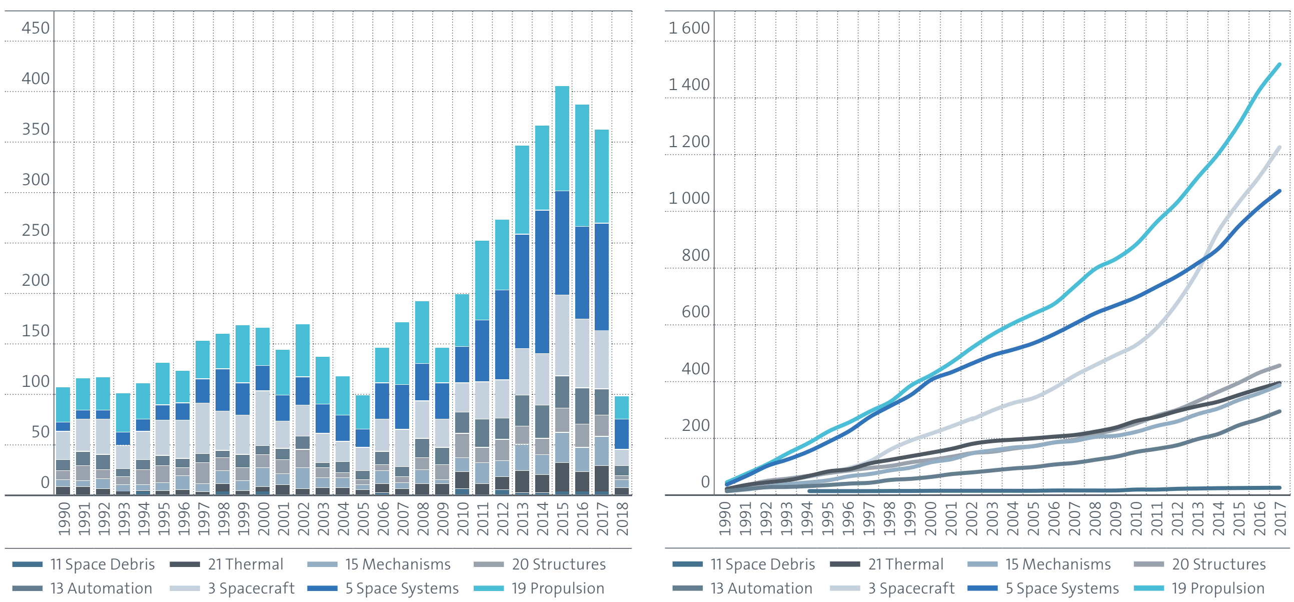


Figure 14:

Development of technology domains in EPO 38+



The figures again show the general, sharp increase after 2011, but also highlight that the largest activity worldwide comes from the propulsion domain, followed by space system control, electrical power and automation and robotics.

More detailed explanations of the underlying trends in the technology domains are provided in the following sections. Additionally, major observations and remarks are provided in the table below.

Table 7:

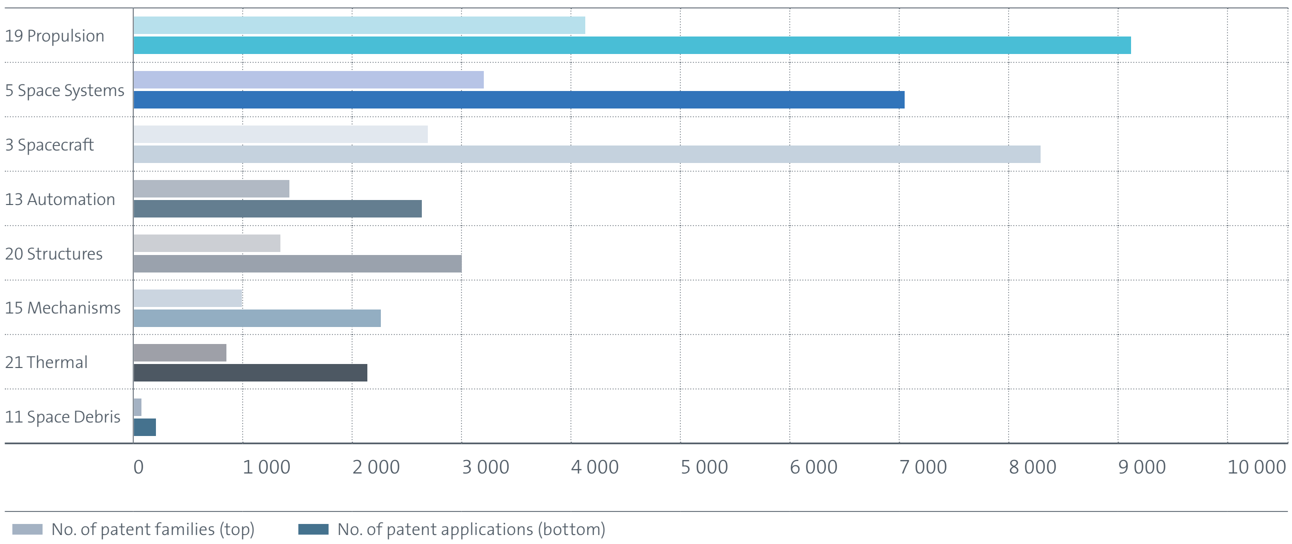
Observations for developments in cosmonautics technology domains

Observations	Additional and explanatory remarks
The average annual increase in the number of patent applications from 2006 to 2016 was higher worldwide for all eight cosmonautics technology domains analysed. While in Europe the number of applications per domain was generally two to three times higher in 2016 than in 2006, worldwide the increase per domain was generally fourfold.	Worldwide growth in patenting activity during the period 2006-2016 was greater than that in Europe. The worldwide picture is undoubtedly influenced by activity in China (see section 2.2).
There are slight differences in the European and worldwide statistics in terms of the proportional representation of each technology domain. The most noticeable differences are: slower rate of increase in the 2015-2016 period in Europe greater prominence of spacecraft electrical power and the higher rate of increase in the past few years in Europe	The rate of increase in Europe for spacecraft electrical power mirrors the steep worldwide increase. However, European patent filings in propulsion and space system control have not kept pace with worldwide ones.
Automation and structures display a very similar worldwide trend of occupying a prominent proportion of the overall figure in 1990 to 1993, followed by a lower and stagnating trend until 2015, when both witnessed significant surges in patent filings. Growth from 2015 onwards is also apparent in mechanisms and thermal.	The upward trend in patent filings is visible in each of the technology domains analysed, which suggests that recent overall growth is made up of partial growth in each domain. This trend is visible both worldwide and in Europe. However, as already mentioned, the rate of increase is generally higher in the worldwide statistics.
Space debris-related technologies have emerged and grown recently	The topics of spaceflight safety and space sustainability have been steadily growing in relevance in recent years, which has contributed to increased interest by both public and private actors in the development of technologies aimed at supporting debris monitoring, protection, mitigation and remediation. It is likely that patent activity in space debris technologies will experience noticeable growth in the next few years, fuelled by growing investment and demand worldwide.

Figure 15 provides more precision on the number of patent families and on the number of patent applications in the various domains. Throughout this analysis, patents may apply to more than one technical domain. Therefore, the absolute numbers of applications and rights should be treated with caution.

Figure 15:

Worldwide distribution and number of patent applications and families in technology domains



The following sections aim to provide further insights regarding the underlying trends in the technology domains. A short introduction to the domain is followed by highlighted observations on technology developments, the respective players and their patent activity.

2.3.1 Propulsion

The in-space propulsion system is the primary mobility system of any spacecraft. Its main function is to produce thrust to permit orbit acquisition, orbit changes, orbit maintenance, position control, station-keeping, attitude control, proximity operations, collision avoidance, disposal at end of life and deep-space manoeuvres including landing and ascent.
The ability to perform these tasks with high precision is a key requirement for deep-space exploration and scientific, Earth observation, telecommunication and navigation missions. Alongside classic chemical and electric propulsion systems, numerous concepts for advanced in-space propulsion technologies are being studied or at the research stage, such as air-breathing propulsion, hybrid propulsion, nuclear propulsion, tether and solar sail propulsion.

Finally, efforts are being made to increase the competitiveness of existing propulsion systems, to facilitate their manufacturing, to increase their production rate (industrialisation) and to reduce their cost.

Today, a large proportion of spacecraft still use only classic chemical propulsion systems, but electric propulsion systems are also widely used on geosynchronous equatorial orbit (GEO) commercial communication satellites for orbit-raising and station-keeping manoeuvres and are intended to be used on constellations of satellites in low Earth orbit (LEO) and GEO for information, telecommunication and navigation.

While interplanetary vehicles mostly use chemical systems as well, a few are using ion thrusters with success. In addition, some interplanetary mission scenarios for the Moon, Mars and outer planets are expected to require thrust systems that provide means to adjust the thrust throughout the mission duration. SmallSat and CubeSat business is expected to increase, with specific requirements for increasing the delta-v budget.[24]

For satellites operating in LEO, the development of chemical or electric propulsion systems is ongoing to enable deorbiting at end of life in addition to orbit maintenance in line with space debris mitigation regulations.

For human exploration, chemical propulsion remains the only propulsion technology capable today of producing the magnitude of thrust necessary for a human space flight. Electro-thermal and nuclear-thermal propulsion will be studied further as space colonisation is a growing field of interest.

A particular point of interest in the filing statistics (Figure 13) of this technology domain is the staggering increase of 200 protected inventions between 2015 and 2016. The increase can be observed in South Korean filing activities, notably from the Korea Aerospace Research Institute and Hanwha Corp., activities from Russia (Roscosmos and further unitary enterprises) and individual filings from companies and inventors. Other top-filing corporations during these years – with patents for technologies including turbopumps, solid rocket propellants and motors, additive manufacturing methods for propulsion components and electrically operated propellant components – are Aerojet Rocketdyne Inc., Boeing and Raytheon Technologies Corporation. Furthermore, Airbus Group increased its patent portfolio, including in joint ownership with Safran Launchers SAS and ArianeGroup, during this period. The players mentioned above filed close to 30% of the patent families between 2015 and 2016 in this domain.

In comparison to the worldwide increase, the increase in the number of European patent applications is not as high in those years. However, it remains to be seen whether increased filing internationally will be translated into (and confirmed by) national patent filings in the EPO member states in coming years.

Overall, with regard to worldwide ownership by governmental or academic entities in the propulsion domain, the data shows that large patent portfolios can be traced back to the Korea Aerospace Research Institute, DLR (in the Helmholtz Association), unitary enterprises in Russia, the Harbin Institute of Technology and NASA. However, of the top 15 government and academic players, around 40% of the filings are accounted for by Chinese filings. As Chinese filing activities have increased in recent years (see section 2.2), a high proportion of these patents are originally applied for by universities and research institutes and are subsequently transferred to China Aerospace Science and Technology Corporation (CASC).

2.3.2 Space system control

Space system control covers the technologies and methods which allow spacecraft to determine and control their attitude and orbit. With almost 7 000 patent rights found worldwide, this technology domain ranks number 3 in the cosmonautics search. The growth in the number of patent

[24] The delta-v budget provides an estimate of the total change of velocity during, for example, a satellite mission. The budget consists of the sum of all changes in velocity required for the individual mission manoeuvres.

rights has been steady over the years but, in line with the general trend, a steeper increase has been seen since 2013. The number of new filings tripled worldwide between 2013 and 2017.

The attitude and orbit control system (AOCS) provides the means to identify the orientation of a spacecraft, stabilise it, compute the necessary commands to reorient it, control its rotational state and point onboard systems in desired directions during the mission. In fact, the AOCS is essential for pointing the solar arrays, rockets and antennas, stabilising the spacecraft and telling it where to go. The determination and control of the spacecraft orbit to achieve an end orbit or position (e.g. transfer, rendezvous, repositioning and interplanetary), or to overcome a perturbation, is achieved thanks to the guidance and navigation control (GNC).

The space system control must support a variety of operational modes during the complete mission time of a spacecraft. The traditional AOCS components comprise sensors (e.g. sun/star/horizon sensors, gyroscopes, magnetometers and positioning systems), algorithms and actuators. Passive and active methods and capabilities help to stabilise the spacecraft. In addition, the AOCS/GNC interface with a large set of subsystems in an increasingly intertwined manner.

The search reveals that technologies for autonomy and fault detection, isolation and recovery (FDIR) are the most patented both worldwide (1 133 patent families were found) and in Europe (382). This is followed by optical sensors, high-accuracy pointing technologies, inertial and magnetic sensors/actuators and AOCS/GNC architecture. Patent families for cruise, rendezvous and docking or capture (657) and technologies for entry, descent and landing (437) were also part of the corresponding dataset.

In worldwide filing developments (Figure 13), a constant increase in activity is recorded between 2013 and 2016. The distribution of top company players worldwide shows that CASC has largely overtaken other players in terms of filing, with 100 more inventions than the runner-up, Airbus. Boeing, AT&T Inc.[25] and Lockheed Martin then follow. The number of CASC-owned patent families accounts for more than 25% of total families filed during this period.

In line with the general trend (see section 2.2), CASC is not found among the top filing players for Europe. Instead Airbus, Honeywell, Maxar Technologies, Thales and Boeing fill the spots for the top 5 largest patent portfolio owners in Europe.

When comparing the companies that have fewer than 500 patents in their portfolio, Maxar Technologies appears at the top of the ranking with 70 patents, due to its acquisition of the patent assets of its subsidiary Loral Space Systems. This puts it well ahead of runners-up such as RUAG Holding, OHB and Astroscale Japan in this domain, as their portfolio size is less than 10 each. The academic/governmental entities Korea Research Institute, NASA and the French Government[26] own relatively significant portfolios in this field.

Developments are driven by missions' requirements for higher performance and greater robustness of AOCS/GNC sensor and actuator hardware. Megaconstellations and telecommunications in GEO require more competitive solutions for large volumes.

Depending on the type of components and sensors used in AOCS systems and GNC software, further technology developments are expected in the future with regard to:

cost-effectiveness and miniaturisation for compatibility with the emerging CubeSat/SmallSat market
qualification lead time and processes
support for management of complex cyberphysical systems, autonomy and space robotics
digital interfaces and digital control

2.3.3 Spacecraft electrical power

This search looked at the technologies that are needed to support operation of the payload and the other subsystems. The reliability requirements in this domain are essential given the fact that this subsystem is nominally operating 24/7.

The functions that are covered under electrical power are production, conversion and storage of power, switching power, receiving commands and producing telemetry. A wide variety of technology and implementation options are available for the design of the electrical power subsystem.

To produce energy, solar arrays, are used. When a spacecraft is too far away from the sun to rely on solar energy, batteries, fuel cells, radio isotope thermal generators and nuclear reactors are used. Batteries are used to store power. A regulator will match the production of power and changing needs. Hardware (CPUs, Field Programmable Gate Arrays, DC/AC-AC/DC convertors, etc.) and software will ensure the control and distribution of power within the spacecraft.

[25] AT&T Inc., although not recently active in cosmonautics, has incorporated assets from the former Hughes Electronics Corporation (DirecTV) in its portfolio.

[26] Patents currently (co-)owned by the French Government. Almost all patents solely owned by the French Government were originally applied for by the Centre national d'études spatiales (CNES).

There has been a steep increase in filings, which is most noticeable in Europe. In terms of the number of patent families and patent applications, the family sizes are comparatively larger by a factor of three, compared with all of the other technology domains in this study.

Furthermore, 7 of the top 10 patent owners from the period of this study are automotive-related, including Nissan, Toyota and Robert Bosch GmbH. Airbus, Boeing and Thales, which are established space industry players, complete the top 10. The number of patent families filed by these latter companies over the period 2010 to 2014 remained more or less constant. In this period, the automotive-related companies showed increasing filing numbers with a strong focus on battery and fuel cell technology. Almost 90% of the patent families of Robert Bosch GmbH relate to battery technology, while fuel cell technology is addressed in 74% of Toyota's inventions in the dataset.

2.3.4 Automation, telepresence and robotics

Automation, telepresence and robotics (AT&R) have a history that is interwoven with human space exploration, enabling the execution of tasks in remote and extreme environments, such as exploration of celestial bodies, payload control and in-orbit servicing. The application and concepts of these systems are most prominent in planetary robotics and orbital robotics.

In the past, worldwide patent activities in AT&R have shown steady growth, with a notable spike in the late 1990s and a particular increase in portfolio size from 2015 onwards (see Figure 13). Ten years ago, filing activity was dominated by Canadian, US and European entities. The most active players between 2010 and 2012 included NASA, DLR, MacDonald, Dettwiler and Associates Inc. and IHI Aerospace Co., Ltd. However, the steep increase in newly filed patent families between 2015 and 2016 is mainly the result of Chinese entities, most notably Northwestern Polytechnical University and the Shanghai Aerospace System Engineering Institute. Overall, the dataset indicates that the number of Chinese filings quadrupled between 2015 and 2016 and amounted to almost 50% of the total filings in 2016. Outside of China, the US-based Boeing Co. remains the most active player with 23 patent families between 2015 and 2017.

Through its Technology Harmonisation process, ESA has identified that robotic systems for future missions and applications in planetary exploration will facilitate:

— Robot agents for the exploration of poorly reachable scientific sites (e.g. Moon pole craters). They are likely to take the form of climbing/rappelling systems (legged or wheeled) equipped with instrumented robot arms.
— Robot agents teleoperated from orbit. These are likely to take the shape of a humanoid torso placed on a mobile platform (propelled by articulated wheels); the humanoid similarity will allow scientists orbiting the explored planet to operate the agent in telepresence.
— Robot explorers for returning samples from remote celestial bodies (e.g. Mars, Deimos, asteroids). They are likely to take the form of vehicles (rovers for Mars and hoppers for low-gravity environments) with sophisticated sampling and sample-preparation tools.
— Robot explorers for carrying scientific instruments in the atmosphere and into the underground of celestial bodies. They will take the form of aerobots (balloons, gliders) and smart moles.[27]

For orbital systems, the use of AT&R technology is indispensable for the mitigation of space debris. In particular, active debris removal concepts rely on AT&R for critical tasks such as the localisation, capture and manipulation of space debris. Advanced robotic agents are likely to assist in the assembly and deployment of large modular orbital structures.

2.3.5 Structures

The function of the structure subsystem in a spacecraft is to provide a rigid framework for the payloads and spacecraft equipment during the ground, launch and in-orbit environments. Typically, the launch will impose the most severe environmental loads on the spacecraft structure through acceleration, vibration, shock and noise.

Stiffness, strength, mass and stability requirements generally drive the structural design together with accommodation constraints required by the payloads of spacecraft equipment. The need to optimise mass while meeting the stiffness, strength and environmental requirements often drives technology selection, including the choice of material.

Further to the primary and secondary structure subsystem, all payloads and hardware provide a certain structural function. Accordingly, the patent search included technologies relating to advanced tank design and verification, habitation primary and secondary structures, landing attenuation systems and mechanical aspects of extravehicular activity suits. While these do not belong to the structure subsystem, they are included in the field given their relationship with the structure function.

[27] IPC – Technology Harmonisation Advisory Group (THAG), European Space Technology Harmonisation Dossier – Automation and Robotics, 2018, available at https://tec-polaris.esa.int/

The aggregate numbers of filings, including all structure-related inventions, have risen continuously, and the worldwide statistics show that new filings doubled from 2015 to 2016 due to Airbus, Boeing, CASC-related institutes, Collins Aerospace (United Technologies) and a number of individual players. This doubling has not been seen in the European statistics yet. This seems to be related to the push for human exploration activities.

Airbus and Boeing have the highest numbers of filings and are followed by CASC, Safran and Mitsubishi Heavy. In Europe the entities that have filed most patents are Airbus, with twice as many as Safran, followed by Boeing and United Technologies. The French Government, DLR, JAXA and ESA are building portfolios in this field in Europe, whilst the top three governmental/academic patentees worldwide are NASA, the Harbin institute of Technologies (Chinese) and the CNES/French Government.

A further detailed study is still necessary to determine specific trends in different fields of application.

2.3.6 Mechanisms

In the context of the ESA's Technology Tree, mechanisms incorporates a broad field of technologies. Applicable subdomains address core technologies such as actuators, dampers and motion transformers, but also tribology, pyrotechnics and micro-/nano-technologies. In line with the CPC classification for cosmonautics, this study has opted only to evaluate patents in the domain of non-explosive release technologies, as this helps to limit the scope of analysis but also includes a natural overlap with core technologies, hold-down mechanisms and deployment mechanisms.

In general, such mechanisms are incorporated in every space mission, i.e. as hold-down and release mechanisms for solar arrays, radiators, antennas and their reflectors or for the deployment of booms and other mission-specific appendages. Separable or modular structures and robotic arms also rely on these technologies. Depending on the spacecraft and mission architecture, the mechanisms developed need to fulfil widely varying requirements in terms of total lifespan (including hibernation modes), service life, size (pointing through micro-/nano-mechanisms as well as large systems for the stable deployment of arrays) and environmental conditions faced during a spacecraft's mission.[28]
ESA's Technology Harmonisation process has identified trends towards lower shock levels for hold-down and release actuators as well as the gradual abandonment of pyrotechnic systems. This is for multiple reasons: on the one hand the increasing complexity of spacecraft, and on the other the impact of pyrotechnics regulations on spacecraft and the opportunities for substantial cost savings on the basis of avoiding safety-related costs. Developments relating to deployment hinges with damping mechanisms are expected in the future, as traditional arrangements are facing operational limitations for certain configurations.[29]

The dataset analysed shows a constant but low level of activity during the 1990s and early 2000s when compared to other domains. However, since 2011 a gradually increasing trend for filings can be observed both worldwide and in Europe. As has been mentioned, the greatest rise can be noted around 2015 and in the following years, admittedly not to as great an extent in Europe. This is partially related to the strong activity of Chinese players (see additional remarks in section 2.3), as they account for 40% of all patent families filed between 2013 and 2017. After CASC, the runner-up companies during this period include Airbus (also in joint ownership with Safran), Boeing, Maxar Technologies and Thales. Although all players incorporate mixed technologies and applications in their mechanism patent portfolio, some developments relating to (pre-) loaded hinges and springs, satellite antenna and reflector mechanisms as well as coupling and deploy mechanisms for stacked spacecraft and modules were identified in the dataset.

2.3.7 Thermal

Virtually all spacecraft, instruments and related equipment require some level of thermal control to maintain temperatures, temperature gradients and/or temperature stability within specified/acceptable ranges during all mission phases.

Temperatures result from the heat balance of a system. Depending on the requirements, thermal control is achieved by adequately taking into account the external solar, albedo and planet heat fluxes and internal dissipations, the heat rejected to the external environment such as cold space, heat transfer and heat storage. Passive and active thermal control are both used and this covers various technologies such as coatings, multi-layer insulations, heaters, heat pipes, radiators, louvres, advanced two-phase and single-phase fluid loops, heat pumps, cryogenics systems and thermal protection systems.

[28] http://www.esa.int/Enabling_Support/Space_Engineering_Technology/Making_space_systems_mobile_website_highlights_ESA_s_Mechanisms_section

[29] IPC – Technology Harmonisation Advisory Group (THAG), European Space Technology Harmonisation Dossier – Technologies for Hold Down and Release Mechanisms and Deployment Mechanisms (HDRM & DM), 2016, available at https://tec-polaris.esa.int/

Thermal control needs are very much dependent on the particular mission because they are closely linked to the environment and to the need to maintain advanced payloads at different levels of temperature, including cryogenics, depending on the application. ATHENA,[30] for instance, is a very challenging scientific mission for cryogenics, and the thermal control for JUICE,[31] another key scientific mission, manages a wide variety of environments (going beyond Venus' orbit and then 5 AU from the Sun) and limited power during colder phases. Some telecommunications missions require advanced heat transport techniques for high-power applications. Exploration missions also bring many challenges, such as the adaptation of thermal control means to demanding atmospheres and environments.

2 122 inventions are protected worldwide, of which 1 535 are protected in Europe. The growth in the number of filings over time has been slower than for other technology domains, but stable. The increase was steeper in 2015 and 2016 with Airbus, Boeing, CASC, WorldVU (OneWeb) and unitary enterprises from Russia being active during this period.

Most of the patent families in the thermal domain are found in the subcategory referred to as "radiators", followed by "coating and insulation" and "ablative systems".

The players with the largest portfolios of patents worldwide are Airbus, Boeing, Lockheed Martin, CASC and Northrop Grumman. CASC does not appear to seek protection in Europe, leaving Airbus, Boeing, Thales, Safran and Lockheed Martin in the top positions for the highest number of patents filed in Europe. NASA, the CNES, the Korea Research Institute and Unitary Enterprises Russia are the governmental or research institutes that file the most worldwide in this technical domain.

2.3.8 Space debris

The vast majority of objects currently in orbit are space debris, which, according to the Inter-Agency Space Debris Coordination Committee (IADC) definition, encompasses all non-functional man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere. Operating satellites represent only 7% of space objects larger than 10 cm and a negligible proportion of the total population of objects in space.

The increase in spaceflight and in particular the space debris environment in near-Earth orbits pose a safety hazard to operational spacecraft, hazards to human life and property on Earth and hazards in the context of the long-term sustainability of space activities. ESA's technology domain relating to space debris covers aspects concerning debris mitigation, debris environment remediation and protection, as well as modelling and risk analysis and debris and meteoroid surveillance. The inventions identified by this search only relate to the detection and surveillance of space debris. Technologies related to deorbiting, active debris removal, passivation and onboard tracking devices are not explicitly included, though the patent data shows some overlap, i.e. with the domain of AT&R.

Detection and surveillance technologies are either ground- or space-based, and utilise optical or radar measurement technology to identify, observe and track debris objects. Related developments include techniques for orbit determination, data processing and technology performance modelling.

Today, it is estimated that 34 000 objects larger than 10 cm are orbiting the Earth, along with 900 000 objects between 1 and 10 cm in size and roughly 128 million objects of between 1 mm and 1 cm.[32]

The current ground-based surveillance technologies for tracking debris in Earth orbit only allow the detection of objects larger than 2 to 10 cm. However, in orbit, impacting objects of between 1 and 10 cm can already result in a catastrophic collision releasing thousands of new pieces of debris, while impacts with sub-cm debris can be critical and result in a premature end of mission. The closure of the gap to identify and track sub-cm debris is therefore being addressed as a priority. Furthermore, developments in advanced automated collision avoidance and management of space-related traffic are expected.

This increasing safety hazard has pushed various space agencies and international organisations to develop guidelines and standards to prevent the propagation of space debris, such as the IADC Space Debris Mitigation Guidelines, which were also endorsed at UN level in 2007, or the Guidelines for the Long-term Sustainability of Outer Space Activities, which were adopted by COPUOS[33] in 2018.
Debris-related regulations and requirements will have significant impacts on the design of all future space missions operating in Earth orbit. These impacts are particularly significant for missions operating in the LEO protected region

[30] https://sci.esa.int/web/athena/-/49996-spacecraft
[31] https://sci.esa.int/web/juice/-/50069-spacecraft

[32] http://www.esa.int/Our_Activities/Operations/Space_Debris/Space_debris_by_the_numbers
[33] United Nations Committee on the Peaceful Uses of Outer Space.

(<2 000 km altitude), which will have to be designed either for controlled atmospheric re-entry, targeting a re-entry over an unpopulated area or uncontrolled reentry, allowing for disposal of the satellite in an orbit leading to a natural decay over 25 years. Such scenarios call for an evolution of current satellite platforms.

On the costs of space debris, the Organisation for Economic Co-operation and Development (OECD) has reported: "Space debris protection and mitigation measures are already costly to satellite operators, but the main risks and costs lie in the future, if the generation of debris spins out of control and renders certain orbits unusable for human activities."[34] It has further reported that, for satellites in geostationary orbit, such costs amount to an estimated 5–10% of the total mission costs, which could be hundreds of millions of dollars. In LEOs, the proportional costs per mission could be even higher than 5–10%.

To reduce the risks related to space debris for operational missions and guarantee the sustainable use of Earth orbits, a combination of innovative solutions in different complementary areas is necessary. New technologies need to be developed to respond to such needs for space surveillance and tracking capabilities, in-orbit servicing solutions, active debris removal, satellite designs and technology for enhancing end-of-life operations. Methods to mitigate the generation of space debris, such as passive deorbit systems and design for demise, are also needed.

While the number of patents filed in relation to detection and surveillance remains low, more activity has been noted since 2010. The number of filings has increased slowly but steadily since 2010. Worldwide, some 69 inventions covered by 195 patents were identified in this search. 23 inventions were protected in Europe by 138 property rights. Airbus, Safran, Thales and Boeing are the players with the most registered patents in Europe and worldwide. NASA, Roscosmos, the Korea Aerospace Research Institute and unitary enterprises in Russia also appear to be active in the field.

Bottom line for Europe:

— Propulsion remains a field of active development with recent growth in patent families and players. For the purposes of Europe's and ESA's road to independence in technology, application and access to space, this domain should be continuously monitored with caution. Furthermore, policy developments, i.e. REACH[35] for non-toxic propellants, may have an impact on future developments.
— Increasing levels of support for complex systems are steadily attributed to spacecraft system control. As a result of recent patent developments, this domain may be exposed to large amounts of prior art, which may stand in the way of future protection for European players.
— For AT&R the recent ratio of patent families from Chinese players to those from others is very imbalanced. However, most of these inventions are only protected domestically and therefore do not present a major threat in European markets. Nevertheless, the technology domain may also face increasing obstacles to future protection as a result of drastically increasing prior art.
— The automotive industry's increasing interest in electric mobility appears to be radiating into the domain of spacecraft electrical power, as a strong showing by automotive players with patents in the basic R&D of battery and fuel cell technology is noticeable. The development of this common technology interest should be monitored, as it may create opportunities for technology spin-in and spin-out in cosmonautics.
— Recently, interest in space debris mitigation applications and markets has been growing at an unprecedented pace. While the patent statistics suggest this is a new market, it is also closely connected to AT&R technology and satellite design. European players should therefore be aware of developments in multiple domains if they are seeking to do business in the context of the growing commercial exploitation of LEO. Europe has played a pioneering role in aspects such as design for demise, passivation solutions and satellite preparation for removal from orbit, as well as active debris removal (e.g. the ADRIOS mission[36]). This domain may also be impacted by future guidelines and policies regarding debris mitigation.

2.4 Player analysis

Owner-type analysis is often considered to be a measure of the degree of maturity of a technology, in that it looks at the share of patents held by academic institutions compared to those held by companies. When the share of patents held by academic institutions in a given field is low (<1-5%), this is often an indication of an established market with only company players left in competition. Fields where a high proportion (up to 50% and more) of patents are held by academic institutions are often ones in which final end-user products have not yet been developed and research is still dominant.

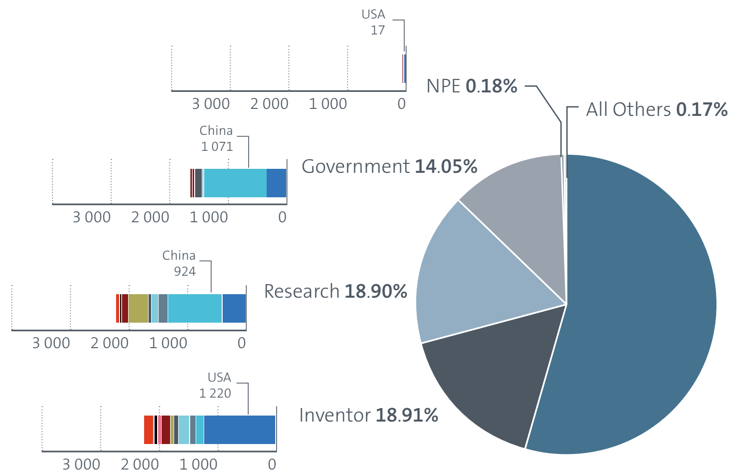
[34] Space Sustainability: The economics of space debris in perspective, OECD Science, Technology and Industry policy papers, April 2020, No. 87.
[35] https://ec.europa.eu/environment/chemicals/reach/reach_en.htm
[36] https://www.esa.int/Safety_Security/Clean_Space/ESA_commissions_world_s_first_space_debris_removal

However, in areas of significant interest to governments, there is often a higher proportion of academic or governmental players (up to 20-25% and more). This is the case with cosmonautics, even though the degree of maturity might be relatively high.

Figure 16:

Cosmonautics – applicant analysis, worldwide[37]

Type of applicant/owner, Owner Type by origin



Portfolio Size

Owner Type	Portfolio Size	Granted (share)
Company	7 271	77.1%
Inventor	2 202	63.9%
Research	2 201	70.9%
Government	1 636	70.3%
NPE	21	90.5%

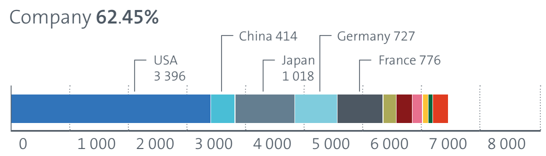
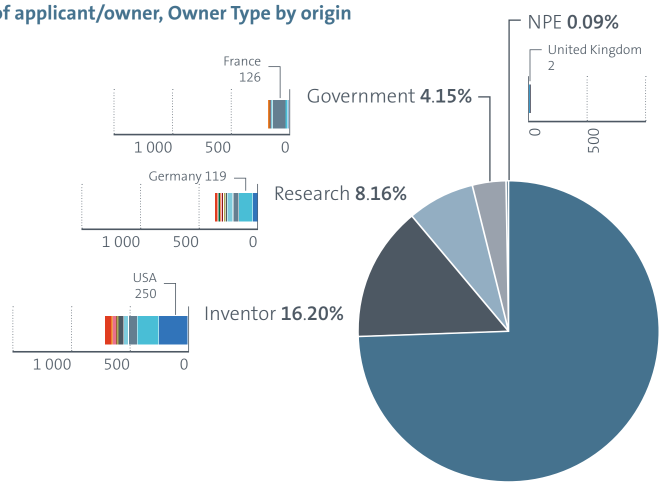


Figure 17:

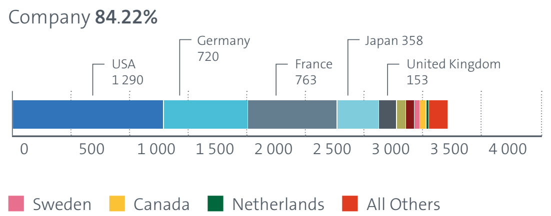
Cosmonautics – applicant analysis in EPO38+

Type of applicant/owner, Owner Type by origin



Portfolio Size

Owner Type	Portfolio Size	Granted (share)	No. of protected authorities
Company	3 613	84.6%	2.7
Inventor	695	67.9%	1.7
Research	350	75.4%	2
Government	178	94.9%	2.8
NPE	4	75.0%	0.3



[37] The term "NPE" in the figure refers to "non-practising entities".

The owner-type analysis in this study contains some particular weaknesses. In the case of Russia and China, “university” in an applicant’s name leads to its being classed as academia. State organisations such as Roscosmos are classified as a “company”. Conversely, in Europe and the USA, ESA and NASA are both classified as “research”. Elsewhere, outside Europe, government players are identified as “companies”. Individual inventors, such as academics, are treated as applicants in their own name. Owner-type analysis therefore serves only as a guide, and individual cases may require deeper investigation. Nevertheless, major observations and additional analysis are provided below.

Table 8:

Observations for applicant analysis

Observations	Additional and explanatory remarks
The worldwide and European statistics are comparable overall. The major differences are in the proportions of applicants/owners classified as a «company» or «research».	The difference is caused by Chinese patent filing activity, which is less strong in Europe. As a relatively high proportion of Chinese patents originate from academic/research institutions, «research» accounts for a higher percentage worldwide and «company» has a higher percentage in the EPO38+.
China›s extensive patenting activity worldwide is not visible in Europe. The largest proportion of Chinese applicants/owners is in the «research» category.	As set out in section 2.2, Chinese patent filing activity generally takes place domestically, and more recently also through PCT filings. Increased national funding available for basic technology research, government incentives for the filing of patent applications and the commercialisation of technology appear to facilitate the high number of research-related applicants.[40 41]
French Government patents dominate the statistics both worldwide and in the EPO38+.	The dominant position of France in government patents is likely to be due to the particular approach of French governmental actors; see section 2.4.2.
For companies, patent filings in Europe, Germany and France dominate.	This is in line with previous statistics that also highlight the dominant position of France and Germany in terms of patent filings originating in Europe. It underlines that most cosmonautics-related research and innovation in Europe stems from players based in these two countries.

Bottom line for Europe:

— There is a noticeably high number of Chinese patents that originate in academia and research institutions. Some patents are transferred to CASC afterwards. (See section 2.3.1, “Propulsion”.)
— For companies filing in Europe, the dominant positions of France and Germany are apparent. However, the approaches of German and French actors seem to differ: in the case of Germany, patents owned by the DLR are included in the “research” category, whereas inventions that are the subject of patent applications filed by the CNES are then owned by the French Government.
— There is a high percentage of company patents in Europe, which indicates a mature market for space as compared with markets with high proportions of patents owned by academia or government.

[38] https://www.researchgate.net/publication/265175931_Research_Funding_Demystifying_central_government_RD_spending_in_China

[39] https://www.swissnexchina.org/wp-content/uploads/sites/4/2014/07/Higher-Education-in-China-2014.pdf

2.4.1 Top players and smaller players

Top players

The analysis of the top players in cosmonautics worldwide results in a rather mixed collection of large international companies, governmental institutions and academic players that is shown in the following figures. The dedicated section 2.4.2 provides additional remarks in respect of academic and government-related entities.

Figure 18:

Cosmonautics – top players, worldwide

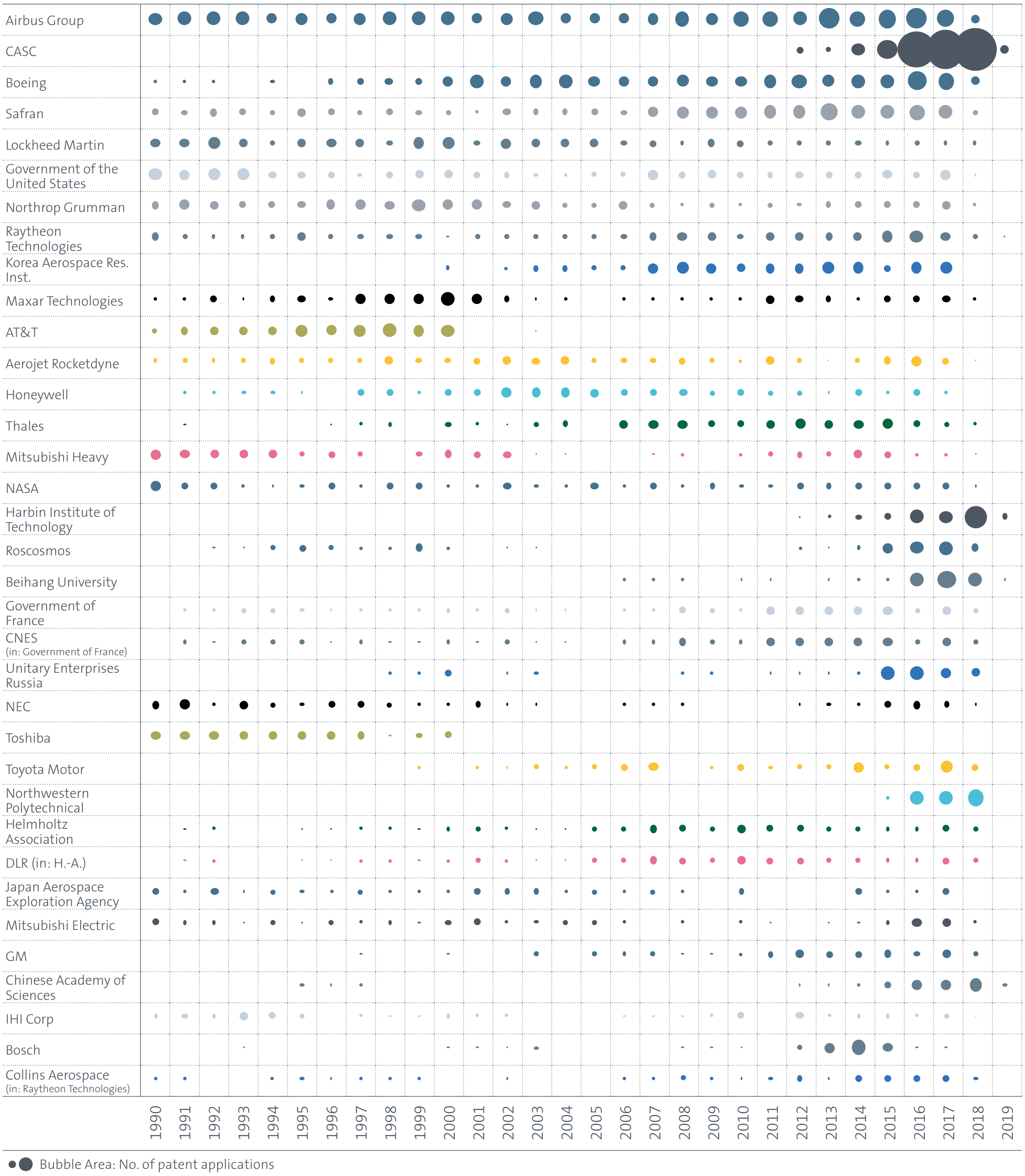
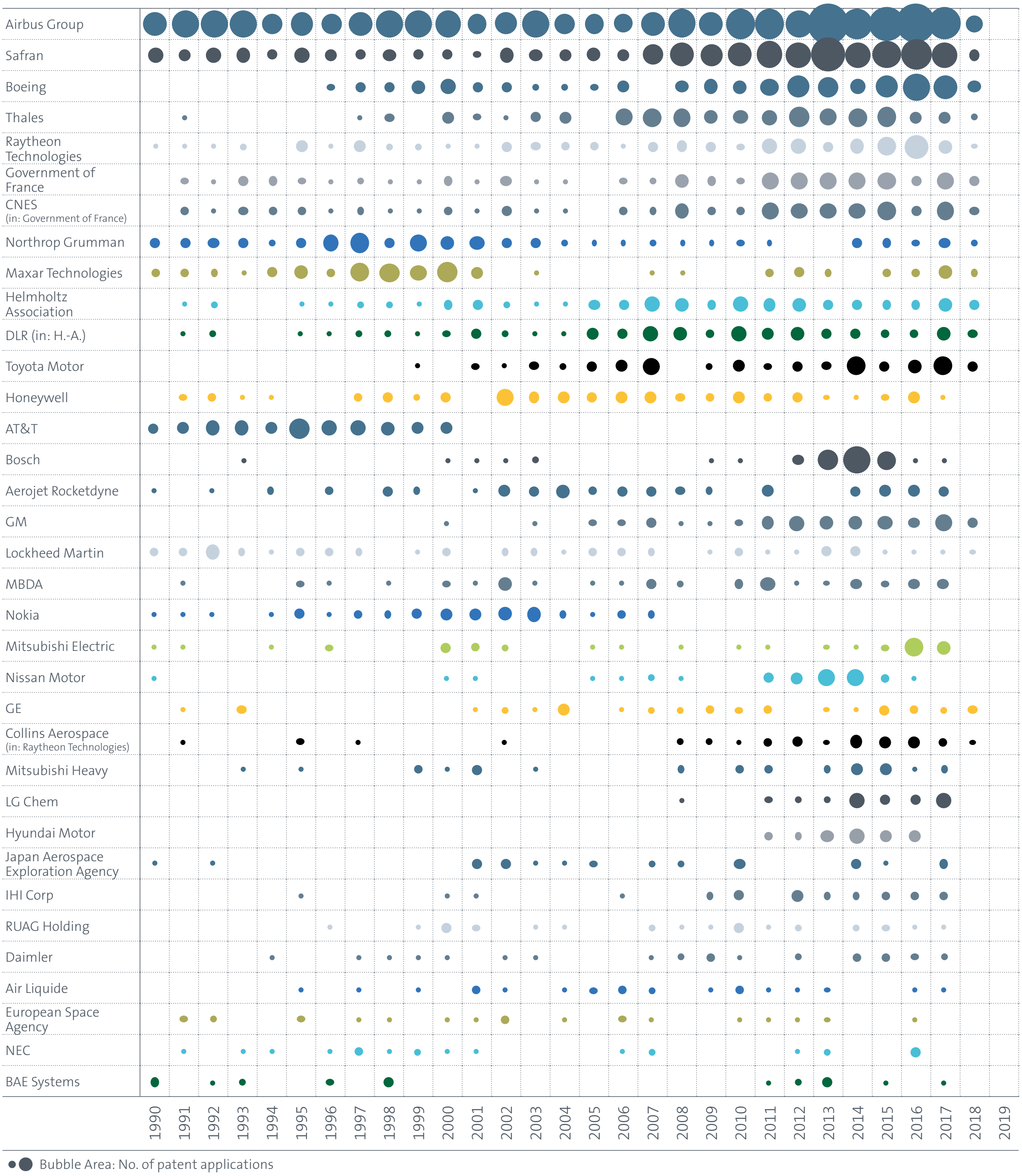


Figure 19:

Cosmonautics – top players, in EPO38+



Major observations and additional analysis for top players

Table 9:

Observations for top players

Observations	Additional and explanatory remarks
The analysis of the top players in cosmonautics worldwide results in a rather mixed collection of large international companies, governmental institutions and academic players.	In line with the previous owner-type analysis, the majority of the top players are companies. While the actors in the top 15 are mostly well-known players in the space sector, the actors lower down the top players list are increasingly companies with core businesses outside the space sector. Overall, the total number of patent filings made by these players is generally around a few dozen, which suggests that the bulk of patent activity is distributed among several main players.
In Europe, the significant patenting activity of the USA and Japan that has already been observed is evidenced by the activities of US and Japanese companies.	In fact, just 6 of the top 15 players in patent filings in Europe are based in Europe, with the rest being mainly US and Japanese companies. Their interest in filing for patent rights in Europe suggests the importance attributed to European space markets.
The statistics display some level of dynamism – some of the players have ceased their activity in the field, such as AT&T or Toshiba, while other actors have only recently started to emerge and grow, such as the Chinese players.	Actors with a core business not necessarily in the space sector are increasingly entering the cosmonautics field. Overall, the activity of Japanese applicants in Europe has been apparent mostly recently. The emergence of companies such as Bosch or Toyota in the list is due to the increasing demand for battery technology in the space environment.
The leading player worldwide is a European company – Airbus. It leads the patent filing statistics in the EPO38+ too. Recently, however, patent filings by CASC have risen dramatically, going beyond the relatively stable yearly figures of Airbus.	The state-owned CASC – the main contractor for the Chinese space programme – is by far the largest Chinese player for Chinese patent filings.

Smaller players

After the top players, which are likely to be large companies or institutions due to their resources in R&D and ability to protect and defend their inventions, an examination of smaller players shows activity in special business areas or specialised technology development. As is shown in Figure 21, this study characterises “smaller” players. Small is defined as less than 500 patent families (simple family) total portfolio size, active at the time of the analysis.

The positions of certain players and their filing dynamics may be worthy of note. Further major observations and additional analysis for smaller players are listed below.

Table 10:

Observations for smaller players

Observations	Additional and explanatory remarks
In total, the number of patent filings for smaller players remains quite low, both worldwide (4 065 patent families, 37%) and in Europe (1 294 patent families, 28%).	The majority of patenting activity in cosmonautics is undertaken by actors with large portfolio sizes. Overall, only a relatively small proportion of patents are attributed to players with 500 or fewer patents in total. Worldwide, only Maxar Technologies and Aerojet Rocketdyne are present in both the top players (Figure 18) and smaller players (Figure 21) lists.
The list of major smaller players also comprises a diverse set of actors, which are mostly companies.	Maxar, Aerojet Rocketdyne, ESA, OHB and RUAG are positioned at the top of both sets of patent filing statistics for smaller players. The European statistics unsurprisingly include a higher number of European companies. SMEs are the most numerous technology-based enterprises.
Narrowing down the focus to smaller players shows patent activity relating to some of the more recent technology trends in the space sector.	In both smaller player figures, some of the players have a narrow focus and their activity in patent filings arose recently, This highlights the technology trends that have emerged in the space sector: — Astroscale is one of the pioneering companies developing active deorbiting technologies to solve the problem of space debris. — WorldVu satellites, subsequently known as OneWeb, has been one of the first actors in the domain of LEO megaconstellations. — Shanghai Engineering Center for Microsatellites, now known as the Innovation Academy for Microsatellites of the Chinese Academy of Sciences, has worked on microsatellite research and has also been involved with the new generation of Chinese BeiDou navigation satellites.

Figure 20:

Cosmonautics – top smaller players (total No. of patent applications < 500 Patent Families), worldwide

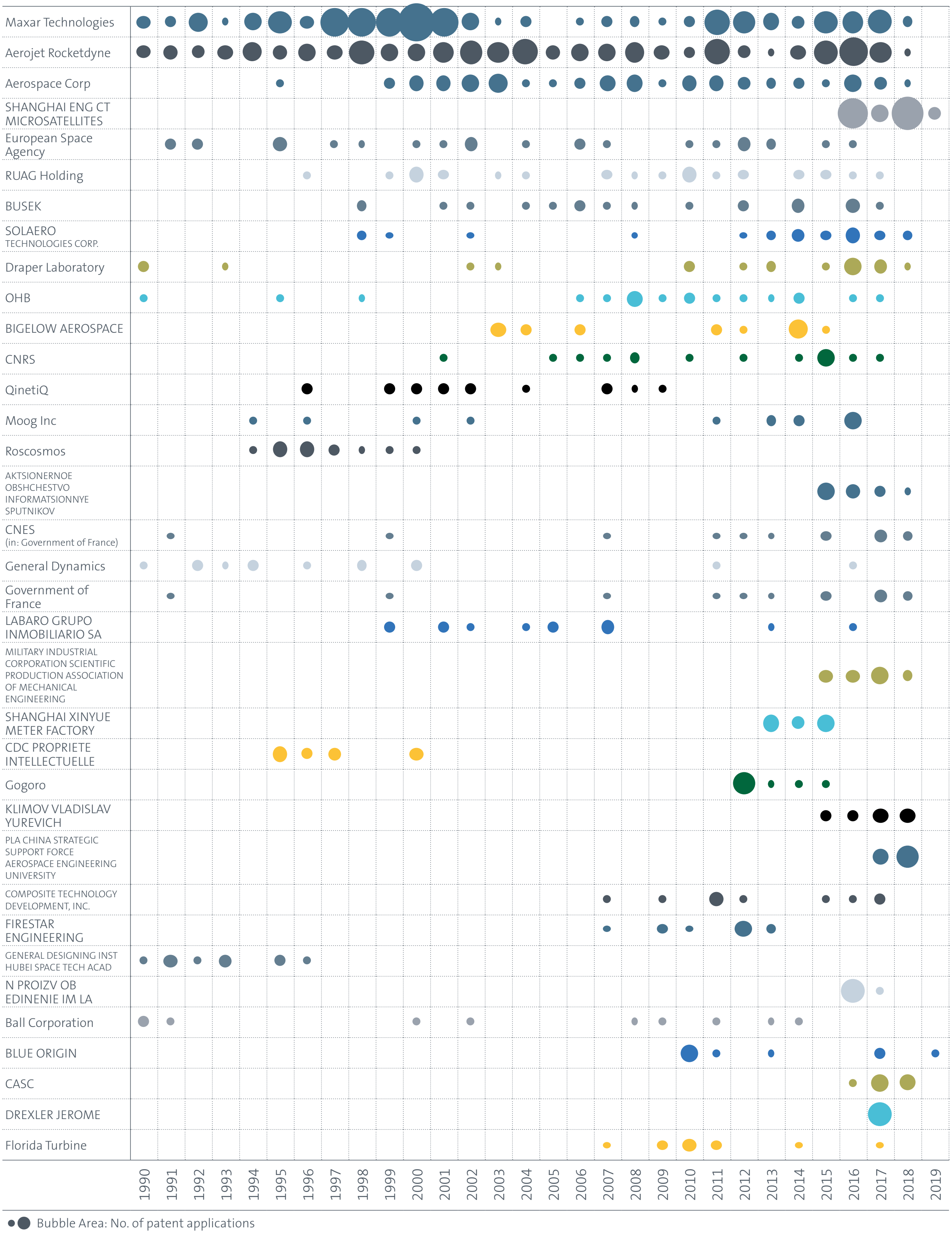
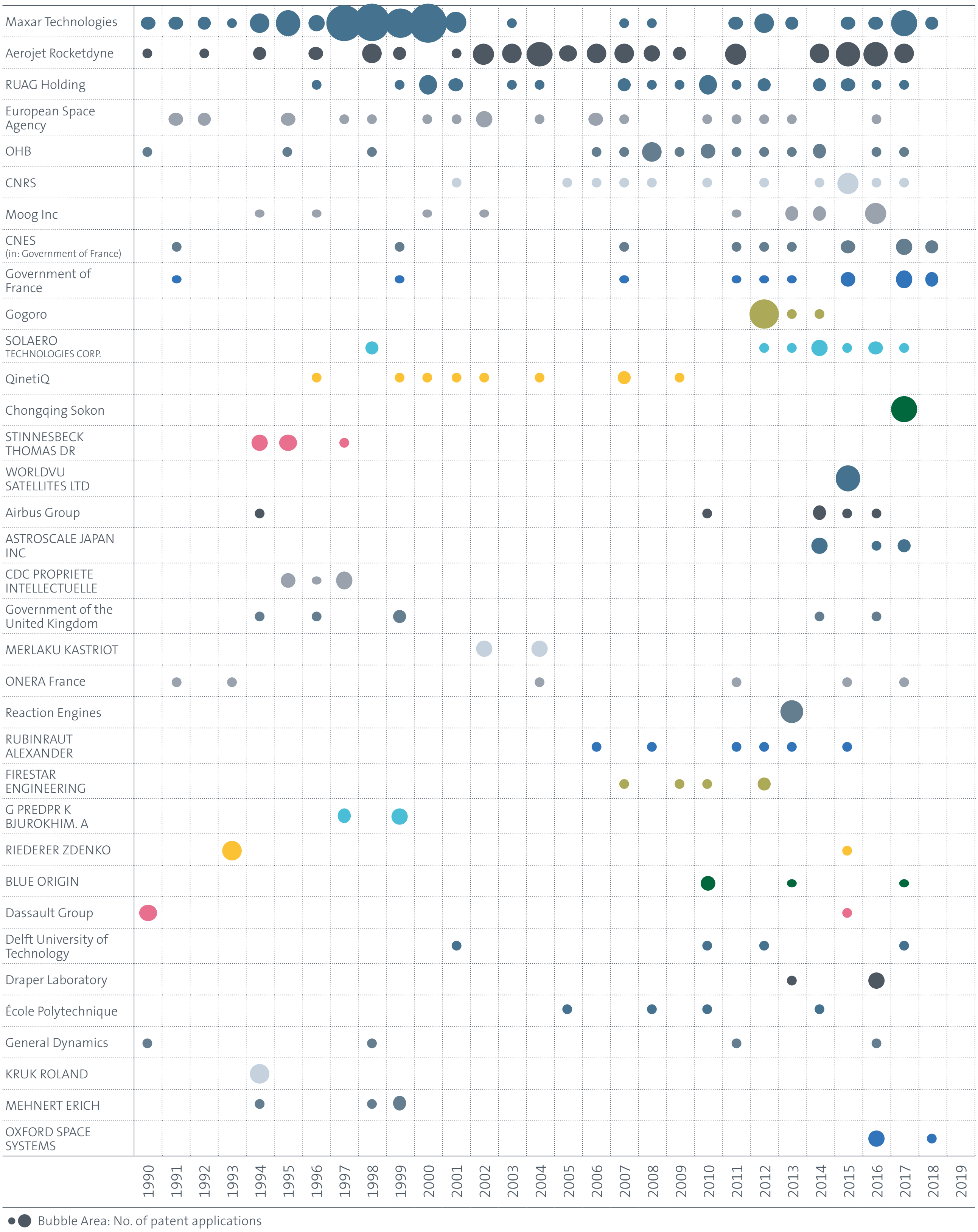


Figure 21:

Cosmonautics – top smaller players (total No. of patent families < 500), Filings in EPO38+



Bottom line for Europe:

- As can be seen from the overall trends, the European market is evidently perceived as relevant and important by non-European players.
- The overwhelming majority of patent families are concentrated in the hands of several major players: Airbus, CASC, Boeing, Safran and Lockheed Martin.
- The statistics also show an increasing rate of the phenomenon of spin-in – companies outside the space sector are entering the space field, usually leveraging expertise in a small number of technological domains.
- The dynamism and variety of smaller players suggest continuous opportunities for smaller European players, including start-ups and SMEs, to enter the cosmonautics field.
- Some smaller players can be viewed as indicators for technology trends by virtue of their patent filing. However, it is much easier to identify such trends retrospectively.

2.4.2 Academia and government

The top 20 academic and governmental players worldwide (see Figure 23) are the representatives of the major space and industrial nations, led by the USA (the US Government and Roscosmos are included as governmental players even though they are labelled as companies in PatentSight). The US Government is followed by the Korea Aerospace Research Institute, NASA (not counted as the US Government, but as an academic player) and several Chinese players. Europe is represented among the top 20 players by the French Government, the German DLR and ESA.

Bottom line for Europe:

- Academic and governmental players contribute to innovation in cosmonautics in Europe. The CNES and DLR are the major space agencies involved in patenting. To a lesser degree, ESA has also been continuously filing a certain number of patent applications every year.
- There is significant patenting activity in the non-European academic environment. In Europe, the driving forces appear to be French, German and Dutch academic institutions.

Major observations and additional analysis

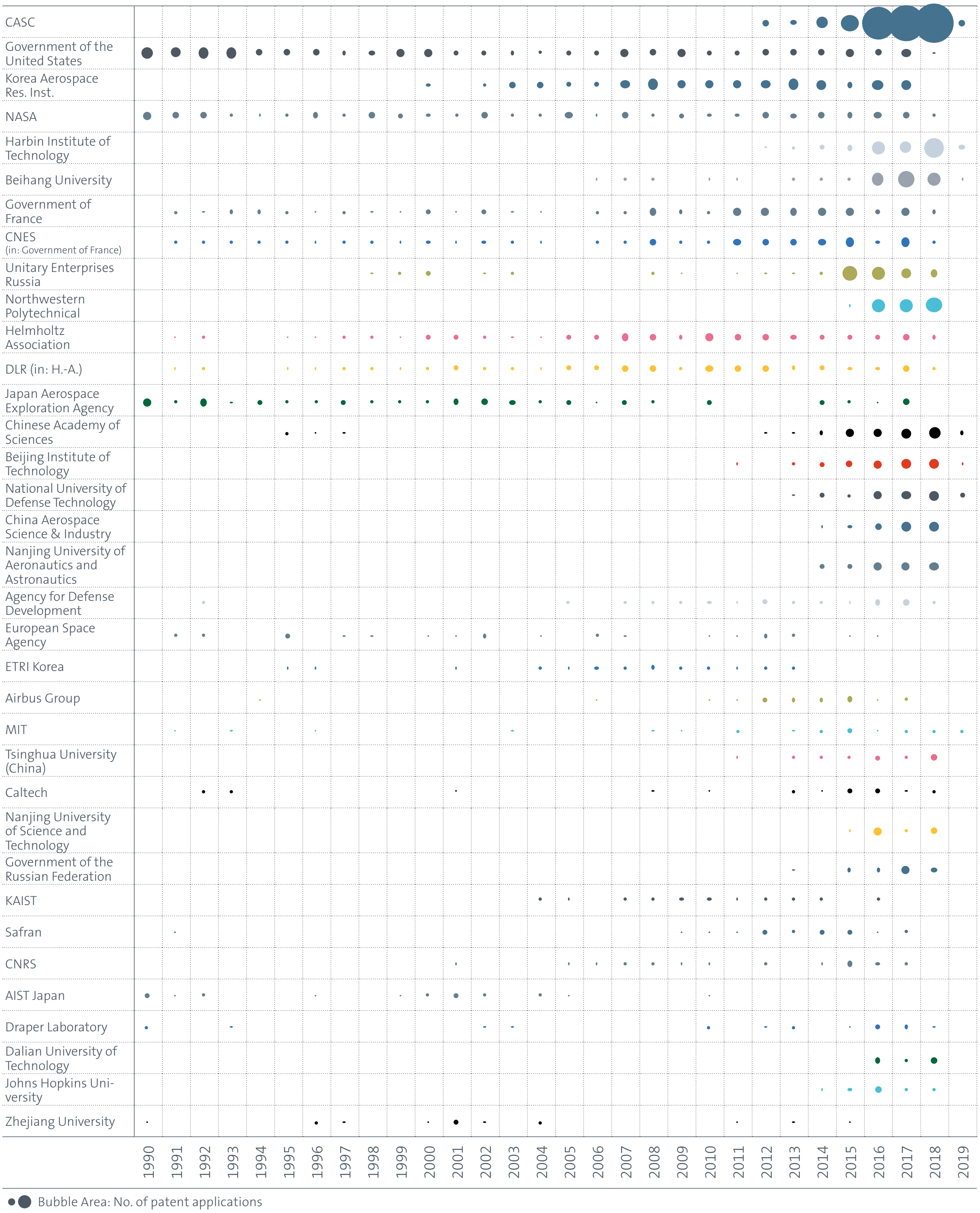
Table 11:

Observations for academic and governmental players

Observations	Additional and explanatory remarks
The major academic and governmental players worldwide come from the major space-faring nations, cumulatively led by the USA.	The other players are institutions primarily from South Korea, Russia, China and Japan. The most active European actors are French or German entities and ESA.
Recent patent activity is marked by an increase in Chinese activity, which is distributed among several actors, most of them academic.	While, from a company perspective, CASC has been the clearly dominant Chinese player, the statistics relating to Chinese governmental and academic entities seem to be more evenly distributed.
The majority of European patenting activity, in terms of both filings worldwide and those in the EPO38+, comes from French and German actors, namely the French Government and DLR.	The prominent position of the DLR, ESA and the French Government underscores the important position of space agencies in European cosmonautics R&D, as it provides evidence of their ability to spur innovation.
The French Government is often involved in joint applications.	A high-level analysis of patents involving collaboration, such as joint applications or co-ownership by government or academic players from an EPO member state and companies, academia or government players worldwide, shows quite a number of individual collaborations. The most active collaboration participant appears to be the French Government. The collaboration network in France is generally rather large, whereas there are only few collaborations by academia and governmental players in the other EPO member states.
In Europe, the patent activity of governmental and academic players is visibly dominated by European entities, contrary to the situation in the top and smaller players lists.	This finding is consistent with the argument that companies seeking patent rights in Europe do so for market-related reasons, which are generally not of interest to academic and governmental entities.

Figure 22:

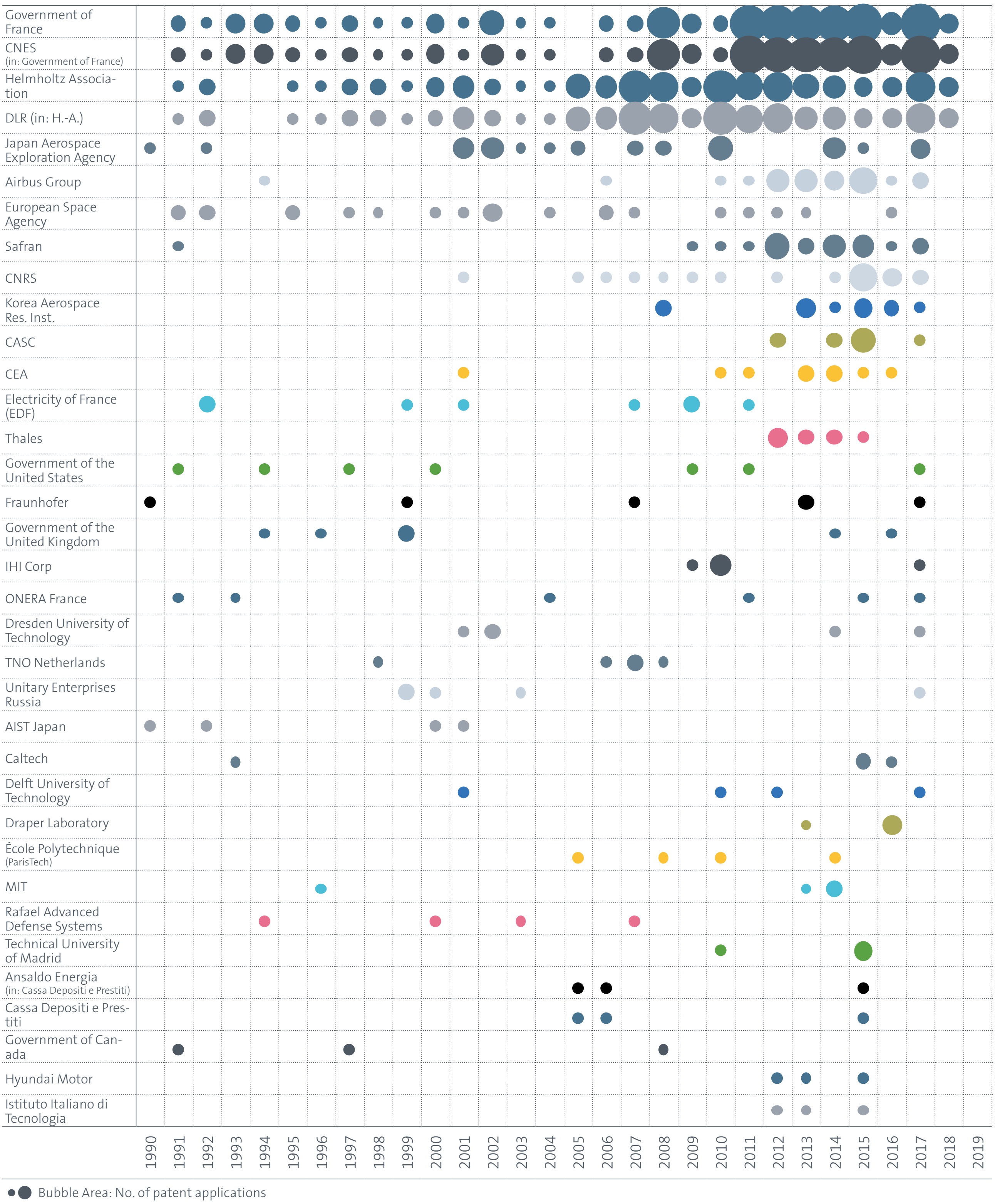
Cosmonautics – top players from academia and government, filings worldwide



For the filings undertaken in the EPO38+ the landscape changes, with higher numbers for French and German players (see Figure 24).

Figure 23:

Cosmonautics – top players from academia and government, filings in EPO38+



3. Conclusions/key findings

This study, produced jointly by the EPO and ESPI with the support of ESA, has been a pilot project in the institutions' ongoing collaborative effort to investigate patent filing statistics for technologies relevant to the global space sector. This study has undertaken an analysis of patent filing statistics in cosmonautics.

While showing similar trends to other indicators that suggest the growth of the space sector and highlight burgeoning technology fields, the results of this analysis do not provide a comprehensive picture of the status of the global or European space sector and do not account for all the different variables that distort the data and yield potentially unexpected results.

Nevertheless, by analysing a large structured dataset and placing a particular focus on the European perspective, it enables several key findings to be made.

Key finding 1: There has been a steep worldwide growth in patent filing in cosmonautics in the past decade, and European activity has been a contributing factor to this trend.

While the dramatic increase in worldwide cosmonautics patent filings in recent years has largely been driven by Chinese filings, the overall increasing trend would be present even if the activity of Chinese applicants were disregarded. In Europe, cosmonautics patent filing activity has also experienced growth since 2010.

Patent filing activity is visible in each of the eight cosmonautics domains analysed in this study, both worldwide and in Europe. Propulsion, spacecraft electrical power and space system control account for the largest proportion of patent filing activity.

Key finding 2: European patent filings are driven primarily by German and French actors and there is limited activity beyond ESA member states.

European innovators in cosmonautics usually have their address in Germany (1 270 patent families) or France (1 219 patent families), and are followed in smaller numbers by players from the United Kingdom (283 patent families), Italy (95 patent families), Sweden (68 patent families), the Netherlands (51 patent families), Spain (49 patent families) and Switzerland (47 patent families).

The fact that the overwhelming majority of cosmonautics patents originate in ESA member states underscores the position of ESA as a grouping of major European space-faring nations. As far as non-ESA member states are concerned, the statistics bear witness to the activity of Turkey, followed by Lithuania and Serbia.

Key finding 3: Cosmonautics patents in Europe are mostly company-owned.

85% of cosmonautics patents in Europe are owned by companies. 13 of the top 15 players filing cosmonautics patent applications are either European companies (Airbus, Thales, Safran), US companies (Boeing, Northrop Grumman, Maxar Technologies, Aerojet Rocketdyne, GM, etc.) or Japanese companies (Toyota). The other two are the French Government/CNES and the DLR.

Key finding 4: A significant share of patents in Europe are applied for by non-European countries, suggesting that Europe is an important market for non-European players where innovation is an important competitive factor.

There is a strong tendency for US, Japanese and Korean actors to file for cosmonautics patents in Europe, with the USA being the number 1 country in the list of actors filing in Europe ranked by the origin of the applicant.

The situation is different as regards other countries, as there are not so many filings by Russian actors and hardly any by Chinese actors.

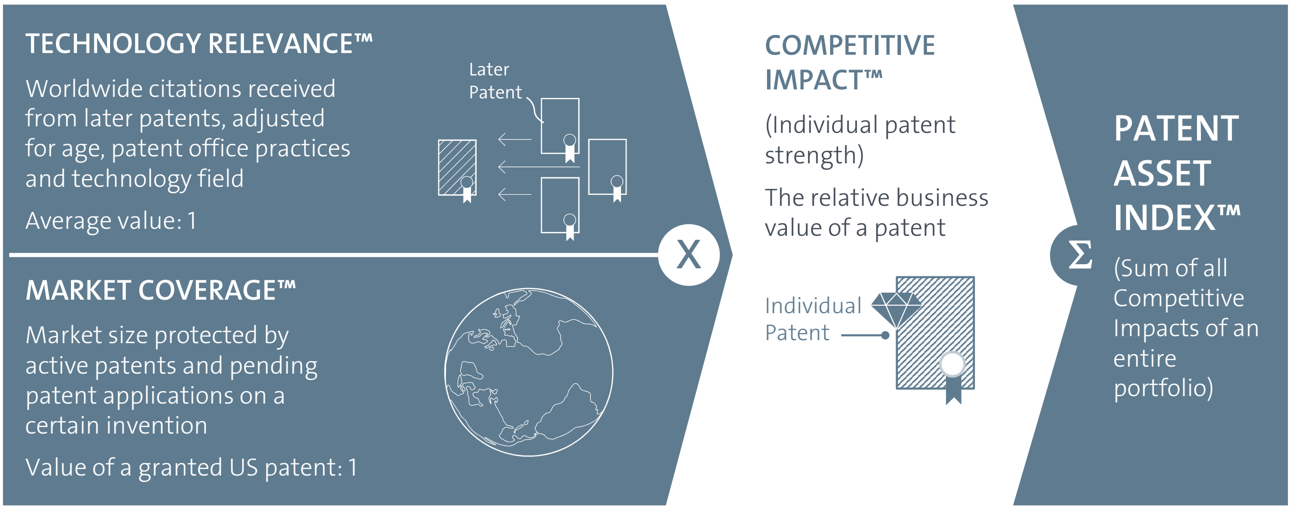
Key finding 5: Cosmonautics patent filing statistics show dynamism in the sector and the growing phenomenon of spin-in.

The patent filing statistics show that new players are entering the cosmonautics field and incumbents are leaving it, contributing to a noticeable dynamism in the sector. There has also been an increase in the number of non-space actors with limited, specific expertise entering the field.

4. Annex

Supplementary information

Further supplementary information on the data basis, databases, search queries and patent dataset used for this study is available in digital form at
EPO - Patent insight reports



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