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2023 RESEARCH FRONTS

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2023 RESEARCH FRONTS

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2023 RESEARCH FRONTS

BACKGROUND AND METHODOLOGY

1. BACKGROUND

The world of scientific research presents a sprawling, ever-changing landscape. The ability to identify where the action is and, in particular, to track emerging specialty areas, provides a distinct advantage for administrators, policy makers, and others who need to monitor, support, and advance the conduct of research in the face of finite resources.

To that end, Clarivate generates data and reports on "Research Fronts." These specialties are defined when scientists undertake the fundamental scholarly act of citing one another's work, reflecting a specific commonality in their research – sometimes experimental data, sometimes a method, or perhaps a concept or hypothesis.

By tracking the world's most significant scientific and scholarly literature and the patterns and groupings of how papers are cited – in particular, clusters of papers that are frequently cited together, "Research Fronts" can be discovered. When such a group of highly cited papers attains a certain level of activity and coherence (detected by quantitative analysis), a Research Front is formed, with these highly cited papers serving as the front's foundational "core." Research Front data reveal links among researchers working on related threads of scientific inquiry, even if the researchers' backgrounds might not suggest that they belong to the same "invisible college."

In all, Research Fronts afford a unique vantage point from which to watch science unfold – not relying on the possibly subjective judgments of an indexer or cataloguer, but hinging instead on the cognitive and social connections that scientists themselves forge when citing one another's work. The Research Fronts data provide an ongoing chronicle of how discrete fields of activity emerge, coalesce, grow (or, possibly, shrink and dissipate), and branch off from one another as they self-organize into even newer nodes of activity. Throughout this evolution, the foundations of each core – the main papers, authors, and institutions in each area – can be ascertained and monitored. Meanwhile, analysis of the associated citing papers (those papers that cite the core literature) provides a tool for unveiling the latest progress and the evolving direction of scientific fields.

In 2013, Clarivate published an inaugural report in which 100 hot Research Fronts were identified. In 2014 and 2015, *Research Fronts 2014 and Research Fronts 2015* were undertaken as a collaborative project by the Joint Research Center of Emerging Technology Analysis established by Clarivate and the National Science Library, Chinese Academy of Sciences (CAS). From 2016 to 2022, the Institutes of Science and Development, CAS, National Science Library, CAS, and Clarivate jointly released a succession of annually updated reports of Research Fronts. These reports have gained widespread attention from around the world.

This year, the same methodology with some modifications was employed. For the newest edition, *Research Fronts 2023*, 110 hot Research Fronts and 18 emerging Research Fronts were identified based on co-citation analysis that generated 12922 Research Fronts in the Clarivate database Essential Science Indicators (ESI).

2. METHODOLOGY

The study was conducted in two parts. The process of selecting and naming 128 Research Fronts was completed collaboratively by Clarivate and the Institute of Strategic Information within the Institutes of Science and Development, CAS. Moreover, Clarivate provided data on the core papers and citing papers of the selected 128 Research Fronts. Final selection of key Research Fronts (i.e., hot Research Fronts and emerging Research Fronts), and the interpretation of these respective specialty areas, were completed by the Institute of Strategic Information. For the 2023 update, the Research Fronts drew on ESI data from 2017-2022, which were obtained in March 2023.

2.1 RESEARCH FRONTS SELECTION AND NAMING

Research Fronts 2023 presents a total of 128 Research Fronts, including 110 hot and 18 emerging ones. In 2023, the Research Fronts are classified into 11* broad research areas in the sciences and social sciences. Starting from 12922 Research Fronts in ESI, the objective was to discover which Research Fronts were most active or developing most rapidly.

The specific methodology used for identifying the 128 Research Fronts is described as follows.

2.1.1 SELECTING THE HOT RESEARCH FRONTS

This year, two methods were used for selecting hot Research Fronts. Method 1 continued the selection methods from previous years. Method 2, based on the Research Front selection methods in the fields of mathematics and information in 2022, was further improved in 2023.

Method 1: Research Fronts in each ESI field were first ranked by total citations, and the Top 10% of the fronts in each ESI field were extracted. These Research Fronts were then merged into 11 broad areas and re-ranked according to the average (mean) year of their core papers to produce the "youngest" ones in each broad area. Based on these data, the strategic information professionals with domain knowledge adjusted and merged some Research Fronts. Through the aforementioned steps, several hot Research Fronts were selected in 11 broader areas.

Method 2: Research Fronts were ranked based on their average citations per core paper, and those above the mean calculated independently in each of the 11 broader areas were selected. Then, re-ranked them according to mean publication years of their core papers. The Research Fronts that met the criteria were selected and have the strategic information professionals assess whether the candidate fronts have accelerated the advancements of knowledge in each area. By combining the two methods mentioned above, a total of 110 hot Research Fronts were selected, with 10 in each of the 11 broader areas. The 10 fronts selected for each of the 11 highly aggregated main areas of science and social sciences represent the hottest of the largest fronts, not necessarily the hottest Research Fronts across the database (all disciplines). Due to the different characteristics and citation behaviors in various disciplines, some fronts are much smaller than others in terms of number of core and citing papers.

2.1.2 SELECTING THE EMERGING RESEARCH FRONTS

A Research Front with core papers of recent vintage indicates a specialty with a young foundation that is rapidly growing. To identify emerging specialties, the immediacy of the core papers is a priority, and that is why it is characterized as "emerging." For the 11 broader areas, to identify emerging specialties,

* 11 broader areas include "Agricultural, plant and animal sciences", "Ecology and environmental sciences", "Geosciences", "Clinical medicine", "Biological sciences", "Chemistry and materials science", "Physics", "Astronomy and astrophysics", "Mathematics", "Information science", and "Economics, psychology and other social sciences".

extra preference, or weight, was given to the currency of the foundation literature: only Research Fronts whose core papers dated, on average, to the second half of 2021 or more recently were considered. Then these were sorted in descending order by their total citations in each ESI field corresponding to the 11 broader areas. The top 10% Research Fronts were selected and delivered to the Institute of Strategic Information, where information professionals with domain knowledge made the final selection of emerging Research Fronts and grouped them into 11 broader fields. Eighteen fronts were selected as emerging for the 11 broader areas. Because the selection was not limited to any research area, the 18 fronts are distributed unevenly in the 11 fields. For example, there are five emerging Research Fronts in "Clinical medicine", but only one in "Geosciences".

Based on the above two methods, the report presents the Top 10 hot fronts in each of the 11 broad areas (110 fronts in total) and 18 emerging ones.

2.1.3. NAMING THE RESEARCH FRONTS

Based on the research themes, main contents, and characteristics of the selected Research Fronts, the strategic information professionals re-named each of the 128 Research Fronts and made some adjustments after consulting the domain experts.

2.2 FINAL SELECTION AND INTERPRETATION OF KEY RESEARCH FRONTS

Based on the core papers and citing papers of 128 Research Fronts provided by Clarivate, information professionals at the Institute of Strategic Information, conducted a detailed analysis and interpretation to highlight 31 key Research Fronts (Chapter 2 to Chapter 12) of particular interest, including both hot and emerging fronts.

As discussed above, a Research Front consists of a core of highly cited papers along with the citing papers that have frequently co-cited the core. In other words, core papers are all highly cited papers in ESI – papers that rank in the top 1% in terms of citations in the same ESI field and in the same publication year. Since the authors, institutions and countries/regions listed on the core papers have made significant contributions to the particular specialty, a tabulation of these appears in the analysis of the Research Fronts. Meanwhile, by reading the full text of the citing articles, greater precision can be obtained in specifying the topic of the Research Front, especially in terms of its recent development or leading-edge findings. In this case, it is not necessary that the citing papers are themselves highly cited.

2.2.1 FINAL SELECTION OF KEY RESEARCH FRONTS

In Research Fronts 2014, an index known as CPT was designed to select key Research Fronts. From 2015 on, a scale indicator, the number of core papers (P), has also been considered.

(1) The number of core papers (P)

ESI classifies Research Fronts according to the co-cited paper clusters and reveals their development trend based on the metadata of the paper clusters, along with statistical analysis. The number of core papers (P) indicates the size of a Research Front, and average (mean) publication year and the time distribution of the core papers demonstrates the progress of the area. The number of core papers (P) also illustrates the importance of the knowledge base in the Research Fronts. In a certain period of time, a higher P value usually represents a more active Research Front.

(2) CPT indicator

The CPT indicator was applied to identify the key Research Fronts. C represents the number of citing articles, i.e., the tally of articles citing the core papers; P is the number of core papers; T indicates the age of citing articles, which is the number of citing years, from the earliest year of a citing paper to the latest one. For example, if the most-recent citing paper was published in 2022 and the earliest citing paper was published in 2018, the age of citing articles (T) equals 5.

$$CPT = (C / P) / T = \frac{C}{P \cdot T}$$

CPT is the ratio of the average citation impact of a Research

Front to the age/occurrence of its citing papers, meaning the higher the number, the hotter or the more impactful the topic. It measures how extensive and immediate a Research Front is and can be used to explore the emerging or developing aspects of Research Fronts and to forecast future possibilities. The degree of citation influence can be seen from the amount of citing papers, while it also takes the publication years of citing papers into account and demonstrates the trend and extent of attention on certain Research Fronts across years.

Given the condition that a particular Research Front was cited continuously,

1) When P as well as T is equal in two Research Fronts, the higher C is, the higher CPT will be, indicating the broader citation influence of the Research Front with higher C.

2) When C as well as P is equal in two Research Fronts, the lower T, the higher CPT, indicating the Research Front with lower T attracts more intensive attention in a short period.

3) When C as well as T is equal in two Research Fronts, the lower P, the higher CPT, indicating the broader citation influence of the Research Front with lower P.

In the *Research Fronts 2023,* for each of the 11 broad research areas, one key hot Research Front was selected based on the number of core papers (P) in combination with the professional judgment of analysts from the Institute of Strategic Information. Another key hot Research Front was chosen by the indicator CPT. Based on their knowledge, the analysts assessed the significance of the key hot Research Fronts in addressing major issues in the given area. Firstly, the Research Front with the greatest number of core papers (P) in a broad research area was selected. If the front with the greatest P had been interpreted in previous years and there was no significant change of the core papers, then the Research Front with the second highest P would be selected as the key hot Research Front, and so on. Furthermore, another key hot front was selected based on the integration of CPT and professional judgement.

By taking advantage of the above two indicators as well as our domain experts' judgment, we selected 22 key hot Research Fronts from the 110 hot Research Fronts in the 11 broad research areas. Moreover, based on CPT and experts' judgment, nine key emerging Research Fronts were selected from the emerging Research Fronts. Thus, we interpret in detail the selected 31 key Research Fronts from the 128 Research Fronts.

2.2.2 ANALYSIS AND INTEPRETATION OF KEY RESEARCH FRONTS

Based on the data of the selected 128 Research Fronts, the development trends of the 110 hot Research Fronts in the 11 broad areas were analyzed, and the research themes of the emerging Research Fronts were revealed and researched. The 31 key Research Fronts were subsequently examined in greater detail.

(1) Examination of key hot Research Fronts

In each broad area, the development trends of the Top 10 hot Research Fronts, including the important research directions, distribution characteristics, and evolving trends of Research Fronts, were analyzed based on the number of core papers, times cited, mean publication year of core papers, and the annual change of the citing paper distribution.

The first table under each discipline section lists the 10 top ranked Research Fronts for each of the 11 broad areas, as well as the number of core papers, total citations, and the average publication year of the core papers of each Research Front. A bubble diagram shows the age distribution of the citing articles in the 10 Research Fronts listed for each broad area. The size of the bubble represents the quantity of citing articles per year. Key hot Research Fronts can be easily identified, particularly when large amounts of citing papers appear in a very short publication window (i.e., the first two explanations for CPT's values, as discussed above). But other data must be considered when the number of core papers is small. Generally speaking, the number of citing papers in most fronts will grow with time, so the bubble diagram can also help us understand the development of the Research Fronts.

For the two key hot Research Fronts selected in each broad area, their concepts and connotations, development contexts, layout of research force were further analyzed and interpreted, and the research content, value, and impact of the top cited core papers were revealed.

The first table for each key hot Research Front statistically analyzes the affiliated countries/regions and institutions represented in the core papers and summarizes their active status, thereby revealing the players making fundamental contributions in the key hot Research Front. Countries/regions and institutions of the citing papers in a key hot Research Front are analyzed in the second table to reveal their research strategy as they carry forward the work in these specialty areas.

(2) Interpretation of key emerging Research Fronts

Because the emerging Research Fronts identified were usually small in terms of number of core and citing papers, the figures did not generally lend themselves to detailed statistical analysis. Nevertheless, information professionals endeavored to examine and interpret the research topics to better understand the fundamental concepts, the current research breakthroughs, and future development prospects in the key emerging Research Fronts.

2023 RESEARCH FRONTS

AGRICULTURAL, PLANT AND ANIMAL SCIENCES

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN AGRICULTURAL, PLANT AND ANIMAL SCIENCES

The Top 10 hot Research Fronts in agricultural, plant and animal sciences mainly involve six subfields, consisting of food science and engineering; plant immune regulation; abiotic stress responses in plants; plant growth and development regulation; plant genome, and animal nutrition (Table 1, Figure 1). The subfield of food science and engineering accounts for three hot Research Fronts, pertaining respectively to substitution of plant-based meat and cultured meat; microencapsulation of probiotics in food; and structure and function of food protein bioactive peptides. Two hot Research Fronts concern plant immune regulation, focusing on the immune mechanism mediated by NLR immune receptors, and the mechanism of signal transduction regulation mediated by plant RALF peptides. Two fronts occupy the subfield of abiotic stress responses in plants, with one front centering on the mechanism of nanoparticles for enhancing cadmium tolerance and drought resistance in crops, and the other examining physiological mechanisms of drought-induced tree mortality. The subfields of plant growth and development regulation, plant genome, and animal nutrition each account for one front; these research areas are devoted, respectively, to immunoregulatory function of extracellular vesicles in plants, crop pan-genome research, and feed additives for improving the immunity of aquatic animals.

Compared with previous Research Front surveys, research in the aforementioned subfields, as represented by hot fronts, has been ongoing for a decade and has registered frequently in previous Top 10 lists for many years. Notably, both crop pan-genome research in the subfield of plant genome, and the plant immune mechanism mediated by NLR immune receptors in the subfield of plant immune regulation, have continuously appeared in the Research Front roundup for three years since 2021. Meanwhile, the current high research interest in the substitution of plant-based meat and cultured meat has made it into the Top 10 list for the first time.

Table 1: Top10 Research Fronts in agricultural, plant and animal sciences

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Research on feed additives for improving the immunity of aquatic animals	22	1561	2020.3
2	The plant immune mechanism mediated by NLR immune receptors	49	5160	2020.2
3	Research of substitution of plant-based meat and cultured meat	50	3961	2020.2
4	Mechanism of nanoparticles for enhancing cadmium tolerance and drought resistance in crops	22	1790	2020.0
5	Study on microencapsulation of probiotics in food	20	1735	2019.9
6	Structure and function of food protein bioactive peptides	34	3123	2019.8
7	Immunoregulatory function of extracellular vesicles in plants	21	2030	2019.8
8	The mechanism of signal transduction regulation mediated by plant RALF peptides	18	1683	2019.8
9	Physiological mechanisms in drought-induced tree mortality	19	2649	2019.7
10	Crop pan-genome research	17	2864	2019.4

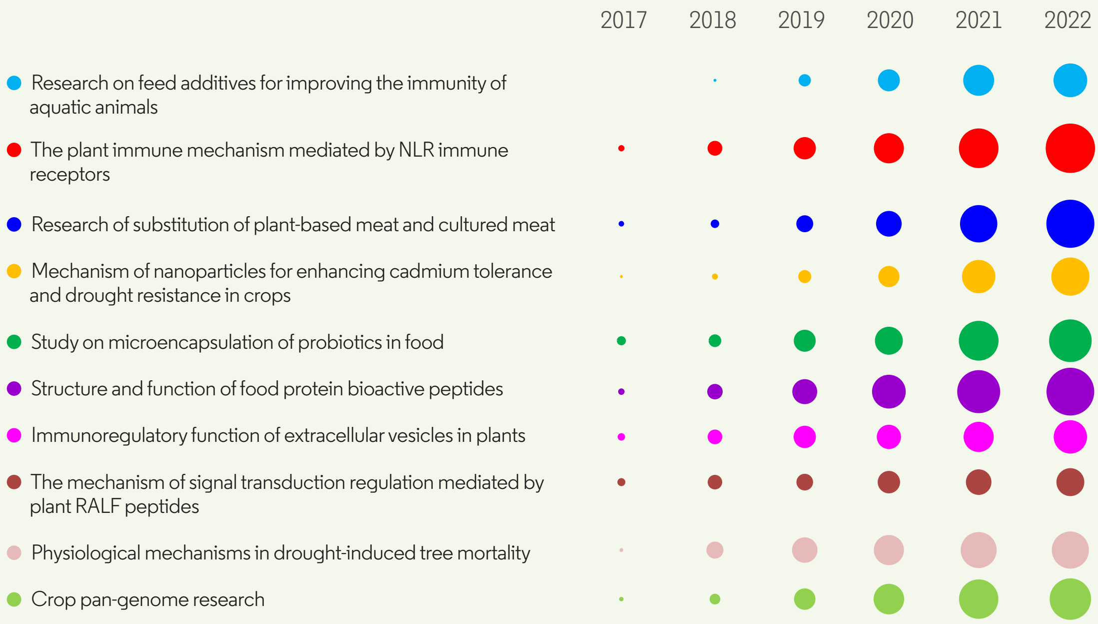


Figure 1: Citing papers for the Top 10 Research Fronts in agricultural, plant and animal sciences

1.2 KEY HOT RESEARCH FRONT – "Research of substitution of plant-based meat and cultured meat"

The advancement of agricultural technology and the intensification of animal husbandry have increased the efficiency and yield of meat production. Therefore, meat is relatively cheap and easy to access in developed countries/regions. However, intensive meat production has adverse effects on public health, the environment, and animal welfare. The Food and Agriculture Organization of the United Nations (FAO) has predicted that global meat demand will reach 455 million tons by 2050, an increase of 76% compared to 2005. Therefore, to reduce the negative impact of animal husbandry, academic and industrial communities are striving to explore the use of non-animal source materials to produce meat—especially through techniques such as cell culture engineering and tissue engineering—to cultivate animal muscle tissue *in vitro*. This type of meat product is called cultured meat. In 2001, the Dutch government provided funding to universities for cultured meat research, and in 2002, NASA funded research on culturing goldfish meat. In 2013, Dutch scientists achieved the first edible cultured meat. Subsequently a company was established to promote its commercial production. In 2019, researchers at Nanjing Agricultural University successfully cultivated the first cell-cultured meat in China using pig muscle stem cells. With the continuous development of technology, the cost of cultured meat is gradually decreasing. In 2021, Future Meat Technologies, an Israeli cell meat company, developed a technology for high-density culture of animal cells in a reactor and established a patented technology for medium filtration and regeneration, reducing the price of laboratory-cultured chicken from $150/pound in 2019 to $3.9/pound. With the ongoing advent of new technologies and the gradual reduction of cost, the research and production of cultured meat will continue to receive attention.

Fifty core papers underlie this hot Research Front, including 22 review articles and 28 research articles. The reviews mainly discuss the technical, socio-political, and regulatory challenges facing the commercialization of cultured meat, including consumer awareness and acceptance of plant-based meat and cultured meat; production methods for plant-based meat and cultured meat; and the history, driving forces, and manufacture of plant-based meat development. On the other hand, the research articles primarily investigate consumer preferences for plant-based meat and cultured meat burgers, compare the climate-change impact of cultured meat production and beef cattle farming, and explore the structural potential and physico-chemical properties of plant-based meat preparation.

Among the 50 core papers, the most frequently cited is a review article, having attracted 287 citations at this writing (Figure 2). It was published in *Trends in Food Science & Technology* in 2017 by researchers at the Swiss Federal Institute of Technology (ETH) in Zurich, providing a systematic review of consumer perceptions and behaviors towards sustainable protein consumption. Among the 28 research articles, the most cited has currently attracted 139 citations (Figure 2). Published in *Appetite* in 2018 by researchers at the University of Saskatchewan in Canda, the paper investigated consumer preferences for plant-based and cultured meat burgers. The results showed that if prices were equal, 65% of consumers would purchase the beef burger, 21% would purchase the plant-based burger, 11% would purchase the cultured meat burger, and 4% would make no purchase. Those two highly cited papers suggest that the further development and large-scale commercial production of plant-based meat and cultured meat still faces consumer-preference issues. Therefore, a high level of attention centers on this area.

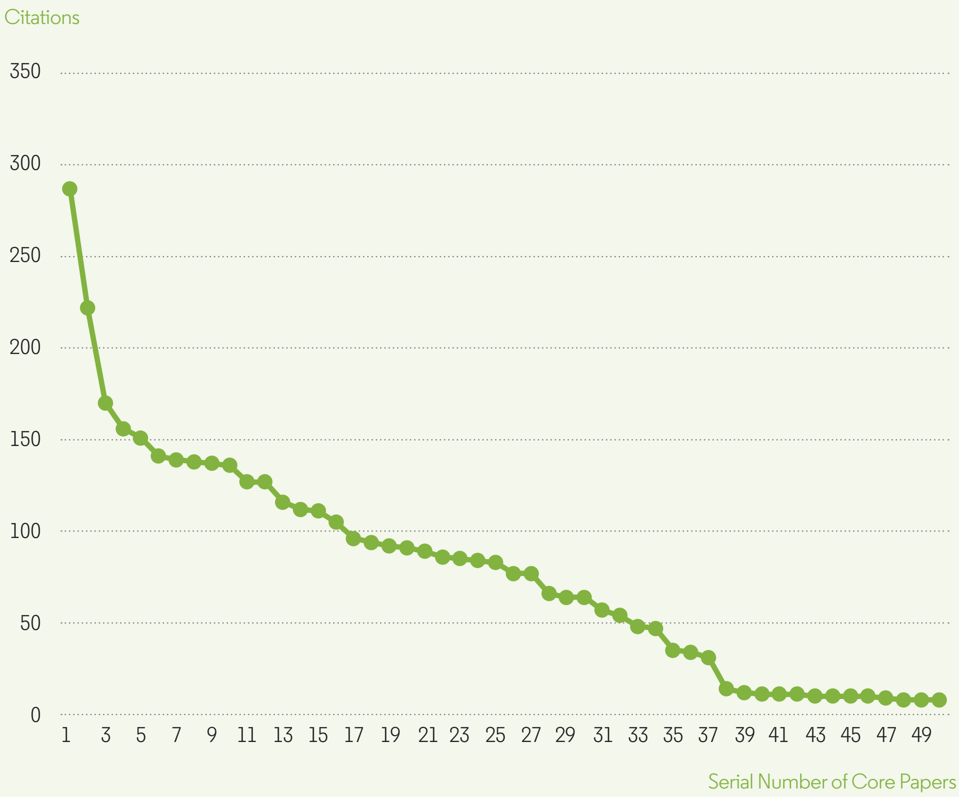


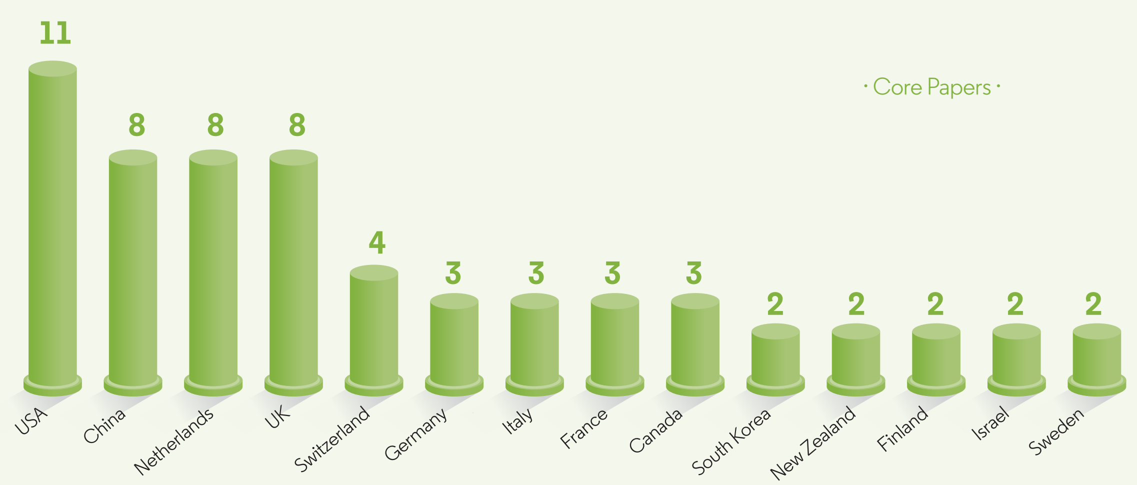
Figure 2: Citation frequency distribution curve of core papers in the Research Front "Research of substitution of plant-based meat and cultured meat"

Among the top countries and institutions producing this front's core papers (Table 2), the USA has the highest contribution rate, with its 11 papers accounting for 22.0% of the total. China, the Netherlands, and the UK each contribute nine papers and are tied for the third place. Among the prolific contributing institutions, Wageningen University & Research Center in the Netherlands has performed strongly, ranking 1st, while the University of Bath in the UK ranks 2nd. Northeast Agricultural University in China, the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland, Tufts University in USA and the National Research Institute for Agriculture, Food and Environment in France stand side by side, ranking 3rd. By this measure, it is demonstrable that the USA, China, the Netherlands, and the UK have devoted a heightened level of attention to meat alternatives research.

Table 2: Top countries and institutions producing core papers in the Research Front "Research of substitution of plant-based meat and cultured meat"

Country Ranking	Country	Core Papers	Proportion
1	USA	11	22.0%
2	China	8	16.0%
2	Netherlands	8	16.0%
2	UK	8	16.0%
5	Switzerland	4	8.0%
6	Germany	3	6.0%
6	Italy	3	6.0%
6	France	3	6.0%
6	Canada	3	6.0%
10	South Korea	2	4.0%
10	New Zealand	2	4.0%
10	Finland	2	4.0%
10	Israel	2	4.0%
10	Sweden	2	4.0%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Wageningen University & Research Center	Netherlands	7	14.0%
2	University of Bath	UK	5	10.0%
3	Swiss Federal Institute of Technology in Zurich	Switzerland	3	6.0%
3	Tufts University	USA	3	6.0%
3	National Research Institute for Agriculture, Food and Environment	France	3	6.0%
3	Northeast Agricultural University	China	3	6.0%
7	University of Massachusetts Amherst	USA	2	4.0%
7	University of Oxford	UK	2	4.0%
7	Michigan State University	USA	2	4.0%
7	Purdue University	USA	2	4.0%
7	University of Kentucky	USA	2	4.0%
7	Aleph Farms Ltd	Israel	2	4.0%
7	Technion Israel Inst Technol	Israel	2	4.0%
7	University of Parma	Italy	2	4.0%

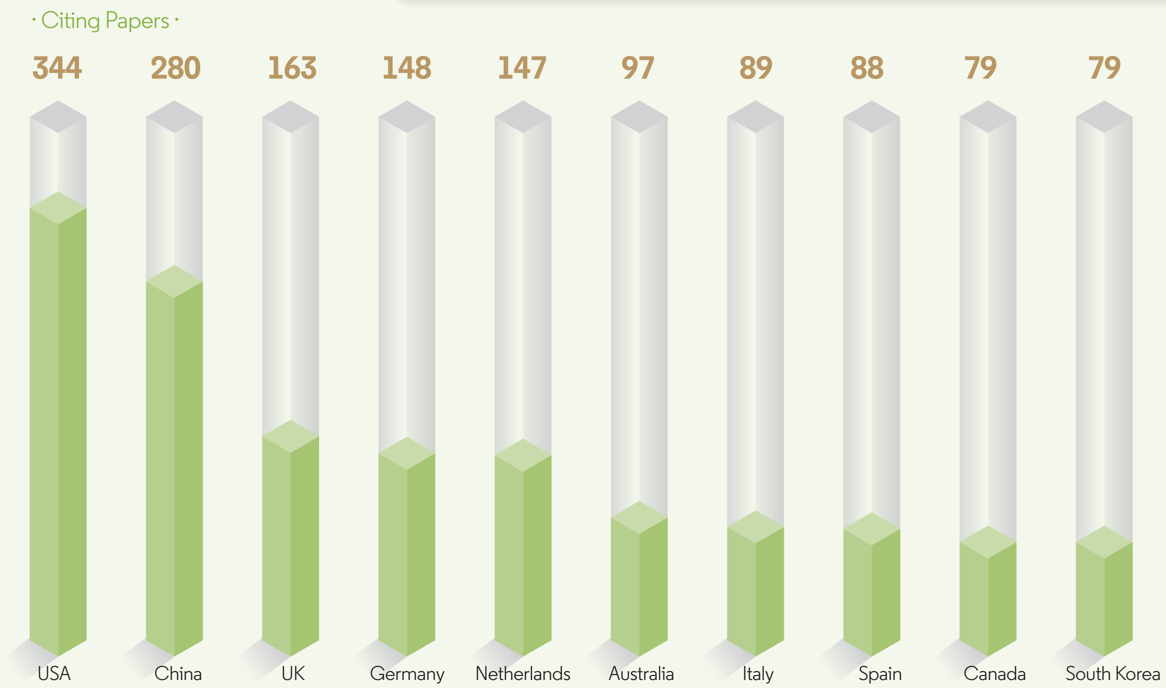


In terms of countries and institutions that cite the core papers in this hot front (Table 3), the USA and China, which, as noted above, rank 1st and 2nd by their respective number of core papers, are also the two most prolific contributing countries in terms of papers that cite the core literature—far ahead of other countries. This is a clear indication that the USA and China continue to maintain robust research activity in this area. The UK, Germany and the Netherlands have actively pursued research in this subfield, forming a second tier according to the measure of citing papers. In terms of citing institutions, researchers at Wageningen University & Research Center in the Netherlands have contributed to 100 citing papers, leading other institutions. Jiangnan University, Nanjing Agricultural University, and the Chinese Academy of Agricultural Sciences in China are also notable for their prolific follow-up research, ranking 2nd, 7th, and 9th, respectively.

Table 3: Top countries and institutions producing citing papers in the Research Front "Research of substitution of plant-based meat and cultured meat"

Country Ranking	Country	Citing Papers	Proportion
1	USA	344	20.1%
2	China	280	16.4%
3	UK	163	9.5%
4	Germany	148	8.6%
5	Netherlands	147	8.6%
6	Australia	97	5.7%
7	Italy	89	5.2%
8	Spain	88	5.1%
9	Canada	79	4.6%
9	South Korea	79	4.6%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Wageningen University & Research Center	Netherlands	100	5.8%
2	Jiangnan University	China	41	2.4%
3	University of Massachusetts Amherst	USA	37	2.2%
4	Helsinki University	Finland	33	1.9%
5	Swiss Federal Institute of Technology Zurich	Switzerland	29	1.7%
6	University of Oxford	UK	24	1.4%
7	Nanjing Agricultural University	China	23	1.3%
7	University of Bath	UK	23	1.3%
9	Aarhus University	Denmark	22	1.3%
9	Chinese Academy of Agricultural Sciences	China	22	1.3%
9	University of Hohenheim	Germany	22	1.3%



1.3 KEY HOT RESEARCH FRONT – "The plant immune mechanism mediated by NLR immune receptors"

The prevention and control of plant diseases in farmland remains an important research challenge to be overcome for agricultural development, and the matter is of great significance for food security, ecological security, and public health. Utilizing disease resistance genes for resistance breeding is one of the most effective means of preventing and controlling plant diseases. Among those genes, the most valuable and widely used is the gene type coding NLR immune receptors, which is the largest type of disease resistance gene in the plant immune system. Although nearly 26 years have elapsed since the NLR disease resistance gene was first cloned, the academic community still knows very little about how the NLR receptors recognize pathogen and initiate disease resistance responses. Many major scientific issues merit further study. As a result, the plant immune mechanism mediated by NLR immune receptors has become a hot frontier in the field of plant immune research, and progress has been continuous.

Forty-nine core papers underlie this hot Research Front, including 32 research articles and 17 review articles. Among the 32 research articles, 21 of were published in *Cell, Science, Nature*, or their respective sub journals. These research articles mainly investigate the immune and pattern recognition receptors mediated by NLR networks against various plant pathogens, the induction of NLR immune receptor complex by pathogens, and the mutual enhancement of plant immunity by cell surface and intracellular receptors. Meanwhile, the review articles mainly elaborate on the structural basis of NLR activation; the evolution, assembly, and regulation of NLR; the diversity of NLR and various strategies for binding to pathogens, as well as its association with other receptors in immunity. Among the 49 core papers, the most cited is a review article with 332 citations at this writing (Figure 3). It was published in *Plant Cell* in 2018 by researchers at Oxford University in the UK, and systematically reviews the cloning of resistance genes and nine resistance mechanisms over the past 25 years, including the important mechanism of the interaction between the NLR protein and pathogens. Among the research articles, the most-cited paper has been cited nearly 300 times to date and was published in *Science* in 2019 by researchers at Tsinghua University, the Chinese Academy of Sciences, the Max Planck Society, and the University of Cologne in Germany. This article reconstructs an immune plant NLR antibody complex for studying the biochemical mechanism of plant NLR activation.

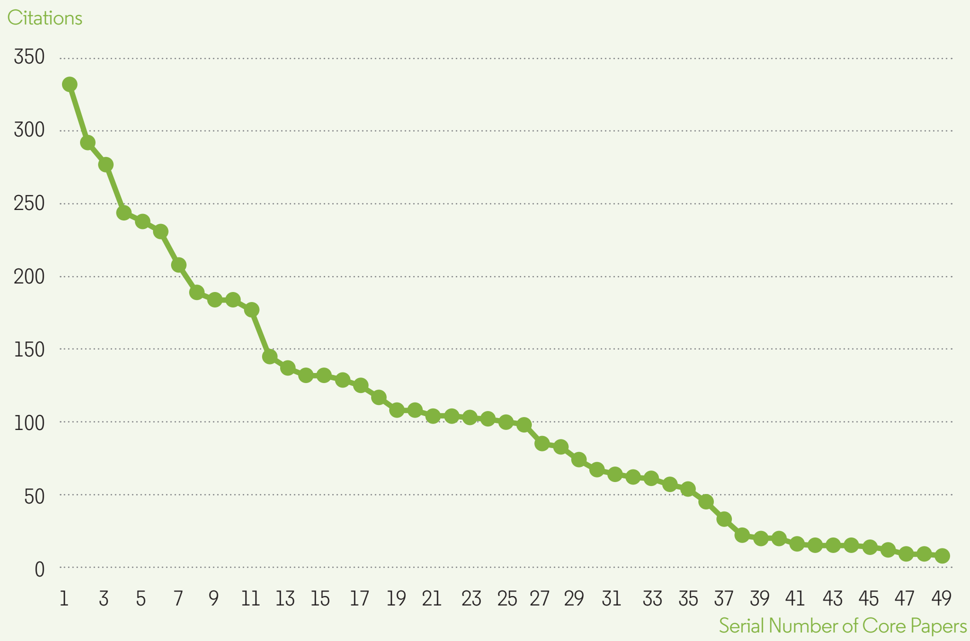


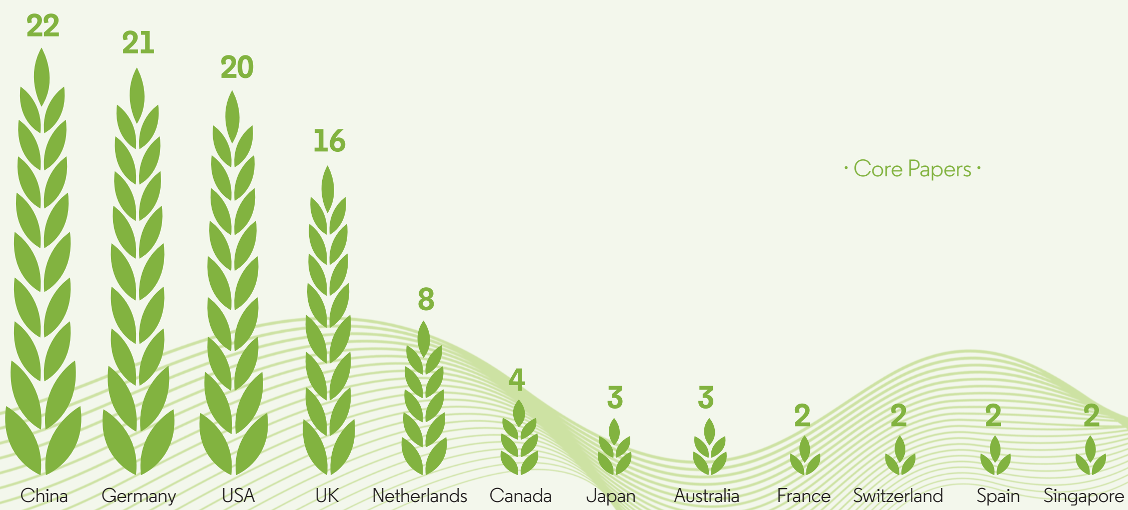
Figure 3: Citation frequency distribution curve of core papers in the Research Front "The plant immune mechanism mediated by NLR immune receptors"

Among the countries and institutions producing core papers (Table 4), China, Germany, and the USA have higher contribution rates, with 22, 21, and 20 papers, all surpassing 40% of the total. Among the prolific contributing institutions, the Max Planck Society performs outstandingly, ranking 1st with 16 core papers and a contribution rate of 32.7%. The Biotechnology and Biological Sciences Research Council (BBSRC) in the UK ranks 2nd, having contributed 24.5% of the core literature. The Chinese Academy of Sciences and University of Cologne rank 3rd with a contribution rate of 20.4%.

Table 4: Top countries and institutions producing core papers in the Research Front "The plant immune mechanism mediated by NLR immune receptors"

Country Ranking	Country	Core Papers	Proportion
1	China	22	44.9%
2	Germany	21	42.9%
3	USA	20	40.8%
4	UK	16	32.7%
5	Netherlands	8	16.3%
6	Canada	4	8.2%
7	Japan	3	6.1%
7	Australia	3	6.1%
9	France	2	4.1%
9	Switzerland	2	4.1%
9	Spain	2	4.1%
9	Singapore	2	4.1%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Max Planck Society	Germany	16	32.7%
2	BBSRC	UK	12	24.5%
3	University of Cologne	Germany	10	20.4%
3	Chinese Academy of Sciences	China	10	20.4%
5	University of East Anglia	UK	8	16.3%
5	Tsinghua University	China	8	16.3%
7	Howard Hughes Medical Institute	USA	7	14.3%
8	University of California Berkeley	USA	5	10.2%
8	University of North Carolina	USA	5	10.2%
10	University of British Columbia	Canada	4	8.2%
10	Washington University in St. Louis	USA	4	8.2%
10	Eberhard Karls University of Tubingen	Germany	4	8.2%
10	University of Cambridge	UK	4	8.2%

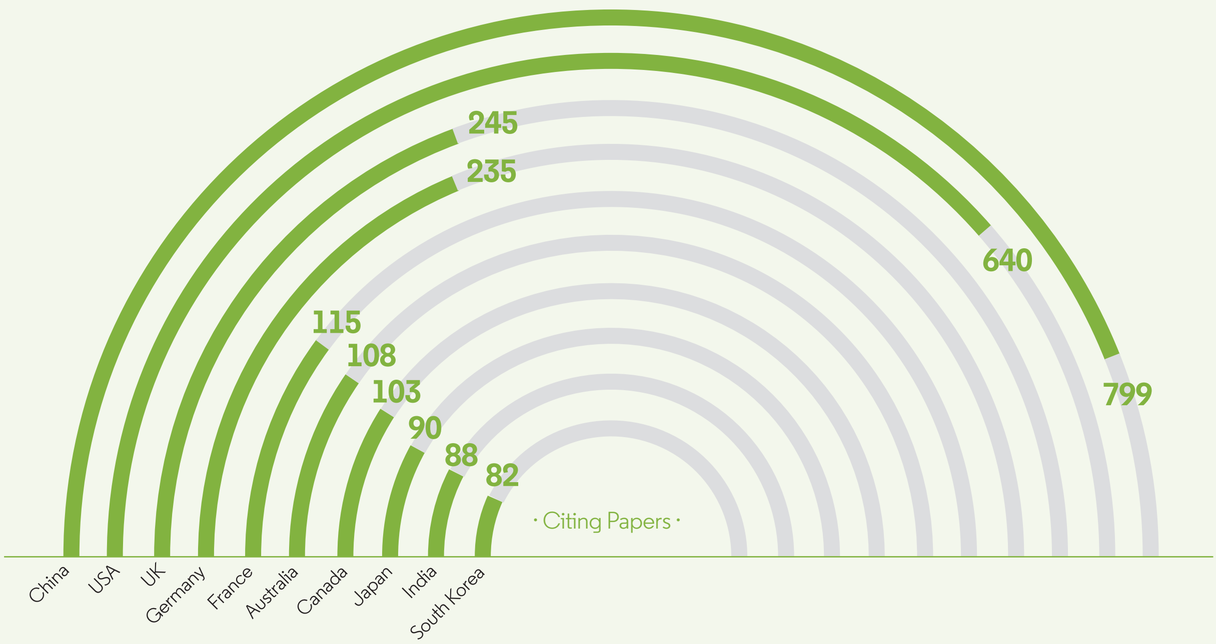


In terms of countries and institutions that cite the core papers of this hot front (Table 5), China and the USA rank 1st and 2nd respectively, matching their ranking in core papers, accounting for over 30%, far surpassing other countries. In terms of citing institutions, BBSRC ranks 1st. China has five institutions in the Top 10: the Chinese Academy of Sciences, the Chinese Academy of Agricultural Sciences, Nanjing Agricultural University, China Agricultural University, and Zhejiang University.

Table 5: Top countries and institutions producing citing papers in the Research Front "The plant immune mechanism mediated by NLR immune receptors"

Country Ranking	Country	Citing Papers	Proportion
1	China	799	39.2%
2	USA	640	31.4%
3	UK	245	12.0%
4	Germany	235	11.5%
5	France	115	5.6%
6	Australia	108	5.3%
7	Canada	103	5.0%
8	Japan	90	4.4%
9	India	88	4.3%
10	South Korea	82	4.0%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	BBSRC	UK	130	6.4%
2	Chinese Academy of Sciences	China	123	6.0%
3	Chinese Academy of Agricultural Sciences	China	88	4.3%
4	Max Planck Society	Germany	87	4.3%
5	Nanjing Agricultural University	China	76	3.7%
6	National Research Institute for Agriculture, Food and Environment	France	73	3.6%
7	University of East Anglia	UK	69	3.4%
8	National Center for Scientific Research of France (CNRS)	France	65	3.2%
9	China Agricultural University	China	45	2.2%
10	Zhejiang University	China	44	2.2%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN AGRICULTURAL, PLANT AND ANIMAL SCIENCES

In the area of agricultural, plant and animal sciences, one emerging Research Front has been identified: "Recognition and localization methods for fruit picking robots" (Table 6).

Table 6: Emerging Research Fronts in agricultural, plant and animal sciences

Rank	Emerging Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Recognition and localization methods for fruit picking robots	8	198	2021.9

2.2 KEY EMERGING RESEARCH FRONT – "Recognition and localization methods for fruit picking robots"

A picking robot is a flexible automated or semi-automatic device that operates on fruits or vegetables. It combines partial human information perception and limb movement functions, and can be repeatedly programmed. It is an intelligent machine that integrates various disciplines such as electronics, machinery, computers, sensing technology, control technology, artificial intelligence, bionics, and agriculture. Using picking robots instead of human labor can not only reduce labor intensity, but also improve labor efficiency and help solve the problem of labor scarcity. Therefore, the picking robot has garnered attention from developed countries with relatively small agricultural workforces and has become one of the competitive focuses of international agricultural machinery technology. For picking robots, especially fruit-picking robots, the complex natural conditions in which the fruits are located often lead to the situation that the fruit is obstructed by branches and leaves or overlapped with other fruits. This significantly hinders the recognition of machine vision systems. Therefore, the methods for fruit recognition and positioning in fruit picking robots have become a hot research topic.

All eight core papers in this emerging Research Front are research articles. The main research contents include: the detection of banana bunches and stalks in banana orchards; a lightweight neural network model of deep learning for real-time detection of banana bunches and stalks; a deep learning algorithm for fast and precise recognition of banana fruits, inflorescence axes, and flower buds; a recognition method for detecting accurate litchi-picking locations on the main stems; a long-close distance coordination control strategy for a litchi-picking robot; the visual positioning of a banana robot for accurately position the rachis and cut off point; and convolutional neural networks for grape object detection.

2023 RESEARCH FRONTS

ECOLOGY AND ENVIRONMENTAL SCIENCES

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN ECOLOGY AND ENVIRONMENTAL SCIENCES

The Top 10 hot Research Fronts in ecology and environmental sciences are mainly distributed in two sub-areas: ecological sciences, and environmental sciences (Table 7 and Figure 4). Emerging environmental issues and innovative solutions are the predominant themes in this year.

The hot Research Fronts in the environmental-science subfield mainly focus on emerging environmental issues such as microplastics, climate change, ozone pollution, as well as innovative solutions or new research area such as new water pollution control technologies and environmental epidemiology.

Research on microplastic pollution has been central to hot fronts in environmental sciences in the past decade, with related topics being selected as Top 10 hot Research Fronts multiple times for the years 2015 to 2017 and 2020 to 2022. Two hot fronts for 2023 focus on microplastics, including "Adsorption of pollutants on microplastics particles" and "Environmental fate and Eco-toxicity of microplastics in soils".

Needless to say, climate change is a significant global environmental issue of current concern, with the capture of carbon dioxide and the reduction methane registering as hot topics in the effort to reduce greenhouse gas emission. There are two related hot fronts in this year: "Techno-economic assessment of CO_2 direct air capture" and "Global trends and sources of methane emissions".

In recent years, China's efforts to prevent and control air pollution have achieved phased results, with a continuous decrease in fine particulate matter (PM2.5) concentration. However, ozone pollution has shown a rapid rise and spread, leading to repeated occurrence of large-scale and long-term ozone pollution. The situation is severe. In response to this issue, "Ozone pollution and its health risks in China" has registered as a hot front this year.

In addition, degradation of organic pollutants by persulfate-related studies emerged in the 2017, 2018, and 2022 surveys. Another of this year's hot fronts, "Activating of peroxymonosulfate with singleatom catalysts", demonstrates that emerging single atom catalysts (SACs) are appealing materials in environmental catalysis with advantages such as ultrahigh performances, environmental friendliness, structural/chemical robustness, and the maximized utilization of active metal sites for advanced oxidation processes in environmental remediation.

Meanwhile, "Detection of SARS-CoV-2 in wastewater and COVID-19 epidemiologi-cal surveillance based on wastewater" has been selected as a hot front for the second consecutive year. In the post-epidemic era, wastewater-based epidemiological research is an innovative, cost-effective solution for monitoring drugs, viruses, superbugs, as well as tracking COVID-19 outbreaks.

The hot Research Fronts in the ecological-science subfield mainly emphasize biodiversity and ecological governance, as examined in three fronts: "The current status of insect declines, extinctions, and driving factors", "The global freshwater biodiversity crisis and the impacts of dams", and "Theory and application of 'Nature-based Solutions'". Among these fronts, biodiversity-related research has been a continuous hot topic for many years, and "The current status of insect declines, extinctions, and driving factors" has now been listed as a hot front for the third consecutive year. "Nature-based Solutions" is a new concept that comprehensively utilizes multidisciplinary management approaches within ecosystems. Pertinent research on the theory, method, and applications in various fields is gradually emerging.

Table 7: Top 10 Research Fronts in ecology and environmental sciences

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Activation of peroxymonosulfate with single-atom catalysts	16	1825	2021.0
2	Detection of SARS-CoV-2 in wastewater and COVID-19 epidemiological surveillance based on wastewater	30	6050	2020.3
3	Techno-economic assessment of CO_2 direct air capture	6	1011	2020.0
4	Adsorption of pollutants on microplastics particles	39	5732	2019.6
5	Environmental fate and eco -toxicity of microplastics in soils	48	9518	2019.5
6	The current status of insect declines, extinctions, and driving factors	12	4449	2019.4
7	Ozone pollution and its health risks in China	23	5898	2019.1
8	The global freshwater biodiversity crisis and the impacts of dams	14	3577	2019.1
9	Theory and application of "Nature-based Solutions"	10	1836	2018.9
10	Trends and sources of global methane emissions	9	1835	2018.9

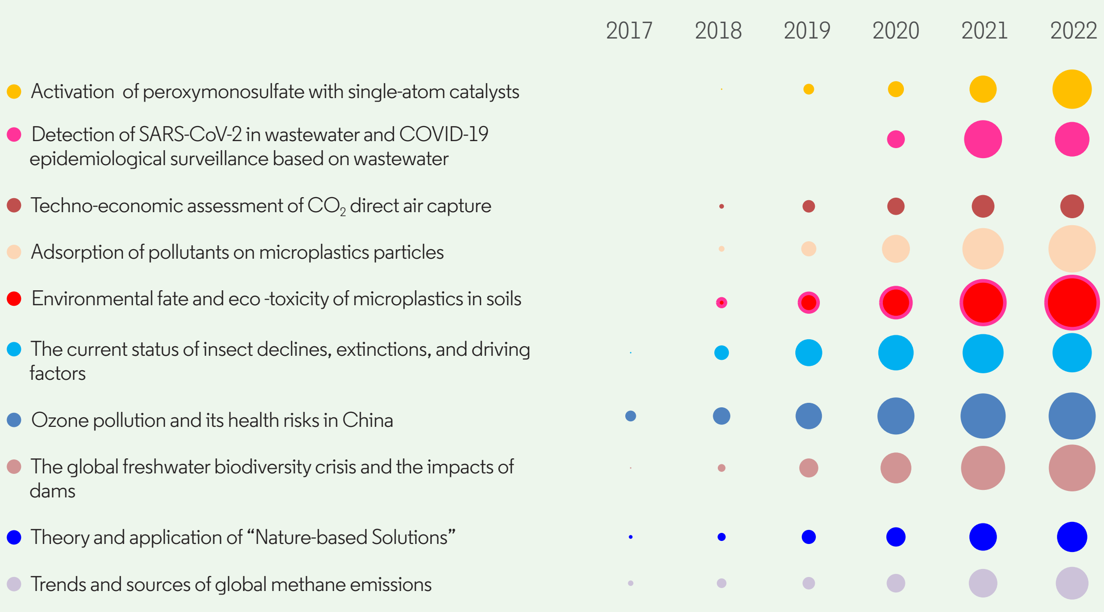


Figure 4: Citing papers for the Top 10 Research Fronts in ecology and environmental sciences

1.2 KEY HOT RESEARCH FRONT "Environmental fate and eco-toxicity of microplastics in soils"

Microplastics are often defined as plastic debris and particles with a diameter smaller than 5 mm. According to specific particle size, they can be categorized into nanoplastics (1~100 nm), submicron plastics (100 nm~1μm), and micron plastics (1μm~5 mm). The concept of microplastics was first proposed by British scientist Richard Thompson in 2004 and has gradually become a focus in global environmental issues. Microplastics are pervasive in the global environment. Research has reported the widespread and substantial presence of microplastics in oceans, lakes, rivers, soil, and the atmosphere. Microplastics have also been found in organisms and human tissue. Due to their tiny size, large quantities, and wide distribution, microplastics are easily ingested by organisms—thereby accumulating in the food chain—and can further concentrate in living tissue, endangering the health of organisms. Microplastic pollution is becoming one of the most serious threats to the entire ecosystem. International actions on plastic pollution have been launched. On March 2, 2022, during the fifth United Nations Environment Assembly, 175 United Nations members reached a consensus to establish a legally binding international agreement to prevent and control plastic pollution.

Microplastic pollution has been a perennial hot topic in the annual Research Fronts, with investigation of microplastic pollution in oceans and terrestrial water bodies having been selected among active fronts over several years. Recently, soil microplastic pollution has emerged as a new research hotspot.

This front includes 48 core papers, focusing on the following main directions: (1) Analytical methods for detecting microplastics in soil. (2) The sources and distribution characteristics of soil microplastics, as well as their distribution and accumulation in different tissues of organisms, especially crops. The use of plastic mulch in farmland has caused serious microplastic pollution and has led to the largescale dispersal of microplastics in agricultural environments. The distribution of microplastic pollution in China has also received considerable attention. (3) The ecological and environmental impacts caused by microplastics alone or in combination with other environmental problems. One example is the synergistic effects of pollution by microplastics and heavy metals such as cadmium, arsenic, and others. Microplastics, serving as the carriers of resistance genes, bacteria, and other pollutants, have implications in crop growth and development, not to mention physiological functions. Additionally, microplastics can influence the physiochemical properties of the soil and the overall soil ecosystem.

In this Research Front, the most-cited core paper was published by researchers at the University of Bonn, Germany. The report reviews methods of analysis and possible sources of microplastics in soil. This article was published in *Science of the Total Environment* in 2018 and has been cited 522 times. In addition, Michael Scheurer and Moritz Bigalke, of the University of Bern in Switzerland, published a paper in *Environmental Science & Technology* in 2018, reporting that 90% of the soil in Swiss floodplains contains microplastics mainly generated by human activities and has been dispersed to remote areas via the wind. The paper has been now cited more than 460 times.

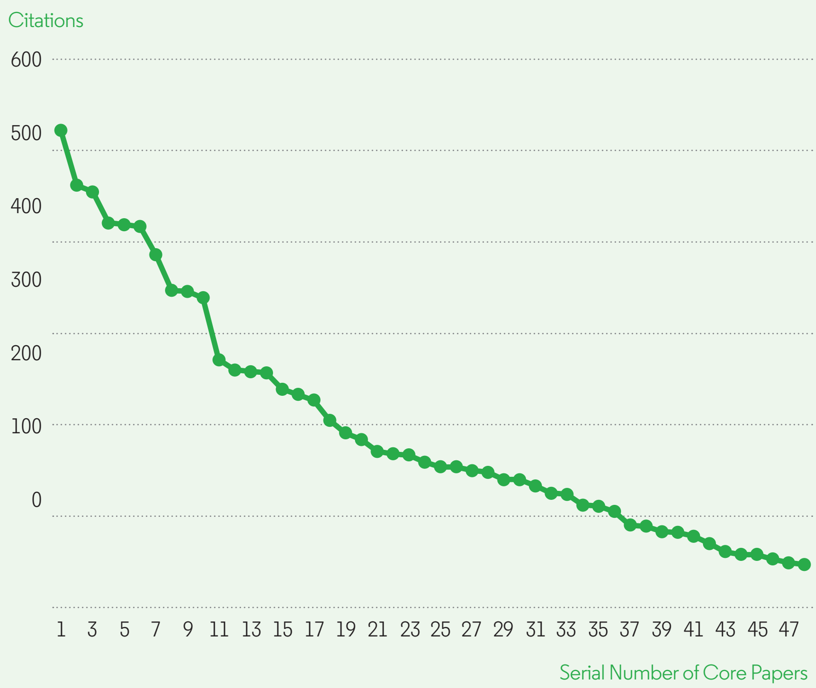


Figure 5: Citation frequency distribution curve of core papers in the Research Front "Environmental fate and eco-toxicity of microplastics in soils"

Regarding the countries and institutions behind the core papers (Table 8): China is the largest contributor to this Research Front, with a total of 34 core papers, accounting for 70.8% of the total, and far exceeding other countries. The Netherlands and Germany rank 2nd and 3rd with 20.8% and 18.8% core papers, respectively. As for the most prolific institutions, the Chinese Academy of Sciences and Wageningen University & Research Center in the Netherlands rank as the top two, respectively fielding 10 and 8 core papers.

Table 8: Top countries and institutions producing core papers in the Research Front "Environmental fate and eco-toxicity of microplastics in soils"

Country Ranking	Country	Core Papers	Proportion
1	China	34	70.8%
2	Netherlands	10	20.8%
3	Germany	9	18.8%
4	Mexico	5	10.4%
5	USA	4	8.3%
6	Chile	3	6.3%
7	Spain	2	4.2%
7	UK	2	4.2%
7	New Zealand	2	4.2%
10	Switzerland	1	2.1%
10	Italy	1	2.1%
10	Croatia	1	2.1%
10	Honduras	1	2.1%
10	Australia	1	2.1%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Chinese Academy of Sciences	China	10	20.8%
2	Wageningen University & Research Center	Netherlands	8	16.7%
3	Colegio de la Frontera Sur	Mexico	5	10.4%
3	Northwest A&F University	China	5	10.4%
3	Free University of Berlin	Germany	5	10.4%
6	East China Normal University	China	4	8.3%
6	Peking University	China	4	8.3%
8	Chinese Academy of Agricultural Sciences	China	3	6.3%
8	Nankai University	China	3	6.3%
8	University of Gottingen	Germany	3	6.3%
8	Zhejiang A&F University	China	3	6.3%
8	China Agricultural University	China	3	6.3%
8	Berlin-Brandenburg Institute of Advanced Biodiversity Research	Germany	3	6.3%

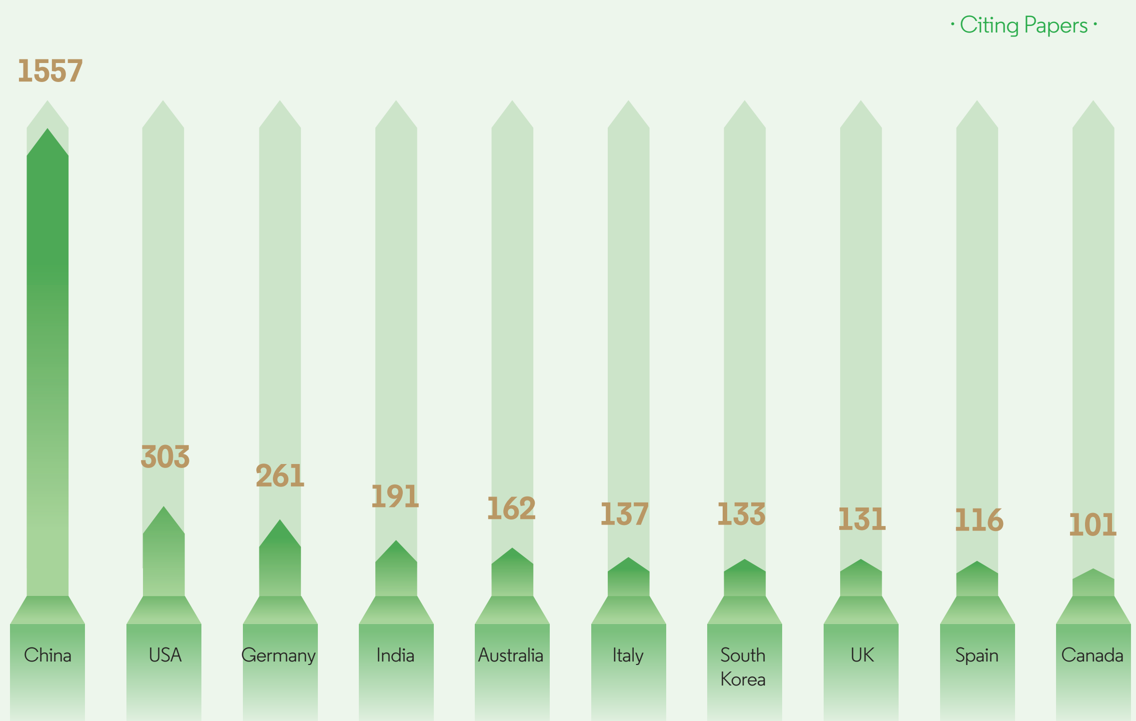
In terms of the countries and institutions citing the core papers (Table 9), China remains the country with the highest number of citing papers, with a total of 1,557, accounting for more than half of the total. The USA and Germany rank 2nd and 3rd with 303 and 261 citing papers, respectively. Among the Top 10 citing institutions, nine are based in China, with the one exception being Wageningen University & Research Center in the Netherlands, ranking 9th. The Chinese Academy of Sciences and Northwest A&F University rank 1st and 2nd with respective totals of 305 and 123 citing papers.

Based on its number of core papers and citing papers, China plays a dominant position and has made significant contributions in this Research Front.

Table 9: Top countries and institutions producing citing papers in the Research Front "Environmental fate and eco-toxicity of microplastics in soils"

Country Ranking	Country	Citing Papers	Proportion
1	China	1557	51.9%
2	USA	303	10.1%
3	Germany	261	8.7%
4	India	191	6.4%
5	Australia	162	5.4%
6	Italy	137	4.6%
7	South Korea	133	4.4%
8	UK	131	4.4%
9	Spain	116	3.9%
10	Canada	101	3.4%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	305	10.2%
2	Northwest A&F University	China	123	4.1%
3	Chinese Academy of Agricultural Sciences	China	69	2.3%
4	Nankai University	China	68	2.3%
5	Nanjing University	China	65	2.3%
6	South China Agricultural University	China	64	2.2%
7	Zhejiang University	China	62	2.1%
8	China Agricultural University	China	59	2.1%
9	Wageningen University & Research Center	Netherlands	57	2.0%
10	East China Normal University	China	53	1.8%



1.3 KEY HOT RESEARCH FRONT "Theory and application of 'Nature-based Solutions'"

According to the definition first proposed by the International Union for Conservation of Nature (IUCN) in 2016, Nature-based Solutions (NbS) are actions to protect, sus-tainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide for both human well-being and bi-odiversity benefits. NbS are not only imperative for addressing the dual crises of global biodiversity loss and climate change, but also a necessary mechanism to achieve the goals of sustainable development, and an essential tool for promoting conservation. The IUCN has put forward 8 Criteria and 28 Indicators for NbS, advocating for relying on the power of nature and ecosystem-based approaches to address societal challenges such as climate change (adaptation and mitigation); disaster risk reduction; ecosystem degradation and biodiversity loss; food security; human health; and water security. As a new concept, NbS was swiftly embraced by the international community upon its in-troduction. Many countries/regions have already taken action to incorporate NbS into their national climate strategies.

Ten core papers anchor this Research Front, largely focusing on the discussion of the connotation of NbS, application principles, implementation framework, cases and experiences of multi-disciplinary practice, and evaluation of value and effectiveness. The most-cited core paper derives from collaborative work by a small group of European countries, published in *Science of the Total Environment*. In this paper, the authors analyze NbS in relation to similar concepts, discussing the impact of NbS on science, policy, and practice, and proposing key elements for its implementation. The report emphasizes ensuring the rational use of multidisciplinary and interdisciplinary knowledge, highlighting the need to connect practitioners, policymakers, and scientists from different disciplinary fields to conduct joint research and design and implement NbS. Fur-thermore, the paper advocates that the practice should be based on a set of balanced, clear, widely accepted, and implementable key principles. This paper was published in 2017 and its citation total currently reach to 370.

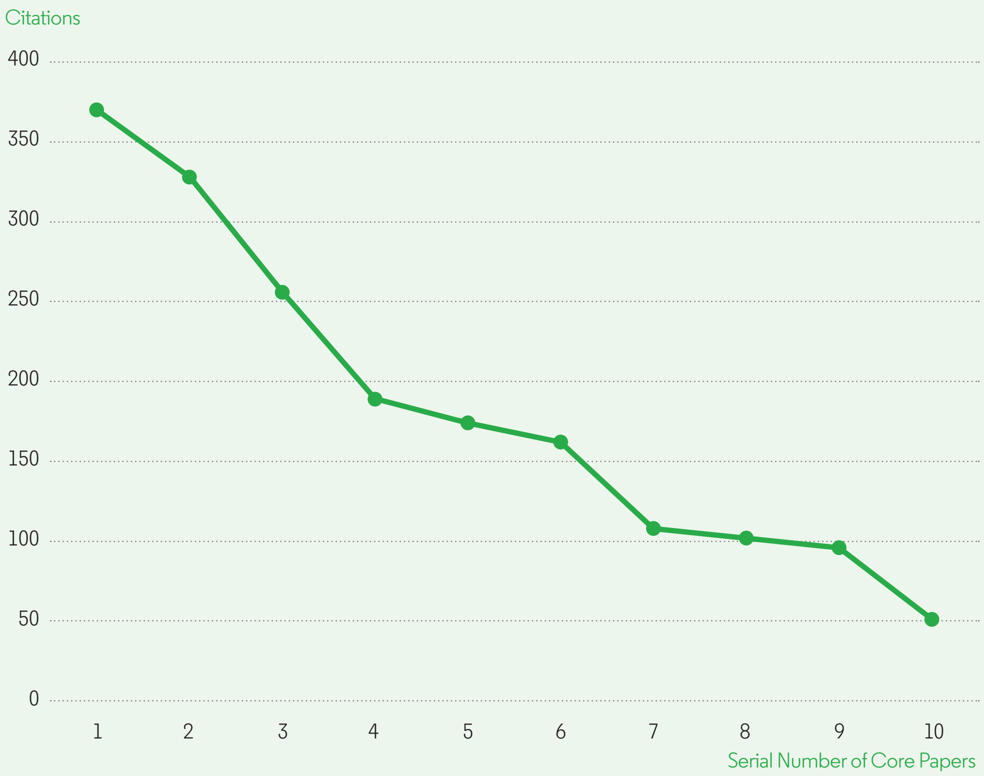


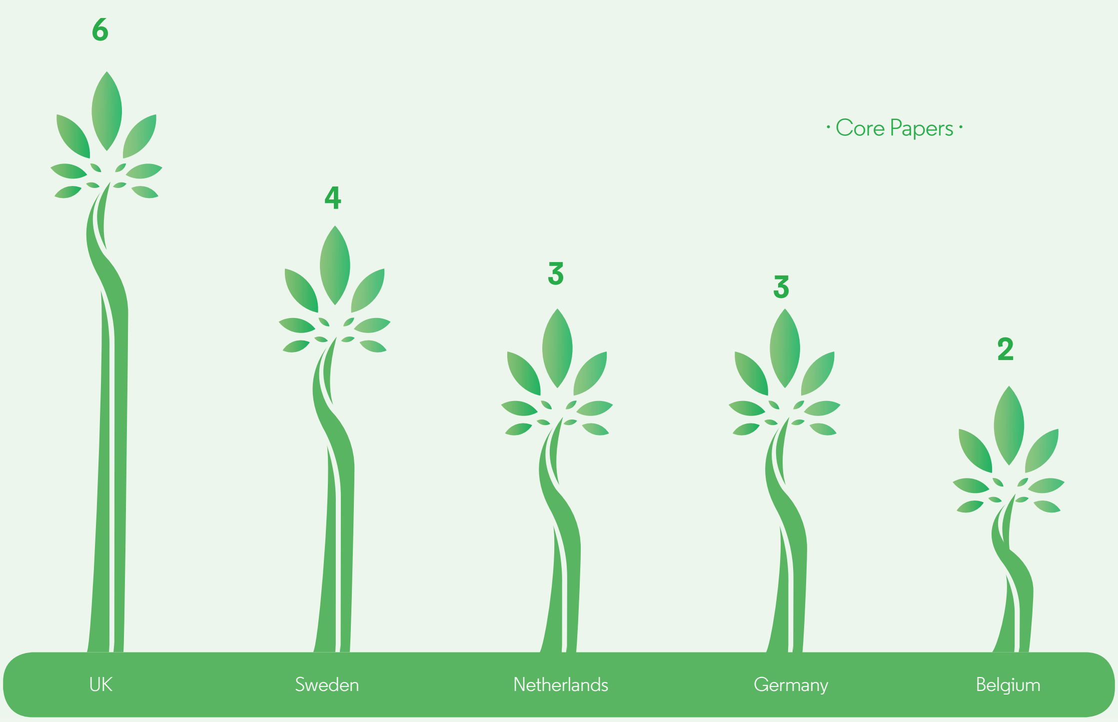
Figure 6: Citation frequency distribution curve of core papers in Research Front "Theory and application of 'Nature-based Solutions'"

Statistics on the countries and institutions in this front (Table 10) indicate that the UK and other European countries have played a leading role in this Research Front, with institutions based in the UK and Germany accounting for the preponderance of core papers.

Table 10: Top countries and institutions producing core papers in the Research Front "Theory and application of 'Nature-based Solutions'"

Country Ranking	Country	Core Papers	Proportion
1	UK	6	60.0%
2	Sweden	4	40.0%
3	Netherlands	3	30.0%
3	Germany	3	30.0%
5	Belgium	2	20.0%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	University of Oxford	UK	4	40.0%
2	Humboldt University of Berlin	Germany	3	30.0%
3	Helmholtz Association	Germany	2	20.0%
3	Erasmus University Rotterdam	Netherlands	2	20.0%

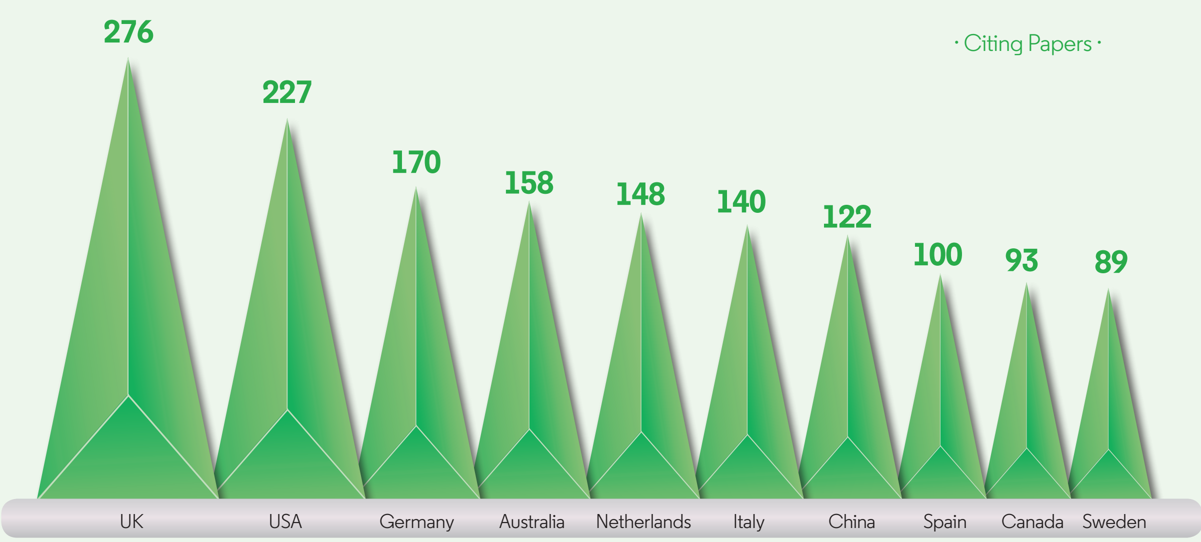


By the measure of citing papers (Table 11), the UK is also the most prolific country in following up on this research, with its 276 citing papers accounting for about a quarter of the total. The USA and Germany rank 2nd and 3rd, respectively. China contributed 122 citing papers, ranking 7th. In terms of citing institutions, Wageningen University & Research Center in the Netherlands and the Helmholtz Association in Germany capture the top two berths, each publishing more than 50 citing papers. The Chinese Academy of Sciences contributes 29 citing papers, ranking 7th. It is the only Chinese institution among the Top 10 institutions.

Table 11: Top countries and institutions producing citing papers in the Research Front "Theory and application of 'Nature-based Solutions'"

Country Ranking	Country	Citing Papers	Proportion
1	UK	276	23.5%
2	USA	227	19.3%
3	Germany	170	14.5%
4	Australia	158	13.4%
5	Netherlands	148	12.6%
6	Italy	140	11.9%
7	China	122	10.4%
8	Spain	100	8.5%
9	Canada	93	7.9%
10	Sweden	89	7.6%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Wageningen University & Research Center	Netherlands	54	4.6%
2	Helmholtz Association	Germany	51	4.3%
3	University of Oxford	UK	45	3.8%
4	Humboldt University of Berlin	Germany	37	3.1%
5	University of Melbourne	Australia	32	2.7%
5	Utrecht University	Netherlands	32	2.7%
7	Chinese Academy of Sciences	China	29	2.5%
8	National Center for Scientific Research of France (CNRS)	France	26	2.2%
9	University of Exeter	UK	25	2.1%
10	University of British Columbia	Canada	24	2.0%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ECOLOGY AND ENVIRONMENTAL SCIENCES

The area of ecology and environmental sciences features one emerging Research Front: “Detection and exposure of microplastics in human tissue”.

Table 12: Emerging Research Fronts in ecology and environmental sciences

Rank	Emerging Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Detection and exposure of microplastics in human tissue	2	216	2022.0

2.2 KEY EMERGING RESARCH FRONT “Detection and exposure of microplastics in human tissue”

As discussed above, microplastics constitute a global pollutant that has been widely detected in oceans, fresh water, terrestrial soil, sediments, atmosphere, organisms, and food and drinking water. Research shows that microplastics may enter the human body through various pathways including air, water, food, or personal care products such as toothpastes, cosmetics, and the like.

Two core papers in this emerging front focus on quantitative detection and exposure studies of microplastics in human tissue. In 2022, a study led by Netherlands-based scientists at the Vrije Universiteit Amsterdam, was published in *Environment International*. This research team reported the detection of microplastics in human blood. Microplastics were detected in 80% of blood samples from 22 healthy volunteers. This pioneering human-biomonitoring study demonstrated that plastic particles are bioavailable for uptake into the human bloodstream. At this writing, the paper has been cited 172 times. Another core paper was also published in 2022, in *Science of the Total Environment*. Researchers at the University of Hull in the UK reported for the first time that microplastic pollution was detected in human lung tissue. Microplastics even exist in the lower lung regions.

This emerging front sparks further contemplation of troubling questions: Where in the human body will microplastics next turn up? Can they be eliminated or will they accumulate in certain organs, potentially even pass through the blood-brain barrier? Therefore, it is necessary to continue to monitor the prevalence and character of microplastics in the human body and the hazards associated with microplastics exposure, and to determine the precise extent of the public-health risks posed by these pollutants.

2023 RESEARCH FRONTS

GEOSCIENCES

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN GEOSCIENCES

The multidisciplinary field of geosciences is highly dependent on observation technology. In 2023, six of the Top 10 Research Fronts in geosciences focus on geography, with three fronts pertaining to atmospheric science and one to planetary geology. Most of these specialties use advanced technical methods and models such as Earth system models and Earth observation technologies to promote new scientific discoveries. “Causes and impact of higher climate sensitivity in CMIP6 models”, and “Configuration optimization and development progress of various Earth System Models” continuously optimize Earth system models to help to better analyze past, present, and future climate change, while providing strong scientific support for the study of global changes. “Ocean and forest mapping through integration of satellite laser altimeter data”, “Changes in land water reserves based on GRACE and GRACE-FO data”, and “Research of urban heat island effect based on remote sensing data” reflect the important role played by Earth-observation technology in obtaining spatiotemporal information on the global surface and on such phenomena as water storage in large lakes and rivers, as well as shifting sea levels and ocean currents. These data points are essential to quantitatively studying the dynamic evolution of Earth’s habitability.

Table 13: Top10 Research Fronts in geosciences

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Ocean and forest mapping through integration of satellite laser altimeter data	15	1439	2020.0
2	Analysis of asteroid surface characteristics and sample composition	15	1969	2019.7
3	Causes and impact of higher climate sensitivity in CMIP6 models	8	1509	2019.5
4	The impact of climate change on forest resilience after wildfires in the western United States	8	1037	2019.4
5	Hydrological response to the Glacier mass change in High Asia	31	5327	2019.3
6	Contribution of Antarctic and Greenland ice-volume loss to the sea-level change	26	4140	2019.3
7	Research of urban heat island effect based on remote sensing data	7	1152	2019.3
8	Measurement and evaluation of global sea WIND-WAVE	6	749	2019.3
9	Configuration optimization and development progress of various Earth System Models	33	5382	2019.2
10	Changes in land water reserves based on GRACE and GRACE-FO data	10	1876	2019.2

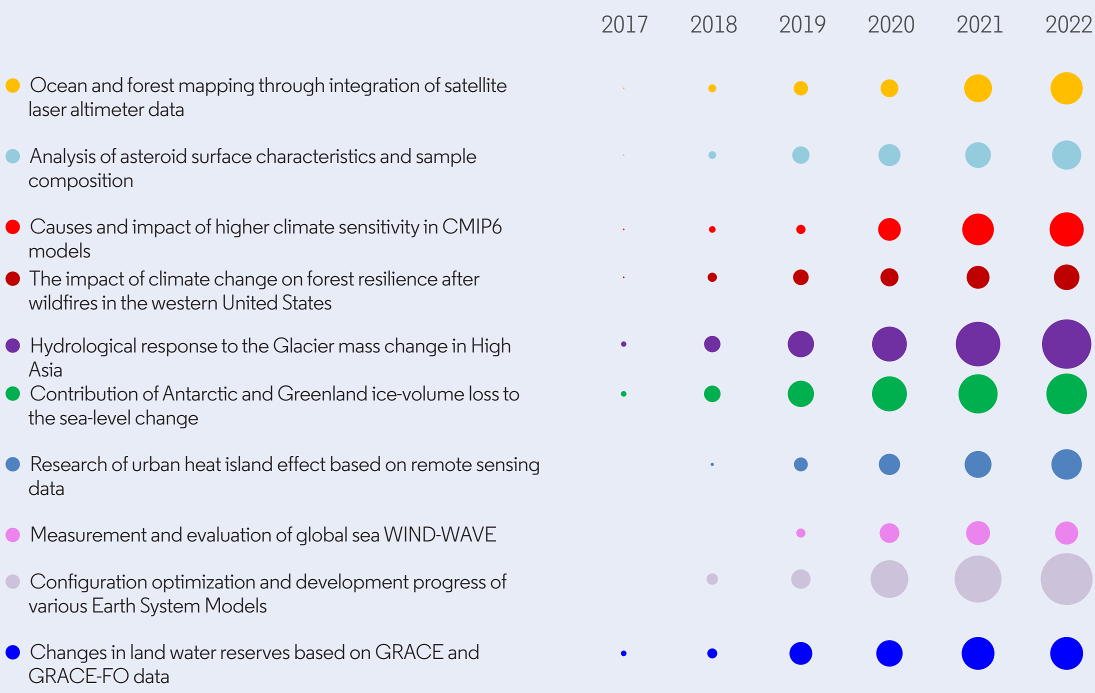


Figure 7: Citing papers for the Top 10 Research Fronts in geosciences

1.2 KEY HOT RESEARCH FRONT – "Causes and impact of higher climate sensitivity in CMIP6 models"

Global climate models are computer programs that incorporate fundamental disciplines such as mathematics, physics, and chemistry in order to simulate the interaction and feedback processes of the various strata of the Earth's climate system. "A National Strategy for Advancing Climate Modeling", a report released in 2012, noted that climate models are one of the most complex simulation tools for human development and are indispensable platforms for understanding the causes of climate change, evaluating its effects, and predicting and estimating its future changes. Relying on the continuous development and improvement of climate models, the level of human awareness of climate change has made great strides, and the global response to climate change has a solid scientific foundation.

In order to improve the accuracy of the simulation results, the "Working Group on Coupled Modelling" of the World Climate Research Programme has organized and implemented the "Coupled Model Intercomparison Project" (CMIP) since 1995. The goal is to better understand past, present, and future climate change, emphasizing the sharing, comparison, and analysis of global climate model results to provide high-quality climate information. The project has played a vital role in the formulation of model experiments, the standardization of model data formats, and the establishment of data-sharing platforms. The latest iteration, CMIP6, has more than 50 models from 28 participating research institutions around the world, focusing on three key scientific issues. These are: how the earth system responds to external forced changes; identifying the causes and consequences of model system deviations; and learning how to predict future climate change under the influence of internal climate variability, predictability, and scenario uncertainty. However, one-fifth of the climate models participating in CMIP6 have an equilibrium climate sensitivity of more than 5°C, which exceeds the range of 2-5°C that the United Nations' Intergovernmental Panel on Climate Change's sixth assessment report considers as very likely (with a probability exceeding 90%), indicating a state of "overheating".

The academic community has conducted extensive research on the causes and effects of the high climate sensitivity of the CMIP6 model. In this hot Research Front, "Causes of higher climate sensitivity in CMIP6 models," a paper published in *Geophysical Research Letters* by researchers based at Lawrence Livermore National Laboratory (USA), the University of Leeds (UK), and Imperial College London (UK), has garnered the most citations. This paper reports that the temperature response to an abrupt quadrupling of atmospheric carbon dioxide has increased substantially in the latest generation of global climate models. This is primarily because low cloud water content and coverage decrease more strongly with global warming, causing enhanced planetary absorption of sunlight—thereby amplifying feedback that ultimately results in more warming.

Another paper, "High Climate Sensitivity in the Community Earth System Model Version 2", by authors affiliated with the National Center for Atmospheric Research (NCAR, USA) was also published in *Geophysical Research Letters*. This report determined that CESM2 has an Equilibrium Climate Sensitivity of 5.3 K, and that cloud radiation is the cause of this change. Meanwhile, the process of cloud feedback affecting equilibrium climate sensitivity also influences the radiative forcing of aerosols.

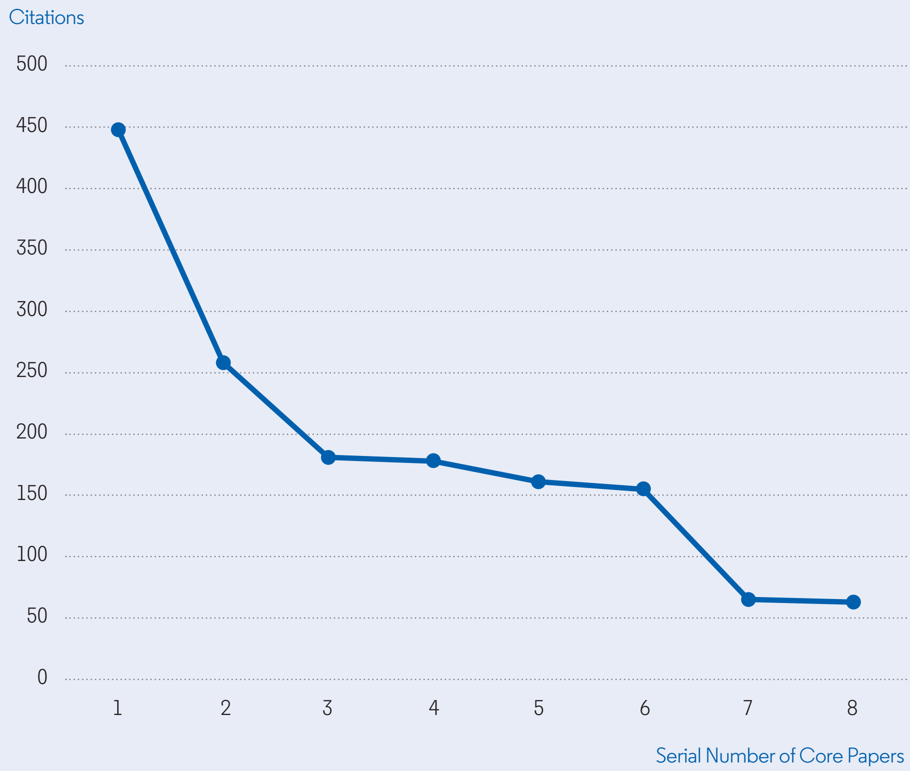


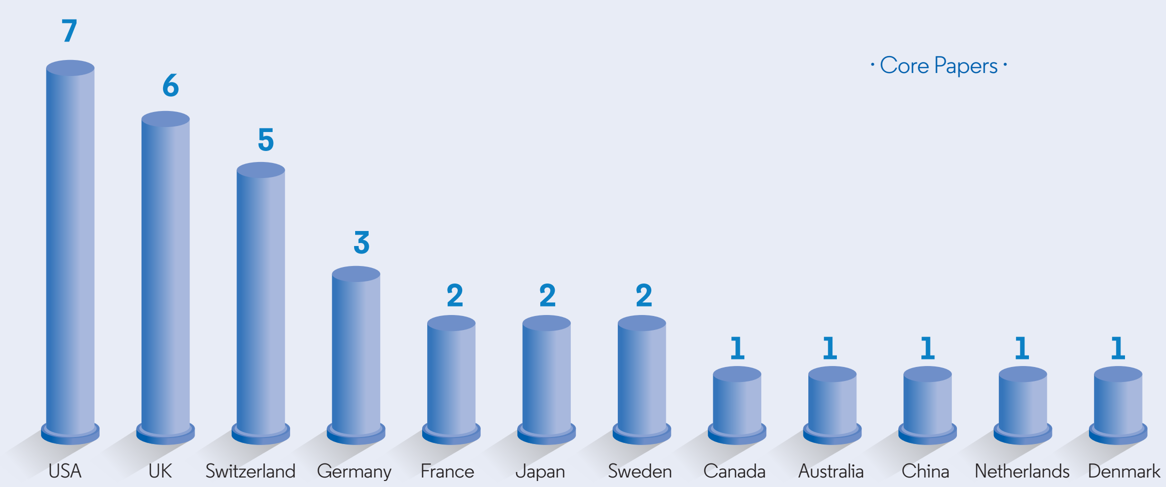
Figure 8: Citation frequency distribution curve of core papers in the Research Front "Causes and impact of higher climate sensitivity in CMIP6 models"

The CMIP6 model that displays the phenomenon of "overheating" was principally developed at the traditionally dominant R&D centers that occupy the leading positions internationally in the development of model physical process solutions. For example, as Table 14 shows, the NCAR ranks 1st, while the UK's Meteorological Office Hadley Centre shares 3rd position with the University of Leeds. In participating in the model version of CMIP6, these institutions updated the important physical process schemes in CMIP5, such as the adoption of a new, more complex physical scheme containing aerosol-cloud interaction, which resulted in an overly strong cooling effect. Among nations, Switzerland actively participates in related research on this topic, with the Swiss Federal Institute of Technology (ETH) in Zurich ranking 2nd among the top-producing institutions.

Table 14: Top countries and institutions producing core papers in the Research Front "Causes and impact of higher climate sensitivity in CMIP6 models"

Country Ranking	Country	Core Papers	Proportion
1	USA	7	87.5%
2	UK	6	75.0%
3	Switzerland	5	62.5%
4	Germany	3	37.5%
5	France	2	25.0%
5	Japan	2	25.0%
5	Sweden	2	25.0%
8	Canada	1	12.5%
8	Australia	1	12.5%
8	China	1	12.5%
8	Netherlands	1	12.5%
8	Denmark	1	12.5%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	National Center for Atmospheric Research (NCAR)	USA	5	62.5%
2	Swiss Federal Institute of Technology Zurich	Switzerland	4	50.0%
3	University of Leeds	UK	3	37.5%
3	Meteorological Office	UK	3	37.5%
5	National Aeronautics & Space Administration (NASA)	USA	2	25.0%
5	University of Edinburgh	UK	2	25.0%
5	University of Tokyo	Japan	2	25.0%
5	Stockholm University	Sweden	2	25.0%
5	Max Planck Society	Germany	2	25.0%
5	National Center for Scientific Research of France (CNRS)	France	2	25.0%

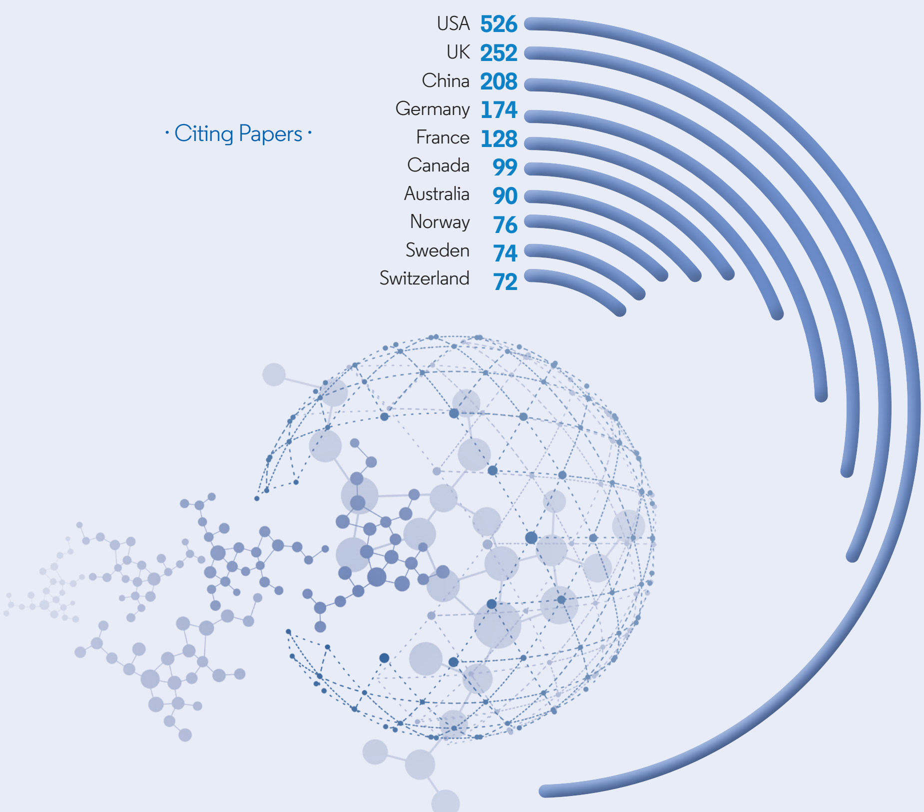


In terms of countries producing the citing papers, the USA and the UK are still the two most prolific. China ranks 8th in core-paper contributions, and 3rd in citing papers. The Chinese Academy of Sciences ranks 5th on the list of citing institutions.

Table 15: Top countries and institutions producing citing papers in the Research Front "Causes and impact of higher climate sensitivity in CMIP6 models"

Country Ranking	Country	Citing Papers	Proportion
1	USA	526	48.8%
2	UK	252	23.4%
3	China	208	19.3%
4	Germany	174	16.1%
5	France	128	11.9%
6	Canada	99	9.2%
7	Australia	90	8.3%
8	Norway	76	7.1%
9	Sweden	74	6.9%
10	Switzerland	72	6.7%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	National Center for Atmospheric Research (NCAR)	USA	126	11.7%
2	United States Department of Energy (DOE)	USA	110	10.2%
3	National Center for Scientific Research of France (CNRS)	France	103	9.6%
4	National Aeronautics & Space Administration (NASA)	USA	94	8.7%
5	Chinese Academy of Sciences	China	87	8.1%
6	National Oceanic Atmospheric Admin (NOAA)	USA	80	7.4%
7	Meteorological Office	UK	78	7.2%
8	Columbia University	USA	74	6.9%
9	Helmholtz Association	Germany	67	6.2%
10	Sorbonne University	France	66	6.1%



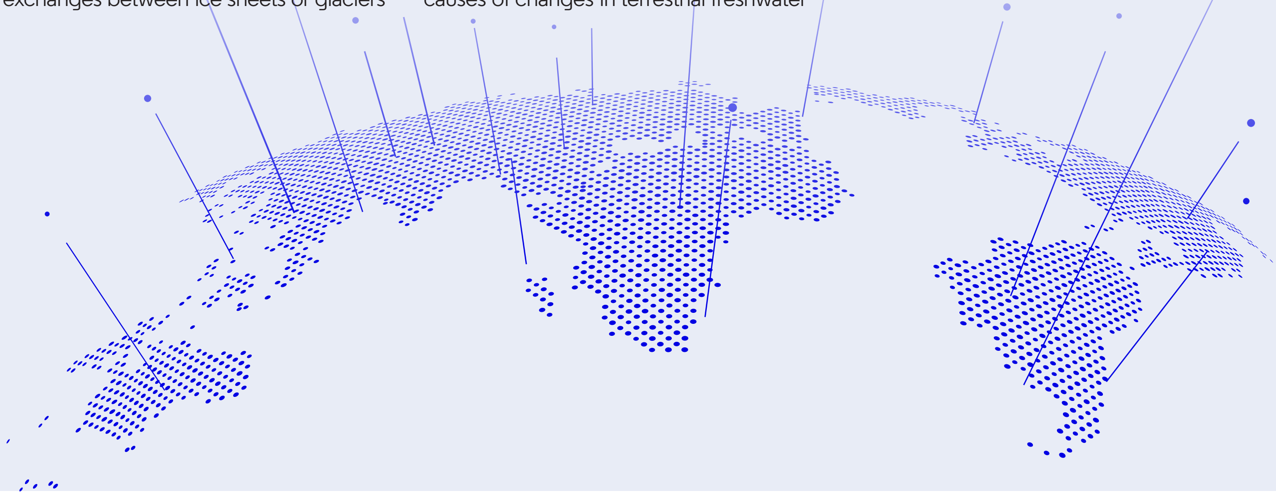
1.3 KEY HOT RESARCH FRONT – "Changes in land water reserves based on GRACE and GRACE-FO data"

Earth's gravity field represents the current heterogeneous distribution of matter inside the Earth and on its surface. On a scale of a few years or less, the migration and exchange of substances such as the atmosphere, water, and shallow groundwater will cause the Earth's mass to redistribute, which in turn will lead to changes in Earth's gravity field. Therefore, the use of static or time-varying gravity field signals can provide insights into the material migration of the Earth's circumpolar layer, especially information on land water reserves and their changes. This is of great significance for the study of global climate change.

The US-German GRACE mission is one of the representative missions of satellite gravity exploration program in this century. Launched in March of 2002, GRACE (Gravity Recovery and Climate Experiment) maps Earth's gravity field by making accurate measurements of the distance between two identical satellites that were launched together. The gravity variations studied by GRACE include changes due to surface and deep currents in the ocean; runoff and ground water storage on land masses; exchanges between ice sheets or glaciers and the ocean; and variations of mass within the Earth. The mission's application results have also been extended to oceanography, glaciology, hydrology, seismology, and other fields. GRACE-FO (GRACE Follow-On) is a successor to the original mission, continuing the work of tracking Earth's water movement to monitor changes in underground water storage, the amount of water in large lakes and rivers, soil moisture, ice sheets and glaciers, and sea level caused by the addition of water to the ocean.

The Research Front "Changes in land water reserves based on GRACE and GRACE-FO data" consists of 10 core papers, focusing on the use of satellite data for research into global climate change, changes in groundwater reserves and global mass, and ice sheet loss in Greenland and Antarctica. Among the core papers, "Emerging trends in global freshwater availability", published in *Nature* by scientists based at NASA and the University of Maryland, is currently the most cited, with 655 citations at this writing. The research reported in this paper used data from the GRACE mission from 2002 to 2016 to assess the trends and causes of changes in terrestrial freshwater reserves and to identify areas where significant changes in land water storage have occurred, while also clearly revealing the impact of human activity on the global water cycle. These findings provide a reference for assessing and predicting the threats of human influence and climate change on water and food security.

During its 15 years of operation, the GRACE mission and its satellite-based findings have accounted for several research highlights. For example, given the increasing number of locations in which humans are pumping out groundwater faster than it is replenished, a third of Earth's largest groundwater basins are being rapidly depleted. Ice losses from Greenland and Antarctica have been shown to be dramatically larger than previously estimated. GRACE findings have also helped to distinguish the extent of the impact of changes in water mass and ocean temperatures on sea-level variations; to calculate the effects of ice sheet loss and groundwater depletion on the rotation of Earth; and to assist in determining the abrupt changes in mass during major earthquakes.



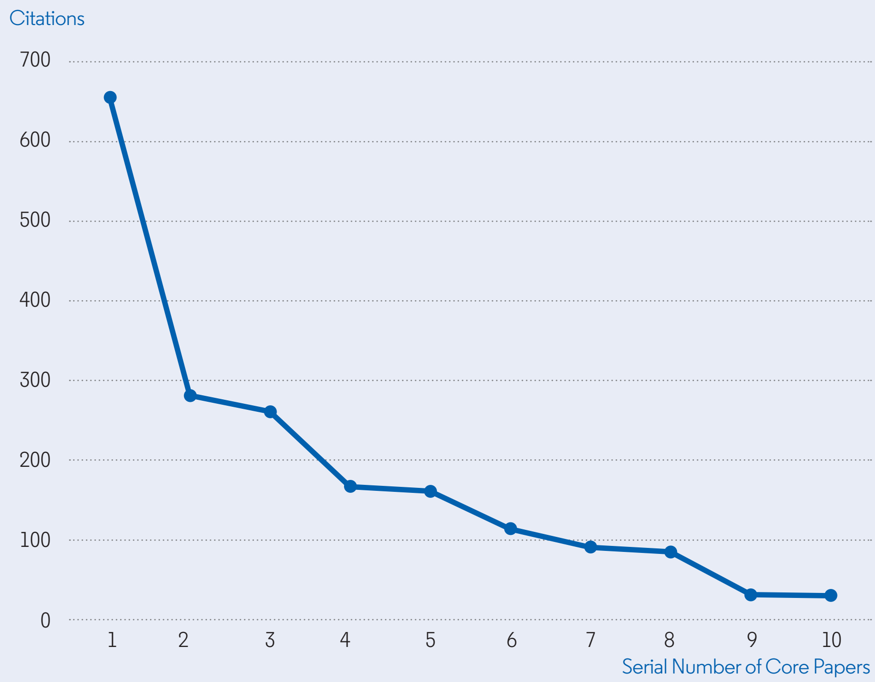


Figure 9: Citation frequency distribution curve of core papers in Research Front "Changes in land water reserves based on GRACE and GRACE-FO data"

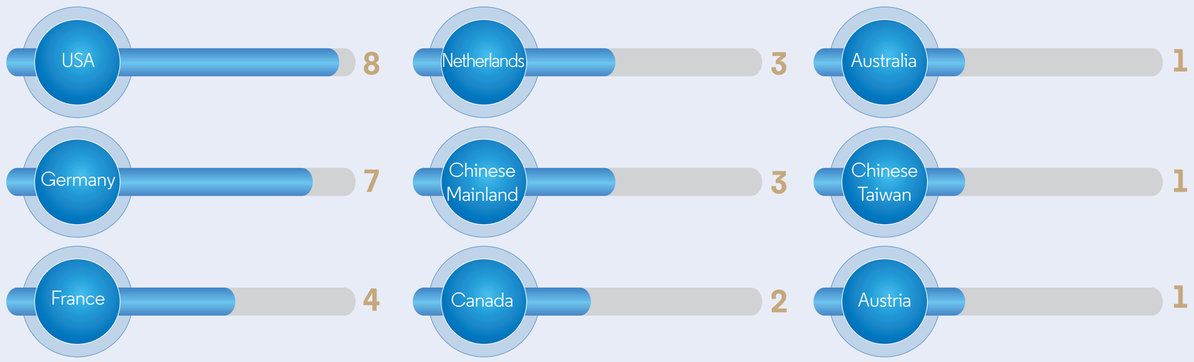
As the countries/regions responsible for developing the satellite mission, the USA and Germany account for the largest output of core papers. The Jet Propulsion Laboratory (administered by the California Institute of Technology), the Helmholtz Centre Potsdam, and the University of Texas, Austin are responsible for satellite data processing and product release, and both rank among the top institutions producing core papers.

Table 16: Top countries/regions and institutions producing core papers in the Research Front "Changes in land water reserves based on GRACE and GRACE-FO data"

Country/ region Ranking	Country/ Regions	Core Papers	Proportion
1	USA	8	80.0%
2	Germany	7	70.0%
3	France	4	40.0%
4	Netherlands	3	30.0%
4	Chinese Mainland	3	30.0%
6	Canada	2	20.0%
7	Australia	1	10.0%
7	Chinese Taiwan	1	10.0%
7	Austria	1	10.0%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	National Aeronautics & Space Administration (NASA)	USA	7	70.0%
2	California Institute of Technology	USA	6	60.0%
3	University of Texas Austin	USA	5	50.0%
4	Helmholtz Association	Germany	3	30.0%
4	Technical University of Berlin	Germany	3	30.0%
6	National Center for Scientific Research of France (CNRS)	France	2	20.0%
6	Tsinghua University	China	2	20.0%
6	University of Bretagne Loire	France	2	20.0%
6	Utrecht University	Netherlands	2	20.0%
6	University of Rennes	France	2	20.0%
6	Chinese Academy of Sciences	China	2	20.0%
6	Univ Saskatchewan	Canada	2	20.0%

· Core Papers ·

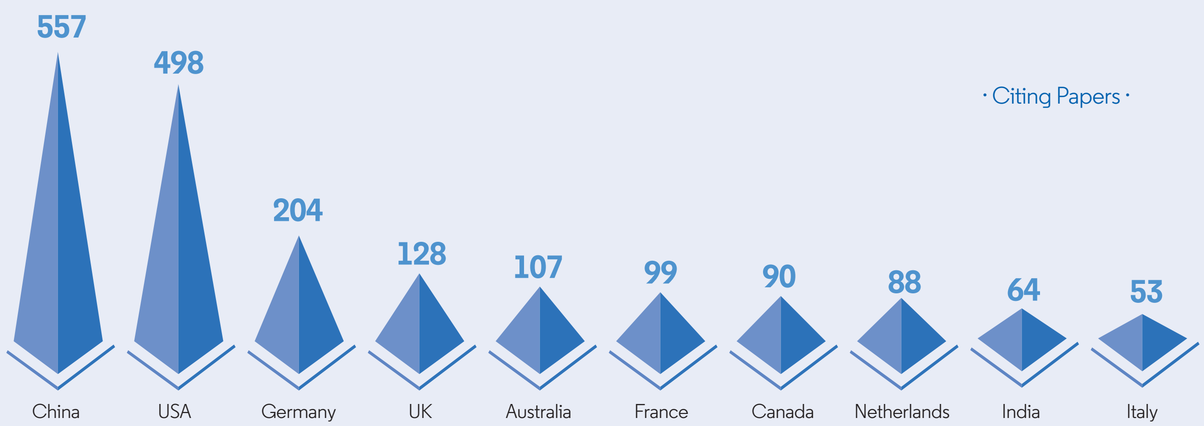


As for countries producing the most citing papers: China has most actively followed up on research in this front, followed by the USA and Germany. The Chinese Academy of Sciences has been the most prolific in terms of citing papers. Meanwhile, NASA and the California Institute of Technology rank 2nd and 3rd.

Table 17: Top countries and institutions producing citing papers in the Research Front "Changes in land water reserves based on GRACE and GRACE-FO data"

Country Ranking	Country	Citing Papers	Proportion
1	China	557	41.5%
2	USA	498	37.1%
3	Germany	204	15.2%
4	UK	128	9.5%
5	Australia	107	8.0%
6	France	99	7.4%
7	Canada	90	6.7%
8	Netherlands	88	6.6%
9	India	64	4.8%
10	Italy	53	3.9%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	206	15.4%
2	National Aeronautics & Space Administration (NASA)	USA	140	10.4%
3	California Institute of Technology	USA	88	6.6%
4	Helmholtz Association	Germany	80	6.0%
5	National Center for Scientific Research of France (CNRS)	France	77	5.7%
6	Wuhan University	China	65	4.8%
7	University of Texas Austin	USA	61	4.5%
8	French National Research Institute for Sustainable Development (IRD)	France	45	3.4%
9	University of Toulouse	France	42	3.1%
10	Beijing Normal University	China	39	2.9%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN GEOSCIENCES

"Global Impact of the Tonga volcanic eruption" was selected as the emerging Research Front in Geosciences for 2023.

Table 18: Emerging Research Front in geosciences

Rank	Emerging Research Front	Core Papers	Citations	Mean Year of Core Papers
1	Global Impact of the Tonga volcanic eruption	17	328	2022.0

2.2 KEY EMERGING RESARCH FRONT – "Global Impact of the Tonga volcanic eruption"

On 14 January 2022, the submarine volcano Tonga-Hon'aha'apai Island Volcano (HTHH), located in the back-arc region of the Tonga Subduction Zone in the South Pacific Ocean, produced a "volcanic explosivity index" (VEI) 6 eruption. The event released enormous amounts of energy, and most of the main body of the volcano fell into the ocean, triggering a global tsunami due to seawater transport and atmospheric resonance. This wave spread rapidly to the Pacific Rim coastal region within a matter of hours, leading to tsunami warnings for the region's at-risk countries/regions. Tsunami signals then reached the Atlantic, Indian, and Caribbean Oceans, and even in the Mediterranean Sea 18,000 km away from the source of the volcanic eruption, a low amplitude far-field tsunami occurred.

Atmospheric waves caused by sudden movements of the Earth's surface propagate into the upper atmosphere, eventually causing traveling ionospheric disturbances (TIDs). Such changes have been observed in the past in scenarios such as earthquakes, tsunamis, volcanic eruptions, and underground nuclear explosions. Satellite observations showed that the enormous energy released by the HTHH eruption threw debris high into the air, creating a volcanic plume up to 58km high that reached the middle layer of the atmosphere and was accompanied by 200,000 lightning flashes per hour. The global nature of the eruption was monitored by a variety of sensors—for example, barometers in Japan observed four transit disturbances of atmospheric pressure waves three days after the eruption. In addition, the explosion generated multi-band atmospheric resonances that propagated sufficiently to reach the ionosphere, causing detectable electron density fluctuations.

This emerging front has 17 core papers, focusing on the atmospheric waves and global seismoacoustic observations of the HTHH eruption, as well as observations of the global propagation of tsunamis and ionospheric disturbances. The most-cited paper, "Atmospheric waves and global seismoacoustic observations of the January 2022 Hunga eruption, Tonga" was published in *Science* in July 2022, and as of this writing has received 110 citations. The research team reported that the atmospheric waves propagated for four passages around the Earth over six days. The paper observes and analyses the fluctuations and seismoacoustic observations of the Tonga eruption, revealing the contribution of atmospheric Lamb waves to the propagation of the tsunami. The paper also emphasizes that the Tonga eruption produced "an explosion in the atmosphere of a size that has not been documented in the modern geophysical record".

2023 RESEARCH FRONTS

CLINICAL MEDICINE

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN CLINICAL MEDICINE

The Top10 Research Fronts in clinical medicine focus mainly on these subfields: immunotherapy; targeted therapy and molecular specific PET imaging of tumors; gene therapy for genetic diseases; and COVID-19-related drug treatment and vaccine evaluation. Tumor immunotherapy and targeted therapy have maintained a high profile over the years and are the core topics of hot research fronts this year. In addition, after years of development, the clinical application of gene therapy has emerged this year as a hot front for the first time, with other, related areas expected to distinguish themselves as hot fronts in the future. Meanwhile, with the COVID-19 epidemic coming to an end, research interest in clinical medicine regarding the 2019 novel coronavirus and its infection has decreased compared to the past two years, and the focus has shifted. Research over the previous two years primarily concerned the clinical manifestations, complications, and pathogenesis of COVID-19. Since last year, COVID-19 drug treatment and vaccine evaluation have become new hot fronts. This year, all four COVID-19 hot fronts focus on those aspects, representing a continuation of last year's trend.

Table 19: Top10 Research Fronts in clinical medicine

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Early administration of antiviral drugs can effectively reduce the severity rate and mortality of COVID-19 infection	3	972	2021.3
2	Anticoagulant therapy for patients with severe COVID-19 infection	12	2131	2021.1
3	Fibroblast activating protein specific pet/ct for tumor imaging	32	2589	2021.0
4	Thrombosis and thrombocytopenia after inoculation of COVID-19 vaccine CHADOX1	4	2482	2021.0
5	BCMA CAR-T therapy for the treatment of recurrent or refractory multiple myeloma	2	632	2021.0
6	New gene therapies such as CRISPR/Cas9 gene editing and shRNA targeting BCL11A for sickle cell disease and β- thalassemia	2	479	2021.0
7	Safety and efficacy of COVID-19 vaccine	4	13014	2020.8
8	KRAS(G12C) Inhibitors and tumor targeted therapy	31	5665	2020.5
9	Efficacy and safety of PD-L1 preparations in patients with non-small-cell lung cancer	4	2090	2020.3
10	Influence of gut microbiota status on efficacy of anti PD-1 immunotherapy for melanoma	26	10137	2019.7

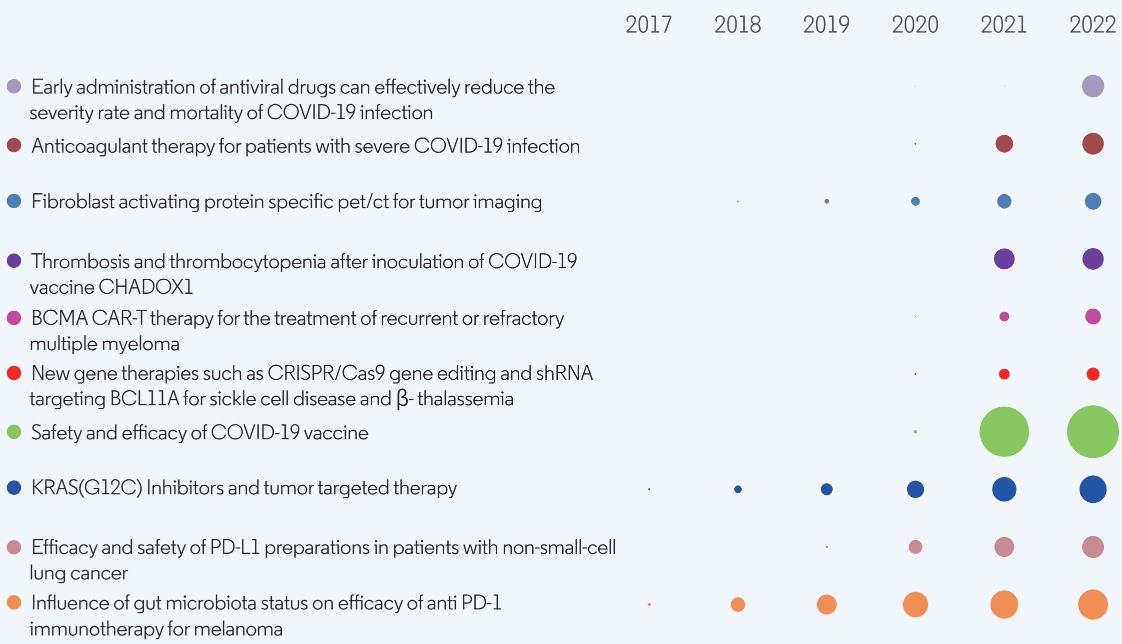


Figure 10: Citing papers for the Top10 Research Fronts in clinical medicine

1.2 KEY HOT RESEARCH FRONT – “New gene therapies such as CRISPR/Cas9 gene editing and shRNA targeting BCL11A for sickle cell disease and β-thalassemia”

Sickle cell disease and β-thalassemia are the most common single-gene hereditary diseases worldwide. Both result from mutations in the hemoglobin β subunit (HBB), leading to abnormal hemoglobin and subsequently causing hemolytic anemia, which can be life-threatening in severe cases. At present, although allogeneic bone-marrow transplantation can eradicate the two diseases in clinical practice, the procedure is costly, also presenting difficulty in the matching of donors with patients, and carrying the risk of complications. Only a few patients can be cured through this method, and most can only rely on conventional blood transfusion and other auxiliary supportive therapies, which cannot effectively provide a cure. Therefore, gene therapy that corrects pathogenic gene expression at the molecular level has become a new direction of effective treatment for sickle cell disease and β-thalassemia.

The technical solution of gene therapy mainly includes gene replacement therapy, RNA silencing therapy (RNAi), and gene editing. Among these approaches, CRISPR-Cas9, as a new generation of gene-editing technology, has developed in just a few years into the most mainstream gene-editing system, due to its advantages of efficiency, simplicity, and low cost. The technology won the Nobel Prize in Chemistry in 2020, triggering a new wave of research in gene therapy. Clinical findings suggest that a high level of erythrocyte fetal hemoglobin (HbF) expression may ameliorate the manifestations of sickle cell disease and β-thalassemia by mitigating abnormal hemoglobin polymerization and erythrocyte deformation. BCL11A is a transcription factor in adult erythrocytes that regresses γ-globin expression and HbF production in erythroid cells; therefore its down-regulation induces HbF and becomes a promising target of gene therapy for these two diseases.

The key hot research front “New gene

therapies such as CRISPR/Cas9 gene editing and shRNA targeting BCL11A for sickle cell disease and β-thalassemia" includes two core papers, which were simultaneously published online in December 2020 in *The New England Journal of Medicine*. Both are clinical trials to treat sickle cell disease or beta-thalassemia by specifically down-regulating the expression of BCL11A in erythroid cells, achieving γ-globin reactivation and inducing fetal hemoglobin production—but the research methods are different. The paper with a higher citation frequency is "CRISPR-Cas9 Gene Editing for Sickle Cell Disease and β-Thalassemia"(H. Frangoul, et al.), coauthored by researchers at the Sarah Cannon Cancer Institute (Nashville, Tennessee, USA) and the University of Regensburg, Germany. The work described in this report edits autologous CD34+ cells to reduce BCL11A protein expression in erythroid cells with CRISPR-Cas9 targeting the BCL11A erythroid-specific enhancer. It is the first peer-reviewed case of CRISPR gene-editing for the treatment of hereditary anemia worldwide.

The other NEJM paper, "Post Transcriptional Genetic Silencing of BCL11A to Treat Sickle Cell Disease" (E.G. Esrick, *et al.*) represents a collaboration by researchers based at the Harvard Medical School and Bluebird Biology (both in Cambridge, Massachusetts, USA). This research transduced autologous CD34+ cells with the BCH-BB694 lentivirus vector encoding a short hairpin RNA (shRNA) targeting BCL11A mRNA, allowing erythroid lineage-specific knockdown.

Both studies demonstrate the effectiveness of the gene-therapy strategy targeting BCL11A and the possibility of functional cure for sickle cell disease and β- thalassemia with CRISPR-Cas9 and shRNA technology. Although both studies represent successful cases of gene therapy transitioning from basic research to clinical application, more patients are needed to further validate the effectiveness and safety of this approach.

As for the top countries producing core papers in this key hot front, the USA has contributed in both of the foundational papers, occupying an absolute advantage in gene-therapy clinical research. Other participating countries are mainly distributed in Europe and North America, with Italy, Germany, the UK, Greece, and Canada among the nations each contributing one core paper.

In terms of the citing papers, the USA contributes nearly half, far surpassing other countries, followed by China, Italy, the UK, and Germany. Among these countries, China ranks 2nd with 59 papers. Regarding the top institutions producing citing papers, nine are based in the USA. Harvard University takes the top spot, while two institutions are situated in France. The Chinese Academy of Sciences is the only China-based institution on the list.

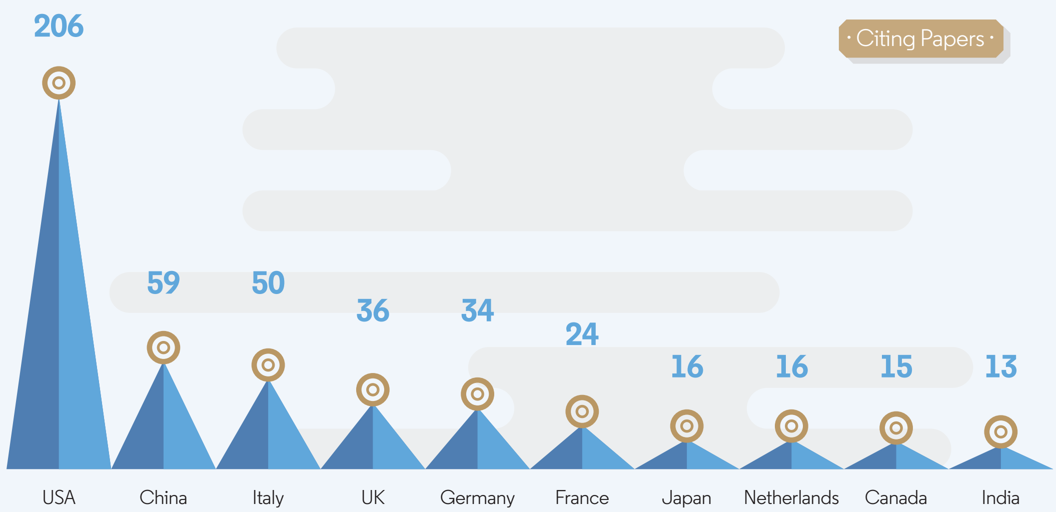
Table 20: Top countries and institutions producing citing papers in the Research Front "New gene therapies such as CRISPR/Cas9 gene editing and shRNA targeting BCL11A for sickle cell disease and β- thalassemia"

Country Ranking	Country	Citing Papers	Proportion
1	USA	206	49.3%
2	China	59	14.1%
3	Italy	50	12.0%
4	UK	36	8.6%
5	Germany	34	8.1%
6	France	24	5.7%
7	Japan	16	3.8%
8	Netherlands	16	3.8%
9	Canada	15	3.6%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Harvard University	USA	41	9.8%
2	National Institutes of Health (NIH)	USA	31	7.4%
3	Boston Children's Hospital	USA	19	4.5%
4	Dana Farber Cancer Center	USA	17	4.1%
4	National Institute of Health and Medical Research (INSERM)	France	17	4.1%
6	University of Paris Cite	France	16	3.8%
7	Broad Institute	USA	15	3.6%
7	Chinese Academy of Sciences	China	15	3.6%
7	Massachusetts Institute of Technology (MIT)	USA	15	3.6%

Country Ranking	Country	Citing Papers	Proportion
10	India	13	3.1%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
10	St. Jude Children's Research Hospital	USA	14	3.3%
10	Stanford University	USA	14	3.3%
10	University of Pennsylvania	USA	14	3.3%



1.3 KEY HOT RESEARCH FRONT – "KRAS(G12C) Inhibitors and tumor targeted therapy"

KRAS is one of the most frequently mutated oncogenes in human tumors and plays an important role in regulating cell growth signaling pathways. Following KRAS mutation, the protein continues to activate, leading to uncontrolled cell growth and tumorigenesis. KRAS has been found to exist in a variety of mutational forms, of which G12C mutation has the highest incidence. KRAS (G12C) specifically refers to the mutation of glycine Gly at position 12 of KRAS to cysteine Cys. In recent years, significant breakthroughs have been made in the research and development of KRAS (G12C) inhibitors, finally breaking the long-standing bottleneck of the non-druggability of KRAS protein. Multiple KRAS (G12C) inhibitors have entered clinical trials and shown good anti-tumor effects. Among these, Sotorasib (R&D code AMG510), developed by Amgen Inc., was first approved in the USA in 2021. However, during continuous clinical use, KRAS (G12C) inhibitors have shown obvious drug resistance, which limits their further role and challenges the development of a new generation of more effective KRAS inhibitors. Therefore, in-depth research on the drug-resistance mechanism and effective reduction of drug resistance is also an important direction in the development of KRAS inhibitors.

The key hot front of "KRAS (G12C) inhibitors and tumor targeted therapy" includes 31 core papers, focusing on anti-tumor mechanisms, clinical trials, research and development, and the drug resistance mechanisms of KRAS (G12C) inhibitors (such as sotorasib, adagrasib, ARS-1620). Other focal areas include RAS protein regulation mechanisms, RAS mutation frequency, and the prospects for RAS targeted therapy. More than 10 of these core papers are related to the first batch of approved KRAS (G12C) inhibitors: sotorasib and Adagrasib (R&D code MRTX849). Among the 24 non-review articles, the two papers with the highest citation frequency respectively discuss anti-tumor immune mechanism (cited 699 times at this writing) and Phase I clinical trial treating advanced solid tumors with sotorasib (563 citations). These citations indicate that the drug has received widespread attention as the first approved KRAS (G12C) inhibitor and played a leading role in the industry.

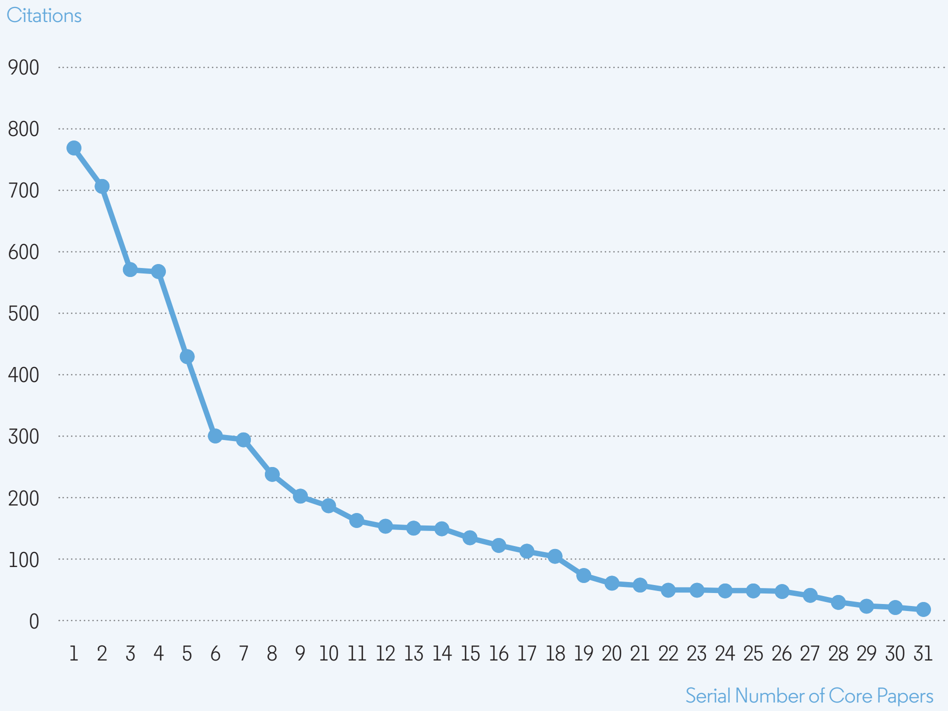


Figure 11: Citation frequency distribution curve of core papers in the Research Front "KRAS (G12C) inhibitors and tumor targeted therapy"

As for the top countries producing core papers in this key hot front: the USA has a contribution rate of 90.3%, far ahead of other countries, reflecting its dominant and leading position in this front. Most of the top institutions producing core papers are based in the USA. Harvard University, Memorial Sloan Kettering Cancer Center, and Mirati Medical Co. Ltd. are the top three, among which Mirati is the developer of Adaglasib. Also appearing on the list are two Australia-based institutions.

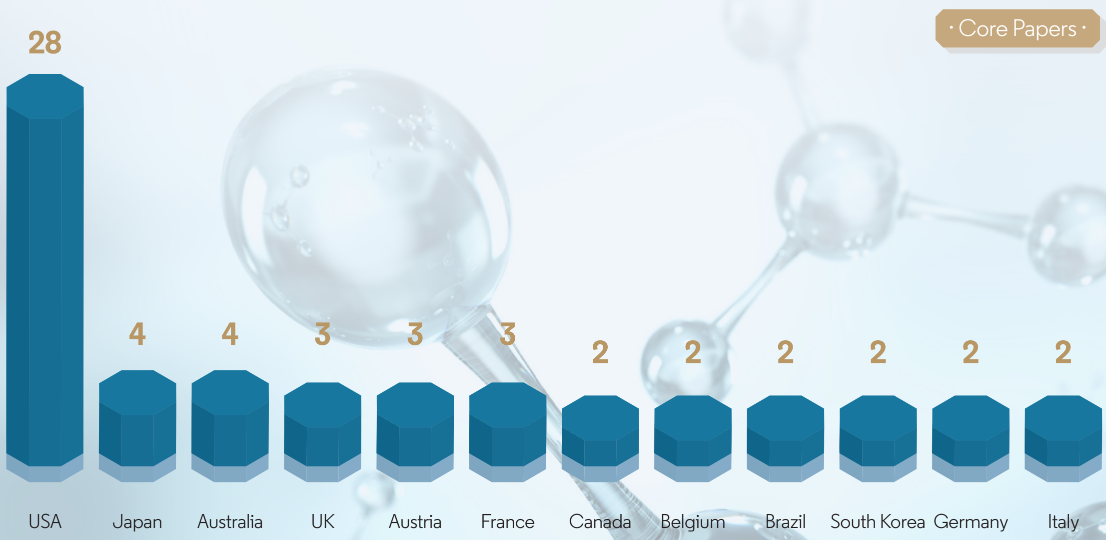
Table 21: Top countries and institutions producing core papers in the Research Front "KRAS (G12C) inhibitors and tumor targeted therapy"

Country Ranking	Country	Core Papers	Proportion
1	USA	28	90.3%
2	Japan	4	12.9%
2	Australia	4	12.9%
4	UK	3	9.7%
4	Austria	3	9.7%
4	France	3	9.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Harvard University	USA	8	25.8%
1	Memorial Sloan-Kettering Cancer Center	USA	8	25.8%
3	Mirati Therapeut Inc.	USA	7	22.6%
4	New York University	USA	6	19.4%
4	Sarah Cannon Research Institute	USA	6	19.4%
6	Dana Farber Cancer Center	USA	5	16.1%

Country Ranking	Country	Core Papers	Proportion
7	Canada	2	6.5%
7	Belgium	2	6.5%
7	Brazil	2	6.5%
7	South Korea	2	6.5%
7	Germany	2	6.5%
7	Italy	2	6.5%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
6	Cornell University	USA	5	16.1%
6	University of California San Francisco	USA	5	16.1%
9	Amgen Inc.	USA	4	12.9%
9	University of California Irvine	USA	4	12.9%
9	Queen Elizabeth Hospital	Australia	4	12.9%
9	University of Adelaide	Australia	4	12.9%
9	Pfizer Inc.	USA	4	12.9%

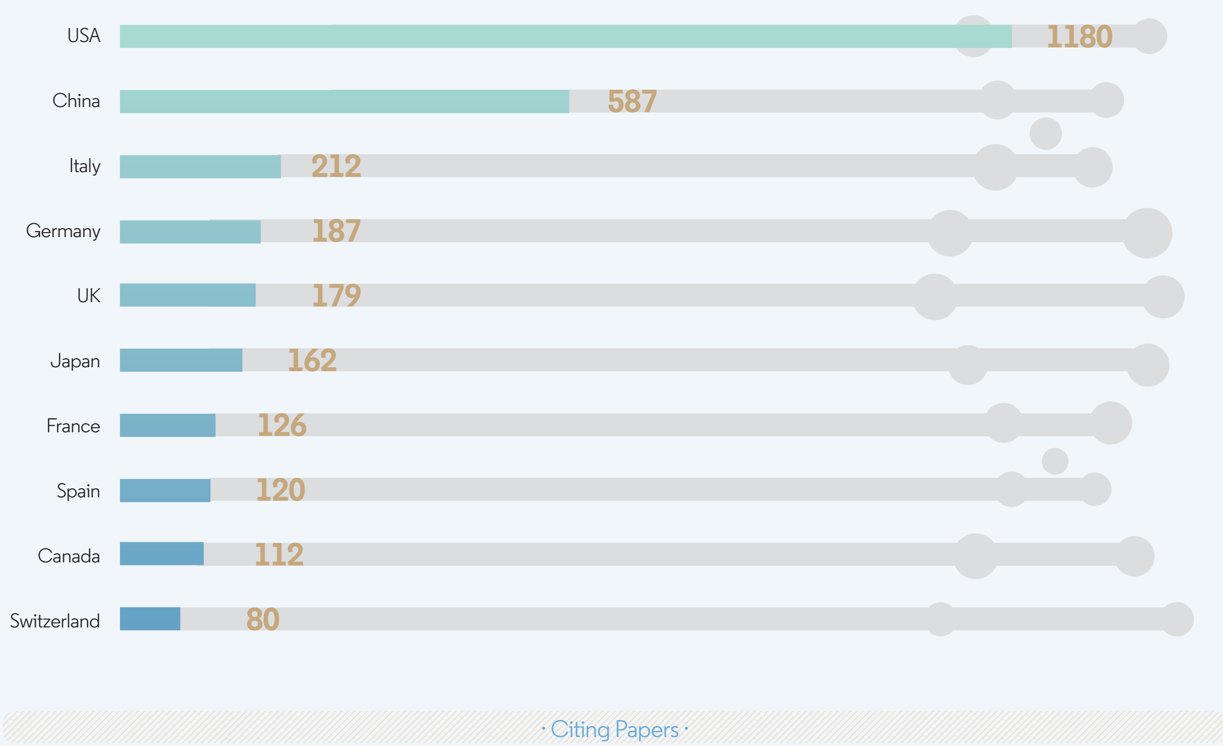


In terms of the papers that cite the core literature in this front, the USA contributes nearly half, reflecting its high level of attention to this area. China ranks 2nd with 587 articles, indicating that the nation's research in this field is also quite active. The majority of Top10 institutions are based in the USA, with a few located in France, China, and Canada. The Chinese institutions on the list are the Chinese Academy of Sciences and Shanghai Jiaotong University, indicating that their relevant research has attained a notable scale.

Table 22: Top countries and institutions producing citing papers in the Research Front "KRAS (G12C) inhibitors and tumor targeted therapy"

Country Ranking	Country	Citing Papers	Proportion
1	USA	1180	44.1%
2	China	587	21.9%
3	Italy	212	7.9%
4	Germany	187	7.0%
5	UK	179	6.7%
6	Japan	162	6.1%
7	France	126	4.7%
8	Spain	120	4.5%
9	Canada	112	4.2%
10	Switzerland	80	3.0%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Harvard University	USA	163	6.1%
2	Dana Farber Cancer Center	USA	99	3.7%
3	University of California San Francisco	USA	94	3.5%
4	Memorial Sloan-Kettering Cancer Center	USA	87	3.3%
5	National Institutes of Health (NIH)	USA	80	3.0%
6	National Institute of Health and Medical Research (INSERM)	France	66	2.5%
7	Chinese Academy of Sciences	China	60	2.2%
8	University of Toronto	Canada	59	2.2%
9	Shanghai Jiao Tong University	China	53	2.0%
10	Cornell University	USA	51	1.9%



2. EMERGING RESEARCH FRONT

2.1 SUMMARY OF EMERGING RESEARCH FRONTS IN CLINICAL MEDICINE

Five emerging research fronts in clinical medicine are mainly related to the epidemiological study of monkeypox, melanoma immunotherapy, cardiovascular risk of Tofatinib treatment, combined treatment of prostate cancer, and the treatment of type 2 diabetes, as shown in Table 23. Based on the comprehensive analysis of CPT indicators (Please refer to the methodology section for details), development potential of the fronts, and the judgment of scientific and technological information researchers, "Ongoing monkeypox virus outbreak" is ultimately selected as the focal point of analysis.

Table 23: Emerging Research Fronts in clinical medicine

Rank	Emerging Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Ongoing Monkeypox virus outbreak	10	784	2022.0
2	Relatlimab and Nivolumab in advanced melanoma	2	286	2022.0
3	Cardiovascular risk with tofacitinib in rheumatoid arthritis	4	188	2022.0
4	New generation androgen-receptor inhibitor plus ADT in mHSPC	4	208	2021.8
5	Effect of tirzepatide in type 2 diabetes	14	688	2021.7

2.2 KEY EMERGING RESEARCH FRONT – "Ongoing Monkeypox virus outbreak "

In the past, monkeypox had been endemic in the regions of West and Central Africa. Since the first case of monkeypox was reported in the UK in May 2022, multiple countries/regions in Europe and the USA have successively experienced atypical outbreaks of the infection, attracting worldwide attention. On July 23, 2022, the World Health Organization issued the highest-level alert regarding the rapid spread of monkeypox, announcing that the outbreaks occurring in multiple countries and regions worldwide constitutes an "international public health emergency of concern".

The emerging front "Ongoing monkeypox virus outbreak" includes 10 core papers, mainly focusing on case reports, including epidemiological investigations, clinical manifestations, and virus testing. Among them, five papers published in *Eurosurveillance* respectively reported monkeypox cases with genital rash symptoms after returning to Melbourne, Australia from Europe; the interpersonal transmission of monkeypox in the UK from April to May 2022; DNA testing of monkeypox virus in clinical samples from 12 patients in Spain from May to June 2022; epidemiological investigation of confirmed cases of monkeypox in Portugal from April 29 to May 23 2022; and epidemiological, clinical, and virological analysis of monkeypox transmitted through sexual contact in Italy. In addition, a paper published in *The New England Journal of Medicine* analyzed 528 infected individuals from 43 locations within 16 countries/regions and found that sexual contact is the main transmission route of monkeypox. Despite its various clinical manifestations, the mortality rate of monkeypox virus is relatively low.

Studies have shown that gay men, bisexuals, and other men who have sex with men (especially those with symptoms such as blisters or pustular rash) are currently at high risk of contracting monkeypox virus. Rash, mucosal lesion, fever, drowsiness, and lymph node lesions are common clinical manifestations. A few patients may also experience rectal pain and penile edema. Increasing the ability of health professionals to rapidly and accurately identify and diagnose monkeypox infections is an effective way to curb the spread of an outbreak.


2023 RESEARCH FRONTS

2023 RESEARCH FRONTS

BIOLOGICAL SCIENCES

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN BIOLOGICAL SCIENCES

The Top 10 Research Fronts in biological sciences include Prime Editing technology, new sequencing technology, protein structure prediction using artificial intelligence (AI), pan-cancer analysis of whole genomes, blood biomarkers of Alzheimer's disease, biological functions of exosomes, SARS-CoV-2 infection, and other research directions.

Gene-editing technology has been a popular topic at the forefront of biological sciences research for several years. In recent years, this technology has made significant progress and has been selected among the hot Research Fronts in many consecutive annual surveys. The Prime Editing technology selected this year has taken gene editing to a new level. Meanwhile, new sequencing technologies have been continuously updated and improved in recent years, and single-cell RNA sequencing technology broke through as an emerging front in biological sciences in 2020.

In 2023, novel sequencing technologies and auxiliary methods—such as third-generation sequencing technology, spatial transcriptome technology, long-read, and cell communication analysis technology with the characteristics of long-read—have now made the list of hot fronts. AI prediction of protein structure (e.g., the AlphaFold program, from DeepMind) became a key emerging front in biological sciences in 2022 and has now developed into a hot front. This major technological leap will accelerate the development of new drugs, promote basic scientific research, and lead a new revolution in biology. After being selected as an emerging front in 2021, pan-cancer analysis of whole genomes has become a hot front in 2023.

Among the fronts listed in Table 24, research on Alzheimer's focuses on the discovery of new blood biomarkers for early disease. Research on the biological function of exosomes has been selected as a hot Research Front for the first time. In addition, two fronts related to SARS-CoV-2 are "Neutralizing antibody level predicts the immune protective effect of COVID-19 vaccine" and "Genetic mechanism of COVID-19 critical disease".

Table 24: Top10 Research Fronts in biological sciences

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Neutralizing antibody level predicts the immune protective efficacy of COVID-19 vaccine	5	2406	2021.4
2	Artificial intelligence such as AlphaFold predicts protein structure	4	6106	2021.0
3	Blood biomarkers of Alzheimer's disease	25	2974	2020.5
4	Space transcriptomics technology	30	4662	2020.4
5	Genetic mechanism of COVID-19 critical disease	3	1712	2020.3
6	Cellular communication analysis technology	4	1261	2020.0
7	Pan-cancer analysis of whole genomes	8	3280	2019.6
8	Prime Editing techniques	44	11305	2019.4
9	Analysis of structural variations in the human genome using the third generation long-read sequencing technology	11	8878	2018.9
10	The Biological Function of Exosomes	5	11095	2018.8

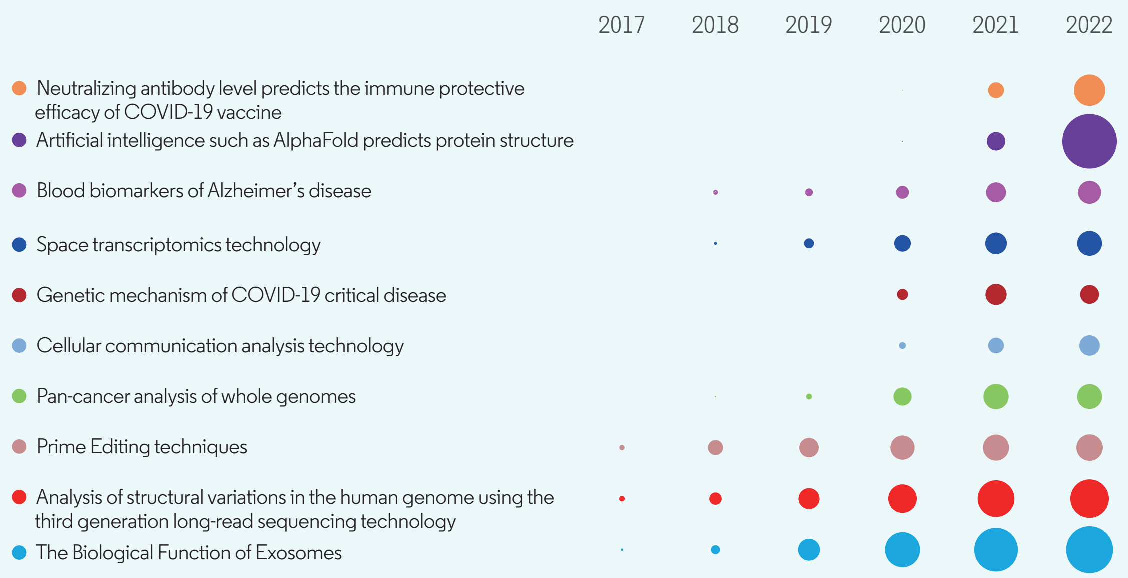


Figure 12: Citing papers for the Top 10 Research Fronts in biological sciences

1.2 KEY HOT RESEARCH FRONT – "Spatial transcriptomics technology"

Spatial transcriptomics is a technique that analyzes and describes the expression profiles of specific cell types at a spatial level to understand the differences in expression between organs, tissue, and pathological states. Spatial transcriptomics sequencing technology has become another hot topic in biotechnological research, following single-cell sequencing technology. In 2020 and 2022, it was rated as one of the seven noteworthy technologies of the year by the journal *Nature Methods*. On June 26, 2023, the World Economic Forum released the "Top 10 Emerging Technologies Report of 2023", and spatial transcriptomics technology was selected as one of the emergent technologies with the greatest potential to have a significant global impact. The era of spatial transcriptomics has arrived, and spatial genomics has opened a new chapter in biomedicine, referred to as the "next big thing" in life sciences.

The hot front on "spatial transcriptomics technology" includes 30 core papers, most of which focus on the proposal of new technologies, including in situ sequencing technology (ISS), which includes STARmap and ExSeq; In situ hybridization (ISH) techniques, including smFISH, seqFISH+, MERFISH, osmFISH; and in situ capture technologies, such as Slide Seq, HDST, Stereo seq, DBiT seq, Seq Scope, and others. Among these core documents, a paper published in *Science* in 2019, "Slide seq: A scalable technology for measuring genome wide expression at high spatial resolution" has achieved the highest citation count, now exceeding 630. Slide seq technology utilizes gene sequencing to draw detailed three-dimensional tissue maps without the need for specialized imaging equipment. It can reveal not only which cell types exist in the tissue, but also their spatial location and function.

Since spatial transcriptomics data contains multiple levels of information, it must be analyzed using a combination of histological experience, bioinformatics tools, and algorithms. In terms of analytical methods, four core papers have proposed clustering methods for spatial transcriptomics data samples, such as SpaGCN and BayeSpace. Another six core papers have reported the development of methods and algorithms for joint analysis of single cell transcriptome and spatial transcriptome (including Giotto, RCTD, MIA, SPOTlight, and Cell2location), which perform deconvolution analysis to improve the resolution of the spatial transcriptome. Moreover, a core paper proposes a new statistical-analysis method, SPARK, that can be used to analyze transcriptome spatial expression patterns.

In addition, AI can help identify tissue substructures from spatially resolved transcriptomics. A core paper published by researchers at the Chinese Academy of Sciences has developed a map attention automatic encoder framework, STAGATE, which integrates spatial information and gene expression profiles to learn low-dimensional embedded parts, thereby accurately identifying the spatial domain.

At present, spatial transcriptomics technology has been widely applied in various fields such as development, neuroscience, and oncology. Several core papers in this Research Front introduce the achievements of spatial transcriptomics technology in physiological, developmental, and disease-mechanism research. For example, the tumor microenvironment of skin squamous cell carcinoma has been mapped using spatial transcriptomics technology, and has also been used to elucidate the relationship between cancer cells in different states. Spatial transcriptomics technology—when combined with conventional single-cell sequencing technology, in situ technology, and other omics technologies—can enable the study of cellular heterogeneity and provide spatial localization within tissue. This offers a more precise research direction for disease studies and is of great significance for in-depth understanding of disease pathogenesis and targeted treatment.

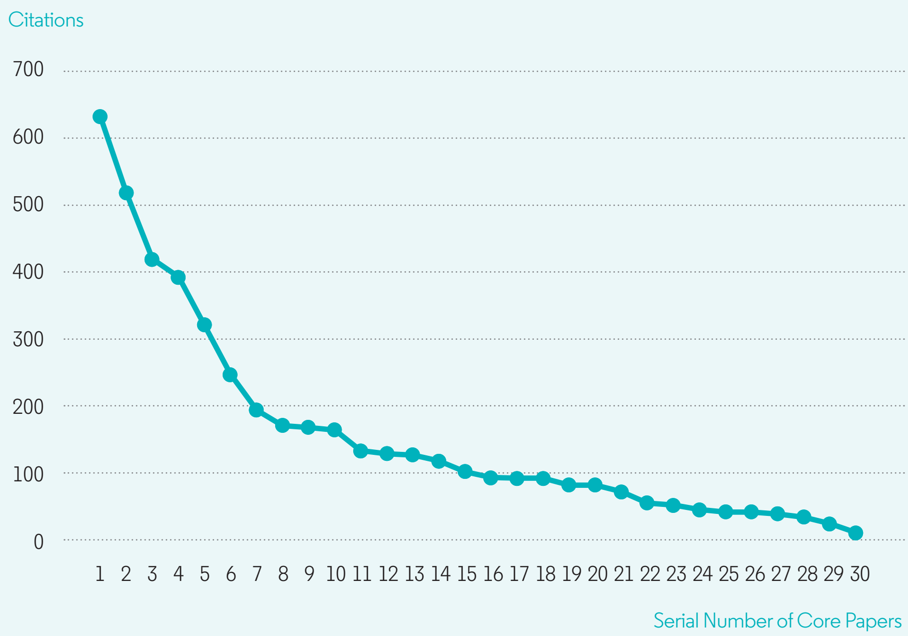


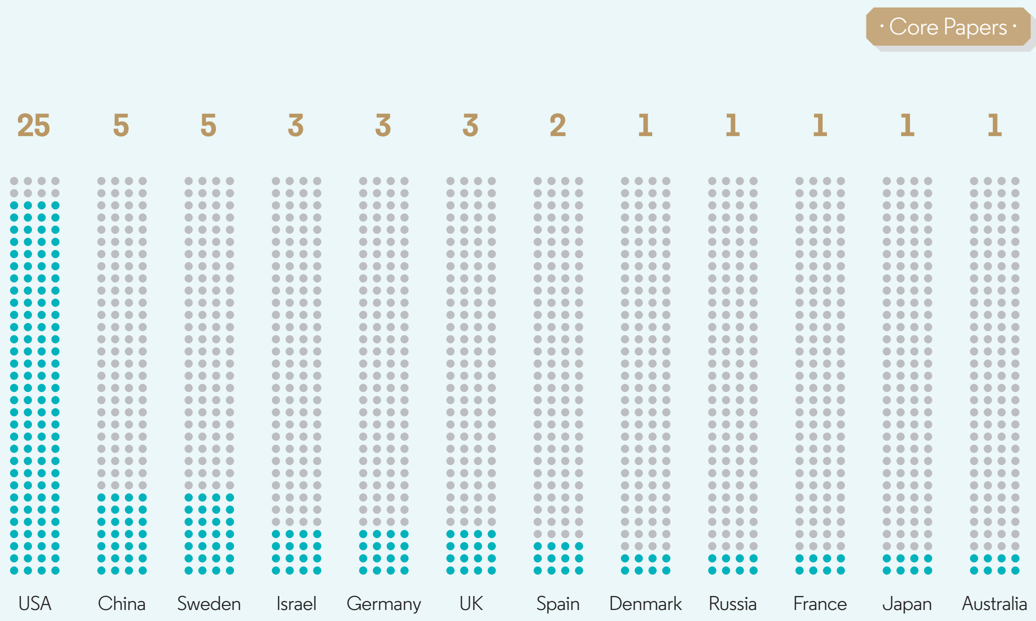
Figure 13: Citation frequency distribution curve of core papers in the Research Front "Spatial transcriptomics technology"

From the perspective of the countries and institutions that produce core papers, the USA has contributed 83.3% of the core, putting it in a leading position. China and Sweden are tied for second place. Seven top-output institutions are based in the USA, with Harvard University having contributed the most core papers, with a total of 11, accounting for more than one-third of the total. The other three institutions are the Royal Swedish Institute of Technology, the Karolinska Institute, and the Helmholtz Federation in Germany (Table 25).

Table 25: Top countries and institutions producing core papers in the Research Front "Spatial transcriptomics technology"

Country Ranking	Country	Core Papers	Proportion
1	USA	25	83.3%
2	China	5	16.7%
2	Sweden	5	16.7%
4	Israel	3	10.0%
4	Germany	3	10.0%
4	UK	3	10.0%
7	Spain	2	6.7%
8	Denmark	1	3.3%
8	Russia	1	3.3%
8	France	1	3.3%
8	Japan	1	3.3%
8	Australia	1	3.3%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Harvard University	USA	11	36.7%
2	Massachusetts Institute of Technology (MIT)	USA	9	30.0%
3	Broad Institute	USA	8	26.7%
4	Howard Hughes Medical Institute	USA	7	23.3%
5	Stanford University	USA	4	13.3%
5	KTH Royal Institute of Technology	Sweden	4	13.3%
5	Dana Farber Cancer Center	USA	4	13.3%
8	California Institute of Technology	USA	3	10.0%
8	Helmholtz Association	Germany	3	10.0%
8	Karolinska Institutet	Sweden	3	10.0%

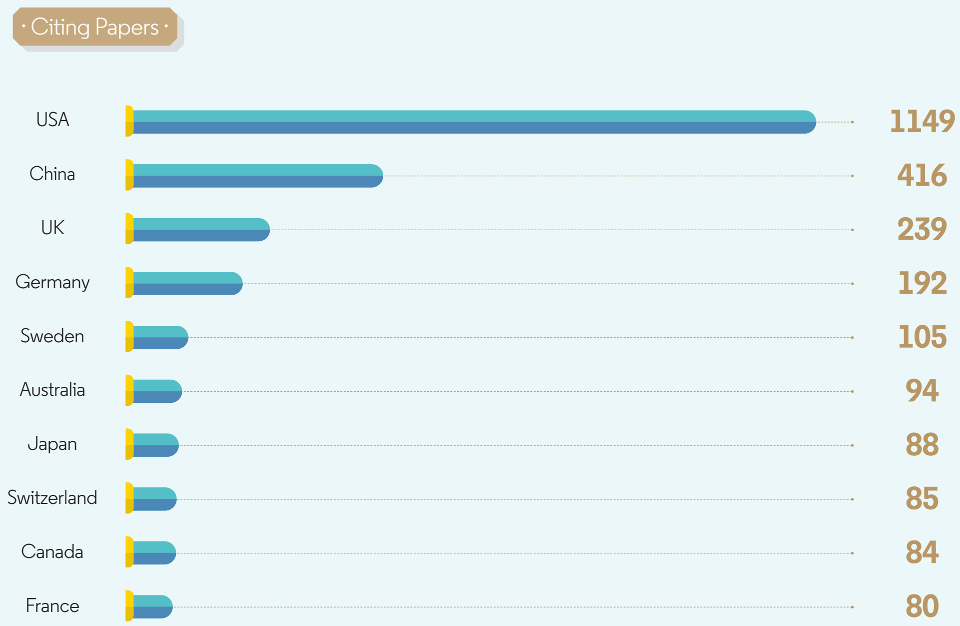


As for the distribution of citing papers (Table 26), the USA is the most active country, participating in 1,149 citing papers, accounting for over half the total. Next is China, actively following up on this research direction and participating in 416 citing papers. Among the Top 10 institutions producing citing papers, seven are based in the USA, including the top five positions. The Chinese Academy of Sciences ranks 6th with 86 citing papers.

Table 26: Top countries and institutions producing citing papers in the Research Front "Spatial transcriptomics technology"

Country Ranking	Country	Citing Papers	Proportion
1	USA	1149	53.1%
2	China	416	19.2%
3	UK	239	11.0%
4	Germany	192	8.9%
5	Sweden	105	4.9%
6	Australia	94	4.3%
7	Japan	88	4.1%
8	Switzerland	85	3.9%
9	Canada	84	3.9%
10	France	80	3.7%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Harvard University	USA	250	11.6%
2	Massachusetts Institute of Technology (MIT)	USA	138	6.4%
3	Stanford University	USA	110	5.1%
4	Broad Institute	USA	107	4.9%
5	Howard Hughes Medical Institute	USA	98	4.5%
6	Chinese Academy of Sciences	China	86	4.0%
7	Helmholtz Association	Germany	69	3.2%
8	University of Cambridge	UK	63	2.9%
9	Karolinska Institutet	Sweden	59	2.7%
10	Johns Hopkins University	USA	56	2.6%
10	National Institutes of Health (NIH)	USA	56	2.6%



1.3 KEY HOT RESARCH FRONT – “Analysis of structural variations in the human genome using the third generation long-read sequencing technology”

DNA-sequencing technology marked by non-amplified single molecule sequencing and long-read length is called third-generation sequencing. Because DNA molecules do not require PCR amplification during sequencing, individual sequencing of each DNA molecule is achieved; this process is also known as single molecule sequencing. At present, the commercially available long-read sequencing platforms mainly include Oxford Nanopore’s Nanopore sequencing platform, and the Single Molecule Real Time (SMRT) sequencing platform, developed by Pacific Biosciences (PacBio) in the USA. Third-generation long-read sequencing has demonstrated its facility in the detection of structural variations and is gradually progressing towards the study of structural variations on a population scale, continuously fueling the hotspots in genomic genetic variation research.

Compared to second-generation sequencing, the third-generation sequencing platform has increased the read length by 10,000 times, but has higher requirements for error rates, costs, and sample. Scientists have gradually developed new algorithms, software, databases, and other supporting tools and technologies. Six of the 11 core papers in this Research Front involve the development of new third-generation long-read sequencing tools and technologies. Minimap2 is a comparison tool developed for third-generation data, published in *Bioinformatics* in 2019 by Heng Li of the Broad Institute, Cambridge, Massachusetts, USA, and colleagues. The article has been cited 2,681 times at this writing and has the highest citation influence in this Research Front.

Other instances of new technology include de novo assembly analysis tools, which compare assembled genomes with reference genes to detect structural variations. Canu is a third-generation data assembly tool written by researchers at the US National Human Genome Research Institute in JAVA language, specifically designed to assemble third-generation sequencing data (applicable to PacBio or Oxford Nanopore sequences). The related paper was published in *Genome Research* in 2017, with 2,616 citations to date. In addition, the core papers also introduce tools such as Racon, Flye, and Wtdbg2 to optimize assembly results. Among these tools, Wtdbg2 runs about 10 times faster than software such as Canu, also improving the analysis speed by 5 times compared to Flye.

The core papers also discusses the application of population-scale third-generation long-read sequencing in the detection of structural variations in the human genome, with the following objectives: 1) Discover new structural variations; 2) Assist in establishing the gold standard for structural variation; 3) Obtain large-scale sequencing data to reveal the role of structural variation in human phenotype; 4) Explore the characteristics of structural variation groups and explore the environmental adaptability of human populations.

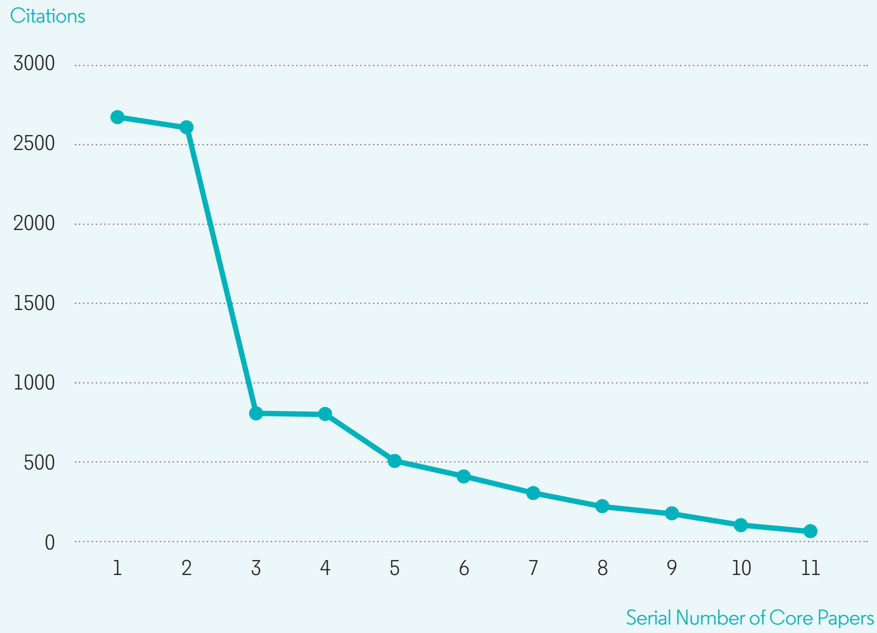


Figure 14: Citation frequency distribution curve of core papers in the Research Front "Analysis of structural variations in the human genome using the third-generation long-read sequencing technology"

From the distribution of core papers, the USA contributes 90.9% of this front's foundational literature, displaying an absolute advantage in this Research Front. Among the top-producing institutions, all nine with more than two core papers are based in the USA. The Broad Institute, Massachusetts Institute of Technology, and Harvard University all participated in publishing six core papers, sharing the #1 ranking.

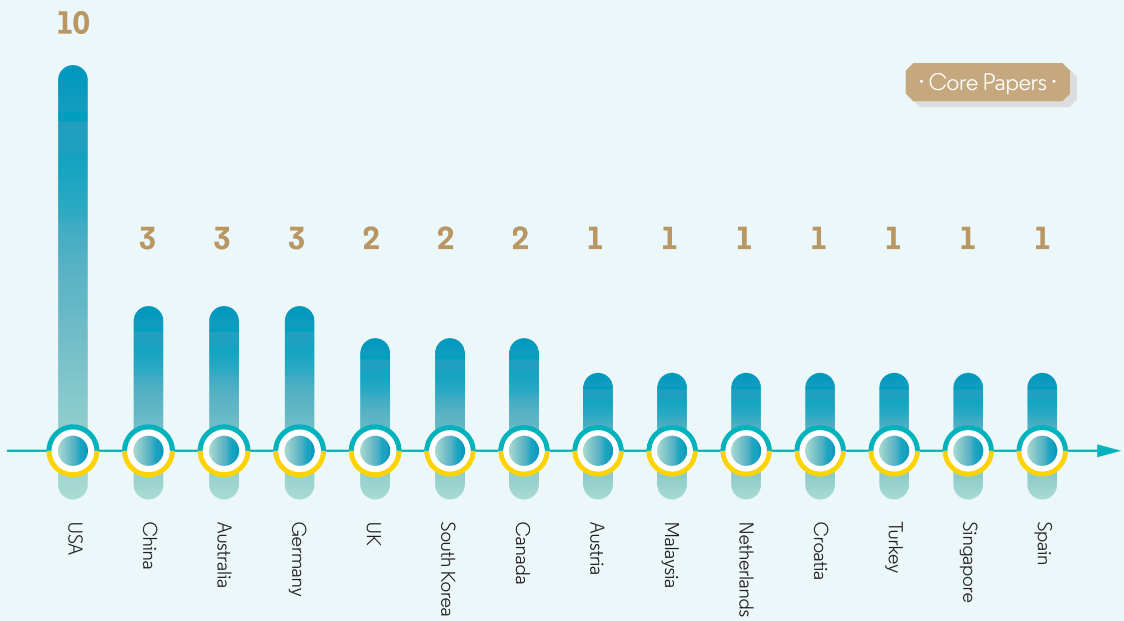
Table 27: Top countries and institutions producing core papers in the Research Front "Analysis of structural variations in the human genome using the third generation long-read sequencing technology"

Country Ranking	Country	Core Papers	Proportion
1	USA	10	90.9%
2	China	3	27.3%
2	Australia	3	27.3%
2	Germany	3	27.3%
5	UK	2	18.2%
5	South Korea	2	18.2%
5	Canada	2	18.2%
8	Austria	1	9.1%
8	Malaysia	1	9.1%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Broad Institute	USA	6	54.5%
1	Massachusetts Institute of Technology (MIT)	USA	6	54.5%
1	Harvard University	USA	6	54.5%
4	University of Southern California	USA	3	27.3%
4	Howard Hughes Medical Institute	USA	3	27.3%
4	University of Michigan	USA	3	27.3%
4	University of Washington	USA	3	27.3%
4	Johns Hopkins University	USA	3	27.3%
4	Washington University in St. Louis	USA	3	27.3%

Country Ranking	Country	Core Papers	Proportion
8	Netherlands	1	9.1%
8	Croatia	1	9.1%
8	Turkey	1	9.1%
8	Singapore	1	9.1%
8	Spain	1	9.1%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion



In terms of countries that cite the front's core papers, the USA and China are the two most active countries, contributing 2,379 and 1,782 citing papers, respectively (Table 28). Among the Top 10 institutions, five are in the USA, while China and France both account for two, and Germany is home to one. The institution with the largest number of citing papers is the Chinese Academy of Sciences, which has published 362 papers following up in this front. In addition, the Chinese Academy of Agricultural Sciences ranks 5th and has published a total of 197 citing papers.

Table 28: Top countries and institutions producing citing papers in the Research Front "Analysis of structural variations in the human genome using the third generation long-read sequencing technology"

Country Ranking	Country	Citing Papers	Proportion
1	USA	2379	37.7%
2	China	1782	28.2%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	362	5.7%
2	National Center for Scientific Research of France (CNRS)	France	261	4.1%

Country Ranking	Country	Citing Papers	Proportion
3	UK	806	12.8%
4	Germany	721	11.4%
5	France	452	7.2%
6	Australia	442	7.0%
7	Canada	361	5.7%
8	Japan	347	5.5%
9	Netherlands	269	4.3%
10	Switzerland	237	3.8%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
3	United States Department of Agriculture (USDA)	USA	213	3.4%
4	Harvard University	USA	212	3.4%
5	Chinese Academy of Agricultural Sciences	China	197	3.1%
6	National Institutes of Health (NIH)	USA	153	2.4%
7	Max Planck Society	Germany	141	2.2%
8	Cornell University	USA	138	2.2%
9	National Research Institute for Agriculture, Food and Environment	France	134	2.1%
10	Johns Hopkins University	USA	128	2.0%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN BIOLOGICAL SCIENCES

Four studies in biological sciences have been selected as emerging fronts, with the main research topics including "Epstein Barr virus (EBV) is the main cause of multiple sclerosis", "The complete sequence of the human genome", "Cuproptosis: mechanism of copper induced tumor cell death", and "Tryptophan metabolism: a new target for disease treatment". Based on the comprehensive analysis of CPT indicators (Please refer to the methodology section for details)., the development potential of these Research Fronts, and the judgment of scientific and technological information researchers, the front "Cuproptosis: mechanism of copper induced tumor cell death" was ultimately selected for key analysis.

Table 29: Emerging Research Fronts in biological sciences

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Epstein Barr virus (EBV) is the main cause of multiple sclerosis	2	334	2022.0
2	The complete sequence of the human genome	10	561	2021.7
3	Cuproptosis: mechanism of copper induced tumor cell death	14	908	2021.6
4	Tryptophan metabolism: a new target for disease treatment	12	404	2021.6

2.2 KEY EMERGING RESARCH FRONT – "Cuproptosis: mechanism of copper induced tumor cell death"

Copper is an essential mineral nutrient for all living organisms and a fundamental element in many biological processes, including mitochondrial respiration, iron absorption, antioxidant, and detoxification processes. Recent reports have noted that copper also has a signaling effect, which can regulate or trigger several biological pathways under external stimuli. Evidence has also suggested that copper may play a role in the etiology, occurrence, development, severity, and progression of cancer. Currently, significant changes in copper levels have been found in the serum and tumor tissues of patients afflicted with various cancers. Therefore, the study of copper is of great significance, and may also become a potential target for inhibiting cancer occurrence.

In March 2022, a research paper titled "Copper induced cell death by targeting lipoylated TCA cycle proteins" was published in *Science*, reporting the discovery that cuproptosis is a new form of cell death caused by excessive copper. In just one year, the paper has been cited 359 times as of this writing. Cuproptosis is a novel cell-death mode that differs from the currently known mechanism of cell death. Intracellular copper stimulates the thioacylation aggregation process of mitochondrial-related proteins, promotes the degradation of iron sulfur cluster proteins, leads to protein toxicity stress, and ultimately concludes in cell death. This major discovery undoubtedly provides a new perspective for the treatment of copper metabolism imbalance, especially in the treatment of diseases related to copper overload.

In addition, multiple core papers in this emerging front have analyzed the molecular changes and clinical relevance of cuproptosis related genes (CRGs) in cancers such as melanoma, renal cell carcinoma, and hepatocellular carcinoma, exploring the potential mechanisms of cuproptosis in the development of related diseases.

The discovery of a new mechanism of cuproptosis has also paved the way for future drug development targeting copper as a therapeutic approach. Further research on cuproptosis related regulatory pathways under different pathological backgrounds holds significant value and transformative significance in the clinical treatment of related diseases.


2023 RESEARCH FRONTS

2023 RESEARCH FRONTS

CHEMISTRY AND MATERIALS SCIENCE

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

The Top 10 Research Fronts in chemistry and materials science in 2023 spotlight specialty areas as diverse as electrochemistry, nanomaterials, organic chemistry, and emerging fields. In the field of electrochemistry, hot fronts have been identified in electrocatalysts for seawater electrolysis, electrocatalytic nitrate reduction, anion exchange membrane fuel cells, and electrocatalytic hydrogen peroxide production. High-entropy alloy catalysts, quantum dot light-emitting diodes, and two-dimensional transistors have been chosen as hot fronts in the field of nanomaterials. This chapter also emphasizes two Research Fronts in the field of organic chemistry—one involving artificial molecular machines and the other supramolecular adhesives. Notably, representatives of an emerging cross-disciplinary research direction—mechanochemistry, and the related specialty of artificial molecular machines—have distinguished themselves by appearing among the Top 10 Research Fronts for the second year in a row.

Table 30 Top10 Research Fronts in chemistry and materials science

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Electrocatalysts for seawater electrolysis	11	2003	2020.0
2	High-entropy alloy catalysts	13	2119	2019.9
3	Electrocatalytic nitrate reduction	13	2673	2019.8
4	Quantum dot light-emitting diodes	13	2391	2019.7
5	Mechanochemistry	16	3095	2019.6
6	Anion exchange membrane fuel cells	15	3096	2019.5
7	Two-dimensional transistors	10	2692	2019.5
8	Electrocatalytic hydrogen peroxide production	39	7728	2019.4
9	Artificial molecular machines	17	3240	2019.4
10	Supramolecular adhesives	13	2987	2019.4

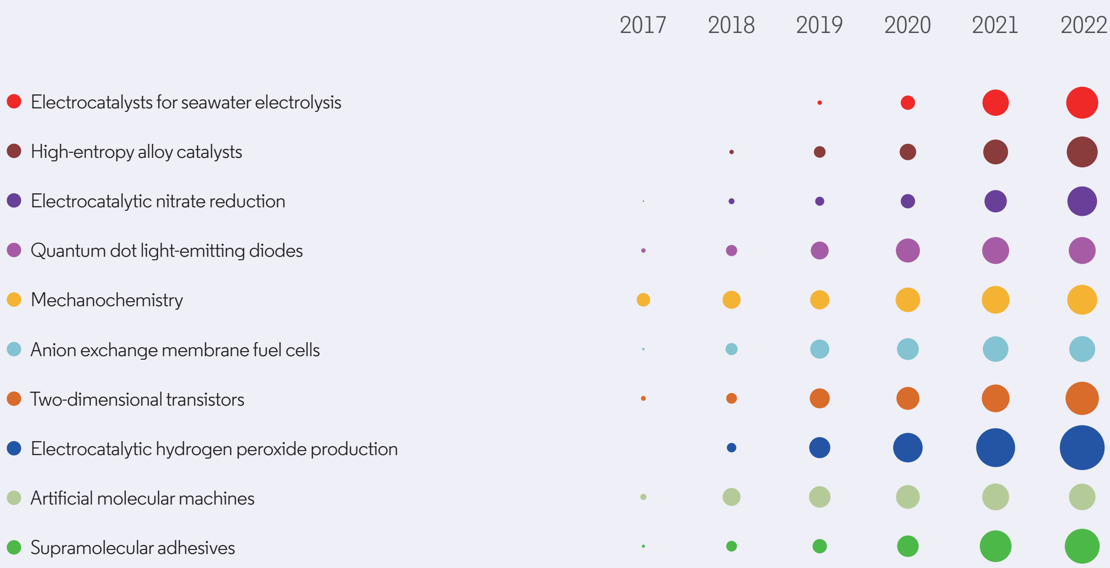


Figure 15: Citing papers of the Top 10 Research Fronts in chemistry and materials science

1.2 KEY HOT RESEARCH FRONT – "Electrocatalysts for seawater electrolysis"

Given the natural abundance of seawater and the low cost of working with it, seawater electrolysis is not only a promising approach to producing clean hydrogen energy, but also of great significance to seawater desalination. However, the undesirable chlorine ion oxidation reactions occurring simultaneously during the process greatly hinder the overall performance of seawater electrolysis. Therefore, the implementation of the process requires efficient and robust electrocatalysts that can sustain oxygen evolution reactions (OER) against chloride corrosion, especially for the anode.

The 11 highly cited papers constituting the core of this Research Front address electrocatalysts for OER or hydrogen evolution reactions (HER), with a focus on the former. Electrocatalysts with various combinations of active elements such as Ni, Fe, and Co have been developed and can afford superior catalytic activity and corrosion resistance in alkaline seawater electrolysis at industrially required current densities and room temperature, outperforming the performance of commercial Ir-based catalysts. The most-cited core paper is coauthored by researchers at Central China Normal University (China) and the University of Houston (USA). In this paper, researchers assemble an outstanding water electrolyzer for overall seawater splitting, which outputs current densities of 500 and 1000 mA cm^{-2} at record low voltages of 1.608 and 1.709 V, respectively, in alkaline natural seawater at 60 °C.

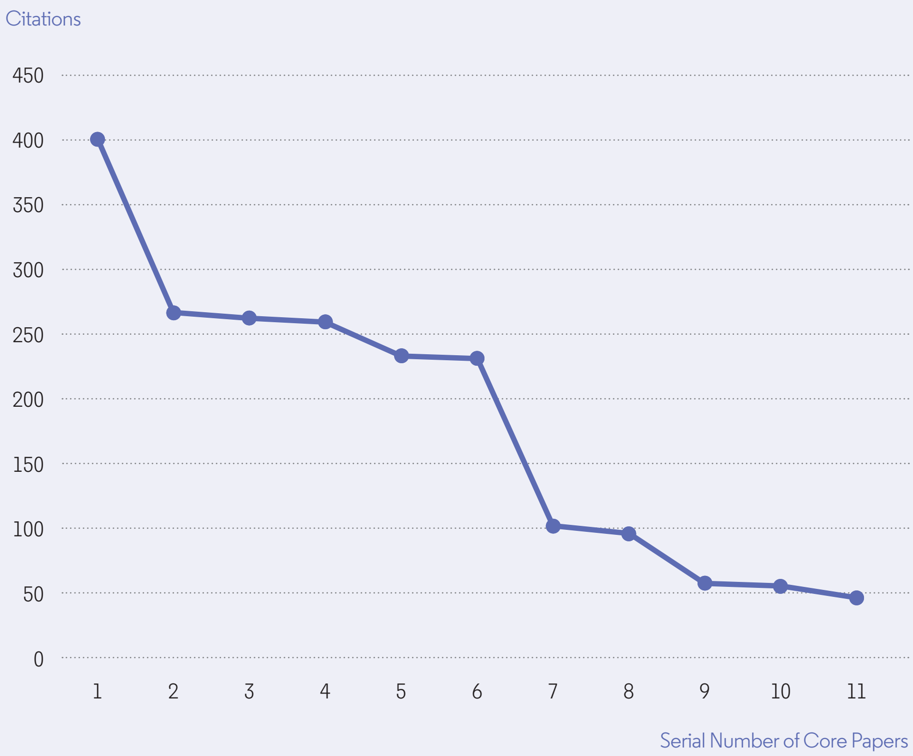


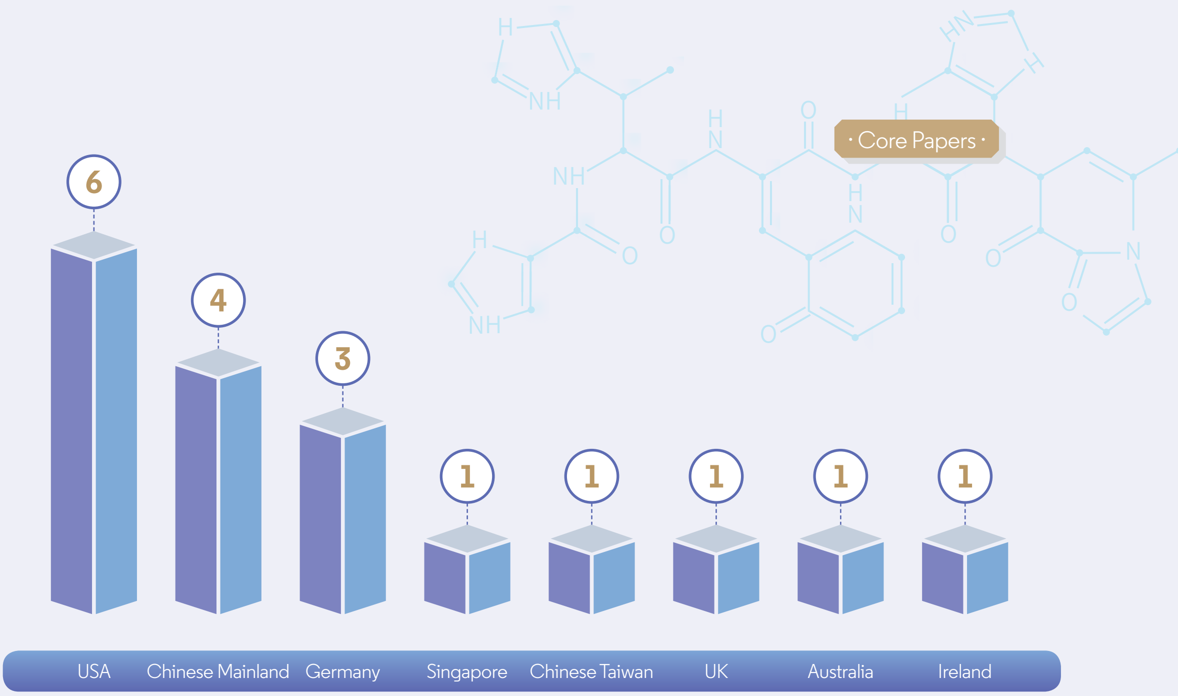
Figure16: Citation frequency distribution curve of core papers in the Research Front "Electrocatalysts for seawater electrolysis"

As shown in Table 31, the USA has contributed six core papers, five of which are from the University of Houston. Chinese Mainland has published four core papers, with half from the collaboration between Central China Normal University and the University of Houston. Three core papers from Germany all represent the Technical University of Berlin.

Table 31 Top countries/regions and institutions producing core papers in the Research Front "Electrocatalysts for seawater electrolysis"

Country/ region Ranking	Country/ Region	Core Papers	Proportion
1	USA	6	54.5%
2	Chinese Mainland	4	36.4%
3	Germany	3	27.3%
4	Singapore	1	9.1%
4	Chinese Taiwan	1	9.1%
4	UK	1	9.1%
4	Australia	1	9.1%
4	Ireland	1	9.1%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	University of Houston	USA	5	45.5%
2	Technical University of Berlin	Germany	3	27.3%
3	Central China Normal University	China	2	18.2%



As shown in Table 32, Chinese Mainland has published the greatest number of citing papers in this front, far more than those of the USA and South Korea, which rank 2nd and 3rd, respectively. All the Top 10 institutions producing citing papers are based in China, demonstrating a strong research-concentration advantage in the field.

Table 32: Top countries/regions and institutions producing citing papers in the Research Front "Electrocatalysts for seawater electrolysis"

Country/ region Ranking	Country/ Region	Citing Papers	Proportion
1	Chinese Mainland	902	73.9%
2	USA	121	9.9%
3	South Korea	90	7.4%
4	Australia	49	4.0%
5	Germany	44	3.6%
5	UK	44	3.6%
7	India	43	3.5%
8	Chinese Hong Kong	38	3.1%
9	Japan	29	2.4%
10	Singapore	23	1.9%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	141	11.6%
2	Qingdao University of Science and Technology	China	44	3.6%
3	Zhengzhou University	China	36	3.0%
4	China University of Petroleum	China	35	2.9%
5	Wuhan University of Technology	China	31	2.5%
6	Beijing University of Chemical Technology	China	27	2.2%
7	Shenzhen University	China	26	2.1%
8	Suzhou University	China	25	2.0%
9	Tianjin University	China	24	2.0%
10	Jilin University	China	23	1.9%

1.3 KEY HOT RESARCH FRONT – "Electrocatalytic hydrogen peroxide production"

As a valuable and environmentally friendly oxidizing agent, hydrogen peroxide (H_2O_2) is widely used in processes such as wastewater treatment and chemical synthesis. However, the current industrial synthesis of H_2O_2 involves an energy-intensive anthraquinone process that is costly and impractical for routine on-site use. Electrochemical synthesis of H_2O_2 through a two-electron oxygen reduction reaction (2e-ORR) or a two-electron water oxidation reaction (2e-WOR) has emerged as an appealing alternative in locally producing this chemical on demand. However, the development of cost-effective, efficient, and selective electrocatalysts for this process remains a challenge.

The 39 highly cited papers constituting the core of this Research Front address the design of electrocatalysts and electrodes, with a focus on the former. Many different types of electrocatalysts, ranging from metal single atoms (e.g., Co, Mo) and carbon-based materials for 2e-ORR to metal oxides (e.g., $BiVO_4$) for 2e-WOR have been developed. The most-cited core paper is coauthored by researchers at Stanford University and SLAC National Accelerator Laboratory (USA). In this paper, researchers demonstrate a simple and general approach to catalyst development via the surface oxidation of abundant carbon materials, which significantly enhances both the activity and selectivity (~90%) for H_2O_2 production by electrochemical oxygen reduction.

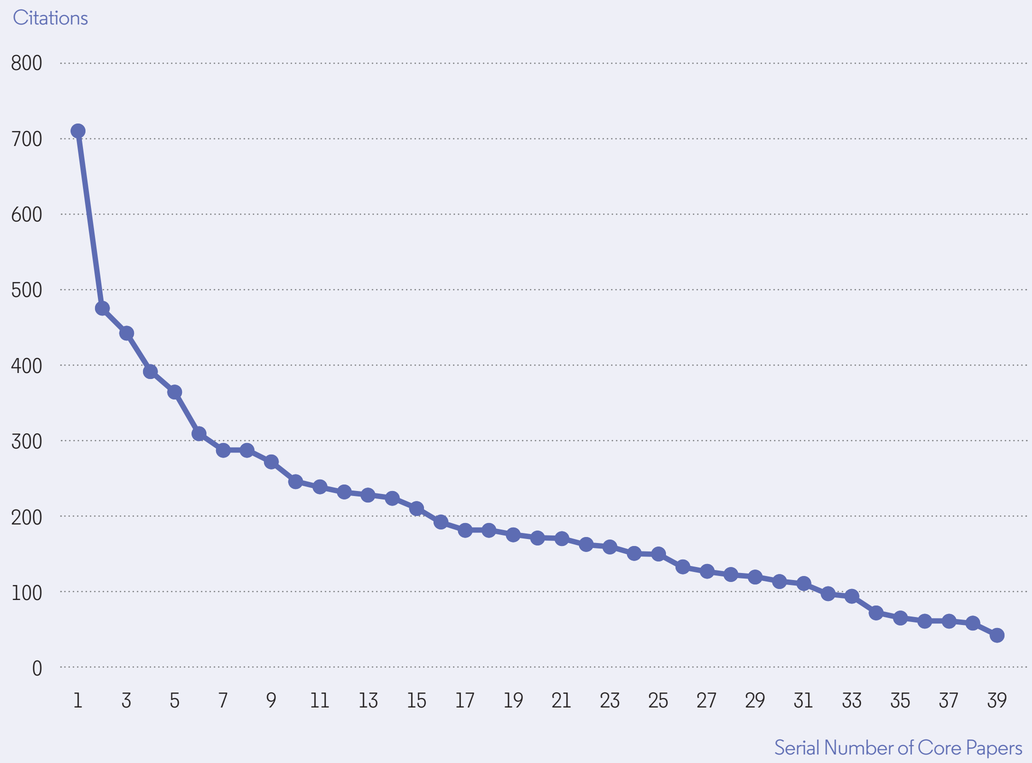


Figure17: Citation frequency distribution curve of core papers in the Research Front "Electrocatalytic hydrogen peroxide production"

As shown in Table 33, China and the USA have respectively contributed 20 and 14 core papers, more than that of the other listed nations, ranking them in 1st and 2nd place. Among the Top institutions producing core papers, the US Department of Energy's National Laboratories have contributed nine core papers, ranking 1st, followed by Stanford University (USA), Chinese Academy of Sciences(China), and the University of Calgary (Canada).

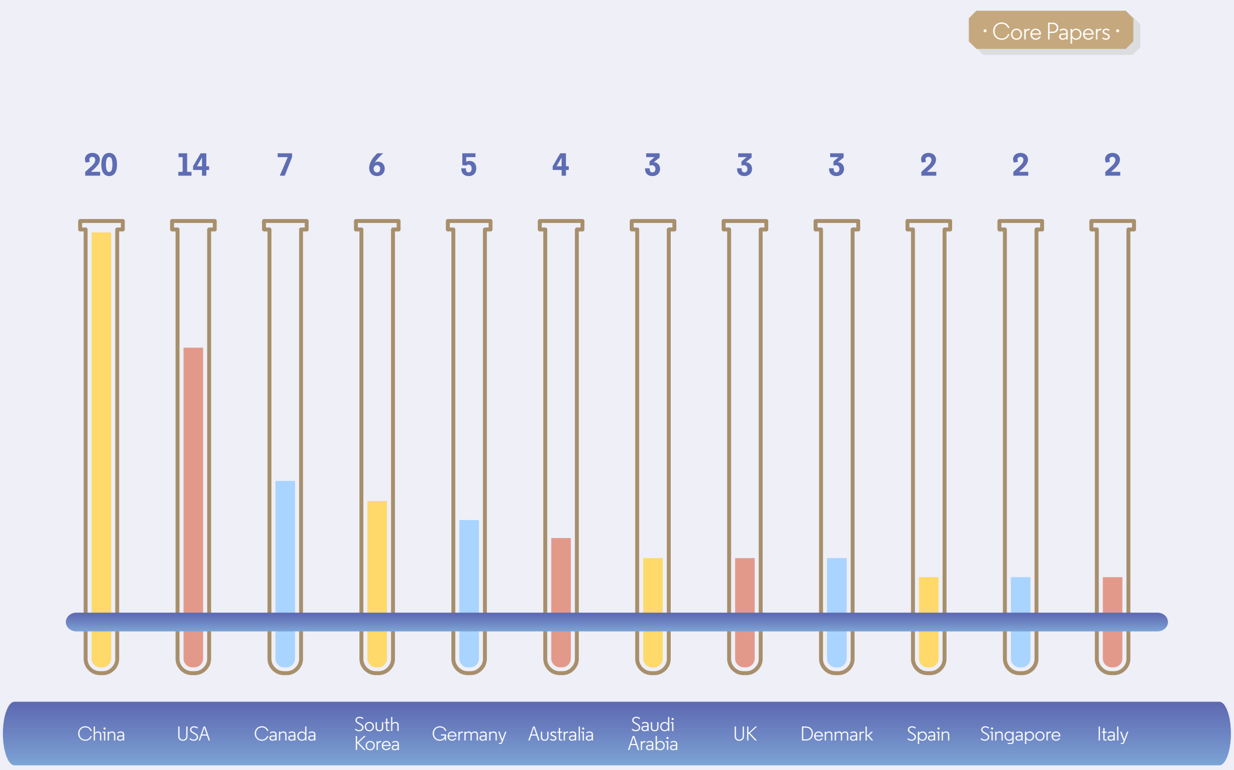
Table 33 Top countries and institutions producing core papers in the Research Front "Electrocatalytic hydrogen peroxide production"

Country Ranking	Country	Core Papers	Proportion
1	China	20	51.3%
2	USA	14	35.9%
3	Canada	7	17.9%
4	South Korea	6	15.4%
5	Germany	5	12.8%
6	Australia	4	10.3%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Department of Energy's National Laboratories	USA	9	23.1%
2	Stanford University	USA	7	17.9%
3	Chinese Academy of Sciences	China	6	15.4%
3	University of Calgary	Canada	6	15.4%
5	Rice University	USA	5	12.8%
6	Tsinghua University	China	4	10.3%

Country Ranking	Country	Core Papers	Proportion
7	Saudi Arabia	3	7.7%
7	UK	3	7.7%
7	Denmark	3	7.7%
10	Spain	2	5.1%
10	Singapore	2	5.1%
10	Italy	2	5.1%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
7	King Abdulaziz University	Saudi Arabia	3	7.7%
7	University of Electronic Science and Technology of China	China	3	7.7%
7	Technical University of Berlin	Germany	3	7.7%
7	Henan University	China	3	7.7%
7	University of Adelaide	Australia	3	7.7%

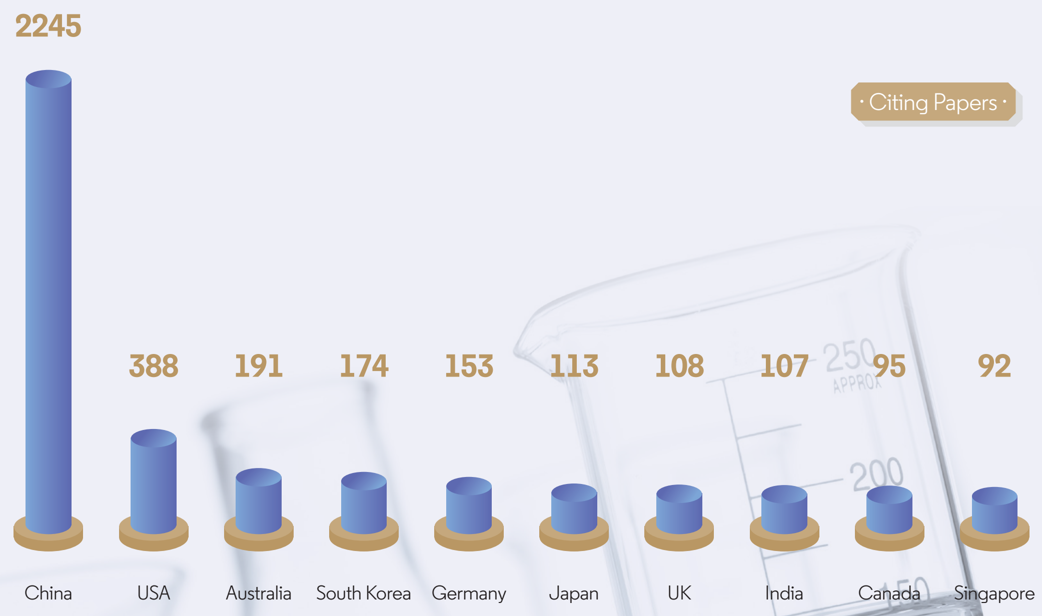


As shown in Table 34, China has published the greatest number of citing papers in this front, far more than that of the other listed nations. The USA and Australia have also made contributions to citing articles, coming in at 2nd and 3rd place, respectively. Among the Top institutions producing citing papers, 10 are based in China, demonstrating that China has a very active group of researchers in the field. The US Department of Energy's National Laboratories come in at No. 6 on the list.

Table 34 Top countries and institutions producing citing papers in the Research Front "Electrocatalytic hydrogen peroxide production"

Country Ranking	Country	Citing Papers	Proportion
1	China	2245	72.5%
2	USA	388	12.5%
3	Australia	191	6.2%
4	South Korea	174	5.6%
5	Germany	153	4.9%
6	Japan	113	3.6%
7	UK	108	3.5%
8	India	107	3.5%
9	Canada	95	3.1%
10	Singapore	92	3.0%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	492	15.9%
2	Tsinghua University	China	130	4.2%
3	Harbin Institute of Technology	China	92	3.0%
4	Tianjin University	China	89	2.9%
5	Nankai University	China	83	2.7%
6	Department of Energy's National Laboratories	USA	82	2.6%
7	Suzhou University	China	73	2.4%
8	Zhengzhou University	China	70	2.3%
9	Beijing University of Chemical Technology	China	68	2.2%
10	Dalian University of Technology	China	65	2.1%
10	University of Electronic Science and Technology of China	China	65	2.1%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

Two topics have been selected as the emerging Research Fronts in the field of chemistry and materials science (Table 35), both related to energy conversion and storage. "The development of high-performance HER and ORR photocatalysts and their applications in the synthesis of solar fuel" principally involves the use of photocatalysts, such as covalent organic framework compounds and metal oxide semiconductors (mainly $BiVO_4$), to convert solar energy into green fuels such as hydrogen and hydrogen peroxide by hydrogen reduction reactions (HER) and oxygen reduction reactions (ORR). "The preparation of polymer dielectric capacitors" chiefly involves using polymers as the dielectric of capacitors, by adjusting their composition and structure, to achieve the simultaneous improvement of capacitor energy density and discharge efficiency.

Table 35: Emerging Research Fronts in chemistry and materials science

Rank	Emerging Research Fronts	Core Papers	Citation	Mean Year of Core Papers
1	The development of high-performance HER and ORR photocatalysts and their applications in the synthesis of solar fuel	8	195	2021.9
2	The preparation of polymer dielectric capacitors	6	245	2021.7

2.2 KEY EMERGING RESEARCH FRONT – "The development of high-performance HER and ORR photocatalysts and their applications in the synthesis of solar fuel"

Using artificial photosynthesis to collect solar fuel is of great value in coping with climate change, environmental pollution, and the energy crisis. In various solar fuel artificial photosynthesis reactions, due to factors such as scalability and cost-effectiveness, solar-driven hydrogen production by water splitting (HER) and two-electron oxygen reduction (ORR) by using abundant water and oxygen to artificially photosynthesize H_2O_2 have attracted the attention of many researchers.

In this emerging Research Front, the preparation and optimization path of high-performance HER and ORR photocatalysts are mainly discussed in terms of achieving the efficient and rapid production of solar fuels (hydrogen and hydrogen peroxide). Among these methods, the strategies for hydrogen production using HER photocatalysts revolve around improving the stability of covalent organic frameworks (COFs) and enhancing the delocalization ability of electrons. Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences (China) adopted the strategy of post-oxidative cyclization to convert N-acylhydrazone-linked COF (H-COF) into a stable and pi-conjugated oxadiazole-linked COF (ODA-COF), achieving the simultaneous enhancement of COF chemical stability and pi-electron delocalization capability throughout the reticular framework, and leading to a high hydrogen evolution rate upon visible light irradiation, which is over four times higher than that of H-COF. Due to the excellent stability and electron delocalization of carbon - carbon double bond as the connecting units of COFs, researchers at Qingdao University of Science and

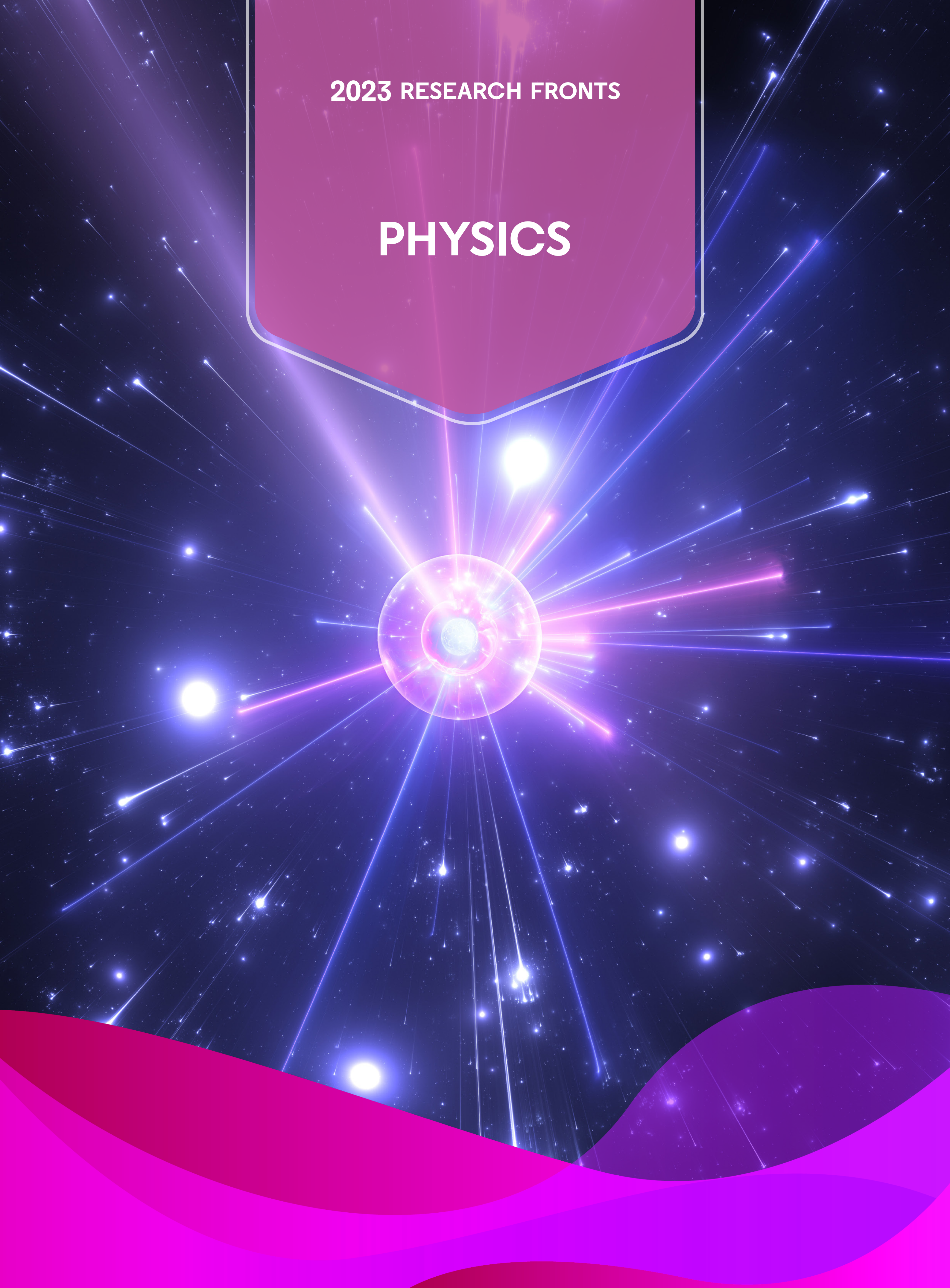
Technology (China) prepared vinylene-linked 2D COFs crystallines (BTH-1, 2, 3) containing benzobisthiazoles units as functional groups COFs (benzodithiazole structure) based on the Knoevenagel reaction, which exhibited an attractive photocatalytic HER of 15.1 mmol h($^{-1}$)g($^{-1}$) under visible light irradiation.

Regarding research on the use of ORR photocatalytic reactions to produce H_2O_2, this emerging Research Front mainly involves the preparation of two types of photocatalytic materials and their applications in H_2O_2 synthesis: covalent organic framework compounds (COFs) and inorganic $BiVO_4$. China Three Gorges University (China) and Swinburne University of Technology (Australia) have initially demonstrated that bipyridine-based covalent organic framework photocatalyst (denoted as COF-TfpBpy) can photocatalytically generate H_2O_2 without sacrificing reagents or buffer solution from water and air; while Beijing Institute of Technology (China) has developed a partially fluorinated, metal-free, imine-linked two-dimensional triazine covalent organic framework (TF50-COF) photocatalyst, which demonstrated high selectivity and stability in O_2 photoreduction into H_2O_2, with a high H_2O_2 yield rate of 1739 μmol h($^{-1}$) g($^{-1}$) and a remarkable apparent quantum efficiency of 5.1 % at 400 nm. In addition, teams at Zhejiang University (China) and Chuo University (Japan) have prepared an efficient overall H_2O_2 photosynthesis system using inorganic Mo-doped faceted $BiVO_4$ (Mo:$BiVO_4$). This system can significantly enhance charge separation and suppress rapid capture and recombination of charge carriers, exhibiting a high overall H_2O_2 photosynthesis efficiency among inorganic photocatalysts, with an apparent quantum yield of 1.2% and a solar-to-chemical conversion efficiency of 0.29% at full spectrum, as well as an apparent quantum yield of 5.8% at 420 nm.


2023 RESEARCH FRONTS

2023 RESEARCH FRONTS

PHYSICS



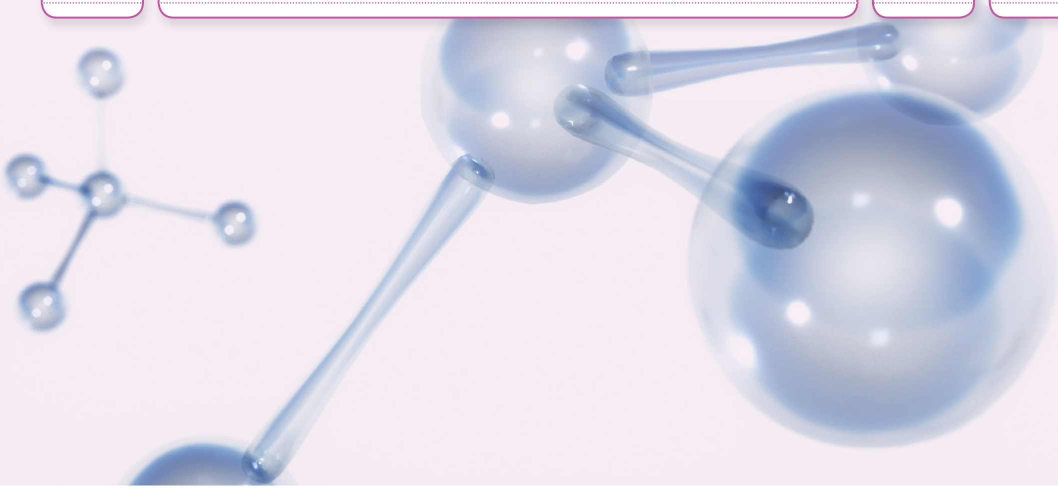
1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN PHYSICS

The Top 10 Research Fronts in physics mainly focus on the subfields of condensed matter physics, theoretical physics, high-energy physics, optics, and quantum physics. There are four Research Fronts in condensed matter physics, in which novel superconducting materials make a strong impression, including Kagome superconductors AV_3Sb_5, infinite layer nickelates, and hydrogen-rich compounds. Moreover, transition metal dichalcogenides Moiré superlattices emerge as a hot topic. In theoretical physics, two hot fronts have attracted much attention: One is focused on the black hole information paradox and entanglement entropy, while the other centers on the study of scattering amplitudes in quantum field theory. In high-energy physics, parton distribution functions has newly emerged, while measurement of the muon anomalous magnetic moment has now registered as a hot topic for two consecutive years. In optics and quantum physics, there are two newly emerging hot fronts. They respectively focus on AlGaN-based deep-ultraviolet light-emitting diodes and twin-field quantum key distribution.

Table 36: Top10 Research Fronts in physics

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Kagome superconductors AV_3Sb_5	45	3121	2021.2
2	Black hole information paradox and entanglement entropy	45	3277	2020.9
3	Studies of scattering amplitudes in quantum field theory	42	3251	2020.2
4	Superconductivity of infinite layer nickelates	22	1981	2020.2
5	High-temperature superconductivity in hydrogen-rich compounds under high pressure	26	4222	2020.1
6	Transition metal dichalcogenides Moiré superlattices	12	1817	2020.1
7	Measurement of the muon anomalous magnetic moment	34	5845	2019.6
8	AlGaN-based deep-ultraviolet light-emitting diodes	11	1957	2019.3
9	Twin-field quantum key distribution	31	5825	2019.2
10	Parton distribution functions	20	3140	2019.2



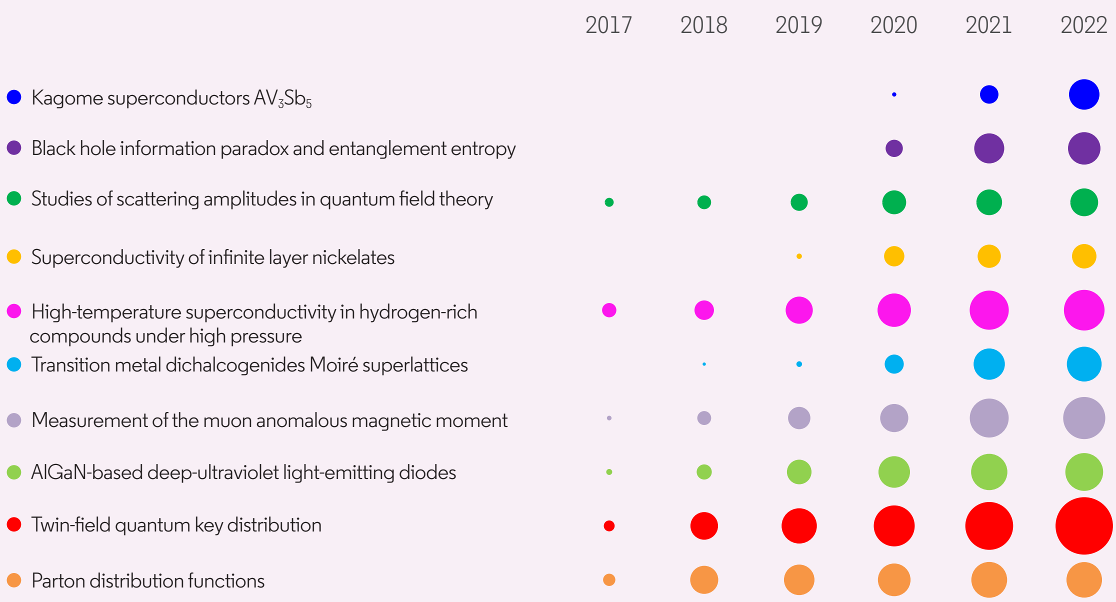


Figure 18: Citing papers for the Top 10 Research Fronts in physics

1.2 KEY HOT RESEARCH FRONT – "Kagome superconductors AV_3Sb_5"

Kagome lattices, made up of corner-sharing triangles, featuring flat bands, van Hove singularities and Dirac cones in its electronic structure, have become a novel platform for studying electron correlations, topological states, and geometrical frustration. Kagome lattice materials have revealed rich emergent phenomena—such as quantum spin liquids, magnetic Weyl fermions, giant anomalous Hall effect—and have subsequently become a hot topic in condensed matter physics.

Previous research on Kagome materials mainly focused on their magnetism and topology. Recently, superconductivity in Kagome materials, observed in Kagome superconductors AV_3Sb_5 (A = K, Rb, Cs), has attracted considerable attention from researchers. The AV_3Sb_5 Kagome family was discovered and synthesized by researchers at the University of California, Santa Barbara (UCSB) and their collaborators in 2019. Subsequently, superconductivity was found in CsV_3Sb_5 in 2020. The finding has triggered an upsurge in research into the properties of Kagome superconductors.

As for the citation frequency of individual core papers (Figure 19): the report on the discovery of superconductivity in CsV_3Sb_5, published in 2020 by researchers at UCSB and collaborating institutions, has garnered the highest citation total, currently exceeding 200. In addition, research findings from institutions including UCSB in 2019 on the AV_3Sb_5 Kagome family, Princeton University in 2021 on the unconventional chiral charge order in KV_3Sb_5, and the Max Planck Institute of Microstructure Physics in Halle, Germany in 2020 on the discovery of Giant anomalous Hall effect in KV_3Sb_5, have been also widely cited.

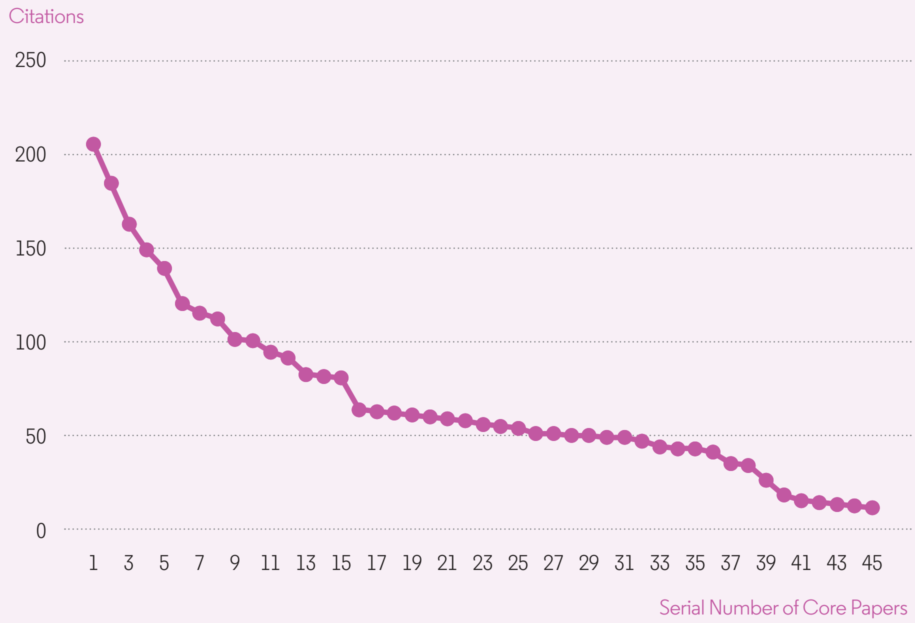


Figure 19: Citation frequency distribution curve of core papers in the Research Front "Kagome superconductors AV_3Sb_5"

China and the USA are the most active countries in this front. Authors based in the two nations participated in 32 and 25 core papers, respectively (Table 37), accounting for 71.1% and 55.6% of the total. Germany and Switzerland also demonstrate strong performance. On the list of top institutions, China is host to five, while the USA contains four, and Germany and Switzerland each claim one. Among individual organizations, the Chinese Academy of Sciences contributed the highest numbers of core papers, followed by UCSB and Renmin University of China.

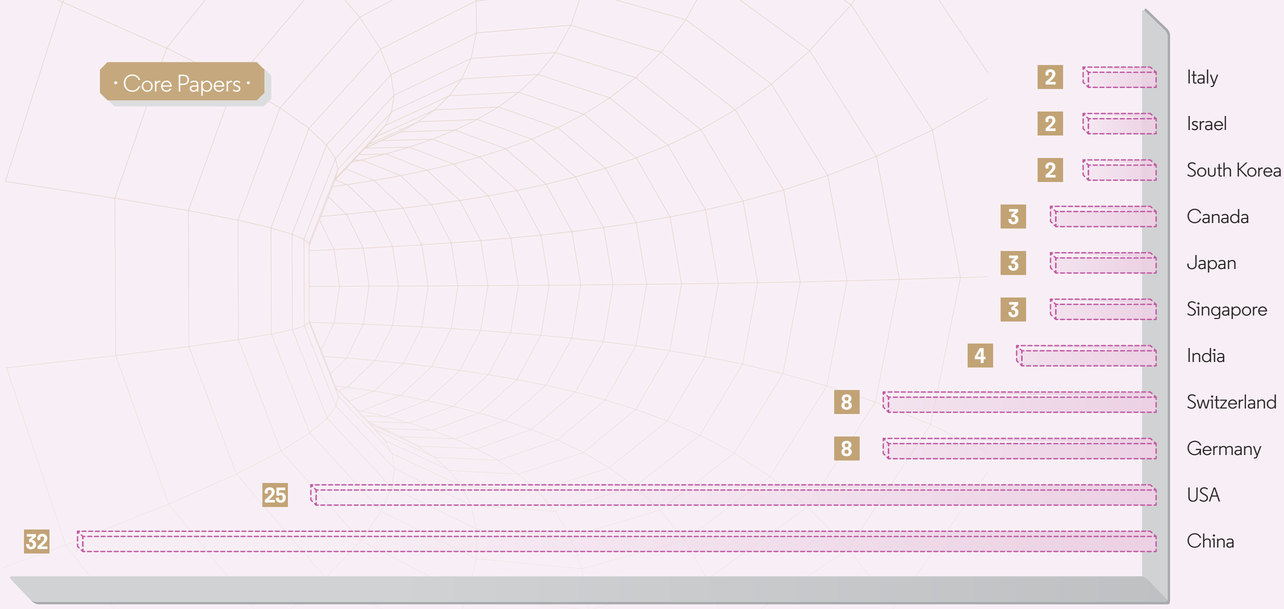
Table 37: Top countries and institutions producing core papers in the Research Front "Kagome superconductors AV_3Sb_5"

Country Ranking	Country	Core Papers	Proportion
1	China	32	71.1%
2	USA	25	55.6%
3	Germany	8	17.8%
3	Switzerland	8	17.8%
5	India	4	8.9%
6	Singapore	3	6.7%
6	Japan	3	6.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Chinese Academy of Sciences	China	23	51.1%
2	University of California Santa Barbara	USA	16	35.6%
3	Renmin University of China	China	9	20.0%
4	Boston College	USA	8	17.8%
5	University of Wurzburg	Germany	7	15.6%
6	Songshan Lake Materials Laboratory	China	6	13.3%
6	Lawrence Berkeley National Laboratory	USA	6	13.3%

Country Ranking	Country	Core Papers	Proportion
6	Canada	3	6.7%
9	South Korea	2	4.4%
9	Israel	2	4.4%
9	Italy	2	4.4%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
6	Paul Scherrer Institute	Switzerland	6	13.3%
9	Nanjing University	China	5	11.1%
9	Princeton University	USA	5	11.1%
9	Beijing Institute of Technology	China	5	11.1%



In terms of papers that cite the core literature (Table 38), Chinese Mainland and the USA are again the most prolific countries/regions, with paper counts far exceeding those of other countries/regions. Meanwhile, Germany, Japan, and Switzerland are actively catching up. On the list of citing institutions, four of the top entities are based in China, while the USA is host to three, while Germany, Switzerland, and Japan each have one.

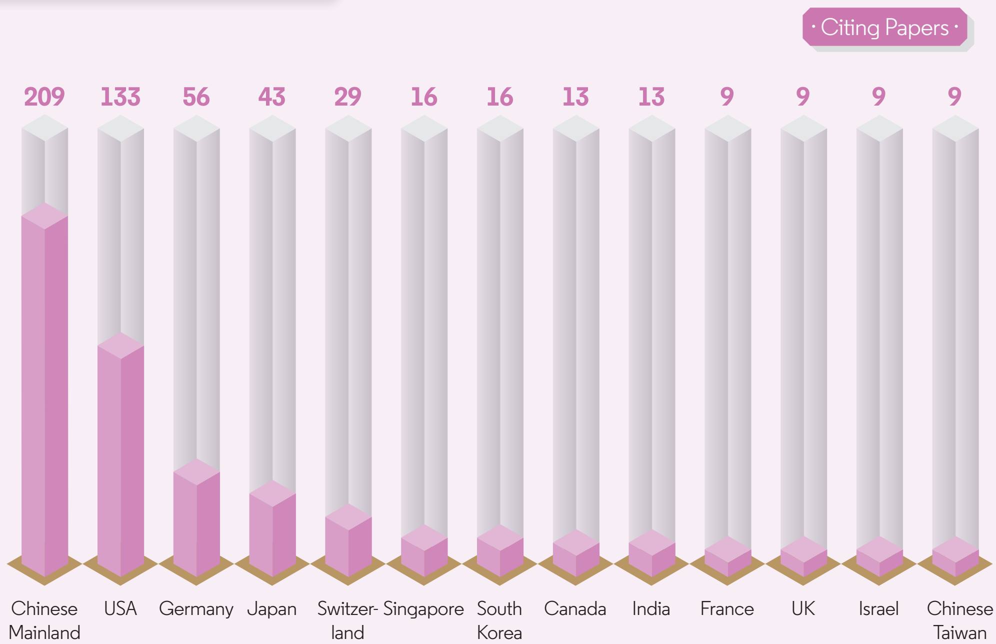
Table 38: Top countries/regions and institutions producing citing papers in the Research Front "Kagome superconductors AV_3Sb_5"

Country/region Ranking	Country/Region	Citing Papers	Proportion
1	Chinese Mainland	209	58.2%
2	USA	133	37.0%
3	Germany	56	15.6%
4	Japan	43	12.0%
5	Switzerland	29	8.1%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	112	31.2%
2	University of California Santa Barbara	USA	39	10.9%
3	Renmin University of China	China	29	8.1%
4	Songshan Lake Materials Laboratory	China	27	7.5%
5	Nanjing University	China	26	7.2%

Country/ region Ranking	Country/ Region	Citing Papers	Proportion
6	Singapore	16	4.5%
6	South Korea	16	4.5%
8	Canada	13	3.6%
8	India	13	3.6%
10	France	9	2.5%
10	UK	9	2.5%
10	Israel	9	2.5%
10	Chinese Taiwan	9	2.5%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
6	Max Planck Society	Germany	23	6.4%
6	Princeton University	USA	23	6.4%
8	Lawrence Berkeley National Laboratory	USA	22	6.1%
9	Paul Scherrer Institute	Switzerland	20	5.6%
10	University of Tokyo	Japan	18	5.0%



1.3 KEY HOT RESARCH FRONT– “Twin-field quantum key distribution”

The field of quantum information has become a focal point of science and technology in major countries/ regions around the world. Quantum communication, one of the key areas of quantum information science, represents a fusion and innovation at the intersection of quantum physics, information technology, and cryptographic technology. Quantum key distribution (QKD) is a successful application in quantum communication and is theoretically secure using the principle of quantum mechanics. QKD realizes secure communication by the preparation, transmission, and detection of quantum states; the rules governing these methods are called QKD protocols. Researchers have proposed various QKD protocols, from the first QKD protocol (BB84 protocol), decoy-state QKD, to measurement-device-independent QKD (MDI-QKD), to continuously improve the security of QKD.

Distance and secret key rate are important for practical applications of QKD. Research has shown that there exists an upper bound for both repeaterless QKD and optical-fiber communication. With the aid of a quantum repeater, it should be possible to overcome this barrier.

However, the matter is still undergoing further development. In 2018, Toshiba Research Europe proposed twin-field quantum key distribution (TF-QKD) based on the idea of single-photon interference, showing the possibility of overcoming the rate–distance limit. TF-QKD is an efficient version of MDI-QKD and has become a hot topic in recent years, resulting in many variants and experimental demonstrations.

Regarding the citation frequency of individual core papers (Figure 20), the three most-cited papers were all published in 2017. These reports include the achievement of a transmission distance surpassing 1,200 kilometers in the satellite-to-ground QKD experiment reported by the University of Science and Technology of China (USTC) and its collaborators (cited 578 times as this writing); the fundamental rate–distance limit of QKD discovered by the University of York, UK (521 citations); and the quantum entanglement distribution over 1,200 kilometers reported by USTC and others (431 citations). Also highly cited is the above-mentioned paper proposing TF-QKD, published in 2018 by Toshiba Research Europe, now approaching 400 citations. Publications on the phase-matching QKD and on the question of sending or not sending TF-QKD, both reported by researchers at Tsinghua University and their collaborators in 2018, as well as the paper by researchers from USTC in 2021, reporting the achievement of more than 511 kilometers of on-site TF-QKD, have also garnered high citations.

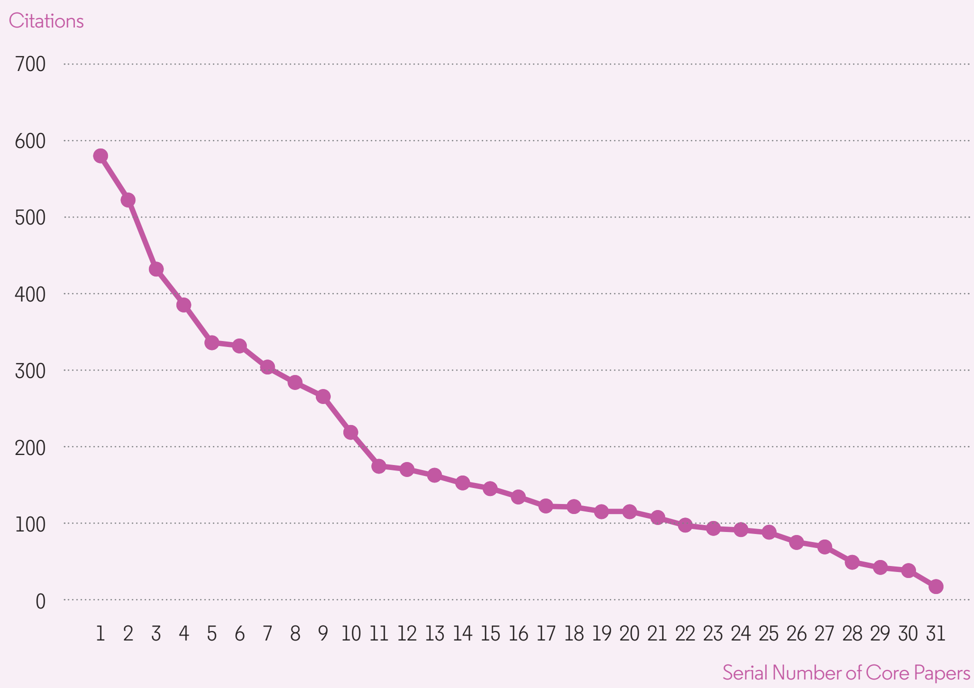


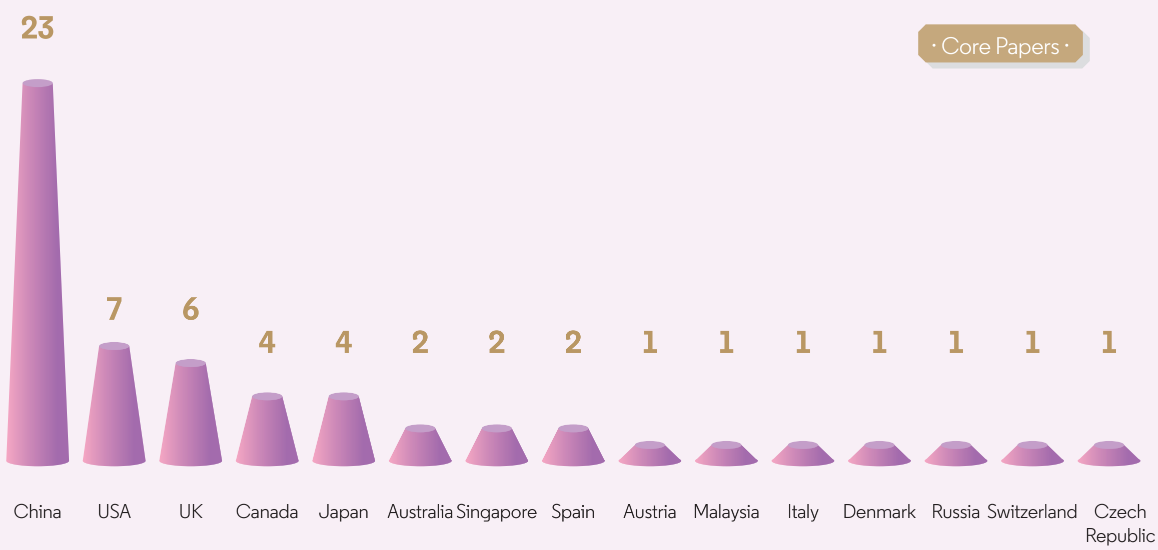
Figure 20: Citation frequency distribution curve of core papers in the Research Front "Twin-field quantum key distribution"

China is the most active country in this front, participating in 23 core papers, and accounting for 74.2% of the total (Table 39). The USA, the UK, and Canada also actively engage in this specialty area. Among individual organizations, the Chinese Academy of Sciences contributed the highest numbers of core papers, followed by Tsinghua University, the University of York, and Jinan Institute of Quantum Technology. Among the top institutions, seven are based in China, while the UK contains two, and the USA and Canada are each home to one.

Table 39: Top countries and institutions producing core papers in the Research Front "Twin-field quantum key distribution"

Country Ranking	Country	Core Papers	Proportion
1	China	23	74.2%
2	USA	7	22.6%
3	UK	6	19.4%
4	Canada	4	12.9%
4	Japan	4	12.9%
6	Australia	2	6.5%
6	Singapore	2	6.5%
6	Spain	2	6.5%
9	Austria	1	3.2%
9	Malaysia	1	3.2%
9	Italy	1	3.2%
9	Denmark	1	3.2%
9	Russia	1	3.2%
9	Switzerland	1	3.2%
9	Czech Republic	1	3.2%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Chinese Academy of Sciences	China	18	58.1%
2	Tsinghua University	China	8	25.8%
3	University ofYork	UK	5	16.1%
3	Jinan Institute of Quantum Technology	China	5	16.1%
5	Shanghai Engineer Center Microsatellites	China	4	12.9%
5	Data Communications Science Technique Research Institute	China	4	12.9%
5	Corning Inc	USA	4	12.9%
8	Toshiba Co Ltd	Japan	3	9.7%
8	University of Leeds	UK	3	9.7%
8	University of Toronto	Canada	3	9.7%
8	Beijing University Posts & Telecommunications	China	3	9.7%
8	Xian Satellite Control Center	China	3	9.7%

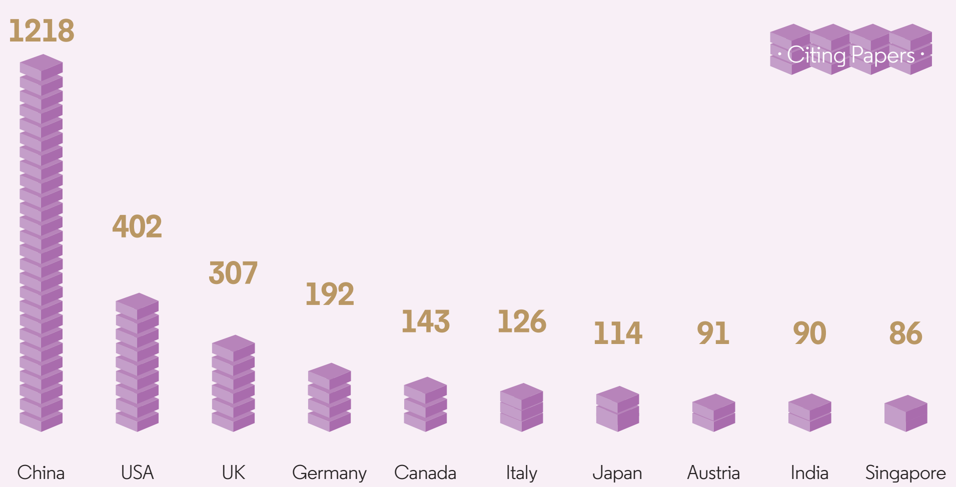


Analysis of the citing papers (Table 40) indicates that China remains the most active in this area, with citing-paper counts far above those of other countries. The USA, the UK, and Germany also perform well. Among the top citing institutions, seven are based in China, while the UK contains two, and the USA and Singapore each claim one.

Table 40: Top countries and institutions producing citing papers in the Research Front "Twin-field quantum key distribution"

Country Ranking	Country	Citing Papers	Proportion
1	China	1218	46.5%
2	USA	402	15.3%
3	UK	307	11.7%
4	Germany	192	7.3%
5	Canada	143	5.5%
6	Italy	126	4.8%
7	Japan	114	4.4%
8	Austria	91	3.5%
9	India	90	3.4%
10	Singapore	86	3.3%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	349	13.3%
2	Beijing University Posts & Telecommunications	China	108	4.1%
3	Central South University	China	76	2.9%
4	Nanjing University of Posts and Telecommunications	China	73	2.8%
5	University of York	UK	65	2.5%
6	Tsinghua University	China	62	2.4%
7	National University of Singapore	Singapore	61	2.3%
8	Nanjing University	China	60	2.3%
9	University of Southampton	UK	58	2.2%
10	Massachusetts Institute of Technology (MIT)	USA	56	2.1%
10	Shanghai Jiao Tong University	China	56	2.1%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN PHYSICS

One topic in physics is highlighted as an emerging Research Front: “Theoretical research on high-precision measurement of the W boson mass".

Table 41: Emerging Research Front in physics

Rank	Emerging Research Front	Core Papers	Citations	Mean Year of Core Papers
1	Theoretical research on high-precision measurement of the W boson mass	25	377	2022.0

2.2 KEY EMERGING RESEARCH FRONT – “Theoretical research on high-precision measurement of the W boson mass”

The W boson is a fundamental particle that carries the weak force. It was discovered by researchers at the European Organization for Nuclear Research (CERN) in 1983 and is a milestone of the Standard Model’s (SM) major successes. The mass of the W boson is an important fundamental parameter of the SM, which has been measured in international experiments with improving accuracy. In 2022, the Collider Detector at Fermilab (CDF) collaboration in the USA published the most precise measurement of W boson mass to date, which was seven standard deviations higher than the SM predicts. In particle physics, exceeding five standard deviations usually means a new discovery. If the result is confirmed, it would necessitate the introduction of new physics to amend the SM. Therefore, the work stimulated great interest among physicists. There are 25 high cited papers in this front, with significant contributions from countries such as the USA, Italy, Switzerland, China, and Japan. The most-cited paper concerns the latest high-precision measurement of the W boson mass by the CDF collaboration in 2022; the report has been cited 60 times at this writing. Other papers have reported theoretical research on the implications for new physics resulting from these advances.

2023 RESEARCH FRONTS

ASTRONOMY AND ASTROPHYSICS

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

The Top 10 Research Fronts in astronomy and astrophysics focus on diverse topics, including gravitational waves, primordial black holes on the Epoch of Reionization, fast radio bursts, weak gravitational lensing surveys, string theory and cosmology, and the Milky Way's stellar halo. In general, gravitational waves present a prominent area of research, with a notable focus on both observational discoveries and theoretical investigations. Related Research Fronts include periodical achievements of LIGO-Virgo, measurements of neutron stars with GW170817, primordial black holes and gravitational waves observation, and black hole shadows and the 4D Einstein-Gauss-Bonnet theory of gravity. The observations and properties of repeating fast radio bursts have been selected among the hot Research Fronts again. An emerging Research Front in 2020, concerning string theory swampland conjectures and its impact on cosmology, has now became one of the hot Research Fronts of 2023. The large-scale scientific platforms, such as LIGO-Virgo and Gaia, continue to exert a very high influence.

Table 42: Top 10 Research Fronts in astronomy and astrophysics

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Population properties of compact objects from the second LIGO-Virgo Gravitational-Wave Transient Catalog	2	899	2021.0
2	Gaia Early Data Release 3	2	485	2021.0
3	Black hole shadows and the 4D Einstein-Gauss-Bonnet theory of gravity	36	3290	2020.3
4	Observations of the Epoch of Reionization	45	5529	2019.8
5	Observations and properties of repeating fast radio bursts	48	6964	2019.6
6	Observational and characteristic research on Primordial black holes and gravitational waves	48	6241	2019.2
7	Cosmological implications of the string theory swampland	23	3322	2019.2
8	Weak gravitational lensing surveys	12	2948	2019.2
9	Measurements of neutron stars with GW170817	35	9158	2019.0
10	Observations of the Milky Way's stellar halo	13	2796	2018.9

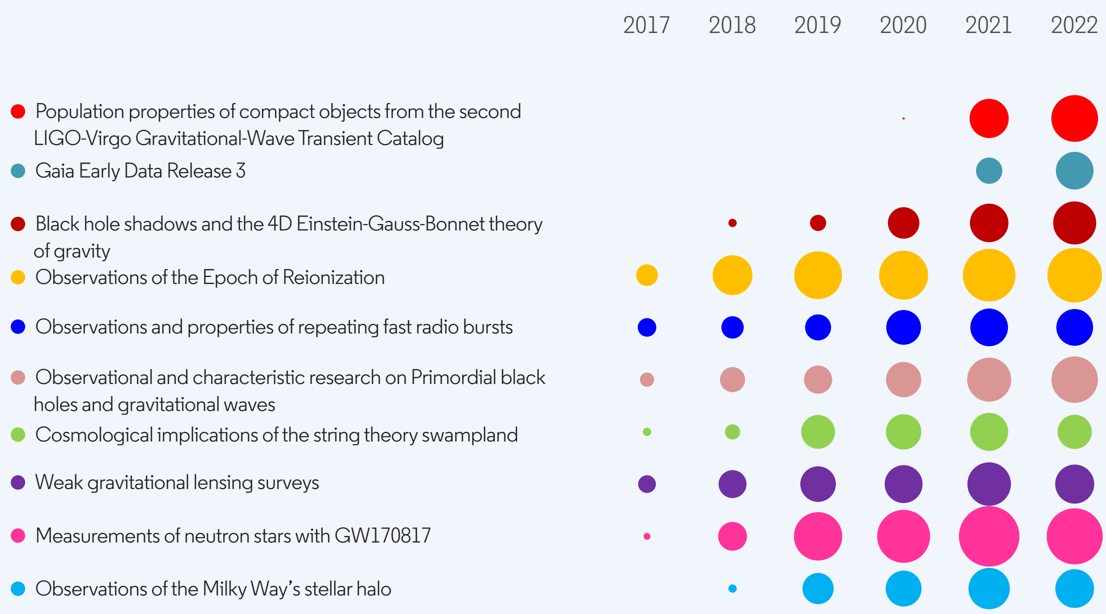
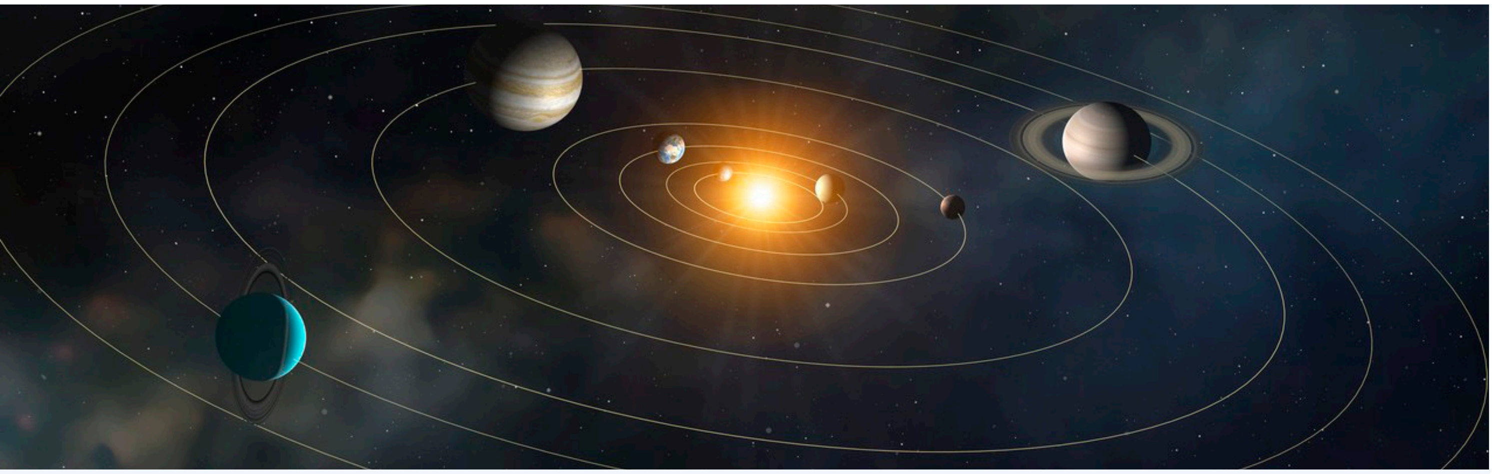


Figure 21: Citing papers for the Top 10 Research Fronts in astronomy and astrophysics

1.2 KEY HOT RESEARCH FRONT – "Population properties of compact objects from the second LIGO-Virgo Gravitational-Wave Transient Catalog"

Gravitational waves are "ripples" in space-time generated by intense physical processes such as the collision and merging of dense celestial bodies in the cosmos. Gravitational wave signals were first observed by Laser Interferometer Gravitational-Wave Observatory (LIGO) in 2015. This confirmed a major prediction of Einstein's theory of general relativity and opened an unprecedented new window onto the cosmos. Virgo Gravitational Wave Interferometer (Virgo) and Kamioka Gravitational Wave Detector (KAGRA) joined together with LIGO in 2017 and 2020, respectively, comprising the advanced gravitational wave detector network. Together the collaborations detect, localize, and characterize the coalescence of compact binary mergers, continuous gravitational waves, and burst gravitational waves. Coordinated observations of the same astrophysical sources enable improved understanding of those sources, especially in localizing their directions via triangulation from different points on the Earth's surface.

The hot Research Front "Population properties of compact objects from the second LIGO-Virgo Gravitational-Wave Transient Catalog" includes two core papers, which provide in-depth discussion of gravitational wave detection by LIGO and Virgo in the first half of the third observing run (O3a), the second Gravitational-Wave Transient Catalog (GWTC-2), and the population properties of compact objects from GWTC-2, including mass distribution, spin distribution, and rate evolution with redshift. O3a ran from April 1st to October 1st, 2019, and added 39 gravitational-wave events to the 11 confirmed events listed in GWTC-1, bringing the total to 50 events in GWTC-2. The discoveries of O3a span a wide range of astrophysical parameters and represent sources



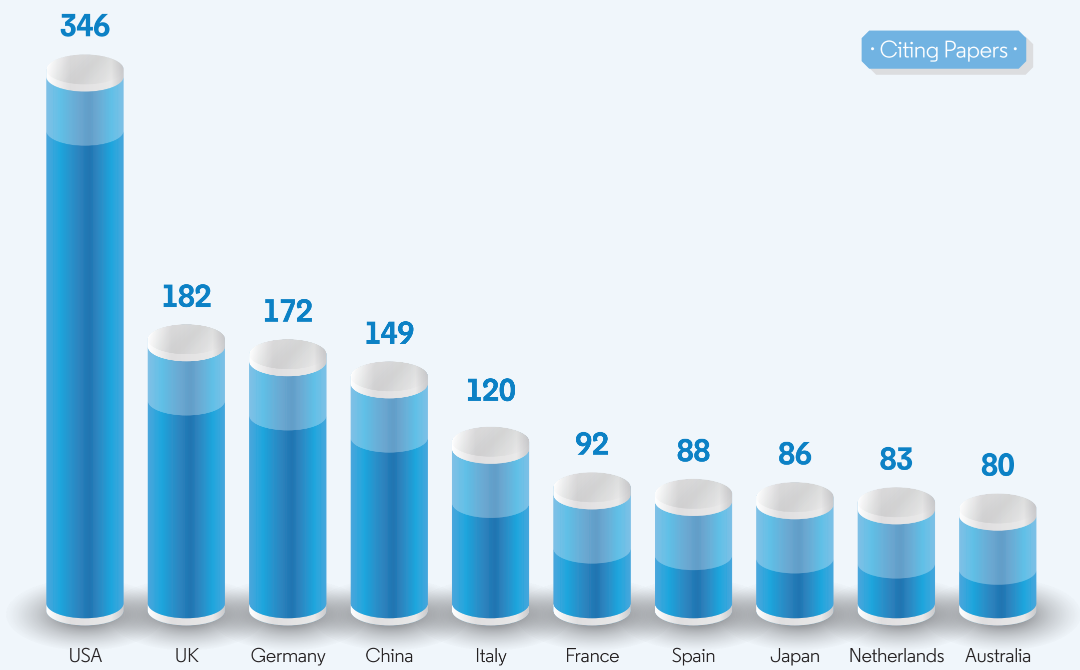
consistent with the coalescences of binary black holes, binary neutron stars, and neutron star black hole binaries. Some especially interesting O3a events include the second-ever gravitational-wave observation consistent with a binary neutron star merger, the first events with unequivocally unequal masses, and a very massive black hole binary with a total mass of about 150 times that of the Sun. The collaborative efforts of more than 200 research institutions worldwide were instrumental in the completion of the two core papers, underscoring the international cooperative characteristics of the gravitational wave detection efforts. Considering the extensive involvement of various countries/regions and institutions, it is not feasible to list them individually.

As for citing papers, the USA ranks 1st, accounting for 45.6% of the citating papers. The UK, Germany, and China rank 2nd, 3rd, and 4th, respectively, with comparable proportions. The Max Planck Society ranks 1st among the Top 10 citing institutions, followed by the National Institute of Nuclear Physics of Italy, the California Institute of Technology, and the Chinese Academy of Sciences. US-based entities occupy three positions among the Top 10 citing institutions, while the other seven positions are evenly occupied by Germany, Italy, China, France, Australia, Japan, and the UK.

Table 43: Top countries and institutions producing citing papers in the Research Front "Population properties of compact objects from the second LIGO-Virgo Gravitational-Wave Transient Catalog"

Country Ranking	Country	Citing Papers	Proportion
1	USA	346	45.6%
2	UK	182	24.0%
3	Germany	172	22.7%
4	China	149	19.7%
5	Italy	120	15.8%
6	France	92	12.1%
7	Spain	88	11.6%
8	Japan	86	11.3%
9	Netherlands	83	10.9%
10	Australia	80	10.6%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Max Planck Society	Germany	113	14.9%
2	National Institute of Nuclear Physics (INFN)	Italy	105	13.9%
3	California Institute of Technology	USA	93	12.3%
4	Chinese Academy of Sciences	China	91	12.0%
5	National Center for Scientific Research of France (CNRS)	France	81	10.7%
6	Northwestern University	USA	61	8.0%
7	Monash University	Australia	56	7.4%
7	University of Tokyo	Japan	56	7.4%
9	Massachusetts Institute of Technology (MIT)	USA	54	7.1%
9	University of Birmingham	UK	54	7.1%



1.3 KEY HOT RESEARCH FRONT – "Observations and properties of repeating fast radio bursts"

In 2007, scientists first discovered the mysterious astronomical phenomenon of fast radio bursts (FRBs) while analyzing the Parkes Pulsar Data Archive. FRBs are the most intense cosmic explosions observed in the radio wave band. These extraordinary events generate as much energy in a thousandth of a second as the Sun does in a year, yet their physical origin is unknown, making them one of the hotspots of astronomical research. Based on observational characteristics, astronomers now generally believe that FRBs are related to the bursting of dense objects, especially those with strong magnetic fields. FRBs can emit radio waves at multiple frequencies and can appear anywhere in the sky at any time. As of July 2023, 675 FRBs events have been reported worldwide.

In observations, although most FRBs are perceived as single events, a small fraction have been observed to repeat on different timescales; the observed FRB population can be divided into one-off and repeating FRBs. During the active period of repeating bursts, astronomers can proactively carry out localization and monitoring. These efforts aid in precise positioning and the search for multi-band counterparts and host galaxies, potentially helping to address key questions regarding the origin and evolution of FRBs.

Astronomers discovered the first repeating FRB, designated 20121102A in 2016, and subsequent observations localized it to a metal-poor dwarf galaxy. Researchers also discovered for the first time that FRB 20121102A has a dense persistent radio source that is significantly brighter than the radio sources in the Milky Way, and that there should therefore be an inevitable link between the persistent radio source and FRB 20121102A.

Chinese research institutes used the Five-hundred-meter Aperture Spherical radio Telescope (FAST) to observe the first repeating FRB 20121102A, which accumulated a large number of pulses with high signal-to-noise ratio. In 2019, an international research team led by scientists at the National Astronomical Observatory of China (NAOC), using data from the FAST, discovered the only case to date of a continuously active repeating FRB (20190520B). By organizing collaborative observations from several space- and earth-based international observatories, and by integrating data from radio interferometry arrays, optical and infrared telescopes, and space-based high-energy observatories, the team has located FRB 20190520B in a metal-poor dwarf galaxy 3 billion light-years from Earth. This work confirmed that the proximate region possesses the highest known electron density, and also discovered the second radio continuum counterpart to FRBs to date. In the future, China's FAST is expected to make more significant discoveries in the field of FRBs.

The hot Research Front "Observations and properties of repeating fast radio bursts" includes 48 core papers, providing detailed discussions on the observations and properties of the first repeating FRB 20121102A, and the first continuously active repeating FRB 20190520B, as well as the localization of their host galaxies. Other important research topics include the study of theoretical modelling of FRBs based on the observations mentioned above.

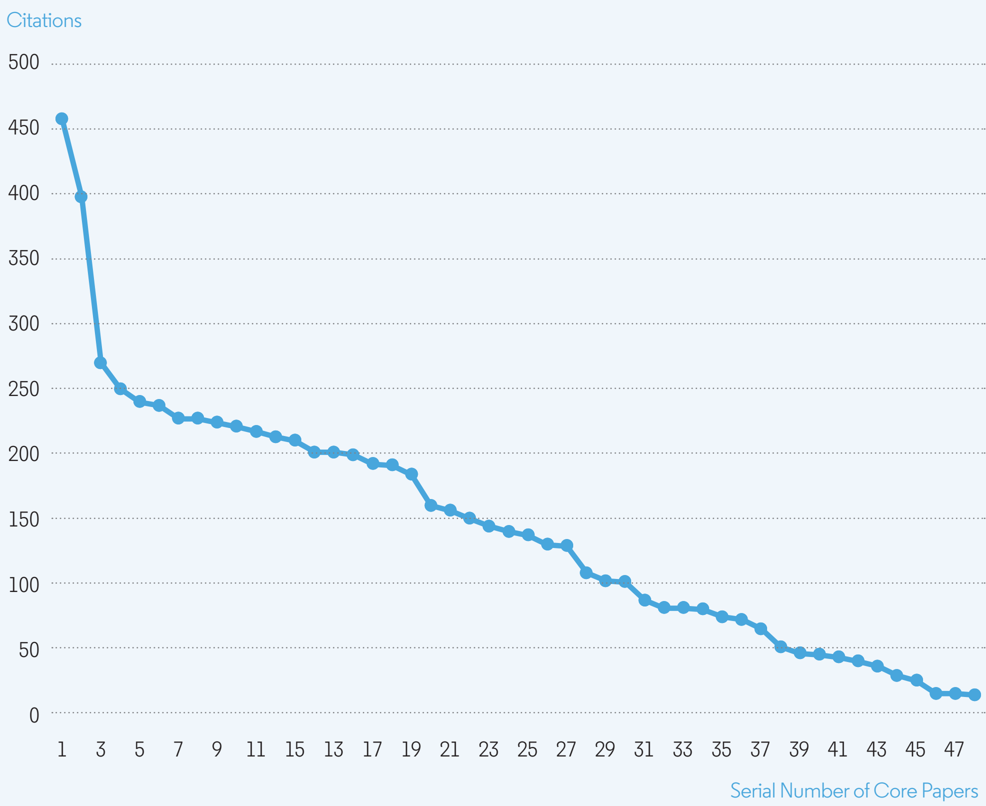


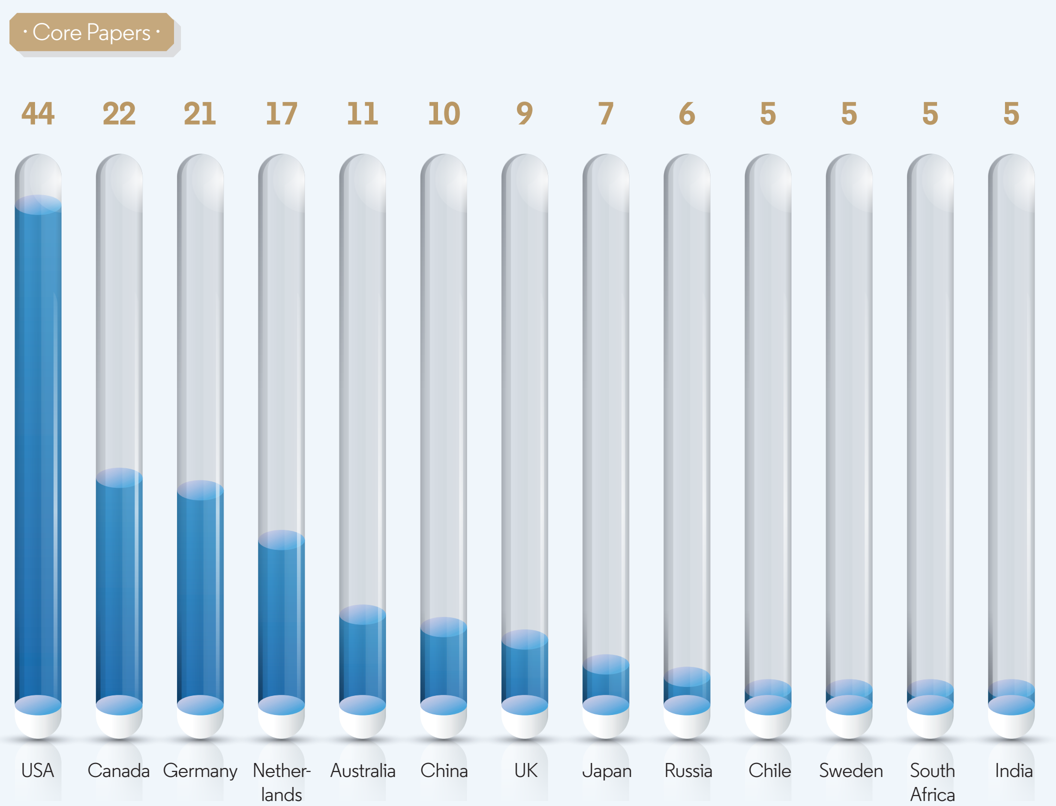
Figure 22: Citation frequency distribution curve of core papers in the Research Front "Observations and properties of repeating fast radio bursts"

The Arecibo Observatory in the USA, the Canadian Hydrogen Intensity Mapping Experiment (CHIME), and the FAST in China are important observational platforms for FRBs. The related countries and research institutes have performed well in terms of the output of core papers and citing papers, with the USA contributing the highest number of core papers (91.7%).

Table 44: Top countries and institutions producing core papers in the Research Front "Observations and properties of repeating fast radio bursts"

Country Ranking	Country	Core Papers	Proportion
1	USA	44	91.7%
2	Canada	22	45.8%
3	Germany	21	43.8%
4	Netherlands	17	35.4%
5	Australia	11	22.9%
6	China	10	20.8%
7	UK	9	18.8%
8	Japan	7	14.6%
9	Russia	6	12.5%
10	Chile	5	10.4%
10	Sweden	5	10.4%
10	South Africa	5	10.4%
10	India	5	10.4%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	West Virginia University	USA	22	45.8%
2	McGill University	Canada	19	39.6%
3	Max Planck Society	Germany	18	37.5%
3	National Radio Astronomy Observatory	USA	18	37.5%
5	Netherlands Institute for Radio Astronomy	Netherlands	15	31.3%
5	California Institute of Technology	USA	15	31.3%
7	University of Amsterdam	Netherlands	14	29.2%
7	National Research council of Canada	Canada	14	29.2%
9	University of Toronto	Canada	13	27.1%
10	Perimeter Institute for Theoretical Physics	Canada	11	22.9%
10	National Aeronautics & Space Administration (NASA)	USA	11	22.9%
10	Massachusetts Institute of Technology (MIT)	USA	11	22.9%

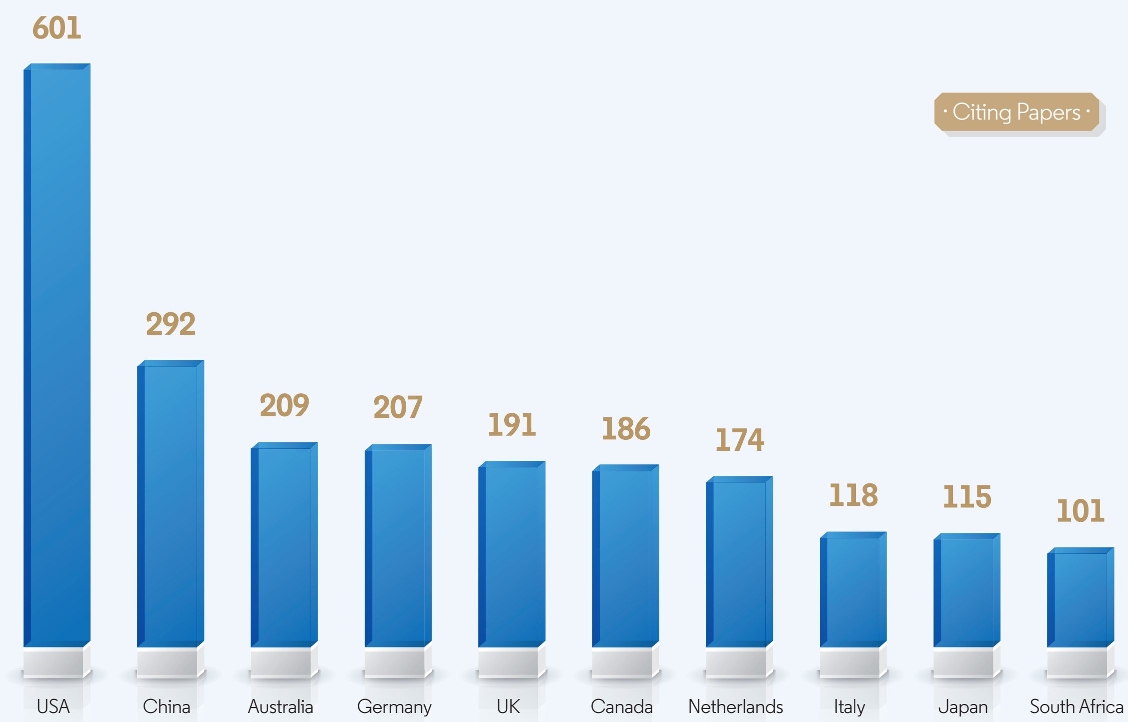


As for citing papers: the USA maintains its leading position, with 53.7% of the total. China is actively pursuing follow-up research and ranks 2nd. Australia, Germany, and the UK rank 3rd to 5th, respectively. Among the top institutions, the Chinese Academy of Sciences contributes the greatest quantity of related research and ranks 1st. The Max Planck Society in Germany and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia are also actively following up on this front, respectively ranking 2nd and 3rd, while US-based entities occupy three positions among the Top 10 citing institutions.

Table 45: Top countries and institutions producing citing papers in the Research Front "Observations and properties of repeating fast radio bursts"

Country Ranking	Country	Citing Papers	Proportion
1	USA	601	53.7%
2	China	292	26.1%
3	Australia	209	18.7%
4	Germany	207	18.5%
5	UK	191	17.1%
6	Canada	186	16.6%
7	Netherlands	174	15.5%
8	Italy	118	10.5%
9	Japan	115	10.3%
10	South Africa	101	9.0%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	177	15.8%
2	Max Planck Society	Germany	145	12.9%
3	Commonwealth Scientific & Industrial Research Organisation (CSIRO)	Australia	125	11.2%
4	California Institute of Technology	USA	119	10.6%
5	University of Amsterdam	Netherlands	109	9.7%
6	West Virginia University	USA	103	9.2%
7	University of Western Australia	Australia	99	8.8%
8	University of California, Berkeley	USA	94	8.4%
9	University of Toronto	Canada	92	8.2%
10	NationalInstitutefor Astrophysics (INAF)	Italy	89	7.9%



2.EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

Two emerging Research Fronts have been identified in astronomy and astrophysics: "Performance and results of eROSITA on the Russian-German space observatory Spektr-RG", and "Sagittarius A* supermassive black hole observations by the Event Horizon Telescope".

Table 46: Emerging Research Fronts in astronomy and astrophysics

Rank	Emerging Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Performance and results of eROSITA on the Russian-German space observatory Spektr-RG	6	344	2021.7
2	Sagittarius A* supermassive black hole observations by the Event Horizon Telescope	7	280	2022.0

2.2 KEY EMERGING RESARCH FRONT – "Performance and results of eROSITA on the Russian-German space observatory Spektr-RG"

Spektr-RG is a Russian-German collaborative astrophysical space observatory launched on July 13, 2019. The mission aims to study our Universe in the X-ray band of the electromagnetic spectrum, once the observatory is in position at the Lagrange point L2 of the Sun-Earth system, 1.5 million kilometers from Earth. This mission intends to map all massive structures in the observable Universe in the X-ray band. Spektr-RG carries two unique instruments: the eROSITA built by the Max Planck Institute for Extraterrestrial Physics, and ART-XC, built by the Space Research Institute of the Russian Academy of Sciences. Spektr-RG is designed to scan the celestial sphere to obtain X-ray maps of the entire sky in several energy ranges (from 0.2 to 8 keV with eROSITA, and from 4 to 30 keV with ART-XC). eROSITA started a survey of the entire sky in December 2019, and planned to perform eight complete scans of the celestial sphere, each lasting six months, till the end of 2023, and followed by a phase of pointed observations. In February 2022, Russian-German cooperation on Spektr-RG was frozen. eROSITA was placed into safe mode, and science operations with the instrument were paused, although analysis of the existing eROSITA data continued.

This emerging Research Front brings together six core papers focusing on the Spektr-RG mission and its telescopes, eROSITA's performance as measured on ground and operation in space, and the results of eROSITA Final Equatorial Depth Survey during the calibration and performance verification phase. These results include the catalog of galaxy clusters and groups, the AGN catalog, the X-ray catalog, and identification and characterization of the counterparts to point-like sources.

The nature of the mysterious dark energy, which drives the accelerated expansion of the Universe, is one of the most exciting questions in the fields of astronomy and physics today. Answers to this question could be the starting point of a fundamental revolution in physics. Clusters of galaxies are the largest collapsed objects in the Universe. Their formation and evolution are dominated by gravity, i.e. dark matter, while their large scale distribution and number density depend on the geometry of the Universe, i.e. dark energy. X-ray observations of clusters of galaxies provide information on the rate of expansion of the Universe, the fraction of mass in visible matter, and the amplitude of primordial fluctuations. eROSITA is designed to perform an all-sky X-ray survey to provide insights into dark energy, dark matter, black holes, and perhaps new phenomena that have so far been invisible.

2023 RESEARCH FRONTS

2023 RESEARCH FRONTS

MATHEMATICS

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN MATHEMATICS

The Top 10 Research Fronts in mathematics mainly focus on: extended physics-informed neural networks; proof of Onsager's conjecture; nonlinear time fractional-order reaction-diffusion equation; optimal estimation method of sample mean; second-order energy stable BDF numerical scheme for a variety of equations; convergence of nonlinear dynamical systems; community detection based on stochastic block models; numerical algorithms for high-dimensional partial differential equations based on deep learning; regression discontinuity designs; and Bayesian multilevel modeling and its application. The Top 10 fronts in 2023 show both continuity and new development compared with the fronts selected in previous years. Research on the properties and solutions of partial differential equations and several fronts in the field of nonlinear systems have been consecutively selected among the hot or emerging Research Fronts in past years. In 2023, the proof of Onsager's conjecture stands out as a highlight of research in this area.

Table 47: Top10 Research Fronts in mathematics

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Extended physics-informed neural networks	8	860	2020.1
2	Proof of Onsager's conjecture	4	294	2019.5
3	Nonlinear time fractional-order reaction-diffusion equation	34	2708	2019.1
4	Optimal estimation method of sample mean	2	962	2019.0
5	Second-order energy stable BDF numerical scheme for a variety of equations	34	2534	2018.6
6	Convergence of nonlinear dynamical systems	12	1270	2018.4
7	Community detection based on stochastic block models	7	561	2018.4
8	Numerical algorithms for high-dimensional partial differential equations based on deep learning	7	3448	2018.3
9	Regression discontinuity designs	7	1052	2018.3
10	Bayesian multilevel modeling and its application	14	9444	2018.0

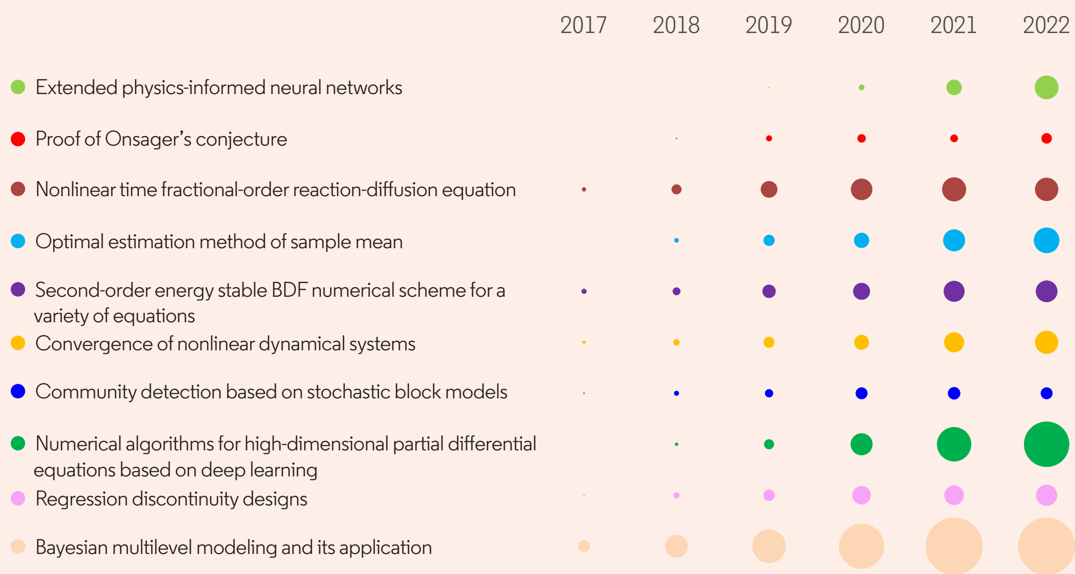


Figure 23: Citing papers for the top 10 Research Fronts in mathematics

1.2 KEY HOT RESEARCH FRONT – "Proof of Onsager's conjecture"

In the field of fluid dynamics, Euler's equations were formulated by mathematician Leonhard Euler in 1757. These equations pertain to the movement of a non-viscosity fluid, illustrating the preservation of mass (continuity), momentum, and energy. Euler's equations correspond to Navier-Stokes equations with zero thermal conductivity and zero viscosity. Due to their fundamental nature, the equations are widely used in fluid dynamics. They have significant applications in various fields, including agriculture, geoscience, life science, and aerospace. Taking aerospace as an example: An aircraft design must account for the craft's aerodynamic structure, and air as a fluid will follow the fundamental principles of fluid dynamics exemplified by Euler's equations.

In 1949, Lars Onsager, the Norwegian-born American chemist and Nobel laureate, deduced a conjecture regarding the ability of a weak solution of the 3D incompressible Euler's equations to obtain energy conservation in the study of turbulence phenomena. According to the conjecture, any solution with spatial Hölder α-continuity maintains energy conservation when α is greater than 1/3. In contrast, when α is less than or equal to 1/3, there could be solutions with spatial Hölder α-continuity that do not conserve energy. In other words, Onsager's conjecture suggests that for anomalous dissipation in the 3D incompressible Euler's equations, the critical index of spatial Hölder continuity is 1/3.

The positive part of the Onsager's conjecture ($\alpha > 1/3$) was advanced by Gregory Eyink in 1994, and in the same year, Peter Constantin, Winan E, and Edriss Titi completed the proof for this part. There were also noteworthy advancements in the negative part of the conjecture. In 2009, Camillo De Lellis and László Székelyhidi, Jr. applied the theory of convex integral functionals to investigate the non-uniqueness of solutions for Euler's equation with low regularity, and later proved that Onsager's conjecture applied for $\alpha \leq 1/10$ in 2014. Between 2018 and 2019, Philip Isett and Tristan Buckmaster, with their colleagues, each established that the converse part of Onsager's conjecture is applied for $\alpha < 1/3$. The endpoint case for $\alpha = 1/3$, however, currently remains an open question[3].

The hot Research Front "Proof of Onsager's conjecture" includes four core papers. The two most cited of these are the final proofs of the converse part of Onsager's conjecture by Isett and Buckmaster *et al*. The other two core papers focus on applying an analytical framework based on the theory of convex integral functionals to address diverse fluid equation problems, including the 3D incompressible Navier-Stokes equations, in order to construct non-unique solutions or solutions possessing special energy functions. Isett, Buckmaster, and Vlad Vicol, who are the main contributors to this research, were honored with the 2019 Clay Research Award for their accomplishments in this area.

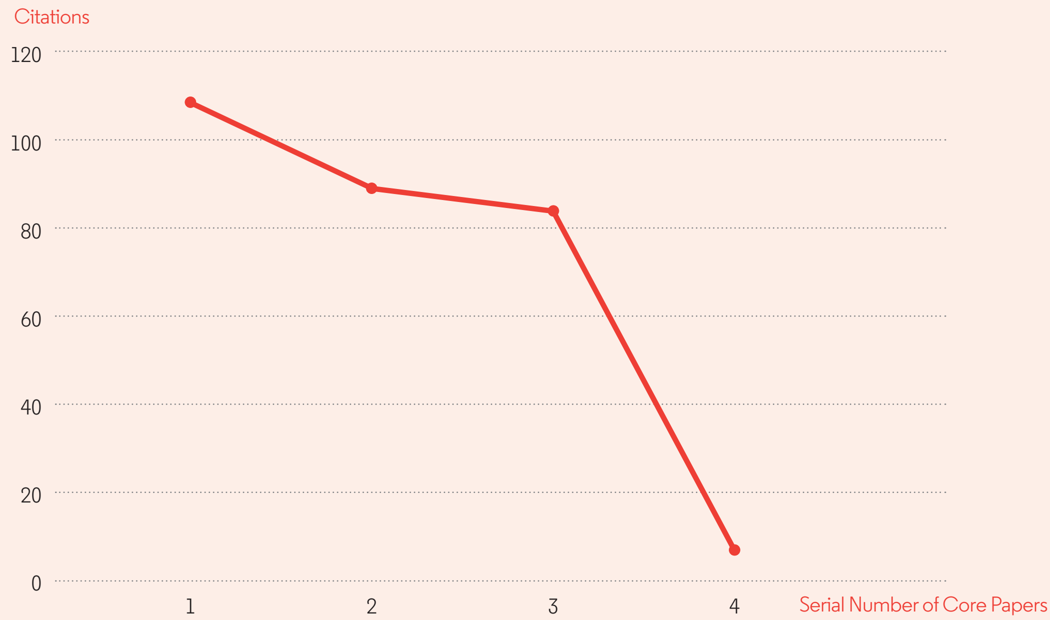


Figure 24: Citation frequency distribution curve of core papers in the Research Front "Proof of Onsager's conjecture"

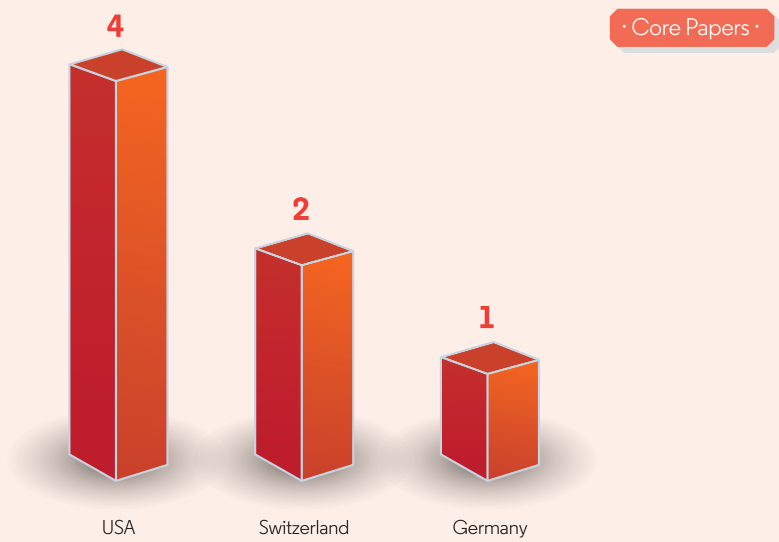
Looking at the distribution of countries and institutions producing the core papers for this front (Table 48), the primary contributors are mainly based in the USA, including at Princeton University, New York University, California Institute of Technology, and the University of Texas at Austin. Research institutions from Switzerland and Germany, including the Swiss Federal Institute of Technology in Lausanne and the University of Zurich, as well as the University of Leipzig in Germany, are also actively involved in this hot front.

Table 48: Top countries and institutions producing core papers in the Research Front "Proof of Onsager's conjecture"

Country Ranking	Country	Core Papers	Proportion
1	USA	4	100.0%
2	Switzerland	2	50.0%
3	Germany	1	25.0%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Princeton University	USA	3	75.0%
2	New York University	USA	2	50.0%
3	California Institute of Technology	USA	1	25.0%
3	Leipzig University	Germany	1	25.0%
3	University of Texas at Austin	USA	1	25.0%
3	Swiss federal Institute of Technology in Lausanne	Switzerland	1	25.0%
3	University of Zurich	Switzerland	1	25.0%

③ Partly from the article "Anomalous Dissipation" by Professor Jiajun Tong of Beijing International Center for Mathematical Research (BICMR).

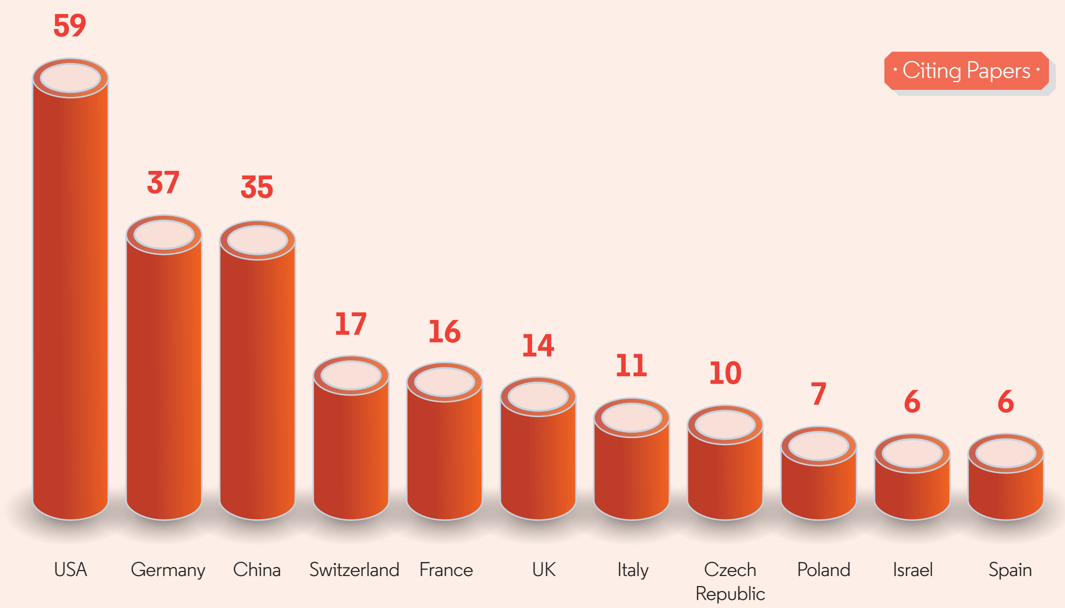


In terms of the citing papers (Table 49), the USA remains dominant, contributing more than one-third of all citing papers. Germany and China are also actively following up on this front. Among the top-producing institutions, research institutions in the USA and Germany hold four and three positions, respectively. Notable contributing institutions with high participation include the French National Center for Science Research (CNRS), the University of Leipzig, Princeton University, New York University, and the Chinese Academy of Sciences.

Table 49: Top countries and institutions producing citing papers in the Research Front "Proof of Onsager's conjecture"

Country Ranking	Country	Citing Papers	Proportion
1	USA	59	35.1%
2	Germany	37	22.0%
3	China	35	20.8%
4	Switzerland	17	10.1%
5	France	16	9.5%
6	UK	14	8.3%
7	Italy	11	6.5%
8	Czech Republic	10	6.0%
9	Poland	7	4.2%
10	Israel	6	3.6%
10	Spain	6	3.6%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	National Center for Scientific Research of France (CNRS)	France	11	6.5%
1	Leipzig University	Germany	11	6.5%
1	Princeton University	USA	11	6.5%
4	New York University	USA	9	5.4%
5	Chinese Academy of Sciences	China	8	4.8%
5	Czech Academy of Sciences	Czech Republic	8	4.8%
5	University of Illinois Chicago	USA	8	4.8%
8	Swiss federal Institute of Technology in Lausanne	Switzerland	7	4.2%
9	Technical University of Berlin	Germany	6	3.6%
9	Texas A&M University	USA	6	3.6%
9	University of Bielefeld	Germany	6	3.6%
9	University of Cambridge	UK	6	3.6%
9	Weizmann Institute of Science	Israel	6	3.6%



1.3 KEY HOT RESEARCH FRONT – "Community detection based on stochastic block models"

Given the ever-increasing research into complex networks—including social and biological networks—community detection has become a fundamental undertaking in network science. A community is typically defined as a subset of nodes in a network where interconnections amongst these nodes are more numerous than those with nodes outside the subset. Traditionally, many community detection methods have been proposed, but they often lack robust statistical models and face numerous challenges when addressing large-scale or multi-layered community structures. Random graph models, like the Erdős-Rényi model, often struggle to capture the subtleties of real-world community structures. However, the Stochastic Block Model (SBM) was introduced to address these limitations. By assigning nodes to distinct "blocks" or communities, the SBM uses specific probability matrices to describe connections between different communities. Additionally, by taking advantage of the heterogeneity of networks, the SBM can integrate diverse attributes of nodes and edges, establishing itself as a crucial statistical framework for community detection, providing a more adaptable, accurate, and systematic approach to interpreting network community structures. Currently, demand is increasing for improved SBM advancements that cater to diverse network data and intricate community configurations, particularly for large-scale networks. These advancements include model refinement and expansion, enhanced computational efficiency and algorithms, multi-layered networks, and dynamic community detection. SBM is becoming an increasingly versatile tool, with wide-ranging applications in various fields, such as social networking, bioinformatics, market analysis, recommendation systems, security monitoring, disease propagation, and epidemiology.

The hot Research Front on "Community detection based on stochastic block models" contains seven core papers, representing cutting-edge research in the statistical domain of mathematical studies among the 2023 Research Fronts. This hot front outlines the seminal and prospective breakthroughs in SBM research, highlighting its application in community detection with respect to information-theoretic and computational thresholds. These include diverse algorithmic approaches to meeting different recovery precision requirements; the statistical clustering of temporal networks by dynamic SBM; the emphasis on efficient cross-validation method tailored to SBM and its derivatives; the global spectral clustering detection techniques used for dynamic network community discovery; the incorporation of Semidefinite Programming (SDP) in community detection and structural identification optimization tasks; and the use of statistical machine learning techniques specific to community detection within SBM. Notably, the most-cited work within this hot front is authored by Emmanuel Abbe of the Department of Applied and Computational Mathematics at Princeton University. Cited more than 220 times at this writing, the paper explains the recent advances of SBM in community detection, with a keen focus on the information-theoretic and computational thresholds essential for extracting authentic community structures from datasets. It further delves into various recovery objectives such as exact, partial, and weak recoveries, and presents algorithms developed to meet these goals, as well as open research questions.

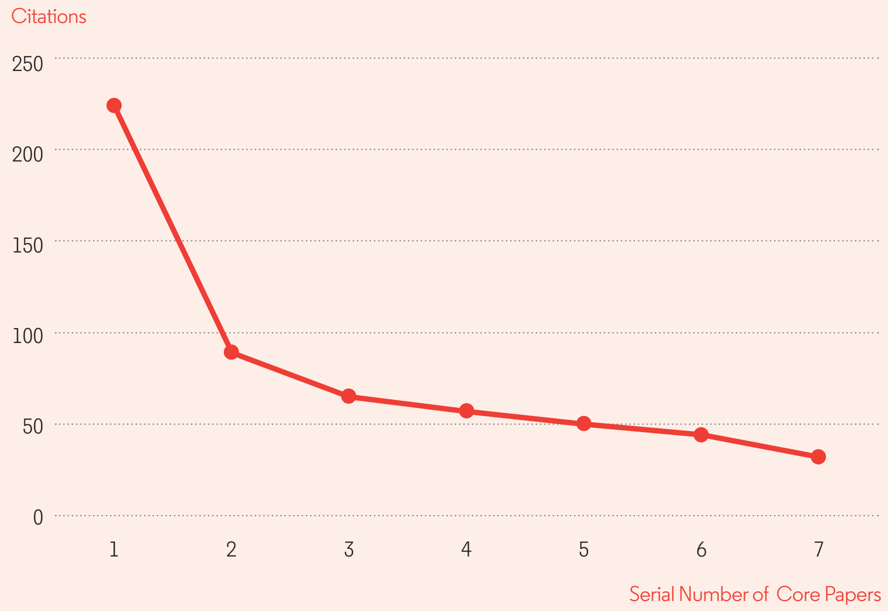


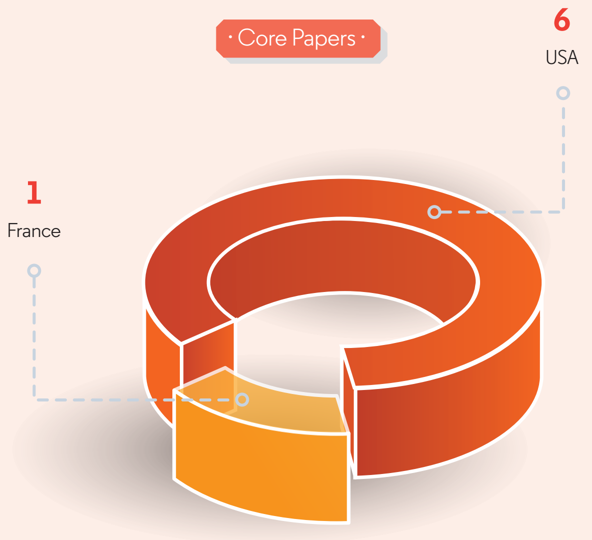
Figure 25: Citation frequency distribution curve of core papers in the Research Front "Community detection based on stochastic block models"

In terms of representation among the core papers in the front (Table 50), the USA holds an absolute advantage. Among the seven core papers included in this front, six originate from the USA, accounting for a substantial share of 85.7%. Apart from the USA, France contributes one core paper. In terms of institutions producing core papers, the top three are all based in the USA—namely, Princeton University, the University of Michigan, and Carnegie Mellon University, each contributing two core papers. Furthermore, among the eight institutions that have produced one core paper each, aside from the three US institutions—the University of California, Los Angeles, the University of Virginia, and the University of Pittsburgh—the remaining five are all based in France, demonstrating the international leadership of both the USA and France in this front.

Table 50: Top countries and institutions producing core papers in the Research Front "Community detection based on stochastic block models"

Country Ranking	Country	Core Papers	Proportion
1	USA	6	85.7%
2	France	1	14.3%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Princeton University	USA	2	28.6%
1	University of Michigan	USA	2	28.6%
1	Carnegie Mellon University	USA	2	28.6%
4	University of Paris Cite	France	1	14.3%
4	Lyon University	France	1	14.3%
4	University of California Los Angeles	USA	1	14.3%
4	University Clermont Auvergne	France	1	14.3%
4	Sorbonne University	France	1	14.3%
4	University of Virginia	USA	1	14.3%
4	National Center for Scientific Research of France (CNRS)	France	1	14.3%
4	University of Pittsburgh	USA	1	14.3%

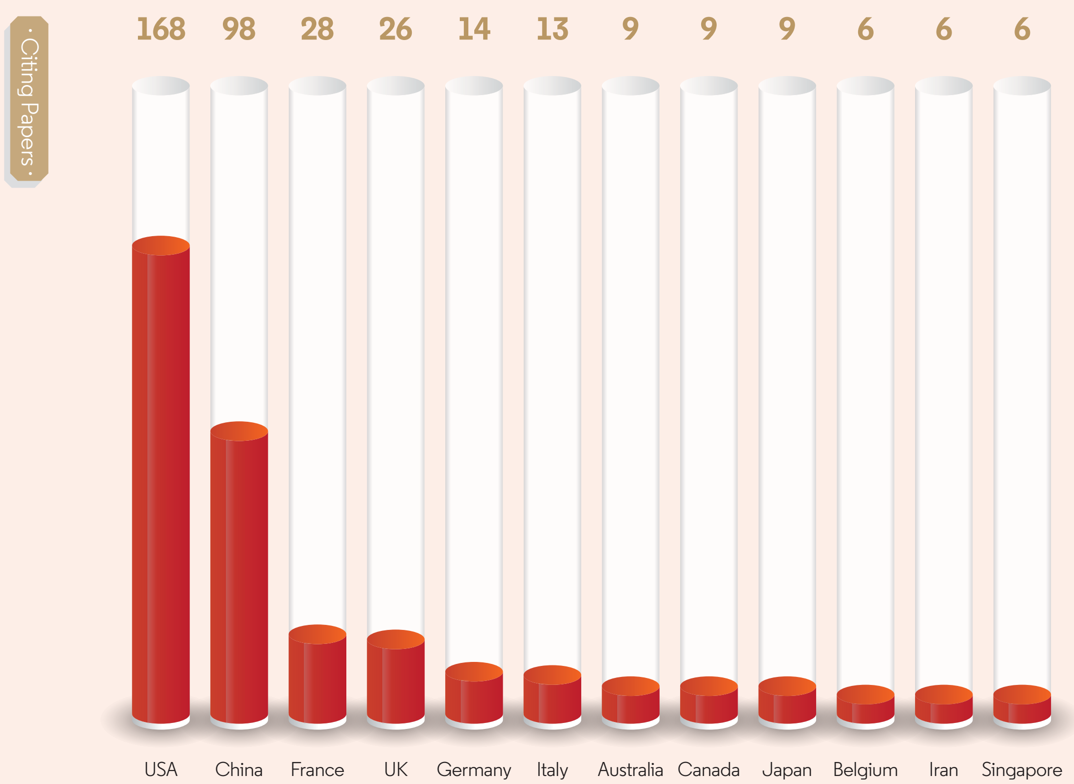


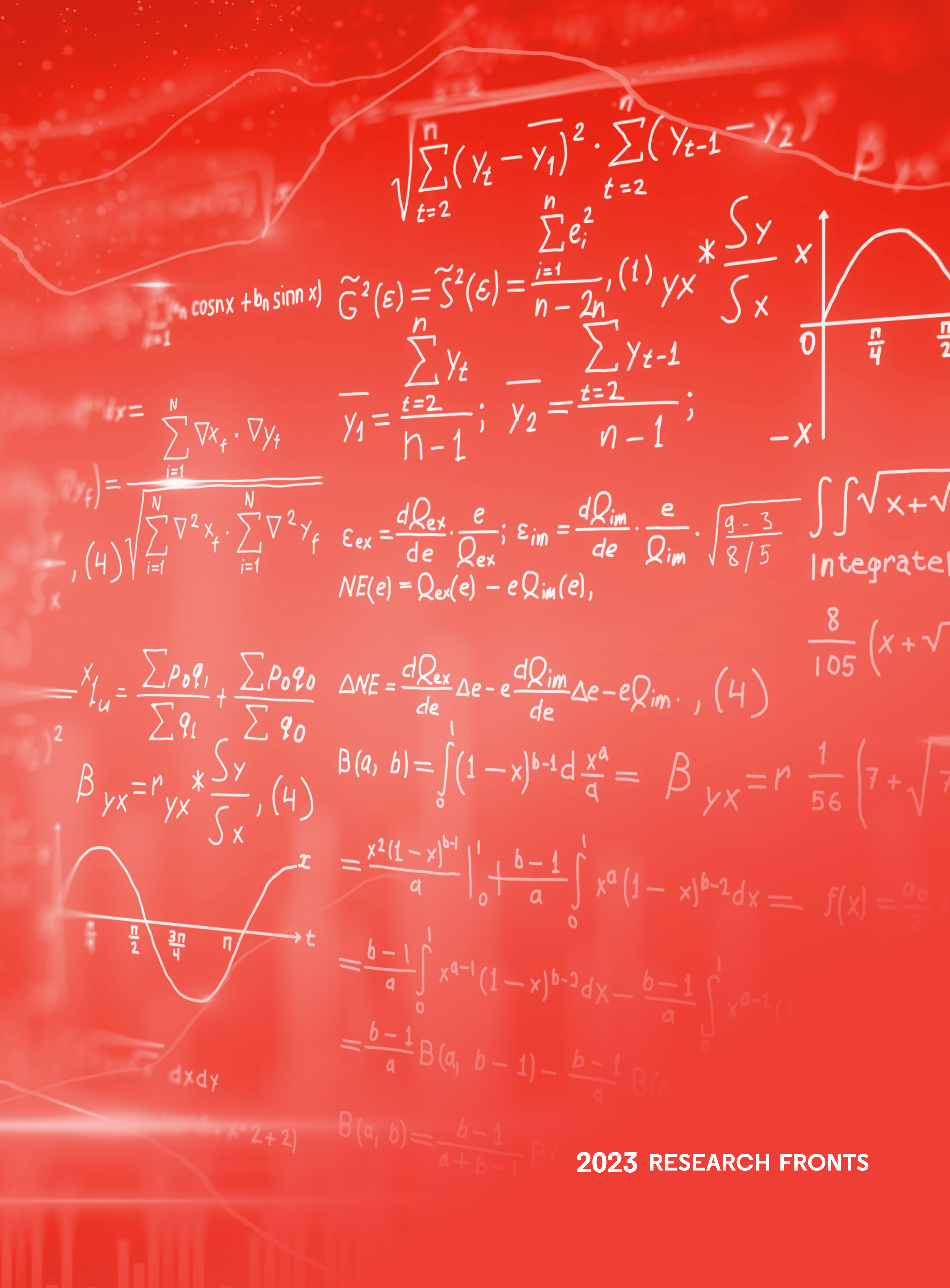
In terms of the citing papers (Table 51), the USA maintains its leading position, producing 168 citing papers, with a contribution rate of over 50%. It is worth noting that China is actively making progress on this front, contributing 98 citing papers and clearly occupying the second position with a significant advantage. Among the top-contributing institutions, seven institutions in the USA are featured on the list, constituting the largest number. In particular, Carnegie Mellon University, Princeton University, and the University of Michigan, which have performed prominently in contributing core papers, maintain their presence on the list. France is represented by three institutions, with France's CNRS demonstrating relatively prominent performance in terms of citing-paper production.

Table 51: Top countries and institutions producing citing papers in the Research Front "Community detection based on stochastic block models"

Country Ranking	Country	Citing Papers	Proportion
1	USA	168	52.5%
2	China	98	30.6%
3	France	28	8.8%
4	UK	26	8.1%
5	Germany	14	4.4%
6	Italy	13	4.1%
7	Australia	9	2.8%
7	Canada	9	2.8%
7	Japan	9	2.8%
10	Belgium	6	1.9%
10	Iran	6	1.9%
10	Singapore	6	1.9%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Carnegie Mellon University	USA	21	6.6%
2	National Center for Scientific Research of France (CNRS)	France	15	4.7%
2	Princeton University	USA	15	4.7%
2	University of Michigan	USA	15	4.7%
5	University of Pennsylvania	USA	12	3.8%
6	University of California Davis	USA	11	3.4%
7	National Research Institute for Agriculture, Food and Environment	France	9	2.8%
7	Stanford University	USA	9	2.8%
7	University of California Berkeley	USA	9	2.8%
7	University of Paris Saclay	France	9	2.8%

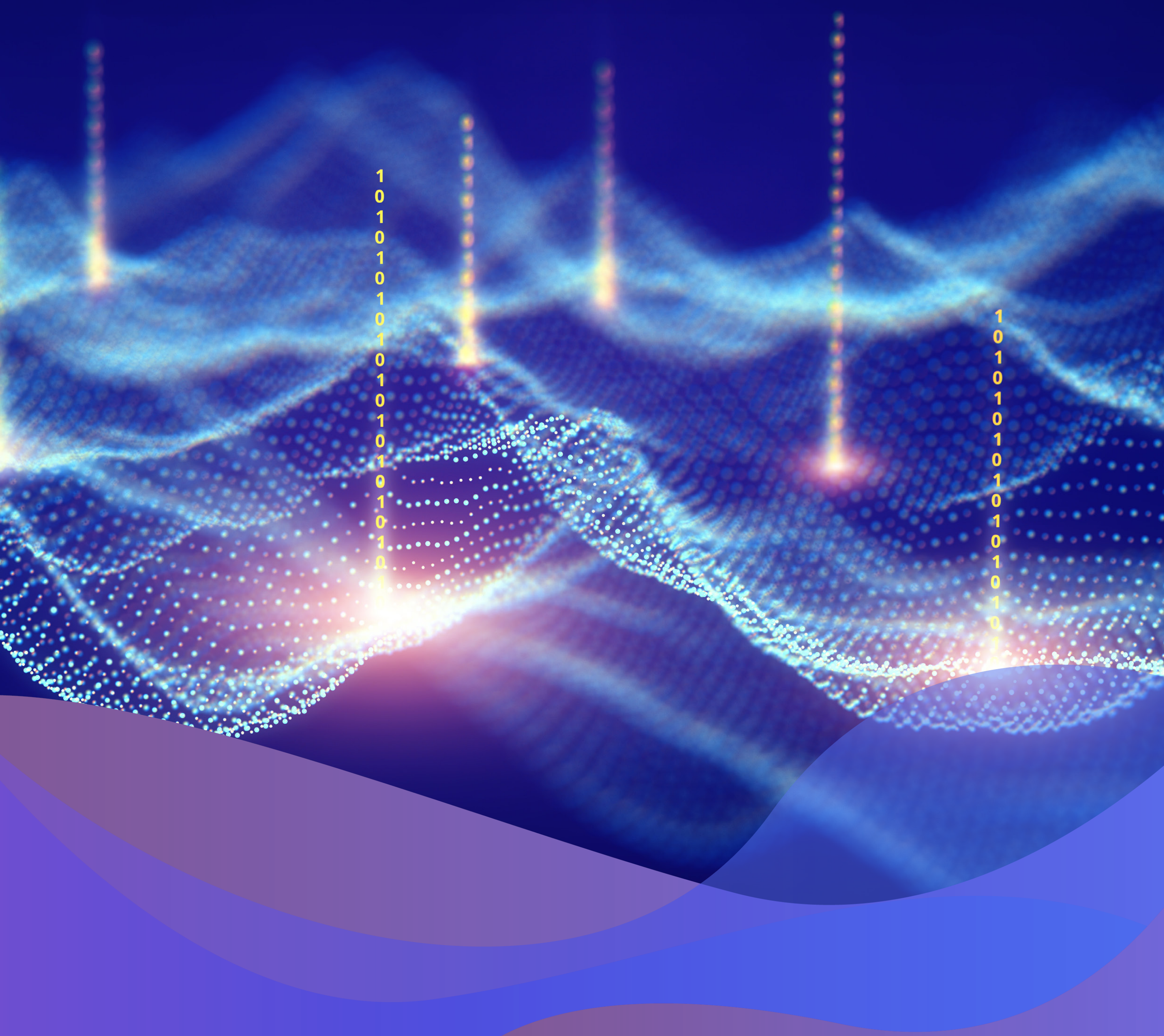




2023 RESEARCH FRONTS

2023 RESEARCH FRONTS

INFORMATION SCIENCE



1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN INFORMATION SCIENCE

The Top 10 Research Fronts in information science mainly focus on basic theory and methods of artificial intelligence (AI), 6G communication, human-computer interaction, brain-inspired intelligence, and medical information processing (Table 52). In basic theory and methods of AI, emerging hot topics include Generative Adversarial Networks, broad learning systems, and federated learning for edge computing. Explainable Artificial Intelligence, which registered as an emerging front in the 2022 survey, has now made the list of hot fronts for 2023. Fronts related to reinforcement learning have appeared several times in previous annual surveys, and the corresponding focus of this latest installment is on the MuZero algorithm, which promotes reinforcement learning for solving real-world problems. In 6G communication, deep learning in physical layer communications emerges as a hot topic, while the specialty area of reconfigurable intelligent surfaces makes the transition from last year's emerging front to one of this year's hot fronts. In human-computer interaction, next-generation real-time holographic near-eye display method for VR/AR becomes a hot front for the first time. In brain-inspired intelligence, spiking neural networks and their neuromorphic chips make their first appearance. Similarly, in the area of medical information processing, the specialty area of convolutional neural networks for EEG analysis makes its debut as a hot front.

Table 52: Top 10 Research Fronts in information science

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Federated learning for edge computing	22	3682	2020.2
2	Broad learning systems	6	1053	2020.0
3	Reconfigurable intelligent surfaces	32	9372	2019.7
4	Next-generation real-time holographic near-eye display method for VR/AR	3	457	2019.3
5	Explainable Artificial Intelligence	4	2900	2019.0
6	Spiking neural networks and their neuromorphic chips	13	2931	2018.6
7	Deep learning in physical layer communications	13	2949	2018.5
8	Generative Adversarial Networks	8	15051	2018.4
9	MuZero reinforcement learning algorithm	6	3607	2018.3
10	Convolutional neural networks for EEG analysis	9	2531	2018.2

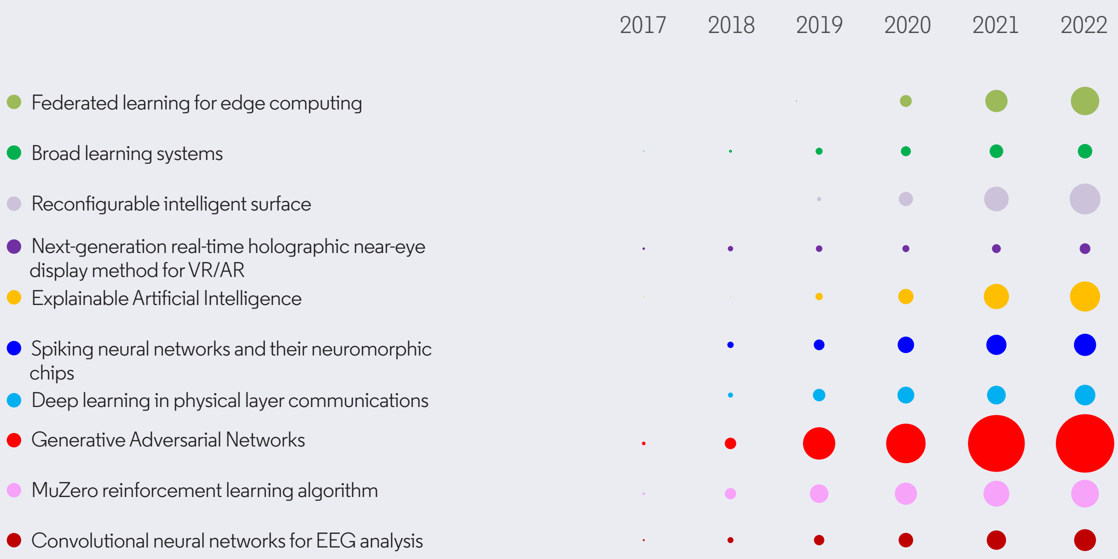


Figure 26: Citing papers for the Top 10 Research Fronts in information science

1.2 KEY HOT RESEARCH FRONT – "Spiking neural networks and their neuromorphic chips"

Two mainstream directions have become prominent in the development of AI chips: deep learning accelerators that support artificial neural networks, and brain-inspired chips that support spiking neural networks. The former approach, exemplified by Google's TPU and Intel's Gaudi2, accelerates the training process of deep learning through computer hardware to realize applications like natural language processing, computer vision, and reinforcement learning. The latter approach, as in IBM's TrueNorth and Intel's Loihi, utilizes large-scale neuromorphic devices, chips, and systems to support neuroscience-derived spiking neural networks (SNNs) by borrowing the working mechanism of the human brain, thus realizing brain-inspired intelligence. Therefore, pulsed neural networks that combine biological rationality and computational efficiency are foundational to further progress in brain-inspired intelligence.

Due to the differences between algorithms and models, AI chips usually only support either artificial neural networks or spiking neural networks, and it is difficult to leverage the cross-disciplinary advantages of computer science and neuroscience. The heterogeneous fusion chip Tianji, developed by Tsinghua University in China, integrates these two methods to provide a hybrid and collaborative platform for the development of Artificial General Intelligence.

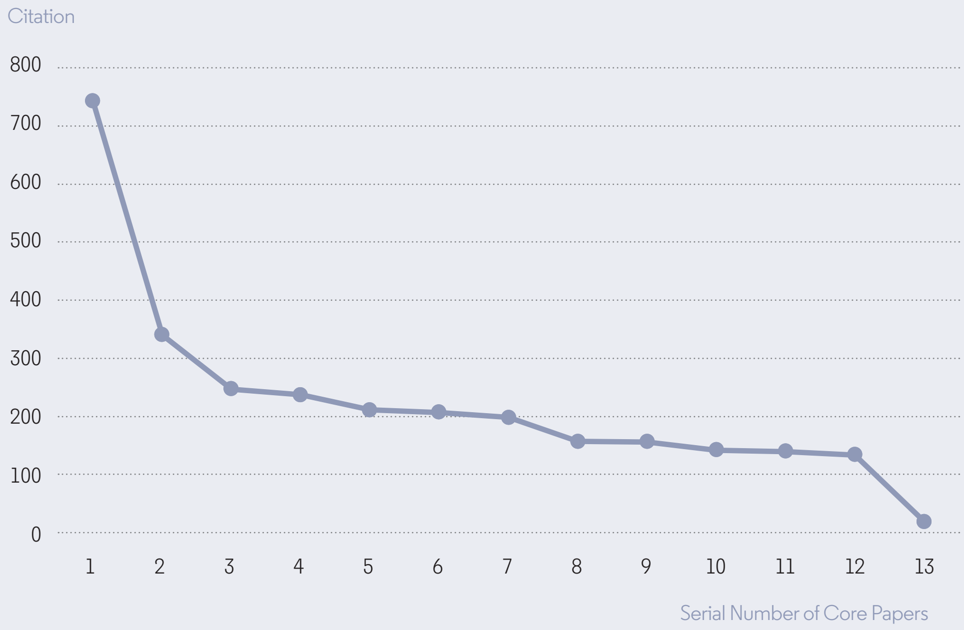


Figure 27: Citation frequency distribution curve of core papers in the Research Front "Spiking neural networks and their neuromorphic chips"

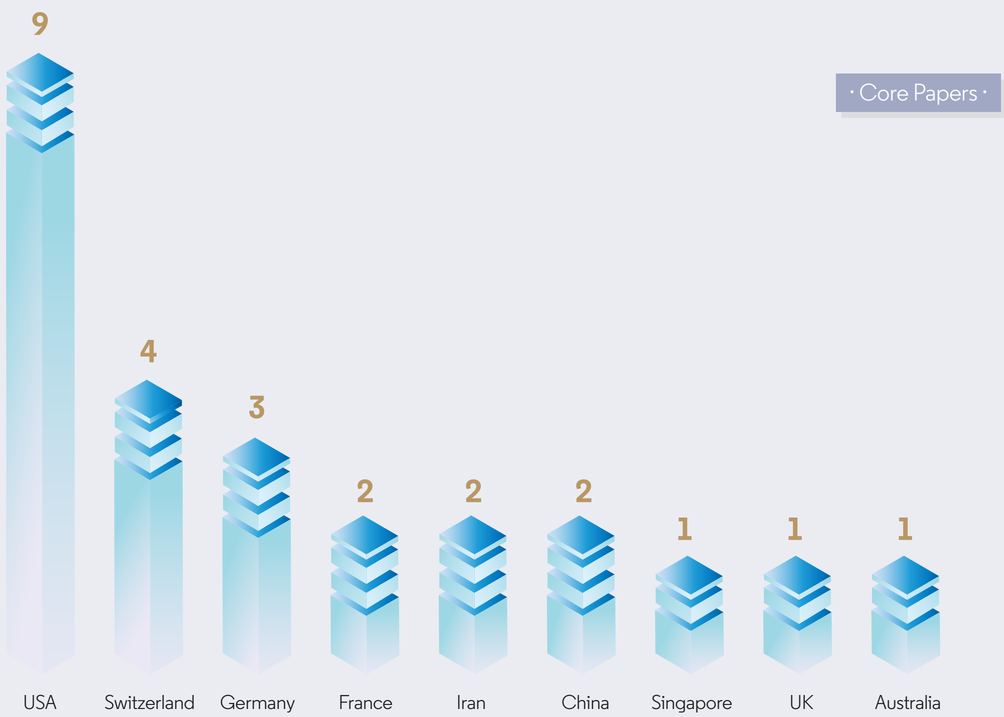
The 13 core papers mainly center on the training methods and neuromorphic hardware of SNNs. In training methods, topics include the conversion of conventional deep networks into SNNs, constrained training before conversion, spiking variants of backpropagation, and biologically motivated variants of spike-timing-dependent plasticity (STDP). In the area of neuromorphic chips, the primary focus includes Intel's Loihi, introduced in 2017, with the related paper besting the rest of the core literature for citations to date; Tsinghua University's "Tianji Chip", developed in 2019, with its related paper ranking 4th by citations; and a neuralmorphic computing system proposed by researchers at Yale University in 2018. In 2019, Kaushik Roy *et al*. at Purdue University published a review article in *Nature*; this is the second-most-cited core paper in the core, outlining developments in neuromorphic computing for both algorithms and hardware, and discussing the main challenges and prospects in this specialty area.

As for the distribution of countries and institutions producing the core papers for this front (Table 53): the USA contributes more than half the core literature, with Switzerland and Germany ranking 2nd and 3rd. In terms of institutions, eight contribute two core papers each, with notable representation by Purdue University, the University of California at Santa Barbara, the Swiss Federal Institute of Technology Zurich, and Tsinghua University, as well as two research institutions based in Switzerland and France.

Table 53: Top countries and institutions producing core papers in the Research Front "Spiking neural networks and their neuromorphic chips"

Country Ranking	Country	Core Papers	Proportion
1	USA	9	69.2%
2	Switzerland	4	30.8%
3	Germany	3	23.1%
4	France	2	15.4%
4	Iran	2	15.4%
4	China	2	15.4%
7	Singapore	1	7.7%
7	UK	1	7.7%
7	Australia	1	7.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Purdue University	USA	2	15.4%
1	University of California Santa Barbara	USA	2	15.4%
1	Swiss Federal Institute of Technology Zurich	Switzerland	2	15.4%
1	University of Zurich	Switzerland	2	15.4%
1	Friedrich Miescher Institute for Biomedical Research	Switzerland	2	15.4%
1	French National Centre for Scientific Research	France	2	15.4%
1	Tsinghua University	China	2	15.4%
1	Université Toulouse III-Paul Sabatier	France	2	15.4%

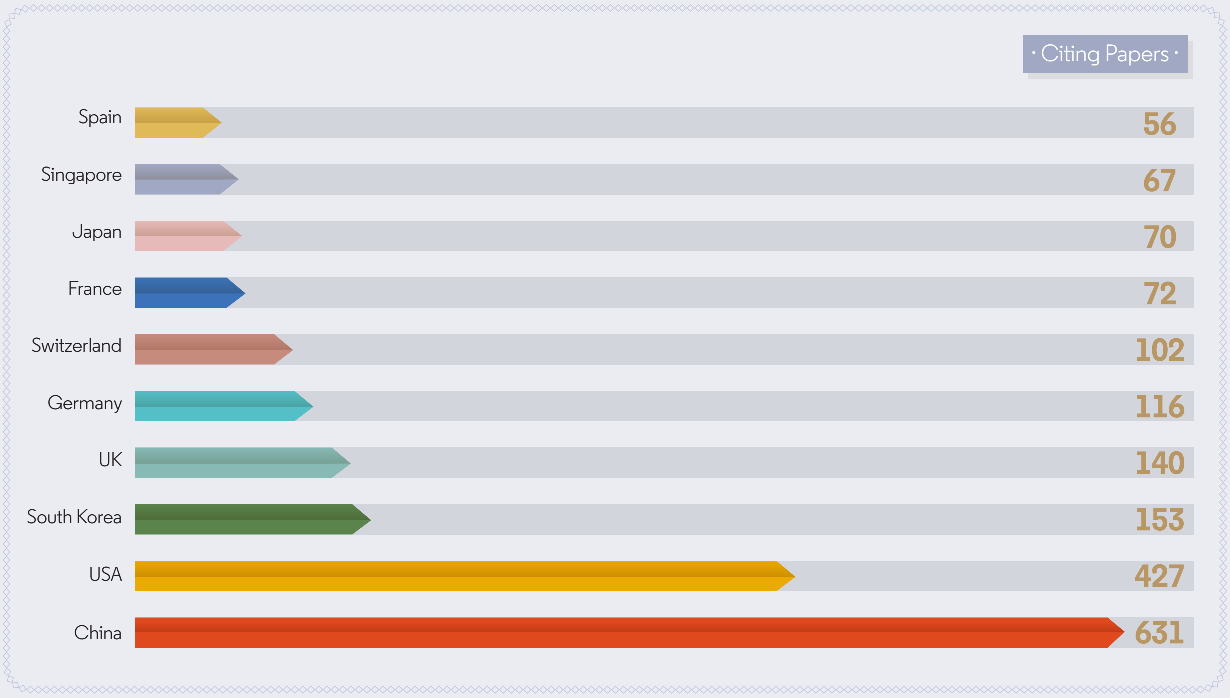


Analysis of the citing papers (Table 54) indicates that China and the USA are the most active countries in terms of follow-up research in this front, while South Korea, the UK, Germany, and Switzerland are also actively pursuing advances. Among the most-prolific citing institutions, the Chinese Academy of Sciences and Tsinghua University rank at the top, with four other China-based universities registering on the list. Although South Korea is not among the top countries based on output of core papers, Seoul National University ranks 3rd in Table 54 with 54 citing papers. Tsinghua University, the Swiss Federal Institute of Technology Zurich, the University of Zurich, the French National Centre for Scientific Research, and Purdue University are also among the most-prolific institutions producing core papers, demonstrating the depth and continuity of their research in this front.

Table 54: Top countries and institutions producing citing papers in the Research Front "Spiking neural networks and their neuromorphic chips"

Country Ranking	Country	Citing Papers	Proportion
1	China	631	37.6%
2	USA	427	25.5%
3	South Korea	153	9.1%
4	UK	140	8.4%
5	Germany	116	6.9%
6	Switzerland	102	6.1%
7	France	72	4.3%
8	Japan	70	4.2%
9	Singapore	67	4.0%
10	Spain	56	3.3%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	98	5.8%
2	Tsinghua University	China	76	4.5%
3	Seoul National University	South Korea	54	3.2%
4	Swiss Federal Institute of Technology Zurich	Switzerland	52	3.1%
4	University of Zurich	Switzerland	52	3.1%
6	French National Centre for Scientific Research	France	45	2.7%
7	Peking University	China	43	2.6%
8	Zhejiang University	China	39	2.3%
9	Purdue University	USA	36	2.1%
10	Fudan University	China	35	2.1%
10	Huazhong University of Science and Technology	China	35	2.1%



1.3 KEY HOT RESEARCH FRONT – "Generative Adversarial Networks"

In 2014, Ian J. Goodfellow, a scientist at Google Brain, and colleagues proposed Generative Adversarial Networks (GANs). Since then, the GANs craze has swept through the top AI conferences, with a continuous influx of high-quality papers. Yann LeCun, a 2018 Turing Award winner, has called GANs "the coolest idea in deep learning in the last

20 years".

The basic principle of GANs is to make two neural networks—generator and discriminator—mutually adversarial, thereby learning the distribution of data. GANs can learn generative tasks without using labeled data. Currently, GANs has achieved amazing results in computer vision, language processing, and other areas, including image generation, image style transfer, image repair, image enhancement, image super-resolution recovery, text generation, speech generation, and video generation. The core principle of the most representative large language model, ChatGPT, also employs GANs.

"Generative Adversarial Networks" includes eight core papers, covering the overview of GANs research, globally and locally consistent image completion, and databases for scene recognition. Among these papers, Goodfellow *et al.*'s "Generative Adversarial Networks" published in the journal *Communications of the ACM* in 2020, is the pioneering work, with nearly 13,000 citations to date (Figure 28). The paper introduces the principles, architectures, and recent applications of GANs, emphasizing the technology's key features, as follows: (1) GANs is a generative model based on game theory, and the adversarial relationship between the generator and the discriminator allows for higher generative and discriminative capabilities; (2) GANs can generate high-quality and diverse samples suitable for various scenarios; (3) GANs is robust and can handle input data of different scales and shapes. The paper also discusses the challenges and problems faced by GANs, such as mode collapse and unstable training.

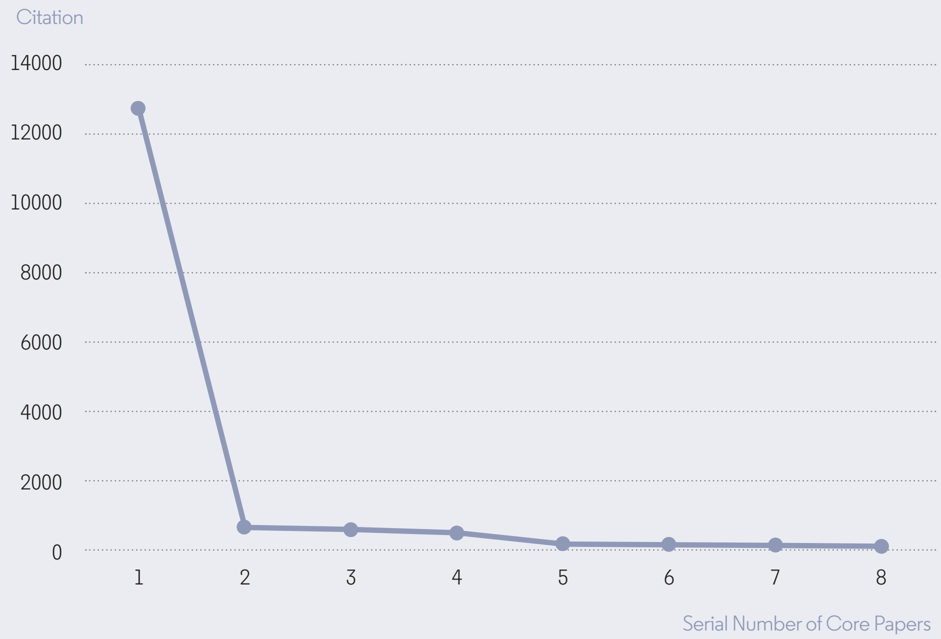


Figure 28: Citation frequency distribution curve of core papers in Research Front "Generative Adversarial Networks"

Among the eight core papers, the USA contributes three, while Canada and China each contribute two. Countries including South Korea, Spain, and Japan each account for one. In terms of institutions producing core papers, the University of Montreal in Canada registers two papers, while various other institutions each contribute one. Among them, the above-mentioned paper "Generative Adversarial Networks" holds absolute leading position in citation impact in this front.

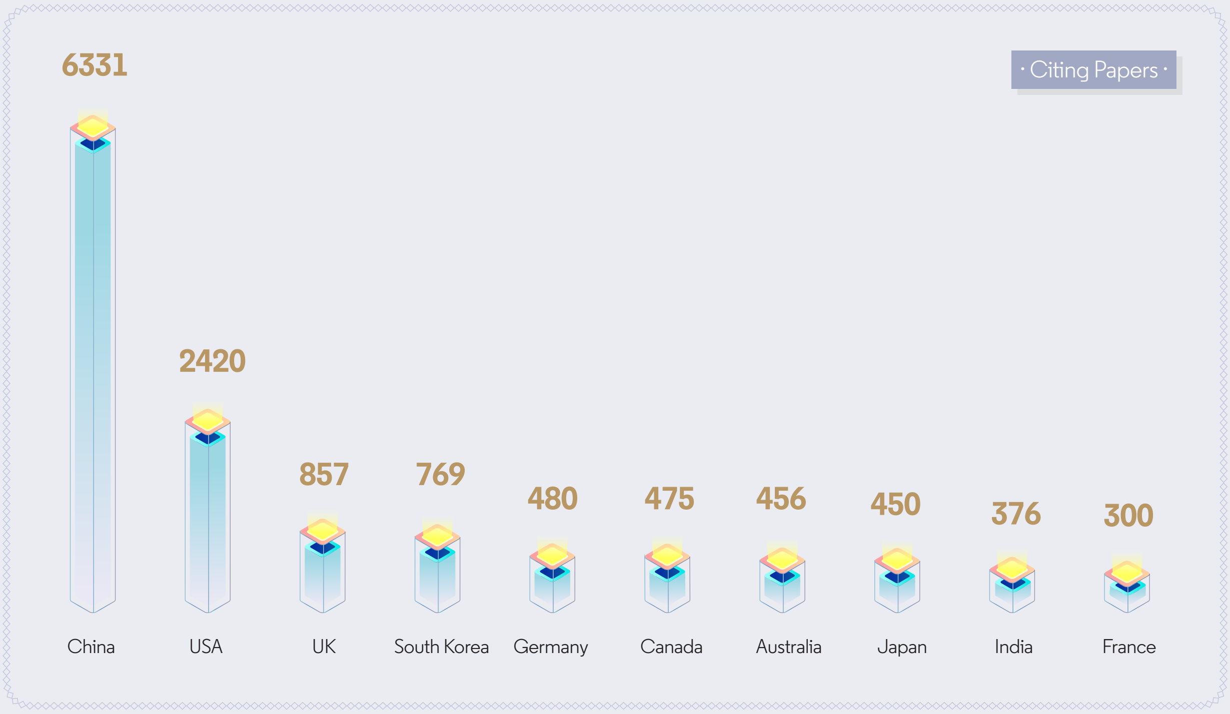
From the perspective of citing papers

(Table 55), China is the largest national source of follow-up reports in this field, with 6,331 papers at this writing, accounting for 53.1% of the total. The USA ranks 2nd, fielding more than 20%. In terms of citing institutions, China-based entities occupy the entire top 10. Among them, the Chinese Academy of Sciences is the most active and ranks 1st, and nine other noted universities such as Tsinghua University, Zhejiang University, and Wuhan University have also made the list.

Table 55: Top countries and institutions producing citing papers in the Research Front "Generative Adversarial Networks"

Country Ranking	Country	Citing Papers	Proportion
1	China	6331	53.1%
2	USA	2420	20.4%
3	UK	857	7.2%
4	South Korea	769	6.5%
5	Germany	480	4.0%
6	Canada	475	4.0%
7	Australia	456	3.8%
8	Japan	450	3.8%
9	India	376	3.2%
10	France	300	2.5%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	747	6.3%
2	Tsinghua University	China	244	2.1%
3	Zhejiang University	China	212	1.8%
4	Wuhan University	China	204	1.7%
5	Shanghai Jiao Tong University	China	183	1.5%
5	Xidian University	China	183	1.5%
7	University of Electronic Science and Technology of China	China	180	1.5%
8	Peking University	China	174	1.5%
9	Harbin Institute of Technology	China	159	1.3%
10	Beihang University	China	153	1.3%



2023 RESEARCH FRONTS

ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

The Top 10 hot Research Fronts in economics, psychology and other social sciences reflect the trend of the digital and "green" transitions currently transforming many aspects of economic and social life. Unlike previous years, when hot Research Fronts in psychology dominated, three of the current hot fronts are related to digital and intelligent transformation, including "Supply chain risk management and the application of blockchain technology", "Research on consumers' use and acceptance of online meal ordering services", and "Artificial Intelligence (AI) ethics". These fronts all focus on analyzing the impact of digital and intelligent development on the economy and society. Green sustainable development is another salient theme of the hot Research Fronts in this field, as embodied by three specialty areas: "Research on the uncertainty of green energy consumption and economic policy", "Land use efficiency and sustainable development issues", and "Green innovation and environmental performance".

"Research on sports psychology" is the only hot front pertaining to psychology on the Top 10 list, focusing on the psychological characteristics and patterns observed in people engaging in sports activities. This interdisciplinary research direction is closely associated with sports science, sports sociology, as well as various theories and methodologies related to organized or competitive physical activities. Moreover, "Research on physical exercise interventions for children and adolescents" also becomes a hot Research Front in 2023, revealing the attention to research areas such as the physical health of adolescents in the wake of the COVID-19 pandemic.

In terms of research methodologies in the spheres of economics and sociology, the two hot Research Fronts on "Application of two-way fixed effects regression model in causal relationship and inverse relationship" and "Analysis of selection factors of asset pricing model" focus on the application of correlation models.

Table 56: Top 10 Research Fronts in economics, psychology and other social sciences

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Research on the uncertainty of green energy consumption and economic policy	39	1961	2021.4
2	Land use efficiency and sustainable development issues	17	1339	2020.8
3	Supply chain risk management and the application of blockchain technology	25	3377	2020.5
4	Application of two-way fixed effects regression model in causal relationship and inverse relationship	10	1854	2020.5
5	Research on consumers' use and acceptance of online meal ordering services	42	2783	2020.4
6	Green innovation and environmental performance	3	585	2020.3
7	Research on physical exercise interventions for children and adolescents	16	5386	2019.8
8	Analysis of selection factors of asset pricing model	13	1586	2019.5
9	Research on sports psychology	7	6864	2019.4
10	Artificial Intelligence (AI) ethics	4	738	2019.3

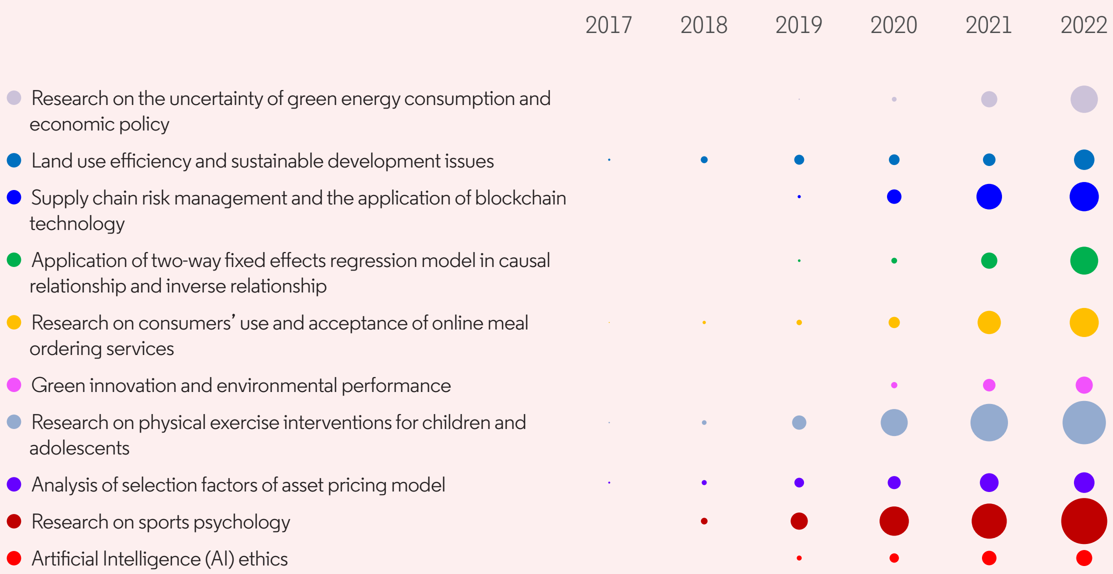


Figure 29: Citing papers for the Top 10 Research Fronts in economics, psychology and other social sciences

1.2 KEY HOT RESEARCH FRONTS - "Supply chain risk management and the application of blockchain technology"

The COVID-19 pandemic, geopolitics, and green transformation have reshaped global supply chains. Many random factors—including demand uncertainty, information asymmetry, and supplier instability during the operation of enterprise supply chains—have led to enormous risks in supply chain management. Enterprises now pay more attention to the difficulty of obtaining expected profits and how to cope with a host of risks. In this context, research on supply chain risk management has once again become a hot topic, and specific analysis is being carried out from the perspectives of supply chain resilience, sustainability, adaptability, and more.

In terms of technical applications, the decentralized architecture of blockchain technology, transparent data flow, high-security data protection, and automatic operation of smart contracts have become hot topics in research on supply chain risk management. For example, to achieve more efficient, safer, and more reliable operations of the supply chain, relevant studies explore the application of blockchain technology to various operations, including information transparency and traceability; contract and payment automation; inventory management and logistics optimization; and anti-fraud and intellectual property rights protection.

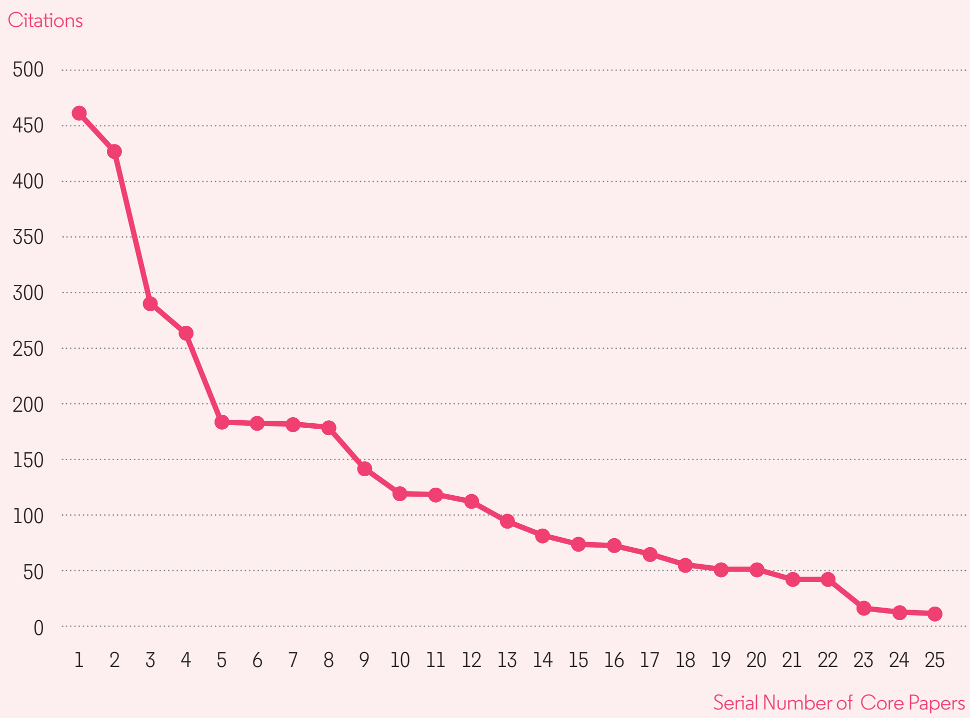


Figure 30: Citation frequency distribution curve of core papers in the Research Front "Supply chain risk management and the application of blockchain technology"

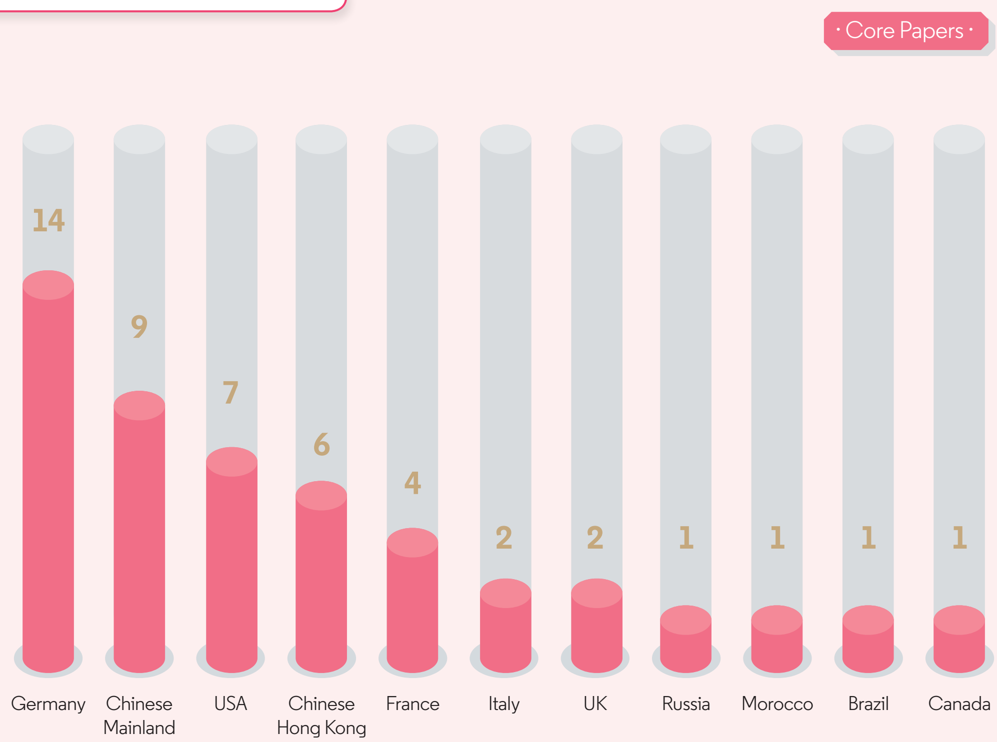
Twenty-five core papers (Figure 30), primarily published between 2020 and 2021, underlie this Research Front. Four papers analyze the concept and measurement of the supply chain, reconfigurability, resilience, ripple effect, and other factors. Nine papers focus on the risks brought by the COVID-19 pandemic to the supply chain as well as post-COVID development and suggestions. Twelve papers focus on the application of blockchain technology to supply chain traceability, cracking down on counterfeit and shoddy products, information disclosure, among other topics. The most-cited core paper, analyzing the impact of the pandemic on global supply chains, was published in *Transportation Research Part E* by researchers at the Berlin School of Economics and Law, Germany; at this writing, the paper has been cited 467 times. The work entailed the construction of a simulation model to examine and predict the impact of epidemic outbreaks on the global supply chain and explore the differences in the impact of epidemic transmission speed, time of interruption to upstream and downstream areas, time of facility shutdown and opening, and other factors, on the supply chain.

Fourteen of the core papers in this hot Research Fronts are attributed to institutions based in Germany, accounting for 56% of the core. Chinese Mainland contributed 9 papers, ranking 2^{nd}. In terms of contributing institutions, four of the top seven are based in France, while the other three are the Berlin School of Economics and Law, Germany, which has produced the most core papers, the Hong Kong Polytechnic University, which ranks 2^{nd}, and, sharing the 6^{th} tier, Donghua University in China (Table 57).

Table 57: Top countries/regions and institutions producing core papers in the Research Front "Supply chain risk management and the application of blockchain technology"

Country/ region Ranking	Country/ Region	Core Papers	Proportion
1	Germany	14	56.0%
2	Chinese Mainland	9	36.0%
3	USA	7	28.0%
4	Chinese Hong Kong	6	24.0%
5	France	4	16.0%
6	Italy	2	8.0%
6	UK	2	8.0%
8	Russia	1	4.0%
8	Morocco	1	4.0%
8	Brazil	1	4.0%
8	Canada	1	4.0%

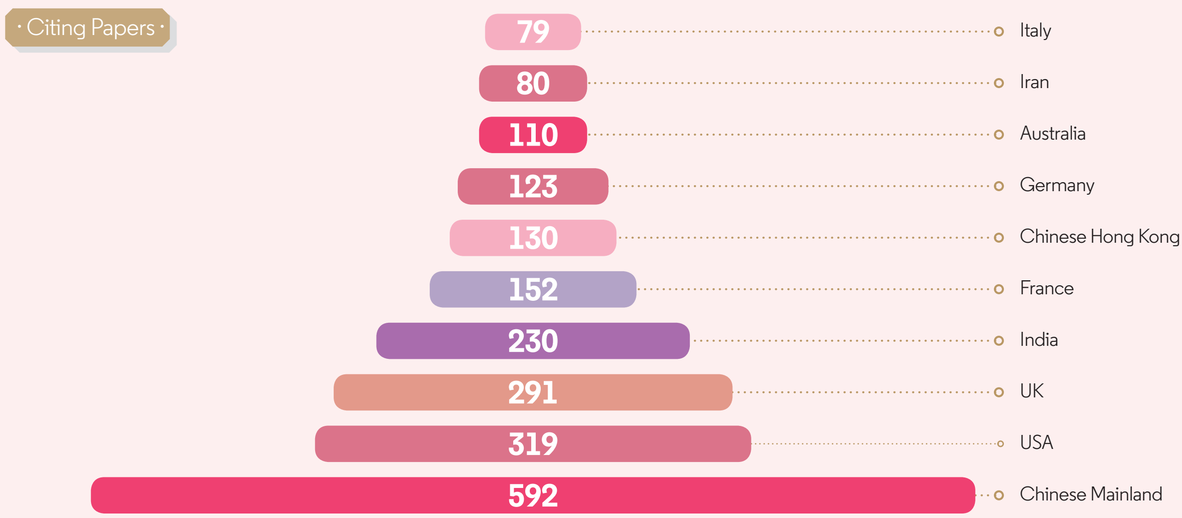
Institution Ranking	Institution	Affiliated Country/ Region	Core Papers	Proportion
1	Berlin School of Economics and Law	Germany	12	48.0%
2	Hong Kong Polytechnic University	Chinese Hong Kong	6	24.0%
3	IMT Inst Mines Telecommunication	France	3	12.0%
3	IMT Atlantique	France	3	12.0%
3	University of Bretagne Loire	France	3	12.0%
6	Donghua University	Chinese Mainland	2	8.0%
6	National Center for Scientific Research of France (CNRS)	France	2	8.0%



In terms of citing papers, Chinese Mainland ranks 1st with 592 papers, USA ranks 2nd, while the UK, India, and France rank 3rd, 4th, and 5th respectively. In terms of citing institutions, the Hong Kong Polytechnic University has the most citing papers, followed by the Indian Institute of Management and the Indian Institute of Technology. South China University of Technology, the Chinese Academy of Sciences, and National Taiwan University respectively rank 7th, 8th, and 9th.

Table 58: Top countries/regions and institutions producing citing papers in the Research Front "Supply chain risk management and the application of blockchain technology"

Country/ region Ranking	Country/ Region	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country/ Region	Citing Papers	Proportion
1	Chinese Mainland	592	33.7%	1	Hong Kong Polytechnic University	Chinese Hong Kong	104	5.9%
2	USA	319	18.2%	2	Indian Institute of Management	India	55	3.1%
3	UK	291	16.6%	3	Indian Institute of Technology (IIT)	India	43	2.4%
4	India	230	13.1%	4	Berlin School of Economics and Law	Germany	37	2.1%
5	France	152	8.7%	5	University of Liverpool	UK	35	2.0%
6	Chinese Hong Kong	130	7.4%	6	University of Technology Sydney	Australia	32	1.8%
7	Germany	123	7.0%	7	South China University of Technology	Chinese Mainland	31	1.8%
8	Australia	110	6.3%	8	Chinese Academy of Sciences	Chinese Mainland	30	1.7%
9	Iran	80	4.6%	9	National Institute of Industrial Engineering India	India	28	1.6%
10	Italy	79	4.5%	9	National Taiwan University	Chinese Taiwan	28	1.6%



1.3 KEY HOT RESEARCH FRONT - "Artificial Intelligence (AI) ethics"

New-generation artificial intelligence (AI) technology featuring deep learning is a great success. The continually developing large models greatly empower the performance of AI in downstream tasks. New AI technologies, as they increasingly integrate with human society, are constantly refreshing people's cognitive limits, disruptively reshaping the ways people live, work, and communicate. However, while the AI industry continues to maintain a high-speed momentum in development, the advancement of AI itself faces many challenges. Ethical issues such as privacy disclosure, bias and discrimination, attribution of responsibility, and technology abuse brought about by AI attract widespread attention. AI ethics has become a significant and unavoidable topic of discussion.

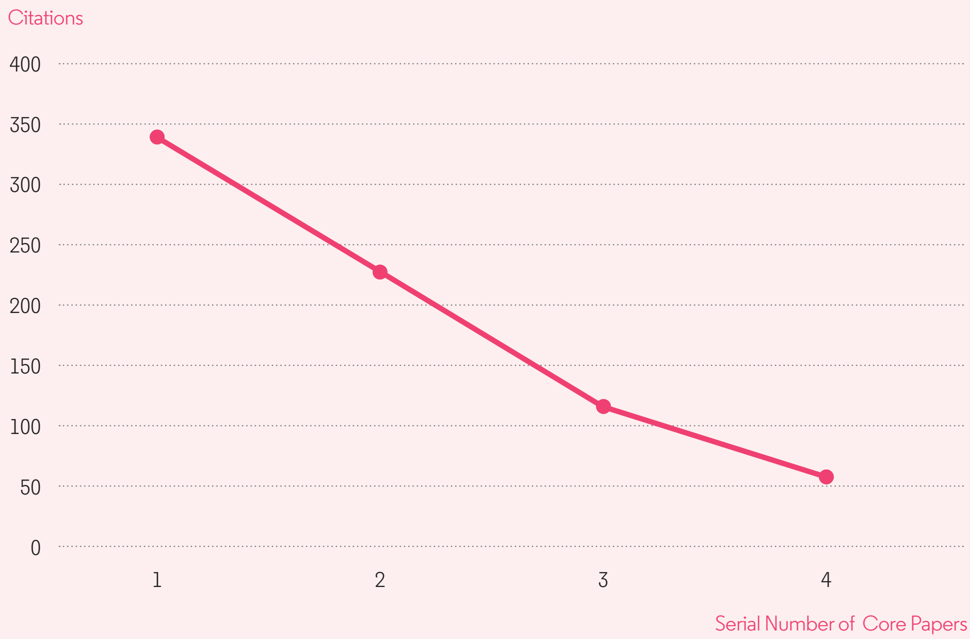


Figure 31: Citation frequency distribution curve of core papers in the Research Front "Artificial Intelligence (AI) ethics"

Four core papers anchor this hot Research Front, focusing on governance criteria, rules and methods, action path, and policy evaluation of AI ethics. The most frequently cited paper is "The global landscape of ethical criteria for artificial intelligence" published in *Nature Machine Intelligence* by researchers at the Swiss Federal Institute of Technology (ETH), Zurich. This paper analyzes the principles and guidelines of AI ethics in major countries/regions around the world, revealing the global convergence of AI governance in five ethical principles: transparency, justice and fairness, non-maleficence, responsibility, and privacy. The second and third most-cited papers, both published in the journal *Minds and Machines*, analyze the core opportunities and risks brought by AI to society from the perspective of AI ethical analysis framework and guide evaluation. The fourth paper, published in *Science and Engineering Ethics* in 2020, focuses on means and tools for advancing AI ethics from principles to practice.

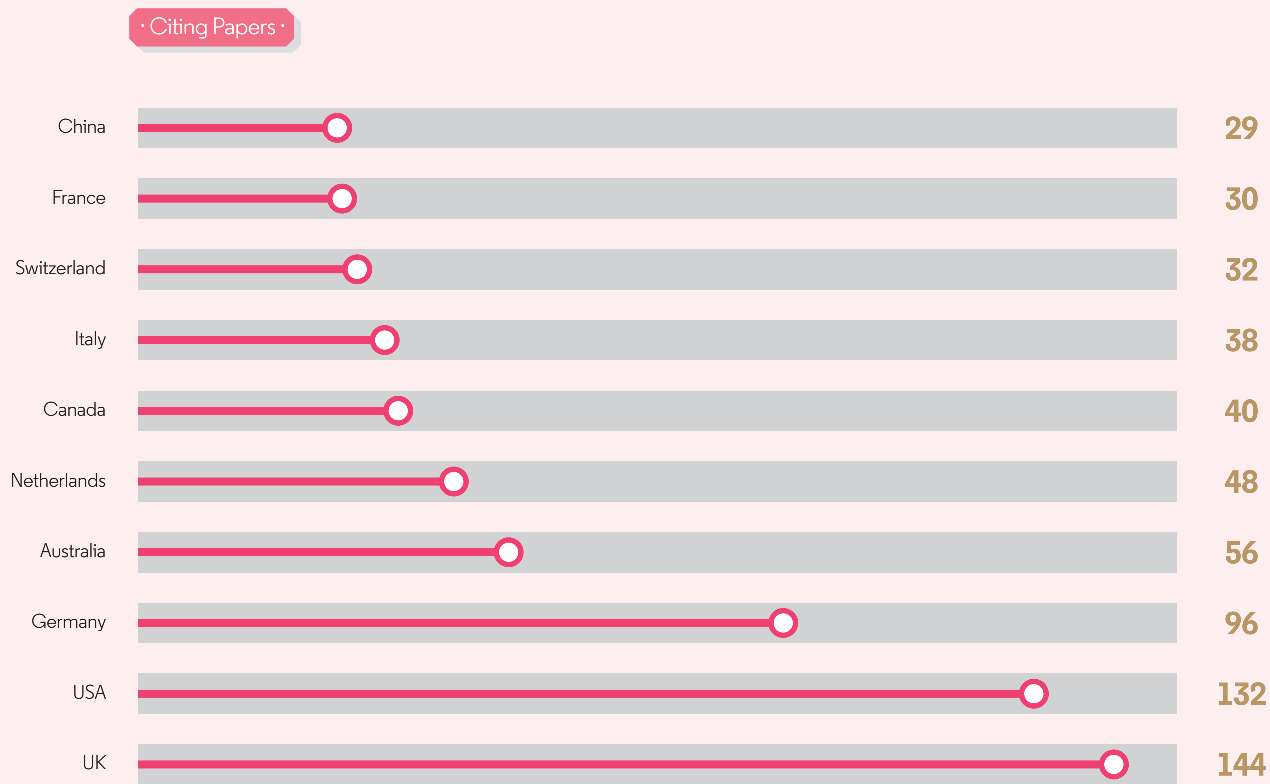
Among the top countries in terms of the output of core papers, Switzerland, Germany, and the UK each published two core papers. In terms of institutions, ETH Zurich and Oxford University are star performers, each publishing two core papers. Moreover, European and American institutions have engaged in close cooperation. Oxford University, the Alan Turing Institute, the University of Grenoble, the French National Centre for Scientific Research (CNRS), Delft University of Technology in the Netherlands, the University of Edinburgh, Technical University of Munich in Germany, the University of Turin in Italy, and other institutions have devoted particular attention to this specialty area and have collaboratively published relevant papers.

In terms of citing papers, the UK ranks 1st with 144 papers that cite the core literature, followed by the USA with 132, while Germany, Australia, and the Netherlands rank 3rd, 4th, 5th respectively. In terms of citing institutions, the University of Oxford fields the most citing papers. The Alan Turing Institute, University College London, and the University of Toronto in Canada are also actively following up on research in this direction.

Table 59: Top countries/regions and institutions producing citing papers in the Research Front "Artificial Intelligence (AI) ethics"

Country Ranking	Country	Citing Papers	Proportion
1	UK	144	24.5%
2	USA	132	22.5%
3	Germany	96	16.4%
4	Australia	56	9.5%
5	Netherlands	48	8.2%
6	Canada	40	6.8%
7	Italy	38	6.5%
8	Switzerland	32	5.5%
9	France	30	5.1%
10	China	29	4.9%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	University of Oxford	UK	35	6.0%
2	Alan Turing Institute	UK	19	3.2%
3	University College London	UK	18	3.1%
4	University of Toronto	Canada	16	2.7%
5	Technical University of Munich	Germany	13	2.2%
5	University of Cambridge	UK	13	2.2%
7	Delft University of Technology	The Netherlands	12	2.0%
7	Harvard University	USA	12	2.0%
9	Imperial College London	UK	11	1.9%
10	Stanford University	USA	9	1.5%
10	University of Amsterdam	The Netherlands	9	1.5%
10	University of Bonn	Germany	9	1.5%
10	University of Twente	The Netherlands	9	1.5%



2.EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

One emerging Research Front has been identified in the field of economics, psychology and other social sciences—namely, "Development of the human-centric, sustainable and resilient Industry 5.0".

Table 60: Emerging Research Fronts in economics, psychology and other social sciences

Rank	Emerging Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Development of the human-centric, sustainable, and resilient Industry 5.0	10	416	2021.6

2.2 KEY EMERGING RESEARCH FRONT – "Development of the human-centric, sustainable and resilient Industry 5.0"

The progression of the Industrial Revolution propelled transformative development across all social subsystems. However, with the introduction of modern concepts such as sustainable development, the concept of "people-oriented," and Carbon Peaking / Carbon Neutrality, manufacturing systems and paradigms have struggled to adapt to the demands of an innovative society. As an emerging concept, Industry 5.0 puts the well-being of workers at the heart of the manufacturing system, with the aim of achieving social goals apart from employment and economic growth, and promoting all-round and sustainable development of human populations. Since the release of the EU Industry 5.0 white paper, research interest in Industry 5.0 has grown, as evinced by the concept's new status as an emerging Research Front.

The European Commission spells out three key pillars of Industry 5.0: human-centric, sustainability, and resilience. Specifically, Industry 5.0 requires that industrial production must respect and protect the Earth's ecology and put the interests of workers at the heart of the production process, so that industry can achieve social goals apart from employment and economic growth and become the cornerstone of social stability and prosperity. Centering on the content related to Industry 5.0, social scientists carry out research and analysis on the comparative aspects between the previous model— Industry 4.0— and Industry 5.0, including technical dimensions, application dimensions, and other aspects.

Researchers have conducted comparative studies of Industry 4.0 and Industry 5.0 in terms of conceptual change, framework comparison, and reasons for transformation. On this topic, researchers have noted that the most important distinction between Industry 4.0 and Industry 5.0 lies in the relationship between human and machine in the production process. In Industry 5.0, the core is "people". The concept pays more attention to the combination of labor and technology, and focuses on the sustainability of the skills and training required by people. Industry 5.0 is intended to achieve the goals of a super-intelligent society and sustainable development of ecological value. It will promote the building of a community with a shared future for industry and facilitate the stability and sustainable development of society.

From the perspective of technology, studies such as "Industry 5.0: A Survey on Enabling Technologies and Potential Applications" (PKR Maddikunta, *et al.*, *Journal of Industrial Information Integration*, 2022) point out that enabling technologies such as the Internet of Things, cloud computing, and AI are combined with cognitive skills and development concepts in innovation, thereby realizing the flow of advanced knowledge among technologies and realizing the value-driven Industry 5.0 model with technical support.

In terms of application dimension, researchers propose that from the perspective of the evolution of the Industrial Revolution, Industry 5.0 has begun to take shape, although it is not yet widely recognized. The concept's goals cannot be achieved overnight, and its progress must be guided by the actual needs of industrial development. Industry 5.0 might achieve its first implementation in scenarios such as smart manufacturing, medical and health care, supply chain management, shipping, engineering education, and smart cities.

2023 RESEARCH FRONTS

APPENDIX
RESEARCH FRONTS: IN SEARCH OF THE STRUCTURE OF SCIENCE

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When Eugene Garfield introduced the concept of a citation index for the sciences in 1955, he emphasized its several advantages over traditional subject indexing.[1] Since a citation index records the references in each article indexed, a search can proceed from a known work of interest to more recently published items that cited that work. Moreover, a search in a citation index, either forward in time or backward through cited references, is both highly efficient and productive because it relies upon the informed judgments of researchers themselves, reflected in the references appended to their papers, rather than the choices of indexing terms by cataloguers who are less familiar with the content of each publication than are the authors. Garfield called these authors "an army of indexers" and his invention "an association-of-ideas index". He recognized citations as emblematic of specific topics, concepts, and methods: "the citation is a precise, unambiguous representation of a subject that requires no interpretation and is immune to changes in terminology."[2] In addition, a citation index is inherently cross-disciplinary and breaks through limitations imposed by source coverage. The connections represented by citations are not confined to one field or several – they naturally roam throughout the entire landscape of research. That is a particular strength of a citation index for science since interdisciplinary territory is well recognized as fertile ground for discovery. An early supporter of Garfield's idea, Nobel laureate Joshua Lederberg, saw this specific benefit of a citation index in his own field of genetics, which interacted with biochemistry, statistics, agriculture, and medicine. Although it took many years before the Science Citation Index (now the Web of Science) was fully accepted by librarians and the researcher community, the power of the idea and the utility of its implementation could not be denied. This year marks the 56th anniversary of the Science Citation Index, which first became commercially available in 1964. [3]

While the intended and primary use of the Science Citation Index was for information retrieval, Garfield knew almost from the start that his data could be exploited for the analysis of scientific research itself. First, he recognized that citation frequency was a method for identifying significant papers—ones with "impact"— and that such papers could be associated with specific specialties. Beyond this, he understood that there was a meaningful, if complex, structure represented in this vast database of papers and their associations through citations. In "Citation indexes for sociological and historical research," published in 1963, he stated that citation indexing provided an objective method for defining a field of inquiry.[4] That assertion rested on the same logical foundation that made information retrieval in a citation index effective: citations revealed the expert decisions and self-organizing behavior of researchers, their intellectual as well as their social associations. In 1964, with colleagues Irving H. Sher and Richard J. Torpie, Garfield produced his first historiograph, a linear mapping through time of influences and dependencies, illustrated by citation links, concerning the discovery of DNA and its structure. [5] Citation data, Garfield saw, provided some of the best material available for building out a picture of the structure of scientific research as it really was, even for sketching its terrain. Aside from making historiographs of specific sets of papers, however, a comprehensive map of science could not yet be charted.

Garfield was not alone in his vision. During the same era, the physicist and historian of science, Derek J. de Solla Price, was exploring the characteristic features and structures of the scientific research enterprise. The Yale University professor used the measuring tools of science on scientific activity, and he demonstrated in two influential books, of 1961 and 1963, how science had grown exponentially since the late 17th century, both in terms of number of researchers and publications.[6, 7] There was hardly a statistic about the activity of scientific research that his restless mind was not eager to obtain, interrogate, and play with. Price and Garfield became acquainted at this time, and Price, the son of a tailor, was soon receiving data, as he said, "from the cutting- room floor of ISI's computer room." [8] In 1965, Price published

"Networks of scientific papers," which used citation data to describe the nature of what he termed "the scientific research front." [9] Previously, he had used the term "research front" in a generic way, meaning the leading edge of research and including the most knowledgeable scientists working at the coalface. But in this paper, and using the short-lived field of research on N-rays as his example, he described the research front more specifically in terms of its density of publications and time dynamics as revealed by a network of papers arrayed chronologically and their inter-citation patterns. Price observed that a research front builds upon recently published work and that it displays a tight network of relationships.

"The total research front of science has never been a single row of knitting. It is, instead, divided by dropped stitches into quite small segments and strips. Such strips represent objectively defined subjects whose description may vary materially from year to year but which remain otherwise an intellectual whole. If one would work out the nature of such strips, it might lead to a method for delineating the topography of current scientific literature. With such a topography established, one could perhaps indicate the overlap and relative importance of journals and, indeed, of countries, authors, or individual papers by the place they occupied within the map, and by their degree of strategic centralness within a given strip."[10]

The year is 1972. Enter Henry Small, a young historian of science previously working at the American Institute of Physics in New York City who now joined the Institute for Scientific Information in Philadelphia hoping to make use of the Science Citation Index data and its wealth of title and key words. After his arrival, Small quickly changed allegiance from words to citations for the same reasons that had captivated and motivated Garfield and Price: their power and potential. In 1973, Small published a paper that was as groundbreaking in its own way as Garfield's 1955 paper introducing citation indexing for science. This paper, "Cocitation in the scientific literature: a new measure of relationship between two documents," introduced a new era in describing the specialty structure of science.[11] Small measured the similarity of two documents in terms of the number of times they were cited together, in other words their co-citation frequency. He illustrated his method of analysis with an example from recent papers in the literature of particle physics. Having found that such co-citation patterns indicated "the notion of subject similarity" and "the association or co-occurrence of ideas," he suggested that frequently cited papers, reflecting key concepts, methods, or experiments, could be used as a starting point for a co-citation analysis as an objective way to reveal the social and intellectual, or the socio-cognitive, structure of a specialty area.

Like Price's research fronts, consisting of a relatively small group of recent papers tightly knit together, so too Small found co-citation analysis pointed to the specialty as the natural organizational unit of research, rather than traditionally defined and larger fields. Small also saw the potential for co-citation analysis to make, by analogy, movies and not merely snapshots. "The pattern of linkages among key papers establishes a structure or map for the specialty which may then be observed to change through time," he stated. "Through the study of these changing structures, co-citation provides a tool for monitoring the development of scientific fields, and for assessing the degree of interrelationship among specialties."

It should be noted that the Russian information scientist Irena V. Marshakova-Shaikevich also introduced the idea of co-citation analysis in 1973.[12] Since neither Small nor Marshakova-Shaikevich knew of each other's work, this was an instance of simultaneous and independent discovery. The sociologist of science Robert K. Merton designated the phenomenon "multiple discovery" and demonstrated that it is more common in the history of science than most recognize. [13,14] Both Small and Marshakova-Shaikevich contrasted co-citation with bibliographic coupling, which had been described by Myer Kessler in 1963. [15] Bibliographic coupling measures subject similarity between documents based on the frequency of shared cited references: if two works often cite the same literature, there is a probability they are related in their subject content. Co-citation analysis inverts this idea: instead of the similarity relation being established by what the publications cited, co-citation brings publications together by what cites them. With bibliographic coupling, the similarity relationships are static because their cited references are fixed, whereas similarity between documents determined by co-citation can change as new citing papers are published. Small has noted that he preferred co-citation to bibliographic coupling because he "sought a measure that reflected scientists' active and changing perceptions."[16]

The next year, 1974, Small and Belver C. Griffith of Drexel University in Philadelphia published a pair of landmark articles that laid the foundations for defining specialties using co-citation analysis and mapping them according to their similarity.[17,18] Although there have since been significant adjustments to the methodology used by Small and Griffith, the general approach and underlying principles remain the same. A selection is made of highly cited papers as the seeds for a co-citation analysis. The restriction to a small number of publications is justified because it is assumed that the citation histories of these publications mark them as influential and likely representative of key concepts in specific specialties, or research fronts. (The characteristic hyperbolic distribution of papers by citation frequency also suggests that this selection will be robust and representative.) Once these highly cited papers are harvested, they are analyzed for co-citation occurrence, and, of course, there are many zero matches. The co-cited pairs that are found are then connected to others through single-link clustering, meaning only one co-citation link is needed to bring a co-cited pair in association with another co-cited pair (the co-cited pair A and B is linked to the co-cited pair C and D because B and C are also co-cited). By raising or lowering a measure of co-citation strength for pairs of co-cited papers, it is possible to obtain clusters, or groupings, of various sizes. The lower the threshold, the more papers group together in large sets and setting the threshold too low can result in considerable chaining. Setting a higher threshold produces discrete specialty areas, but if the similarity threshold is set too high, there is too much disaggregation and many "isolates" form. The method of measuring co-citation similarity and the threshold of co-citation strength employed in creating research fronts has varied over the years. Today, we use cosine similarity, calculated as the co-citation frequency count divided by the square root of the product of the citation counts for the two papers. The minimum threshold for co-citation strength is a cosine similarity measure of .1, but this can be raised incrementally to break apart large clusters if the front exceeds a maximum number of core papers, which is set at 50. Trial and error has shown this procedure yields consistently meaningful research fronts.

To summarize, a Research Front consists of a group of highly cited papers that have been co-cited above a set threshold of similarity strength and their associated citing papers. In fact, the Research Front should be understood as both the co-cited core papers, representing a foundation for the specialty, and the citing papers that represent the more recent work and the leading edge of the Research Front. The name of the Research Front can be derived from a summarization of the titles of the core papers or the citing papers. The naming of Research Fronts in Essential Science Indicators relies on the titles of core papers. In other cases, the citing papers have been used: just as it is the citing authors who determine in their co-citations the pairing of important papers, it is also the citing authors who confer meaning on the content of the resulting Research Front. Naming Research Fronts is not a wholly algorithmic process, however. A careful, manual review of the cited or citing papers sharpens accuracy in naming a Research Front.

In the second of their two papers in 1974, [19] Small and Griffith showed that individual research fronts could be measured for their similarity with one another. Since co- citation defined core papers forming the nucleus of a specialty based on their similarity, co-citation could also define research fronts with close relationships to others. In their mapping of research fronts, Small and Griffith used multidimensional scaling and plotted similarity as proximity in two dimensions.

Price hailed the work of Small and Griffith, remarking that while co-citation analyses of the scientific literature into clusters that map on a two dimensional plane "may seem a rather abstruse finding," it was "revolutionary in its implications." He asserted: "The finding suggests that there is some type of natural order in science crying out to be recognized and diagnosed. Our method of indexing papers by descriptors or other terms is almost certainly at variance with this natural order. If we can successfully define the natural order, we will have created a sort of giant atlas of the corpus of scientific papers that can be maintained in real time for classifying and monitoring developments as they occur."[20] Garfield remarked that "the work by Small and Griffith was the last theoretical rivet needed to get our flying machine off the ground."[21] Garfield, ever the man of action, transformed the basic research findings into an information product offering benefits of both retrieval and analysis. The flying machine took off in 1981 as the ISI Atlas of Science: Biochemistry and Molecular Biology, 1978/80. [22] This book presented 102 research fronts, each including a map of the core papers and their relationships laid out by multidimensional scaling. A list of the core papers was provided with their citation counts, as well as a list of key citing documents, including a relevance weight for each that was the number of core documents cited. A short review, written by an expert in the specialty, accompanied these data. Finally, a large, foldout map showed all 102 research fronts plotted according to their similarities. It was a bold, cutting edge effort and a real gamble in the marketplace, but of a type wholly characteristic of Garfield.

The ISI Atlas of Science in its successive forms— another in book format and then a series of review journals [23,24] —did not survive beyond the 1980s, owing to business decisions at the time in which other products and pursuits held greater priority. But Garfield and Small both continued their research and experiments in science mapping over the decade and thereafter. In two papers published in 1985, Small introduced an important modification to his method for defining research fronts: fractional co-citation clustering. [25] By counting citation frequency fractionally, based on the length of the reference list in the citing papers, he was able to adjust for differences in the average rate of citation among fields and therefore remove the bias that whole counting gave to biomedical and other "high citing" fields. As a consequence, mathematics, for example, emerged more strongly, having been underrepresented by integer counting. He also showed that research fronts could be clustered for similarity at levels higher than groupings of individual fronts. [26] The same year, he and Garfield summarized these advances in "The geography of science: disciplinary and national mappings," which included a global map of science based on a combination of data in the Science Citation Index and the Social Sciences Citation Index, as well as lower level maps that were nested below the areas depicted on the global map. [27] "The reasons for the links between the macro-clusters are as important as their specific contents," the authors noted. "These links are the threads which hold the fabric of science together."

In the following years, Garfield focused on the development of historiographs and, with the assistance of Alexander I. Pudovkin and Vladimir S. Istomin, introduced the software tool HistCite. Not only does the HistCite program automatically generate chronological drawings of the citation relationships of a set of papers, thereby offering in thumbnail a progression of antecedent and descendant papers on a particular research topic, it also identifies related papers that may not have been considered in the original search and extraction. It is, therefore, also a tool for information retrieval and not only for historical analysis and science mapping. [28, 29] Small continued to refine his co-citation clustering methods and to analyze in detail and in context the cognitive connections found between fronts in the specialty maps. [30, 31] A persistent interest was the unity of the sciences. To demonstrate this unity, Small showed how one could identify strong co- citation relationships leading from one topic to another and travel along these pathways across disciplinary boundaries, even from economics to astrophysics.[32, 33]

In this, he shared the perspective of E. O. Wilson, expressed in the 1998 book Consilience: The Unity of Knowledge. [34] Early in the 1990s, Small developed SCI- MAP, a PC based system for interactively mapping the literature. [35] Later in the decade, he introduced Research Front data into the new database Essential Science Indicators (ESI), intended mainly for research performance analysis. The Research Fronts presented in ESI had the advantage of being updated every two months, along with the rest of the data and rankings in this product. It was at this time, too, that Small became interested in virtual reality software for its ability to create immersive, three-dimensional visualizations and to handle large datasets in real time. [36, 37] For example, in the late 1990s, Small played a leading role in a project to visualize and explore the scientific literature through co-citation analysis that was undertaken with Sandia National Laboratories using its virtual reality software tool called VxInsight. [38,39] This effort, with farsighted support of Sandia's senior research manager Charles E. Meyers, was an important step forward in exploiting rapidly developing technology that provided detailed and dynamic views of the literature as a geographic space with, for example, dense and prominent features depicted as mountains. Zooming into and out of the landscape allowed the user to travel from the specific to the general and back. Answers to queries made against the underlying data could be highlighted for visual understanding.

In fact, this moment—the late 1990s—was a turning point for science mapping, after which interest in and research about defining specialties and visualizing their relationships exploded. There are now a dozen academic centers across the globe focusing on science mapping, using a wide variety of techniques and tools. Developments over the last decade are summarized and illustrated in Indiana University professor Katy Borner's 2010 book, which carries a familiar-sounding title: Atlas of Science – Visualizing What We Know.[40]

The long interval between the advent of co-citation clustering for science mapping and the blossoming of the field, a period of about 25 years, is curiously about the same time it took from the introduction of citation indexing for science to the commercial success of the Science Citation Index. In retrospect, both were clearly ideas ahead of their time. While the adoption of the Science Citation Index faced ingrained perceptions and practice in the library world (and by extension among researchers whose patterns of information seeking were traditional), delayed enthusiasm for science mapping— a wholly new domain and activity—can probably be attributed to a lack of access to the amount of data required for the work as well as technological limitations that were not overcome until computing storage, speed, and software advanced substantially in the 1990s. Data are now more available and in larger quantity than in the past and personal computers and software adequate to the task. Today, the use of the Web of Science for information retrieval and research analysis and the use of Research Front data for mapping and analyzing scientific activity have found not only their audiences but also their advocates.

What Garfield and Small planted many seasons ago has firmly taken root and is growing with vigor in many directions. A great life, according to one definition, is "a thought conceived in youth and realized in later life." This adage applies to both men. Clarivate is committed to continuing and advancing the pioneering contributions of these two legends of information science.

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Institutes of Science and Development, Chinese Academy of Sciences
No.15 ZhongGuanCunBeiYiTiao Alley, Haidian District, Beijing P. R. China 100190
http://www.casisd.cn/

The National Science Library, Chinese Academy of Sciences
No.33 North Fourth Ring Road, ZhongGuanCun, Beijing P. R. China 100190
http://www.las.ac.cn/

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