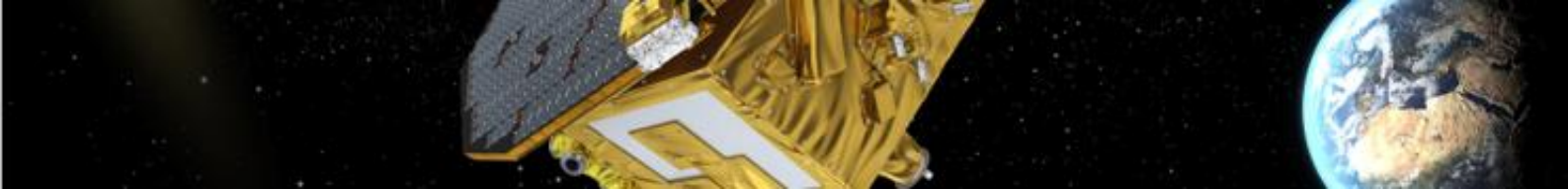*Source: ESA*

Bibliometric analysis of research linked to UK Space Agency funding

Full Report for the **UK SPACE AGENCY**

FINAL REPORT

know.space in association with **DIGITAL science**

March 2021

Contents

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About us

know.space[1] is a specialist space economics consultancy, based in London and Dublin. Founded by the leading sector experts, Greg Sadlier and Will Lecky, it is motivated by a single mission: to be the source of **authoritative economic knowledge for the space sector**.

know. */nəʊ/v.*

to understand clearly
and with certainty

🖥 www.know.space   ✉ hello@know.space

Digital Science is a technology company serving the needs of scientific and research communities at key points along the full cycle of research. They invest in, nurture and support innovative businesses and technologies that make all parts of the research process more open, efficient and effective.

Acknowledgements

We would like to thank our Digital Science colleagues for guidance on the interpretation of data from the Dimensions database. We would also like to acknowledge the useful guidance and feedback provided by the UK Space Agency over the course of the project. Responsibility for the content of this report remains with **know.**space.

Images

Cover and Header: 'LISA Pathfinder in Space' (cropped). ESA/C. Carreau, CC BY-SA 3.0 IGO.

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[1] **know.**consulting ltd. (CRN: 12152408; VAT: 333424820), trading as **know.**space

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Executive Summary

know.space, in association with Digital Science, was commissioned by the UK Space Agency (UKSA) to conduct an independent, detailed bibliometric analysis of publications linked to UKSA funding. The objective was to provide UKSA with a better understanding of the nature and impact of the research funded by the Agency.

Key findings

- We identified over **3,000 global publications linked to UKSA funding,** generated by more than **4,100 unique researchers** over the 2010-2020 period.
- The mean publication rate was around 300 publications per year between 2010 and 2018.
- **88% of research linked to UKSA funding was cited more often than average[2]**, as measured by Field Citation Ratio scores, which compare research published in the same year and subject area.
- Specifically, **half of research linked to UKSA funding produced over the 2010-20 period was 4 to 5 times more cited than average[3]**, when compared to similarly aged publications in the same field of research, while nearly 10% outperformed the average by a factor of 25 or more.
- On average, **7% of publications linked to UKSA funding placed in the global top 1%** across all disciplines in a given year, **25% in the top 5%**, and 38% in the top 10%.
- Research linked to UKSA funding is highly **internationally collaborative**, with 80% of publications between 2010 and 2020 involving some international cooperation.
- The top collaborating countries in *absolute* terms are the US, European Union (EU) countries, Canada, Switzerland, and Russia, while in *per capita* (population weighted) terms, Scandinavian countries, Switzerland, and EU countries stand out, perhaps driven by collaboration in activities related to ESA funding.
- Unsurprisingly, research is concentrated in **Physical Sciences** (specifically Astronomical and Space Sciences). However, many other fields of research are also well represented, such as physical chemistry and geosciences, emphasising the frequently **multi/interdisciplinary nature** of UKSA funding.
- UKSA funds research across the UK, with every UK region and devolved administration having strong representation (though **London, the South East of England, and Scotland dominate**), which correlates with the relative strength of these areas in the space sector more generally, as shown for example by the *Size and Health of the UK Space Industry* series.
- While our patents analysis is illustrative rather than comprehensive[4], **13 worldwide patents** (applied for and/or granted) citing research linked to UKSA funding were identified, in **Physical Sciences, Engineering**, **Technology** & **Biological Sciences**.

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[2] i.e. scored above the *median* FCR, being in the 51st percentile or above for that year. The FCR score required to be in the 51st percentile varies year on year, from a high of 0.91 in 2010 to a low of 0.65 in 2018. All else equal, a longer time since publication will mean more time to accrue citations, so median FCRs tend to be higher in earlier years.

[3] FCR is designed such that a publication with a FCR of 1.0 has received the same number of citations as the mean (not median) for that field of research, with a FCR of 2.0 representing twice as many citations, and so on. Half of publications assessed here had a FCR>4, and 10% had a FCR>25.

[4] i.e. the patents identified show *examples* of patents that reference research associated with UKSA funding, but this is not intended to be a comprehensive list and there are likely to be other patents not captured here.

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- We also identified **15 (global) policy document**[5] references and links to **134 datasets**, related primarily to astronomy and astrophysics research.

Next steps

Certain indicators can be tracked over time to monitor the nature and impact of research linked to UKSA funding, and to inform corporate reporting. On a yearly basis[6] these include:

- Number of publications per year
- Proportion of international collaborations per year
- Field Citation Ratio (FCR) distributions
- Publications in the annual top 1/5/10% in FCR score

On a 3-5 year basis:

- Evolution of the most popular first- and second-level fields of research[7]
- Evolution of the top collaborating countries
- Evolution of the top UK organisations generating research linked to UKSA funding
- Evolution of the mean and median altmetric score[8]

This was also a relatively short study and **further work would be useful to build a more in-depth understanding** of the links between research linked to UKSA funding and impact, and the nature of participating researchers. Specifically, further work could be carried out to:

- Benchmark UK performance relative to (i) other countries and (ii) areas of research.
- Investigate researcher characteristics, with regards to age and diversity characteristics such as gender, background, country of origin, etc.
- Understand the extent and nature of the influence of research linked to UKSA funding on policy documents and datasets, and how information/data is being used.
- Map publications to launch dates for specific missions and data releases, to build an understanding of what activity is driving impact.

These factors – and others – can be linked to, tracked and explored further in UKSA's internal work on monitoring and evaluation, and in the UKSA Results Framework.

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[5] As for patents, this is again illustrative rather than comprehensive.

[6] In some cases a 3-year rolling average or similar indicator may be most appropriate to avoid data comparability issues.
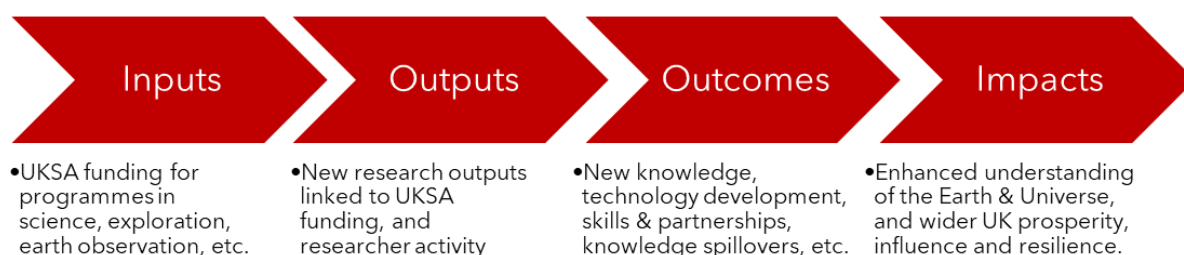
[7] The Fields of Research classification has three hierarchical levels: Divisions, Groups and Fields. The first level, divisions, represents a broad subject area or research discipline, while groups and fields represent increasingly detailed subsets of these categories.

[8] Altmetrics monitor and report on the online discussion surrounding research, with the score representing the weighted count of the amount of attention identified for a research output.

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Introduction

The UK Space Agency (UKSA) commissioned **know.**space, in association with Digital Science, to conduct an independent, detailed bibliometric analysis of publications linked to UKSA funding. This report aims to offer a better understanding of the nature, outcomes, and impact of research linked to UKSA funding, both to the Agency itself and to other stakeholders. It also seeks to report on indicators and metrics that may be useful for UKSA's corporate reporting. The following simple logic chain shows the potential pathways to impact from UKSA funding to new knowledge and other benefits, via the research outputs assessed here.

Inputs	Outputs	Outcomes	Impacts
•UKSA funding for programmes in science, exploration, earth observation, etc.	•New research outputs linked to UKSA funding, and researcher activity	•New knowledge, technology development, skills & partnerships, knowledge spillovers, etc.	•Enhanced understanding of the Earth & Universe, and wider UK prosperity, influence and resilience.

Our analysis is based on a source dataset provided by UKSA, containing bibliographical information on publications linked to UKSA funding since its creation in 2010. Digital Science matched these publications with those in their Dimensions database to enable detailed analysis on their nature and impact. **know.**space then carried out additional analysis and interrogation of the data, which we report on in this summary report.

In 2017, Clarivate Analytics conducted a similar analysis for UKSA, using their 'Web of Science' database. While structural differences between Clarivate Analytics and Digital Science's databases mean that direct comparison and time series analysis between the two studies are not always possible, the present report draws links between its findings and those of the 2017 report when appropriate.

Methodology

This report was developed in collaboration with Digital Science using their ◈ Dimensions database, a global research knowledge system that contains information about global R&D activity: inputs, outputs, and outcomes. This simplifies finding and analysing the most relevant research information, uncovering evidence of impact, reach, and engagement, and gathering insights concerning the global science and technology landscape.

The Dimensions database contains almost 150 million records, offering access to a wider range of impact metrics than other databases, particularly on policy impact, altmetrics (e.g. twitter mentions, references in news articles), patents, and other linked datasets. As of January 2021, Dimensions contains:

- **Publications**: over 114 million publications (incl. journal articles, book chapters, etc.)
- **Grants**: over £1.2 trillion of awarded past and current grant funding; information from over 5.6 million grants
- **Datasets**: over 8 million datasets

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- **Patents**: over 55 million patent records
- **Policy Documents**: over 560,000 policy documents
- **Altmetrics**: over 150 million altmetrics

Additionally, Dimensions provides over four billion connections between the different records and with other data sources. Links between these records, such as citations between publications and patents, offer a comprehensive picture of the research impact.

This report was developed following a 5-step methodology:

Input: Researchfish Publications	➡	Match with Dimensions data	➡	Output: Dimensions datasets	➡	**know**.space synthesis and analysis of results	➡	Reporting & Deliverables

1. Input: researchfish publications data

As in the 2017 Clarivate Analytics study, the primary input for this study was the bibliographic details of unique publications related to UKSA funding (originally 8,770 records total and 4,380 unique publications), provided in MS Excel format by the Agency. Overall, the quality and completeness of the source data was good, as it reliably included standard bibliographic information (e.g. title, publication date, journal name, authors name etc.) and identifiers (e.g. DOI, PMID etc.), enabling the matching process (Step 2).
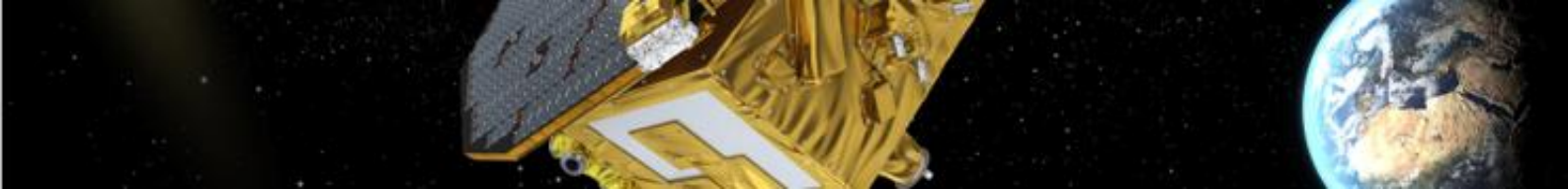
2. Match with Dimensions data

Publications possess a number of identifiers, such as DOIs (Digital Object Identifiers), PMIDs (PubMed IDentifier), PMCIDs (PubMedCentral Identifier), ArXiv ('Archive' open-access repository of electronic preprints), and titles, which were used to match the research in the source dataset to Dimensions data. Overall, **84%** of the UKSA publications were able to be matched to the Dimensions database.

With the agreement of UKSA and according to the primary focus of interest, only journal articles and book chapters were subsequently considered in the data exploitation and analysis, **increasing the match rate between the source dataset and Dimensions database to 92%.** This high match rate demonstrates that the matching process was broadly successful, ensuring a robust basis to enable an accurate and reflective analysis of the nature and impact of research linked to UKSA funding.

3. Output: Dimensions datasets

After restricting to articles and book chapters, removing pre-2010 publications (i.e. those published before creation of UKSA, which were originally linked to UKSA funding due to grants being 'passed over' to UKSA), and matching, to the Dimensions database, the database consisted of over 3,000 publications (specifically, 3,098). Digital Science returned a series of datasets, including:

- **Publications**: data on all publications matched to Dimensions. This dataset contains information on publication impact (citations, Field Citation Ratio, altmetric scores, and policy mentions), fields of research, and collaborations.
- **Researchers**: data on authors of the publications matched to Dimensions. This dataset contains information on researcher productivity (number of publications

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and grants), impact (citations, Field Citation Ratio, altmetric score, and policy mentions), career age, organisations, and funders.

- **Policy documents**: details of policy documents linked to publications (e.g. title, organisation name, field of research, and link to the document). However, these details were relatively incomplete and covered only a subset of the linked policy documents identified (discussed further below).
- **Patents**: details of a selection of patents citing the publication (e.g. on date filed/granted, title, inventors, and patent family).
- **Other datasets**: details of datasets associated with publications linked to UKSA funding. This table provides information about items shared on repositories such as Figshare and Zenodo.

This offers a wide picture on research nature and impact and **maintains consistency** on some variables with the 2017 Clarivate Analytics report. This can also inform the development of new indicators that will be useful for the internal UKSA Results Framework, **showcasing and monitoring UKSA's impact in new ways**.

4. **know.**space synthesis and analysis of results

With the core datasets in hand, we were able to interrogate the data to provide insight into the nature and quality of research linked to UKSA funding, and to develop indicators that may be used in reporting. The **publications** dataset included most of the information required to produce indicators that UKSA are interested in monitoring, e.g. number of citations, Field Citation Ratio (citation impact), and percentage of internationally collaborative papers.

Moreover, we were able to go deeper than basic indicators, generating indicators for the **percentage of UKSA's portfolio in the top X% of research** per year, **altmetrics** (e.g. twitter mentions, references in news articles), **policy impact** (e.g. number of references in policy documents) and **patent impact** (e.g. number and type of patents that can be traced to UKSA funding). Where possible, the datasets also enabled us to see **trends over time**, which may be useful for corporate reporting purposes.
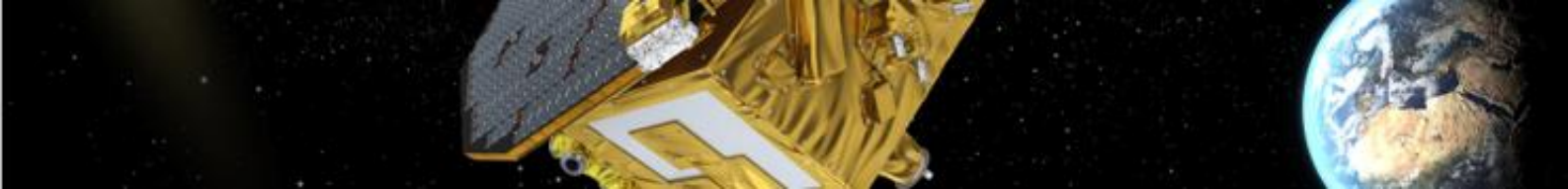
5. Reporting and deliverables

We brought together the findings of the bibliometric analysis, presenting them in a series of visualisations, supplemented by commentary. These are summarised in the following sections.

Caveats, limitations and quality assurance

Bibliometric analysis has inherent limitations, which must be acknowledged to best understand the findings presented in this report:

- Results and the interpretation / insights drawn from them are wholly dependent on the quality and comprehensiveness of the input data provided by UKSA. While the match rate to the Dimensions data was high (92%), it was not perfect.
- The source data is also reliant on researchers having accurately reported their data through the researchfish reporting framework, which may leave room for errors.

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- Additionally, there can be a lag effect in reporting publications to UKSA, which in some cases limited our ability to look at time series and underlying trends, and/or skewed them.
- The list of patents and policy documents citing research linked to UKSA funding was non-exhaustive, meaning our findings in those sections should be interpreted as illustrative rather than absolute.
- Some comparisons are made to averages across all disciplines, which may overlook certain inherent differences between space-related research and other fields.
- While there is a link to UKSA funding in all cases, UKSA is not necessarily the only – or even the prime – funder of research linked to UKSA funding.

Nevertheless, our rounded view is that the data was of sufficiently high quality to enable the **know.**space / Digital Science team to meet the aims of the project, i.e. to robustly identify the nature, outcomes, and impact of research linked to UKSA funding, and to generate useful indicators and metrics.

We also ensured that rigorous **quality assurance** (QA) was put at the heart of our approach, both for the Dimensions data used as an input, and for the additional **know.**space analysis.

Data from the Dimensions database goes through a detailed quality analysis and checking approach (for more detail, see A Guide to the Dimensions Data Approach). Dimensions data is also exposed to customers via the Dimensions API and their cloud data warehouse, Google BigQuery. The use of these customer-facing products to put together the dataset means that the analysis can be checked and verified by anyone with access to these tools. The datasets provided for the project were put together using a Python script, so are fully reproducible, and were QA'd by spot-checking values against the public facing Dimensions database, and by checking outliers and unusual values.

For the additional **know.**space synthesis and further analysis, we ensured that all calculations (undertaken in Excel) were checked by another member of the team, including verifying that steps to reach results were clear and reproducible. We used regular discussions with Digital Science colleagues to discuss and bottom out any analytical issues, and for a 'sense check' on emerging conclusions.
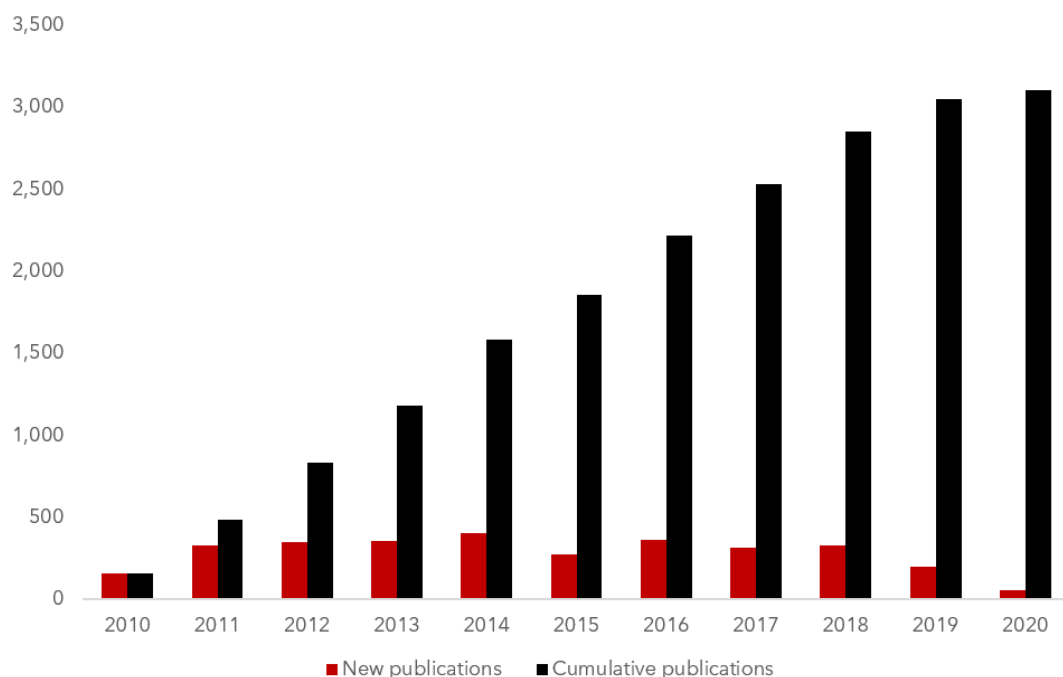
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Nature of research linked to UKSA funding

Publications

Between 2010 and 2020, a total of **3,098 publications**[9] have been linked to UKSA funding. Some were published as book chapters (34), but **the overwhelming majority (99%) were articles disseminated in academic journals**. Research linked to UKSA funding has been relatively stable between 2010 and 2018, with the mean number of yearly publications topping 300 over that period. However, there has been a slowdown in the past two years, which could reflect one or both of the following factors:

- **Lag in reporting** - the input data is based on researchfish submissions completed by researchers, which then need to be collated. The source dataset was provided in late 2020 so naturally will not include those publications at the end of that year. Beyond this, it may also take time to get high completion rates within the researchfish system.
- **Non-linear nature of space mission-related publication outputs** - publications linked to UKSA funding tend to relate to specific missions and data releases. Recently launched missions (e.g. Solar Orbiter, BepiColombo) are in 'cruise' phase and are not generating many papers yet. The tail off could therefore reflect a decrease over time in productivity from older missions, with newer ones not yet reaching full impact.

Figure 1: Annual & cumulative number of publications linked to UKSA funding, 2010-20

Source: know.space analysis

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[9] This excludes publications other than journal articles or book chapters, as discussed above.

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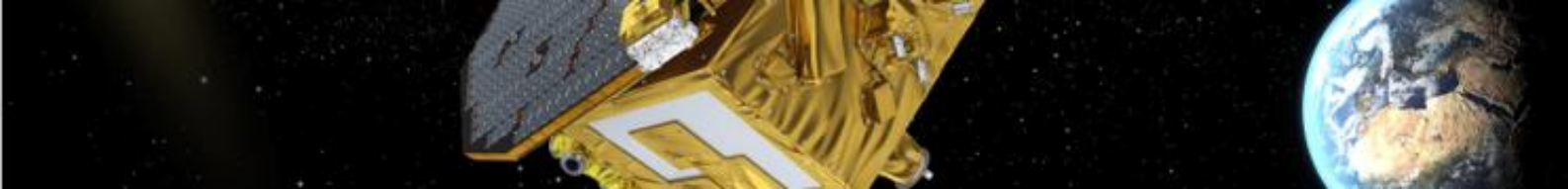
Field of research

Publications linked to UKSA funding principally focus on the field of research[10] (FoR) of Physical Sciences, distantly followed by Earth Sciences, Chemical Sciences, and Engineering. More specifically, the sub-fields of **Astronomical and Space Sciences** and **Atomic, Molecular, Nuclear, Particle and Plasma Physics** were the main areas of contribution. Although the typology used is different, the main FoRs identified are relatively similar to the findings of the 2017 Clarivate Analytics report[11].

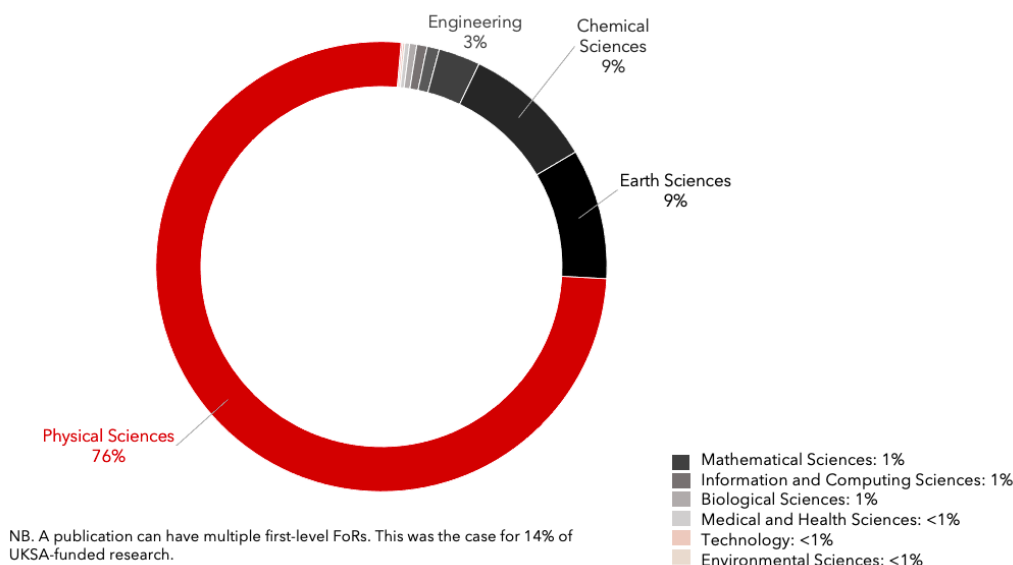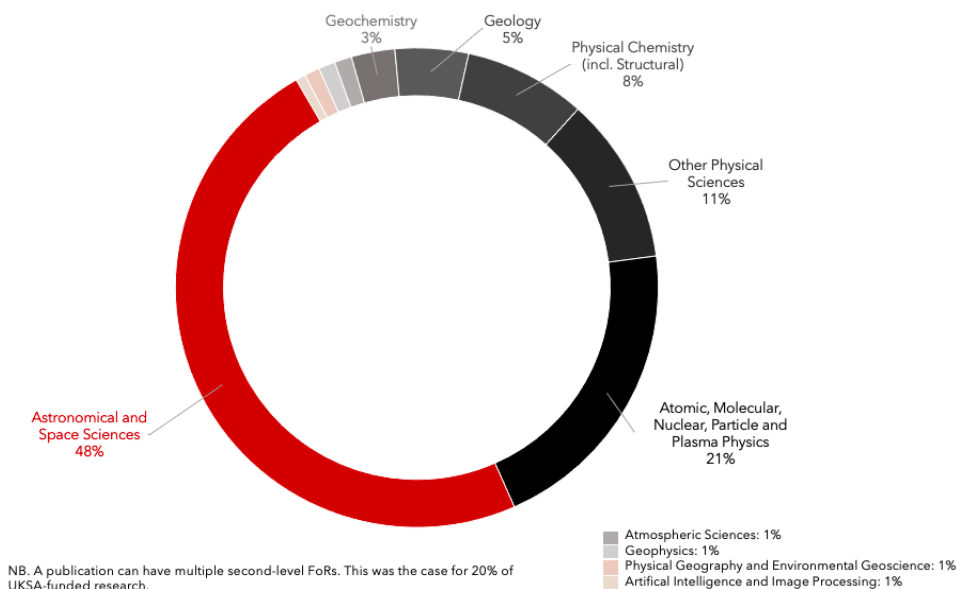## Figure 2: Publications by first-level Field of Research (2010-2020)

NB. A publication can have multiple first-level FoRs. This was the case for 14% of UKSA-funded research.

Mathematical Sciences: 1%
Information and Computing Sciences: 1%
Biological Sciences: 1%
Medical and Health Sciences: <1%
Technology: <1%
Environmental Sciences: <1%

Figure 3: Publications by second-level Field of Research (2010-2020)

NB. A publication can have multiple second-level FoRs. This was the case for 20% of UKSA-funded research.

Atmospheric Sciences: 1%
Geophysics: 1%
Physical Geography and Environmental Geoscience: 1%
Artifical Intelligence and Image Processing: 1%

Source: know.space analysis

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[10] The FoR system covers all areas of research from the Australian and New Zealand Standard Research Classification (ANZSRC) and is on two levels in Dimensions.
[11] The 2017 Clarivate Analytics report found that the top categories for UKSA were Astronomy & Astrophysics; Geosciences (Multidisciplinary); Physics (Multidisciplinary); Physics, Particles & Fields; and Meteorology & Atmospheric Sciences.
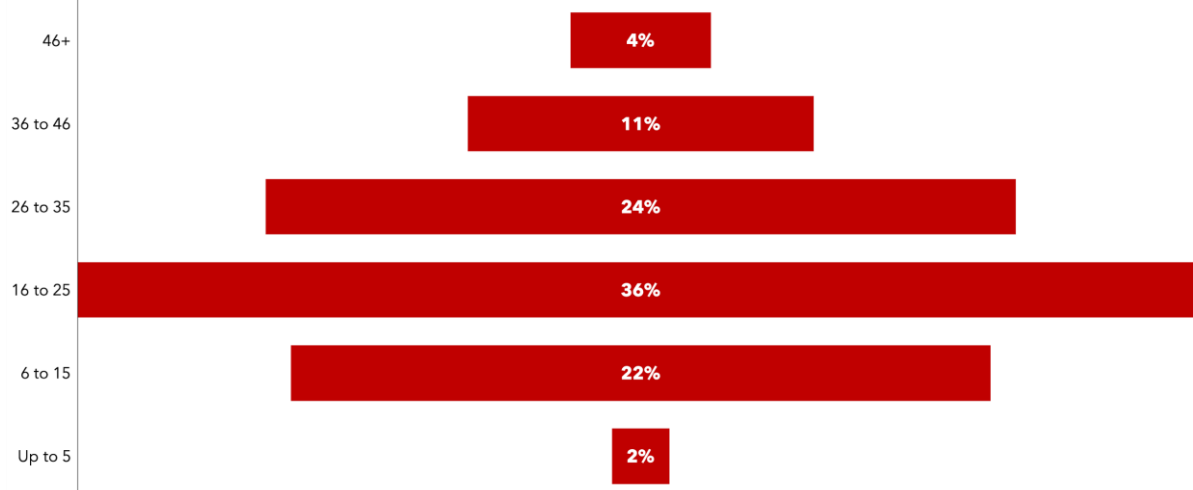
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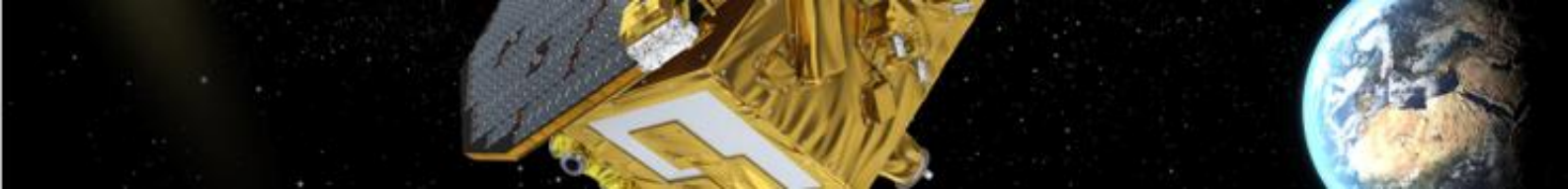
As one may expect, Astronomical and Space Sciences dominate publications linked to UKSA funding. However, the findings reveal that many other fields of research are also represented, such as physical chemistry, and geosciences. This emphasises the frequently **multi / interdisciplinary nature** of UKSA funding.

Researchers

More than **4,100 unique researchers** were listed as authors or co-authors in publications linked to UKSA funding. The difference between the number of publications and authors is due to many papers having multiple co-authors.

Overall, these authors tend to be experienced, as their mean career age (i.e. number of years spent as an academic researcher) is 24, which is almost 5 additional years over the average UK academic for 2018-19 (i.e. 19.4)[12]. Overall, nearly 75% of researchers participating in publications linked to UKSA funding have a career age of 16 years or more.

Figure 4: Career age of authors of publications linked to UKSA funding (2010-2020)

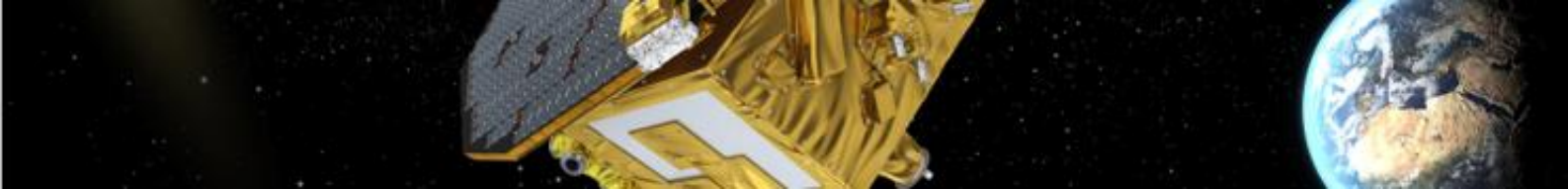Source: know.space analysis

International collaboration

Research linked to UKSA funding is deeply rooted in international collaboration, which reflects the findings of the 2017 Clarivate Analytics report and is consistent with the UK's 4th place in contribution to international academic collaboration (across all disciplines [13]) in the 2019-2020 Nature Index[14]. It is also in line with the higher tendency of

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[12] Assuming UK academics publish their first research (i.e. start their career) at age 24. UK academics' age figures were sourced from the Higher Education Statistics Agency website.
[13] The figures for international collaboration in space-related research were not available within the bounds of this study.
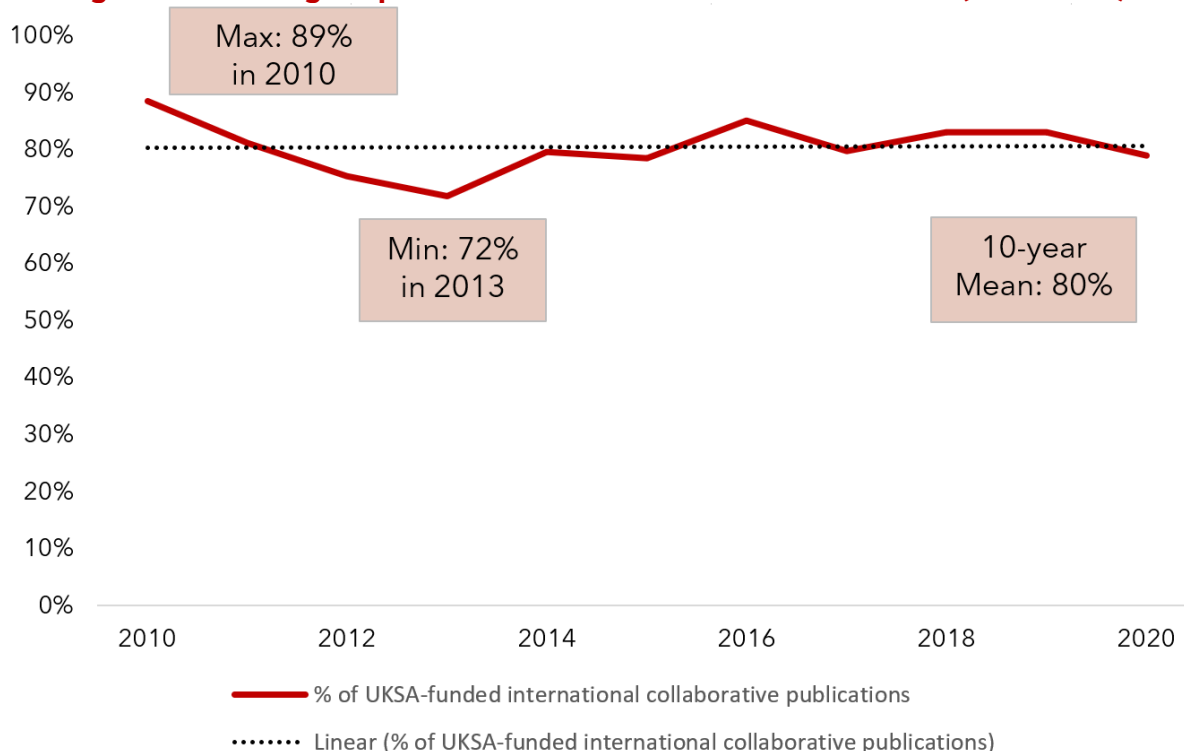[14] "The Nature Index is a database of author affiliation information collated from research articles published in 82 high-quality science journals. The database is compiled by Nature Research. The Nature Index provides a close to real-time proxy of high-quality research output and collaboration at the institutional, national and regional level".

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publications in the fields of astronomy, physics, and geosciences to be the result of international collaboration, as highlighted by Nature.[15]

Since 2010, **80% of publications linked to UKSA funding have been the product of cross-country cooperation**, i.e. where the authors are affiliated to more than one country. The previous Clarivate analysis found a similar figure of 75%, using a similar methodology. While the figure varies year-on-year, international collaborations in research linked to UKSA funding have been relatively static in the past decade.

Figure 5: Percentage of publications with international collaboration (2010-2020)

Max: 89% in 2010

Min: 72% in 2013

10-year Mean: 80%

—— % of UKSA-funded international collaborative publications

•••••• Linear (% of UKSA-funded international collaborative publications)

Source: know.space analysis

The below table and charts show the number of authors of publications linked to UKSA funding based in each country, with countries ranked on an absolute basis. Non-UK-affiliated authors (or at least those who are affiliated to organisations outside the UK *as well as* in the UK) are principally affiliated to organisations in **the United States, the European Union, Switzerland, and Canada.** Again, this is consistent with the UK's top collaborators across all disciplines, as per the Nature Index. There are however some differences to 'average' publication spreads. For example, China, which is the UK's 3rd top collaborator across all academic disciplines, is relatively underrepresented in research linked to UKSA funding (ranked 14th), while Russia is relatively overrepresented, ranking 10th, despite not making it into the UK's top 10 collaborators (all disciplines). This is likely to reflect Russia's historical strengths in space-related studies.
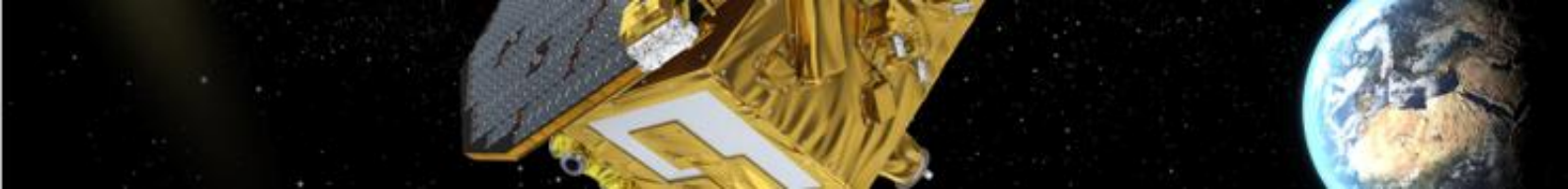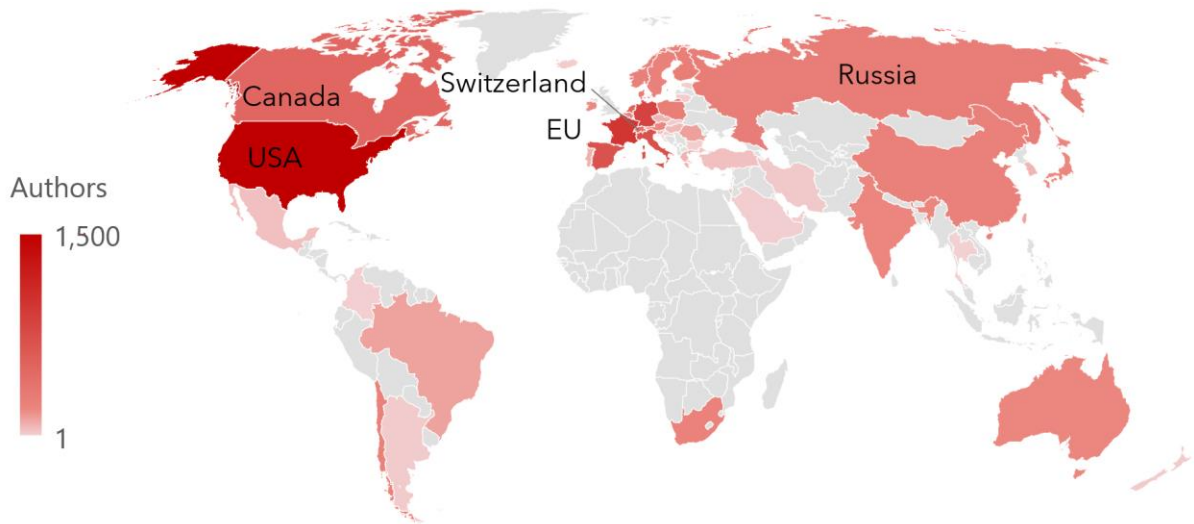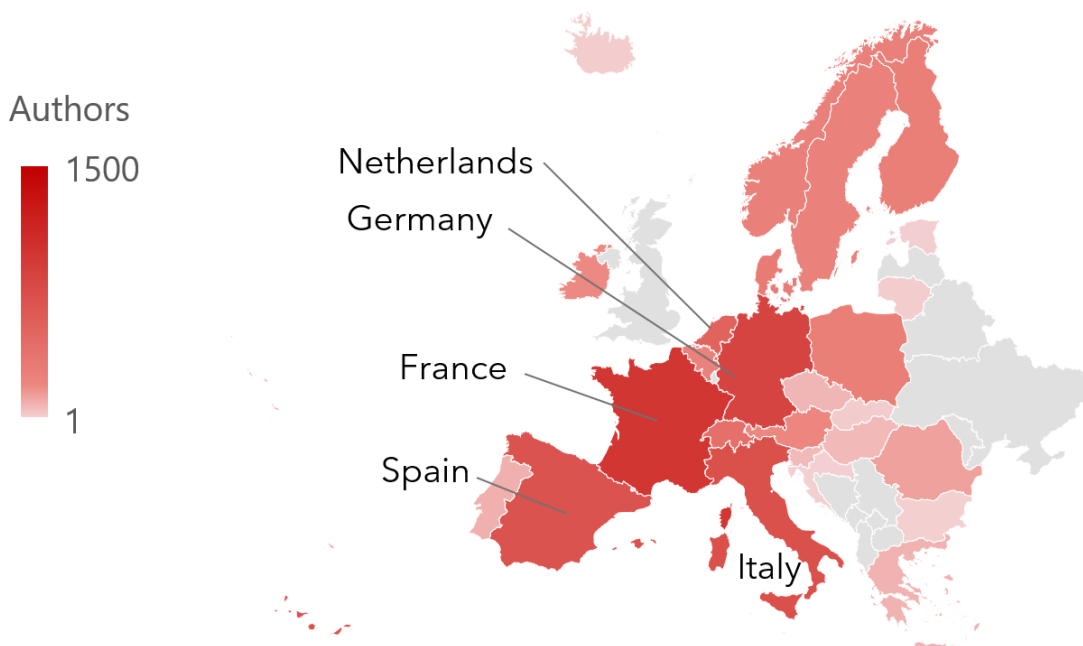
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[15] https://www.nature.com/news/research-gets-increasingly-international-1.19198

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Figure 6: Top collaborating countries (2010-2020)

Source: know.space analysis

Note: **Total**, author affiliation country

Figure 7: Top collaborating <u>European</u> countries (2010-20)

Source: know.space analysis

Note: **Total**, author affiliation country

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Figure 8: Top 10 collaborating countries for research linked to UKSA funding (2010-2020), ranked by number of authors affiliated with an institution in each country

Author affiliation country[16]	Total authors of publications linked to UKSA funding	Authors per million citizens
UK (for context)	1,996	30
United States	1,497	5
France	973	15
Germany	836	10
Italy	719	12
Spain	698	15
Netherlands	544	32
Canada	500	13
Switzerland	421	47
Denmark	311	52
Russia	287	2

Source: know.space analysis

Note: **Total**, author affiliation country

While absolute numbers/rankings are useful to understand who the UK's major collaborating countries are, it is also useful to consider *population-weighted* figures, so that smaller countries are not 'drowned out' in the analysis. Examining the number of authors of publications linked to UKSA funding per capita also helps indicate whether a country focuses relatively significant attention to disciplines related to the space industry. Here, European (especially Scandinavian) countries exhibit the highest number of papers linked to UKSA funding authors per capita. While this gives a useful idea of relative international specialisation, an international benchmarking study (discussed in 'next steps' below) would allow for greater insight to be provided on this, and to better understand the UK's relative performance.

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[16] Note that a researcher may be affiliated with several institutions, in different countries, which affects how these results should be interpreted (e.g. the 'total author' column cannot be summed, as many researchers will be in more than one row).
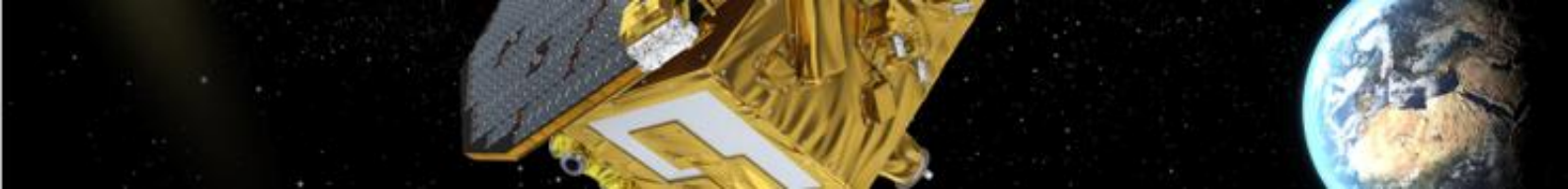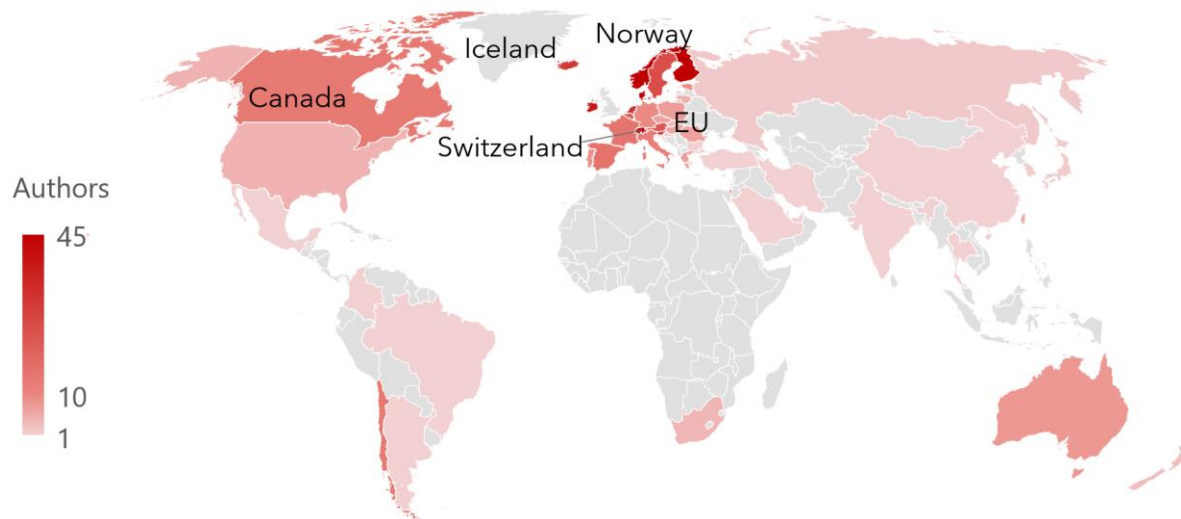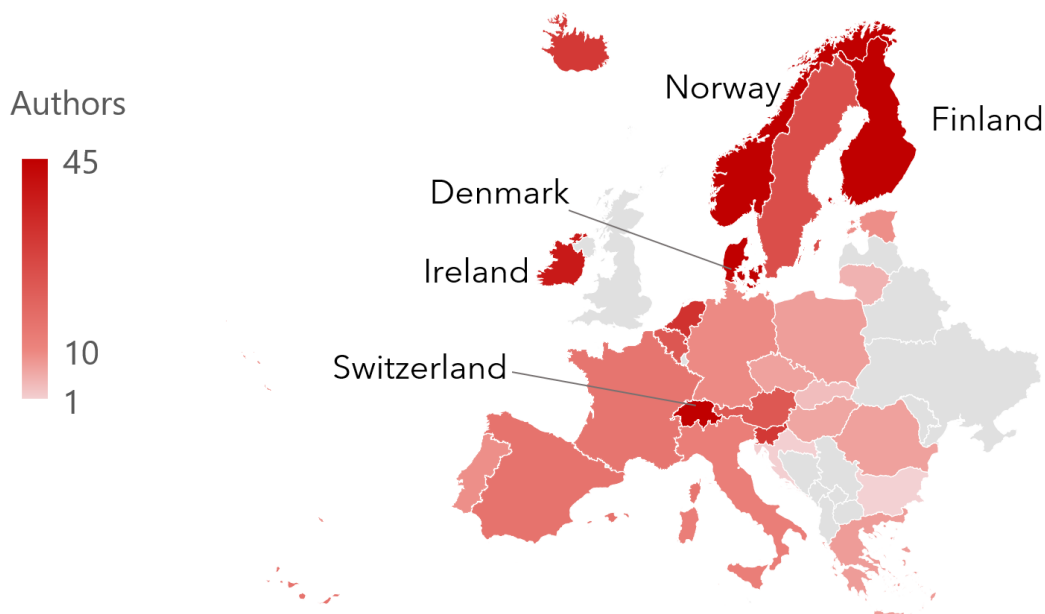
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Figure 9: Top collaborating countries for research linked to UKSA funding (2010-2020), ranked on a population-weighted (authors per million citizens) basis

Source: know.space analysis

Note: **By population** (per million), author affiliation country

Figure 10: Top collaborating European countries for research linked to UKSA funding (2010-2020), ranked on a population-weighted (authors per million citizens) basis

Source: know.space analysis

Note: **By population** (per million), author affiliation country
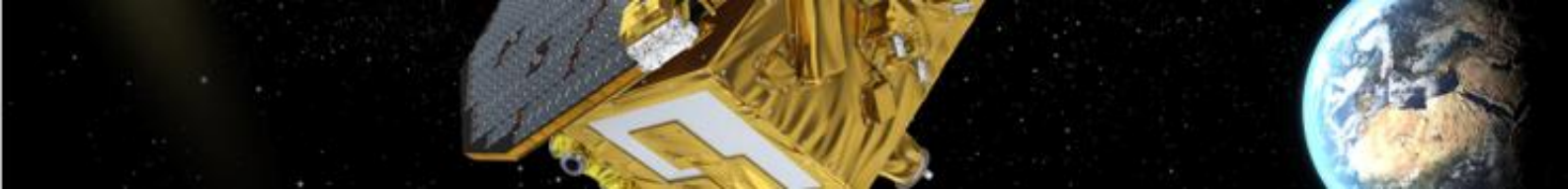
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Figure 11: Top 10 collaborating countries for research linked to UKSA funding (2010-2020), ranked on a population-weighted (authors per million citizens) basis

Country	Total authors	Authors per million citizens
Denmark	311	52
Norway	256	51
Switzerland	421	47
Finland	271	45
Ireland	192	38
Netherlands	544	32
Slovenia	61	31
Iceland	12	30
Sweden	246	25
Belgium	246	22
Austria	199	22

Source: know.space analysis   Note: **By population** (per million), author affiliation country

Within the UK, researchers were (at the time of their research publication) **affiliated with organisations throughout the nation**[17], although London, the South East of England, and Scotland dominated – possibly reflecting the relative strength of the space sector in these areas[18]. Northern Ireland and Yorkshire and the Humber exhibited the lowest ratio of UK-based researchers linked to UKSA funding based on their population, again perhaps reflecting the relatively lower degree of space activity in these regions in general.

Overall, **research linked to UKSA funding was overwhelmingly (and unsurprisingly) generated by universities.** Most institutions placing in the Nature Index's UK top 10 also published the most research linked to UKSA funding (e.g. University College London, University of Cambridge, University of Oxford, and Imperial College London). However, the Universities of Leicester, Glasgow, and Cardiff, and the Open University stood out as significant contributors of publications linked to UKSA funding, indicative of a relative concentration in space-related studies.

The chart and table presented overleaf show a picture of strengths across the UK, with activity in all regions and devolved administrations. Around half of the top 10 institutions measured in this way are in London and the South East (often referred to as the 'Golden Triangle[19]'), while half are elsewhere. We would caution though that total authors is not a perfect measure of activity.[20]

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[17] We used the address of the main campus as reference to determine the regional spread. However, research may have been conducted elsewhere (multiple campuses, e.g. MSSL for UCL) or remotely.
[18] See for example: know.space, *Size and Health of the UK Space Industry 2020, (forthcoming)*
[19] Institutions in the 'golden triangle' tend to generate among the highest research incomes in the UK and have well developed national and international networks, which may be factors in their relative dominance in research linked to UKSA funding.
[20] For example, an organisation with 10 authors carrying out 1 study each would be presented as 10 times more active than an organisation with 1 highly prolific author who published 10+ times.
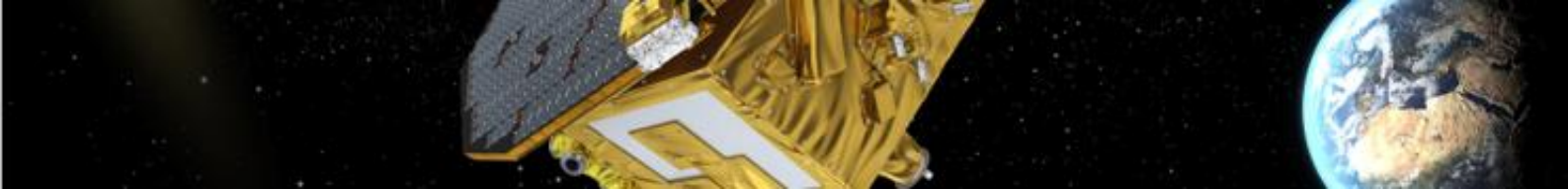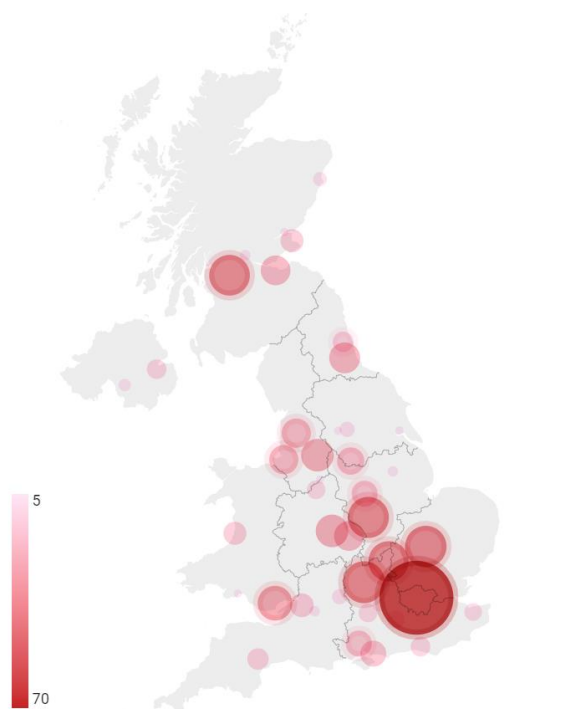
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Figure 12: Top UK regions for researchers with publications linked to UKSA funding
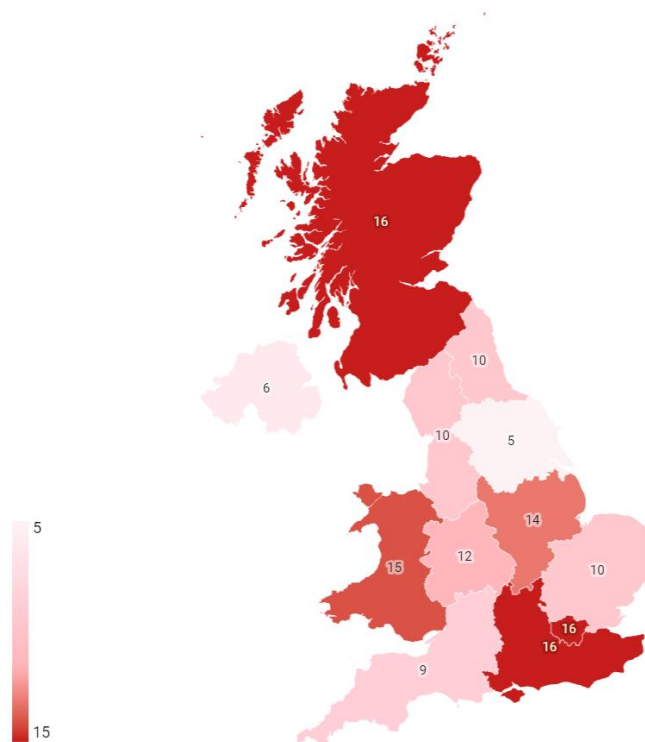

Source: know.space analysis

Figure 13: Top 10 organisations for UK-based researchers with publications linked to UKSA funding (2010-20)

Organisation	Region	Total authors
University College London	London	78
University of Oxford	SE England	46
University of Leicester	East Midlands	45
University of Cambridge	East England	43
The Open University	SE England	42
Imperial College London	London	40
University of Glasgow	Scotland	32
Cardiff University	Wales	31
University of Manchester	NW England	28
University of Birmingham	West Midlands	28
Durham University	NE England	25

Source: know.space analysis

Figure 14: Top UK regions for authors of research linked to UKSA funding (by population; 2010-2020)

Source: know.space analysis

Note: **By population** (per million), researcher organisation

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Impact of research linked to UKSA funding

Citations

Overall, publications linked to UKSA funding have been cited **over 134,000 times** between 2010 and 2020, with a mean of over 12,000 citations per year (and a median of over 11,500). However, there has been a notable tail off since 2017 (with a mean and median of nearly 4,300 citations per year between 2017 and 2020), which mirrors the slowdown of publications discussed above.

As above, this may be due to the nonlinear nature of space mission-related publication outputs, (i.e. recently launched missions in 'cruise' phase and not yet generating many papers), or a result of the lag in reporting recently-published research linked to UKSA funding. Therefore, with fewer publications to examine for the 2017-2020 period, there are naturally fewer new citations counted.

Figure 15: Cumulative citations over time for publications linked to UKSA funding (2010-20)
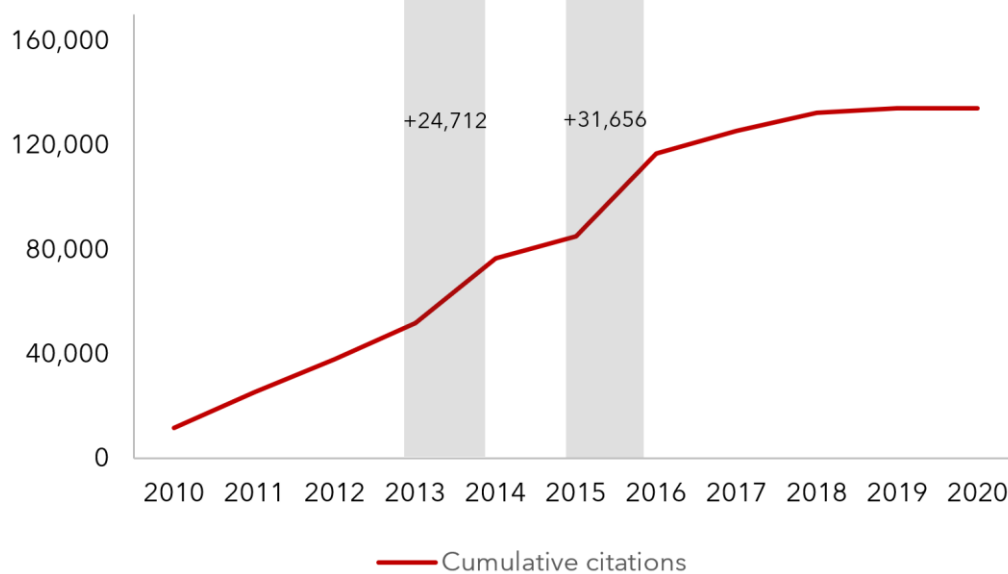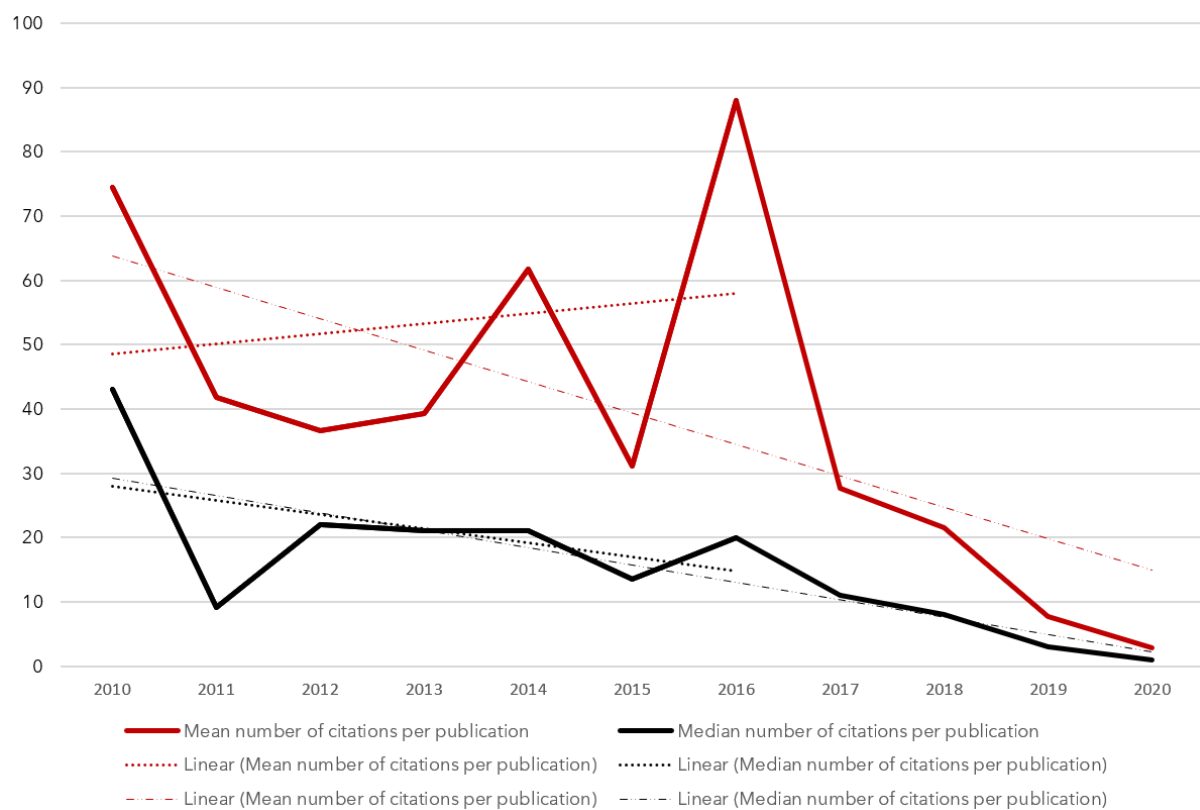

Source: know.space analysis

We can also gain insight by looking at 'per publication' rather than 'total' trends, which can strip out the impact of effects such as lag in reporting. Here, the mean number of citations per publication per year varied significantly between 2010 and 2020. Again, though, trends over time need to be treated with caution, particularly given:

- **Lag in citation impact**: recently-published research has – all else equal – had less time and reach to generate citations than older publications. It is therefore reasonable to expect some 'natural decline' (or immaturity effect) in average citations rates the closer we get to the present day.
- **Outlier skew**: some of the most impactful research linked to UKSA funding reached over 1,000 citations, well above most other publications (discussed more

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below). Years in which these 'top performer' publications appear can skew the data. To account for this, we also present the median citation figures below.

The following chart presents the mean and median figures. Given the above caveats, the decline over time and especially that since 2016 should not be seen as indicative of a decrease in research linked to UKSA funding quality. Trend lines are included for illustrative purposes only, with two sets presented: the 2010-16 trends for mean and median due to these post-2016 limitations, and the 2010-20 trend for completeness. We would caution against over-interpretation of any trend analysis in this relatively 'jumpy' data, though (i.e. it will be influenced by peaks and troughs, especially for the mean).

Figure 16: Mean and median number of citations per publications linked to UKSA funding by year (2010-2020)

Source: know.space analysis

An examination of the most cited papers linked to UKSA funding shows the mission-centric nature of research outputs, with the Planck and Gaia missions and the Herschel-SPIRE instrument accounting for 4 of the top 5 papers:

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Figure 17: Top 5 publications linked to UKSA funding by citation count (2010-2020)

Title	Year	Authors	Journal	Citations	FCR Score
Planck 2015 results - XIII. Cosmological parameters	2016	Ade, et al.	Astronomy & Astrophysics	5,763	1,635
Planck 2013 results. - XVI. Cosmological parameters	2014	Ade, et al.	Astronomy & Astrophysics	3,753	944
The Gaia Mission	2016	Prusti, et al.	Astronomy & Astrophysics	2,064	594
The Herschel-SPIRE instrument and its in-flight performance	2010	Griffin, et al.	Astronomy & Astrophysics	1,538	309
Multi-messenger Observations of a Binary Neutron Star Merger	2017	Abbott, et al.	The Astrophysical Journal Letters	1,391	480

Source: know.space analysis

The **Field Citation Ratio** (FCR)[21] is revealing of the impact of research linked to UKSA funding. This ratio scores the relative citation performance of a publication by comparing it to similarly aged articles in its subject area, with an FCR of 1 representing average (mean) citation impact.[22] A FCR of 2 can broadly be interpreted as 'twice as cited as average'.

Analysis of FCR scores for publications linked to UKSA funding highlights that **research published between 2010 and 2018 is highly impactful** (at least to the extent that citation performance equates to impact). Indeed, compared to research disseminated in the same year and field, around **nine in ten publications linked to UKSA funding performed better than the median**. Half of it was four to five times more cited than the mean for that field of research (i.e. FCR ≥ 4) and nearly 10% outperformed the average by a factor of 25 (i.e. FCR ≥ 25). Overall, these figures emphasise the considerable impact of most research linked to UKSA funding.

While the 2017 Clarivate Analytics report used different indicators, making a direct comparison with the present study inappropriate, it also found that research linked to UKSA funding had a relatively high citation impact[23].

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[21] Only publications older than 2 years old have an FCR score. A score of 1 indicates that the number of citations falls in the average for similarly aged articles in the same subject area. Importantly, the margin of error for what may be qualified as average is +/-0.5 (around FCR=1). Examining FCR trends is not advisable, as the score distribution varies year on year, e.g. a publication may need an FCR of 40 to qualify in the top 1% publications in 2010, but it would only need an FCR of 24.2 in 2018. Therefore, it is best to compare FCR scores within a given year or using a benchmark.
[22] See here for further detail: https://plus.dimensions.ai/support/solutions/articles/23000018848-what-is-the-fcr-how-is-it-calculated-
[23] The 2017 Clarivate Analytics report found that: for field-normalised citation impact, research linked to UKSA funding (top 5 UKSA categories) scored 2.15 compared to 1.72 of UK research (top 5 UKSA categories); for journal-normalised citation impact, research linked to UKSA funding (top 5 UKSA categories) scored 1.76 compared to 1.24 of UK research (top 5 UKSA categories).
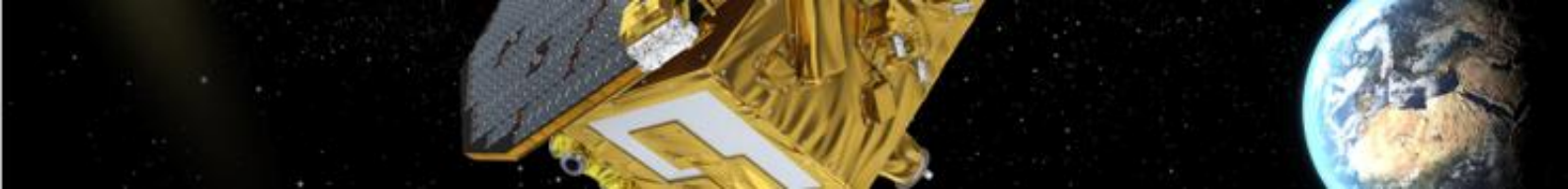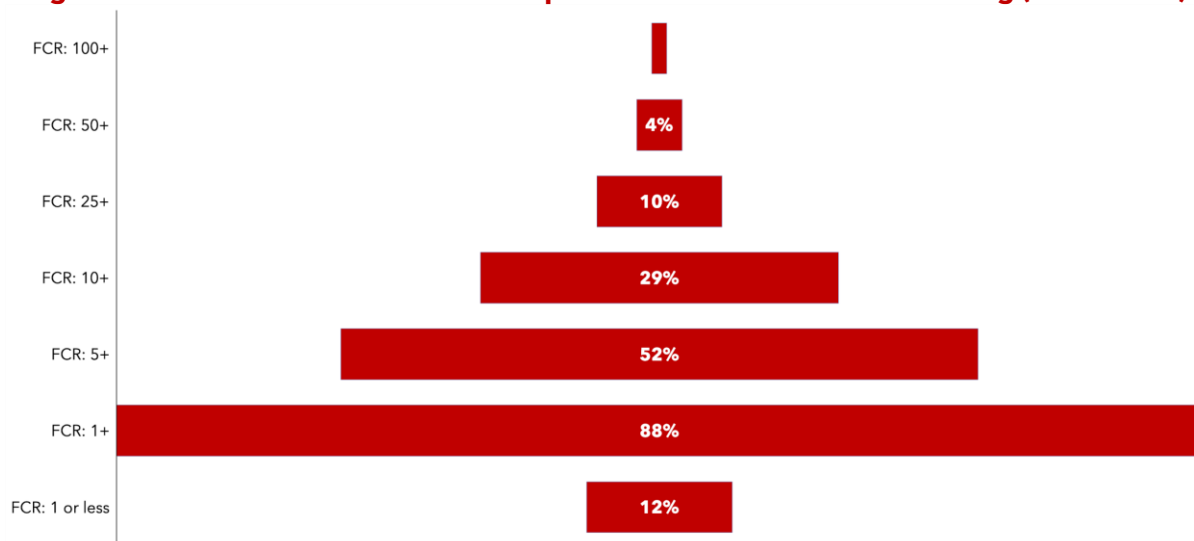
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Figure 18: Field Citation Ratio Score for publications linked to UKSA funding (2010-2018)

FCR: 100+	
FCR: 50+	4%
FCR: 25+	10%
FCR: 10+	29%
FCR: 5+	52%
FCR: 1+	88%
FCR: 1 or less	12%

Source: know.space analysis

Benchmarking citation performance

Benchmarking research linked to UKSA funding's performance, by comparing to averages across all disciplines for a given year, is important for understanding its impact. While the exact figures vary year-on-year, on average **7% of publications linked to UKSA funding placed in the global top 1% of FCR scores for their respective year**, across all disciplines. Around 25% of the examined research systematically performed in the world's top 5%, over 38% was in the top 10%, and 88% placed in the top 50%[24]. The following table shows the proportion of papers linked to UKSA funding in the top 1% over time.

Figure 19: Publications linked to UKSA funding in global top 1% of FCR scores

|	Publications linked to UKSA funding	Number in top 1%	Proportion in top 1%
2010	154	11	7%
2011	314	13	4%
2012	337	10	3%
2013	350	16	5%
2014	395	43	11%
2015	266	12	5%
2016	353	53	15%
2017	300	19	6%
2018	312	28	9%
Total	**2,781**	**205**	**7%**

Source: know.space analysis

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[24] The lower bound of the 51st, 91st, 96th, and 100th percentiles of FCR scores for the examined publications' year were used to determine these figures.

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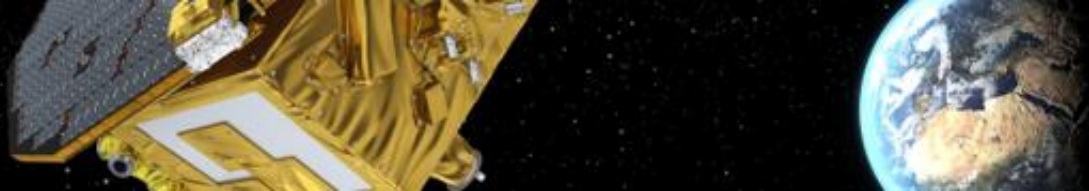
While the trends in the figure below show a decline for publications linked to UKSA funding reaching the world's top 10%, there is an increase for placement in the global top 1%. This could be interpreted as the UK maintaining a strong leadership role in the production of world-leading publications, against a backdrop of a general increase in highly cited publications from other countries, including emerging powers. A full understanding of the reasons for this would require further investigation.

While the exact figures differ due to the use of different indicators and benchmarks, both the present report and the 2017 Clarivate Analytics study find that research linked to UKSA funding has relatively high proportions of papers in the world's top 1% in terms of impact[25].

Figure 20: Percentage of publications linked to UKSA funding in the Top 1-5-10% of Field Citation Ratio score (worldwide; all disciplines) (2010-2018)
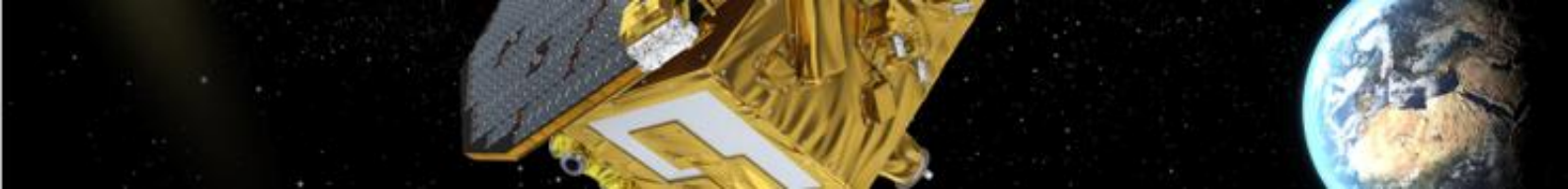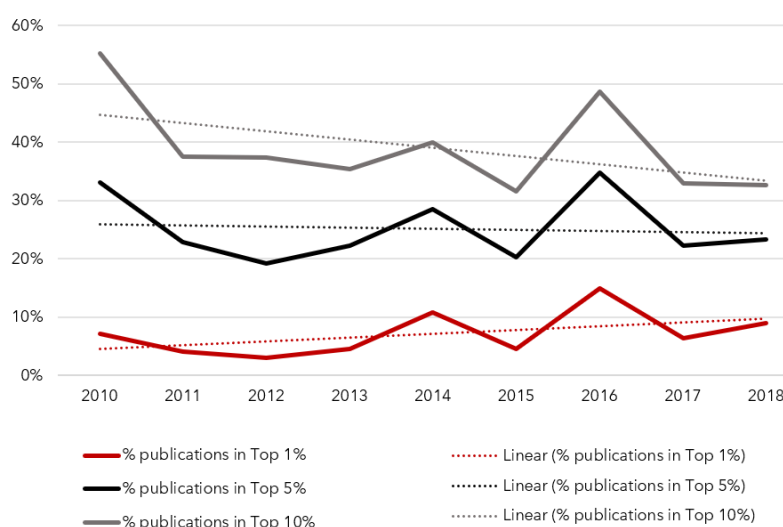

Source: know.space analysis

Altmetric score

Examining publications' altmetric score[26], which measures their attention outside citations (e.g. social media or news article mentions), can complement our understanding of their impact. This indicator can capture a publication's impact on the short-term (in fast-moving media like social and news outlets), which may be overlooked when looking solely at academic impact, as the latter tends to be built incrementally on the medium- and long-term. While it is an interesting indicator, as with any indicator it does have its limitations, such as increasing use of social media over time affecting the baseline, and no distinction being made between 'good' and 'bad' attention.[27]

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[25] The 2017 Clarivate Analytics report found that 3.8% of research linked to UKSA funding (top 5 UKSA categories) placed in the world top 1% in terms of citations, compared to 3.0% of UK research (top 5 UKSA categories).
[26] For further detail on how this is calculated, including caveats and limitations, see here: https://www.altmetric.com/about-altmetrics/what-are-altmetrics/
[27] Digital Science have published 'tips and tricks' for better understanding and use of Altmetrics: https://www.altmetric.com/about-altmetrics/tips-tricks/
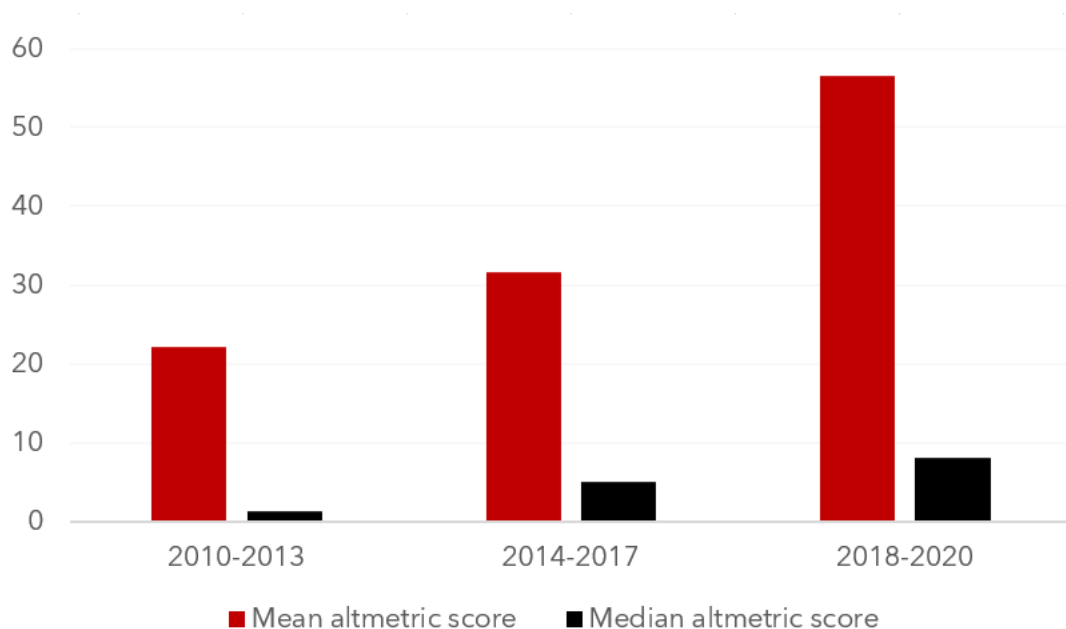
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Research linked to UKSA funding's altmetric performance increased gradually since the founding of the Agency in 2010[28]. This may suggest that recent publications (2018-2020), which tend to display a lower citation count than older research for the reasons discussed above, are already showing impact in other ways and to different audiences.

Two articles performed particularly well, ranking 33rd and 72nd respectively in the Altmetric Top 100, which ranks the leading research published in a given year by altmetric score.

The following chart presents mean and median scores. The mean for 2018-20 is skewed by there being a relatively large proportion of publications scoring particularly well for altmetric score in this period.

Figure 21: Mean and median altmetric score for publications related to UKSA funding (2010-2020)

Source: know.space analysis

The below table presents the 'top performer' publications linked to UKSA funding, in terms of their altmetric scores. As it presents the single highest scorers, it should not be seen as providing commentary on trends or other factors, simply a snapshot of the top five. In interpreting these and the above results, though, we also note that altmetric score is limited in its ability to show trends over time – particularly as social media use has varied so much in extent and type over time.

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[28] The altmetric scores for research published between 2010 and 2014 ought to be interpreted with caution, as the data for that period is sparser than for more recent publications.

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Figure 22: Top 5 publications linked to UKSA funding in altmetric score (2010-2020)

Title	Year	Authors	Journal	FCR score	Altmetric score
Water vapour in the atmosphere of the habitable-zone eight-Earth-mass planet K2-18 b	2019	Tsiaras, et al.	Nature Astronomy	32	3,383 *(ranked 33rd in the world for 2019)*
Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A	2018	Aartsen, et al.	Science	117	2, 174 *(ranked 72nd in the world for 2018)*
Multi-messenger Observations of a Binary Neutron Star Merger	2017	Abbott, et al.	The Astrophysical Journal Letters	479	1,525
Organic matter preserved in 3-billion-year-old mudstones at Gale crater, Mars	2018	Eigenbrode, et al.	Science	40	1,468
Transitory microbial habitat in the hyperarid Atacama Desert	2018	Schulze-Makuch, et al.	Proceedings of the National Academy of Sciences of the USA	19	1,213

Source: know.space analysis

Patents

Examining the references of research linked to UKSA funding in patents is also an interesting way to consider impact. Patent references can take many years to accrue, however, so reflecting (i) the relative youth of the UK Space Agency and (ii) the lag in reporting, the following results are best understood as illustrative of the types of impact we can see, rather than exhaustive.

The available data highlights that research linked to UKSA funding since 2010 was cited in **13 patent** applications, **of which 8 have been granted**.

Over half (7) of them were registered with the United States Patent and Trademark Office, with the rest falling under the jurisdiction of the World Intellectual Property Organization (4) and the European Patent Office (2). These patents are principally related to the research fields of **Physical Sciences** (5 patents/applications), **Engineering** (2) and **Technology** (2), and **Biological Sciences** (4).

These references in patents demonstrate that research linked to UKSA funding can be valuable for the development of implementable innovations. However, only 1 patent application was from a UK institution (University of Leicester) with almost all of the rest from the US. From filing to patents being granted, the average **lag time was 3.9 years.**

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Figure 23: Patent applications linked to UKSA funding

Granted patents	Date filed	Date granted	Lag (years)	Field of Research	Applicant country
Granted patents					
Affinity-based detection of ligand-encoded synthetic biomarkers	Jun-14	Jan-20	5.6	Technology	US
Magnetic probes for in vivo capture and detection of extracellular vesicles	Oct-16	Dec-19	3.2	Biological Sciences	US
Super-resolution systems and methods	Jun-17	Jul-19	2.1	Physical Sciences	US
Enhanced cancer detection through probe modification	Dec-15	May-19	3.4	Engineering	US
Deployable reflectarray antenna	Dec-17	Apr-19	1.3	Technology	US
Multiplexed detection with isotope-coded reporters	Mar-12	Jun-18	6.3	Chemical Sciences Biological Sciences	US
Methods and products for in vivo enzyme profiling	Jan-14	May-18	4.3	Biological Sciences	US
Methods and apparatus for X-ray diffraction	Apr-13	Apr-18	5.0	Physical Sciences	UK
Patents applied for (not yet granted)					
Divided-aperture infra-red spectral imaging system	Apr-19	-	-	Physical Sciences	US
Methods to spatially profile protease activity in tissue and sections	Apr-18	-	-	Biological Sciences	US
Microfluid chip-based, universal coagulation assay	Sep-15	-	-	Engineering	US
Retro-interferometer having active readjustment	Dec-14	-	-	Physical Sciences	Germany
System wirelessly transferring power to a target device over a modeled transmission pathway without exceeding a radiation limit for human beings	Nov-14	-	-	Physical Sciences	US

Policy documents

Publications may be used to develop or substantiate policy documents and, as such, policy document references can be illustrative of research impact. Again, the below figures may not fully capture the extent of publications linked to UKSA funding' policy impact due to the same reasons discussed above, i.e. time to accrue and the age of the Agency, and lags in reporting to the Agency.

Nonetheless, the bibliometric analysis revealed **15 policy document references** for research linked to UKSA funding. 80% of the publications cited were **published within the last 5 years**. Notably, *State of the Climate in 2016*, a publication linked to UKSA funding disseminated in the Bulletin of the American Meteorological Society, was the most cited in policy documents, with three mentions.

While only a few of the policy documents could be consulted, due to not all information being publicly available, the international impact of UKSA-publication is noteworthy. Indeed, three policy documents citing the latter were published in the US-based National Academies Press, highlighting UK-US knowledge transfers.

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The consulted policy documents ranged from an assessment of the review process for NASA missions and agenda-setting, a report on the implications of catalysis advancements for the optimal use of shale gas, and an updated assessment of ozone depletion.

As for patents, these references in policy documents demonstrate that the Agency's funded research is authoritative and useful for various stakeholders.

Datasets

Finally, the Dimensions database contains details of datasets that are associated with UKSA funding. While further research would be required to investigate the nature of these linked datasets in detail, i.e. who is using data linked to UKSA funding and for what purposes, we found that **134 datasets were associated with UKSA funding**. Over 50% of these datasets were from the past 4 years, perhaps indicative of rising impact over time.

Examples of linked datasets from 2019 include:

- Swift XRT follow-up of LIGO/Virgo GW triggers
- Data for: Feasibility Studies for Hydrogen Reduction of Ilmenite in a Static System for use as an ISRU Demonstration on the Lunar Surface
- Data for: Numerical modelling of the microwave heating behaviour of lunar regolith
- An updated study of potential targets for Ariel
- ExoData: A Python package to handle large exoplanet catalogue data

This may demonstrate that - beyond narrower measures such as citation impact - research linked to UKSA funding has great use to the wider community and plugs into a wider range of broader endeavours, setting the groundwork for further future impact.

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Conclusion and next steps

Over 3,000 publications have been linked to UKSA-funding since the creation of the Agency in 2010. Those were generated by more than 4,100 unique researchers. Research linked to UKSA-funding principally focused on the first-level FoRs of Physical Sciences, distantly followed by Earth and Chemical Sciences. More specifically, the examined publications mainly treated the second-level FoRs of Astronomical and Space Sciences and Atomic, Molecular, Nuclear, Particle, and Plasma Physics.

Furthermore, research linked to UKSA-funding exhibited high international collaboration rates, averaging at 80% between 2010 and 2020. The United States, the EU, Canada, Switzerland, and Russia were the main collaborating countries. European countries (especially Scandinavian countries) exhibited the highest number of authors of research linked to UKSA-funding per capita.

UK-based authors of publications linked to UKSA-funding were affiliated with organisations throughout the nation, although London, the South East of England, and Scotland dominated. Nevertheless, every region and devolved administration in the UK were home to organisations generating publications linked to UKSA-funding.

Overall, 88% of research linked to UKSA-funding performed better than average (i.e. above the median FCR for its respective year). Half of the research was 4 to 5 times more cited than average (FCR>4), and nearly 10% outperformed the average by a factor of 25. On average, 7% of publications linked to UKSA-funding placed in the global top 1% across all disciplines in a given year. Additionally, around 25% of the examined research was in the global top 5% and 38% in the top 10%. Over time, we have seen the share of publications linked to UKSA-funding in the top 10% fall slightly, but the share in the top 1% rise.

Moreover, 13 worldwide patents (applied for and/or granted) citing research linked to UKSA-funding were identified, ranging across the fields of Physical Sciences, Engineering, and Biological Sciences. The examined publications also exhibited 15 (global) policy document references and were cited in 134 datasets.

Some indicators may be useful to track over time to monitor the nature and impact of research linked to UKSA-funding and to inform corporate reporting. The following are suggestions of such metrics. In several cases, given the difficulties in year-on-year comparisons, we would suggest that metrics such as a 3- or 5-year moving average may be most appropriate.

On a yearly basis:

- Number of publications per year
- Proportion of international collaborations per year
- Field Citation Ratio (FCR) distributions
- Publications in the annual top 1/5/10% in FCR score

On a 3-5 year basis:

- Evolution of the most popular first- and second-level fields of research
- Evolution of the top collaborating countries
- Evolution of the top UK organisations generating research linked to UKSA-funding
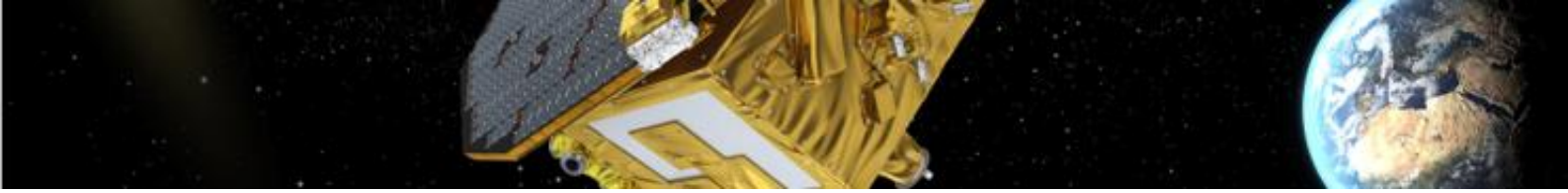
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- Evolution of the mean and median altmetric score

Finally, this was a relatively short study and further work would be useful to build a more in-depth understanding of the links between research linked to UKSA-funding and impact, and the nature of funded researchers. Specifically, further work could be carried out to:

- Benchmark UK performance relative to (i) other countries and (ii) areas of research.
- Investigate researcher characteristics, with regards to age and diversity characteristics such as gender, background, country of origin, etc.
- Understanding the extent and nature of the influence of research linked to UKSA-funding on policy documents and datasets, and how information/data is being used.
- Map publications to launch dates for specific missions and data releases, to build an understanding of what activity is driving impact.

These factors – and others – can be linked to, tracked and explored further in UKSA's internal work on monitoring and evaluation, and in the UKSA Results Framework.

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