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2022 RESEARCH FRONTS

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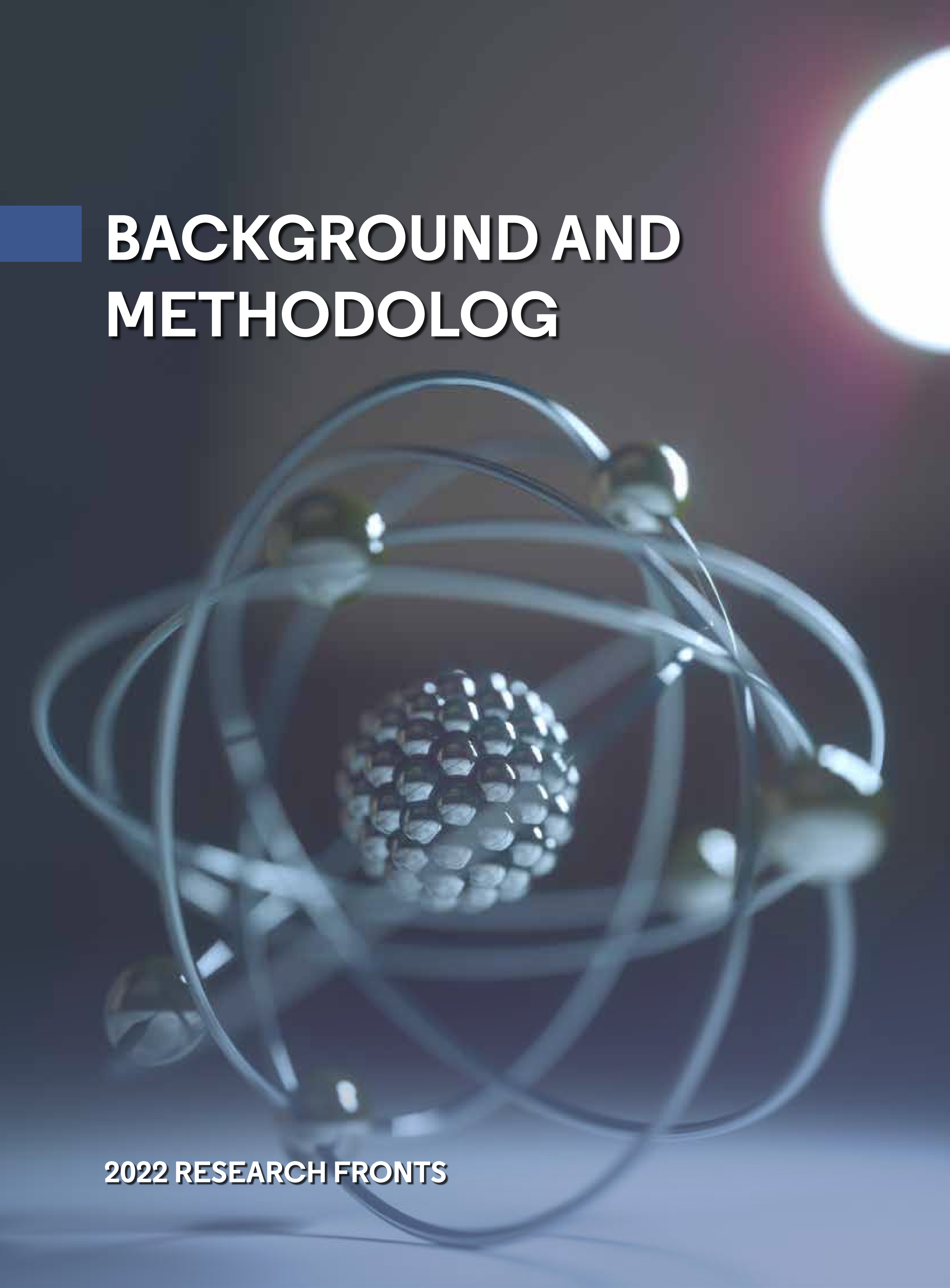


2022 RESEARCH FRONTS

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, buthinging 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). In 2016, 2017, 2018, 2019, 2020, and 2021, the Institutes of Science and Development, CAS, National Science Library, CAS and Clarivate jointly released the *Research Fronts 2016, Research Fronts 2017, Research Fronts 2018, Research Fronts 2019, Research Fronts 2020, and Research Fronts 2021*. 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 2022, 110 hot Research Fronts and 55 emerging Research Fronts were identified based on co-citation analysis that generated 12610 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 165 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 165 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 2022 update, the Research Fronts drew on ESI data from 2016-2021, which were obtained in March 2022.

2.1 RESEARCH FRONTS SELECTION AND NAMING

Research Fronts 2022 presents a total of 165 Research Fronts, including 110 hot and 55 emerging ones. In 2022, the Research Fronts are classified into 11* broad research areas in the sciences and social sciences. Starting from 12610 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 165 Research Fronts is described as follows.

2.1.1 SELECTING THE HOT RESEARCH FRONTS

In addition to the area of Mathematics and Information Science, 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 9 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, resulting in a total of 90 hot Research Fronts. Due to the publication and citation characteristics of "Mathematics" and "Information Science", a new method was applied to select the hot and emerging Research Fronts in these two broad areas in 2022. First, Research Fronts were ranked based on their average citations per core paper, and those above the mean calculated independently in mathematics and information science were selected. Then, based on the ratio of core papers published in Q1 journals※ in these Research Fronts, the ones above the average ratio in a broad area were identified and re-ranked according to mean publication years of their core papers. Among these specialty areas, the Research Fronts that met the criteria were selected and provided to the strategic information professionals. Based on the professionals' judgment of which candidate fronts have accelerated the advancements of knowledge in the two main fields, ten hot Research Fronts were chosen separately for "Mathematics" and "Information Science". 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

* 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".

※ Q1 journals refer to the journals ranked in the top 25% based on the journal impact factors in Journal Citation Reports™."

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 nine broader areas, to identify emerging specialties, 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 2020 or more recently were considered. Then these were sorted in descending order by their total citations in each ESI field corresponding to the nine broader area. We selected the top 10% Research Fronts in each ESI field and ensured that at least one front was selected in an ESI field even if there were only a limited number of research fronts in the field. The selected Research Fronts were 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 9 broader fields. Fifty one fronts were selected as emerging for the nine broader areas, and the earliest mean year of the emerging fronts was 2020.5. The identification of emerging Research Fronts in "Mathematics" and "Information Science" drew upon the same method employed in selecting hot Research Fronts in the two broad areas. Potential emerging Research Fronts were chosen based on their average citations per core paper and, additionally, on the ratio of core papers published in Q1 journals. Ultimately, according to the mean publication years of the fronts, two most-recent Research Fronts were determined as emerging fronts for each of the two broad areas. There are in total 55 emerging Research Fronts in the 11 broader areas. Because the selection was not limited to any research area, the 55 fronts are distributed unevenly in the 11 fields. For example, there is no emerging Research Front in Mathematics, while there are 17 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 55 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 165 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 165 Research Fronts provided by Clarivate, information professionals at the Institute of Strategic Information, conducted a detailed analysis and interpretation to highlight 32 key Research Fronts and 1 key Research Front group (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/territories 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 2021 and the earliest citing paper was published in 2017, 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 2022, 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, 10 key emerging Research Fronts and 1 key emerging Research Front group were selected from the emerging Research Fronts. Thus, we interpret in detail the selected 32 key Research Fronts and 1 key Research Front group from the 165 Research Fronts.

2.2.2 ANALYSIS AND INTEPRETATION OF KEY RESEARCH FRONTS

Based on the data of the selected 165 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 33 key Research Fronts (groups) 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 (groups), 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 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 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.

AGRICULTURAL, PLANT AND ANIMAL SCIENCES

2022 RESEARCH FRONTS

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 four subfields, consisting of food science and engineering, plant genome, plant resistance mechanism, and animal epidemics transmission (Table 1). The subfield of food science and engineering accounts for four hot Research Fronts, pertaining respectively to: oleogel replacement in food fat; application of lactic fermentation in the novel fruit and vegetable functional drinks; pH-sensing intelligent packaging films for meat freshness monitoring; and 3D food printing. Three hot Research Fronts concerning plant genomes, focus, in turn, on tea plant genome, plant pan-genome, and a new-generation plant genome editing system. Two fronts occupy the subfield of plant resistance mechanism – one studying the regulating role of hydrogen sulfide in plant abiotic stress adaptation, and the other the role of plant NLR immune receptors in immune regulation. Another front on animal epidemics transmission is devoted to infection and transmission of SARS-CoV-2 in domestic animals.

Compared with previous Research Front surveys, all four of the subfields mentioned above have registered in previous hot fronts on the Top 10 lists in recent years. In the subfield of plant genome, a key Research Front on plant pan-genome appeared in the 2021 Research Front roundup, and surfaces again in the 2022 Top 10 list thanks to ongoing progress – notably, the application of plant pan-genome. Similarly, the topic of plant genome editing appeared in 2018 and 2021, and does so again this year, having continued to record significant advancement. This continuity shows that these two fronts are in a vigorous development stage and that breakthrough achievements are emerging.

The subfield of animal infectious diseases has also appeared for three consecutive years, having respectively focused on porcine circovirus type 3 in 2020, on African swine fever in 2021, and, in this new survey, on infection and transmission of SARS-CoV-2 in domestic animals. The subfield of plant resistance mechanism has always been a research hotspot, and new achievements have been produced in different directions. Since 2013, related topics have successively registered in the Top 10 list, including oomycete RXLR effectors and suppression of plant immunity (2013), molecular mechanism of inducible plant innate immunity (2015), plant innate immune mechanism (2016), the jasmonate signaling mechanism for regulation of plant growth and defense (2019), and plant immune receptor NLR (nucleotide binding leucine rich repeat) and its mediated disease resistance mechanism (2021). Additionally, in the subfield of food science and engineering, related fronts have repeatedly appeared in the Top 10 list since 2016, including food detection, food pollution prevention and control, food functional packaging film, fruit, and vegetable food processing.

Table 1: Top 10 Research Fronts in agricultural, plant and animal sciences

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Infection and transmission of SARS-CoV-2 in domestic animals	41	5819	2020.4
2	The regulating role of hydrogen sulfide in plant abiotic stress adaptation	34	1267	2019.9
3	Study of oleogels as fat replacers in food	25	1518	2019.4
4	Application of lactic fermentation in the novel fruit and vegetable functional drinks	15	1369	2019.3
5	Genome study and functional gene analysis of tea plant	16	1187	2019.3
6	The role of plant NLR (nucleotide binding leucine rich repeat) immune receptors in immune regulation	41	2975	2019.2
7	A new generation plant genome editing system CRISPR/Cpf1	19	1217	2019.2
8	Research and application of plant pan-genome	18	1925	2019.1
9	A pH-sensing intelligent packaging films based on plant antioxidants for meat freshness monitoring	34	2475	2019
10	3D food printing	24	1837	2019

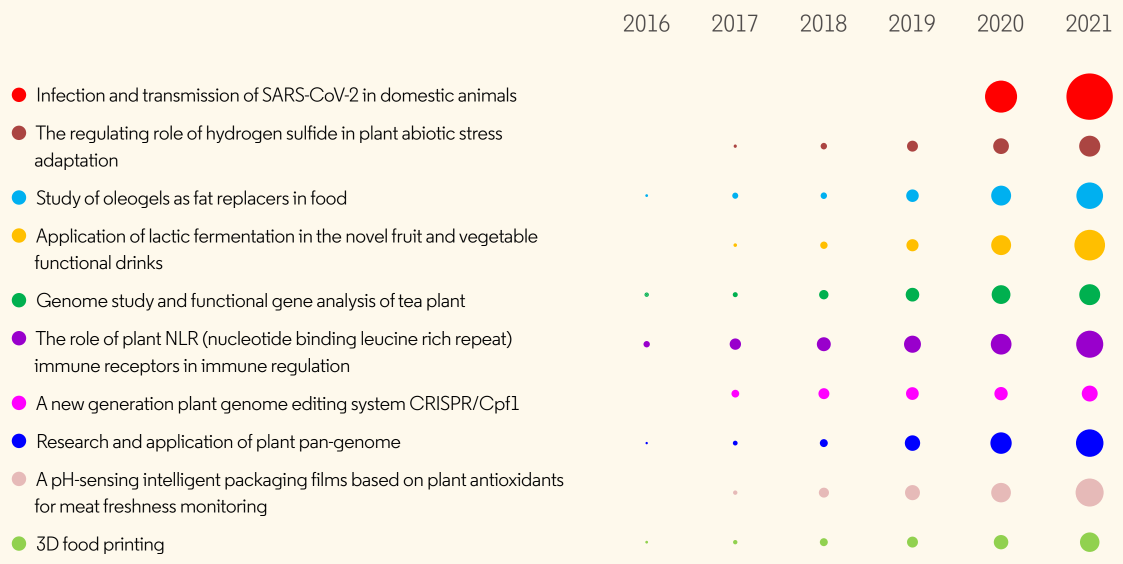


Figure 1: Citing papers for the Top 10 Research Fronts in agricultural, plant and animal sciences

1.2 KEY HOT RESEARCH FRONT – "Infection and transmission of SARS-CoV-2 in domestic animals"

Since its outbreak at the end of 2019, COVID-19 has spread rapidly around the world, exerting profound impact on human health, life, and socio-economic development. In a global effort to effectively control the disease, scientists worldwide have made great efforts. A large number of papers on SARS-CoV-2 have been published and widely cited. In the past two years, many research directions related to SARS-CoV-2, both in biology and clinical medicine, have figured among the top 10 hot Research Fronts. Research on COVID-19 in the field of agricultural, plant and animal sciences, on one hand, seeks to trace the natural host and intermediate host of COVID-19 to cut off the transmission chain; on the other hand, the imperative is to track the variation of virus strains to understand the pathogenesis of the virus. Researchers have done much work on the infection and transmission of COVID-19 to domestic animals – a concentration of activity that has propelled this research concentration into the Top 10 hot Research Fronts list for 2022.

Forty-one core papers underlie this hot Research Front, with nine having been published in prestigious international journals including *Science*, *Nature*, and *Cell*. These papers mainly report on the pathogenesis, virus detection and isolation, pathological characteristics and epidemic investigation of SARS-CoV-2 transmitted to domestic animals in various countries. Those nations include the Netherlands, France, Syria, Spain, Switzerland, the UK, the USA, Brazil, Croatia, and China. The domestic animals studied include cats, dogs, minks, ferrets, pigs, chickens, and hamsters, with cats and dogs commanding the most attention. Other papers in the core have also developed mouse infection models used for animal infection research.

Among the 41 core papers, the most frequently cited paper has now attracted more than 700 citations (Figure 2). The paper was published in *Science* in 2020 by researchers at the Harbin Veterinary Research Institute of the Chinese Academy of Agricultural Sciences and the National Institute for Viral Disease Control and Prevention of China, CDC. The paper explores the sensitivity of ferrets, cats, dogs, and other domestic animals to SARS-CoV-2.

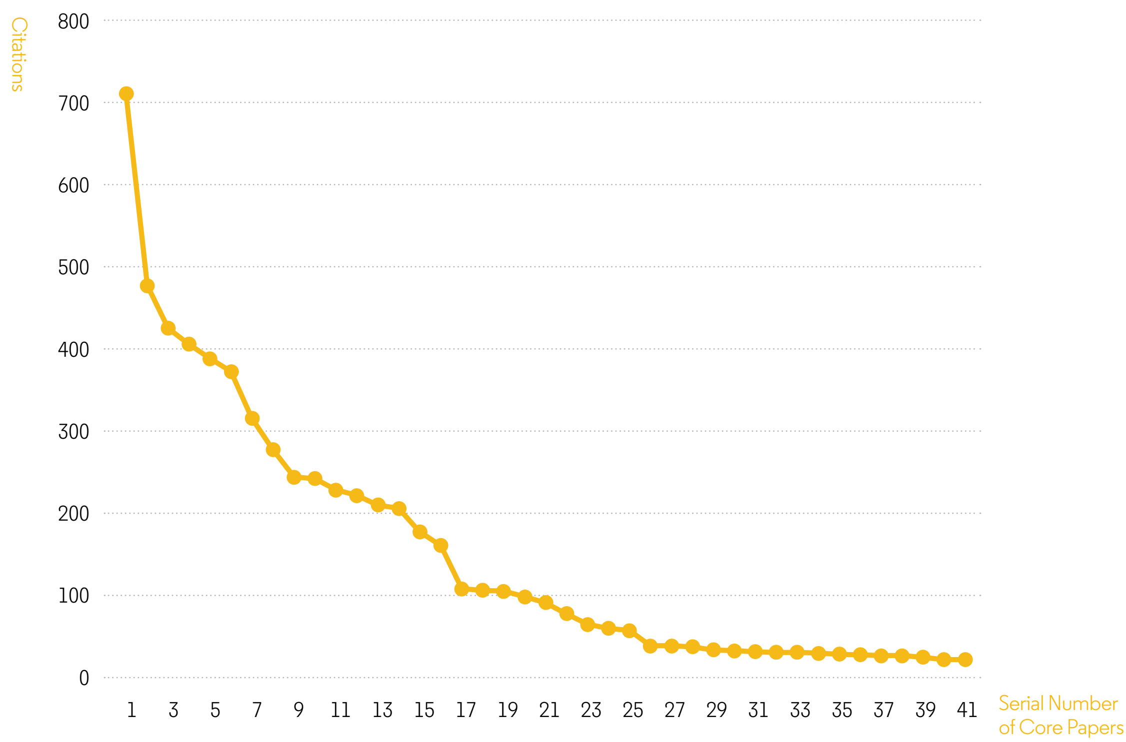


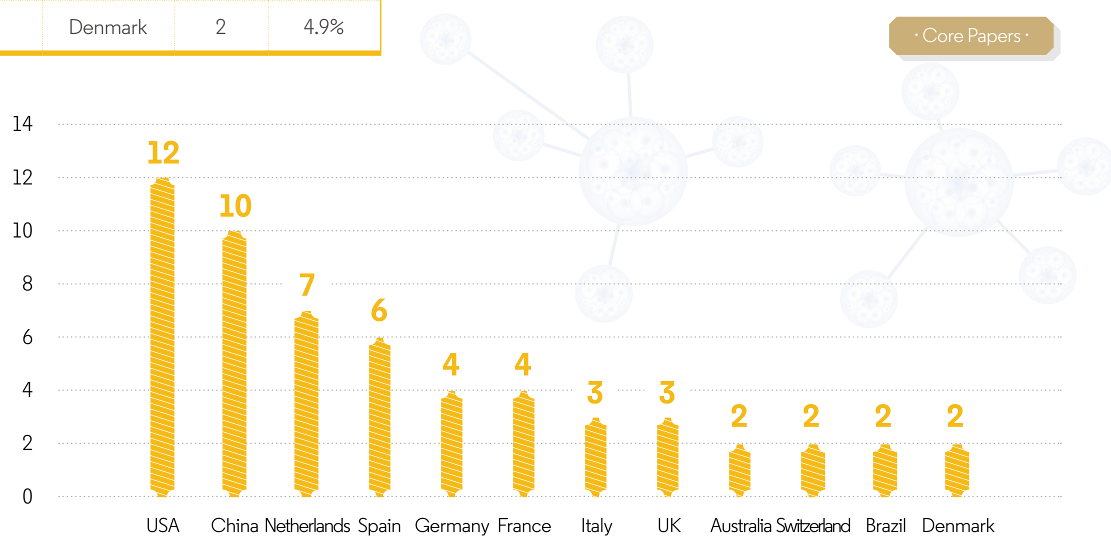
Figure 2: Citating frequency distribution curve of core papers in the Research Front "Infection and transmission of SARS-CoV-2 in domestic animals"

Among the top countries and institutions producing this front's core papers (Table 2), the USA has the highest contribution rate, with its 12 papers accounting for 29.3% of the total. China ①, with 10 papers ranks 2nd, accounting for 24.4% of the core literature. Netherlands ranks 3rd, with 17.1%. Among the prolific contributing institutions, both the University of Utrecht and Erasmus University Rotterdam in the Netherlands have performed strongly, ranking 1st and 2nd, with respective contribution rates of 14.6% and 12.2%. The Chinese Academy of Sciences ranks 3rd, having contributed to 9.8% of the core. By this measure, it is demonstrable that the USA, China, and the Netherlands have devoted a heightened level of attention to transmission research on SARS-CoV-2 in domestic animals.

Table 2: Top countries and institutions producing core papers in the Research Front "Infection and transmission of SARS-CoV-2 in domestic animals"

Country Ranking	Country	Core Papers	Proportion
1	USA	12	29.3%
2	China	10	24.4%
3	Netherlands	7	17.1%
4	Spain	6	14.6%
5	Germany	4	9.8%
5	France	4	9.8%
7	Italy	3	7.3%
7	UK	3	7.3%
9	Australia	2	4.9%
9	Switzerland	2	4.9%
9	Brazil	2	4.9%
9	Denmark	2	4.9%

Institution Ranking	Institution	Affiliated Country	Core papers	Proportion
1	Utrecht University	Netherlands	6	14.6%
2	Erasmus University Rotterdam	Netherlands	5	12.2%
3	Chinese Academy of Sciences	China	4	9.8%
4	Wageningen University & Research Center	Netherlands	3	7.3%
4	Institute Pasteur Paris	France	3	7.3%
4	GD Animal Health	Netherlands	3	7.3%
4	US Department Health and Human Services	USA	3	7.3%
4	University of Glasgow	UK	3	7.3%
4	University of Hong Kong	China	3	7.3%



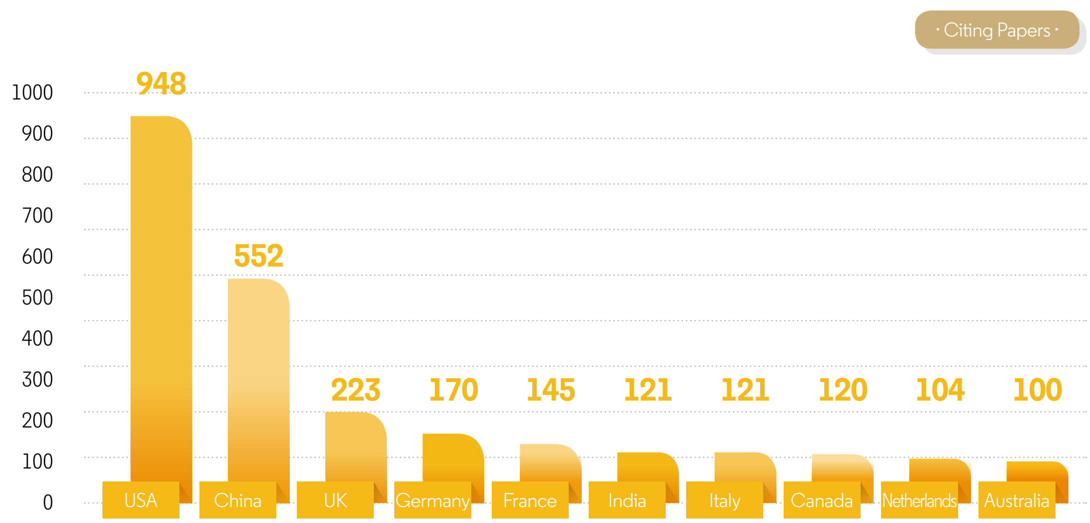
① In this report, China includes Mainland China, Hong Kong, and Macau, but not Taiwan.

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, accounting for 43.7% and 22.7% respectively. This is a clear indication that the USA and China continue to maintain robust research activity in this area. The UK, meanwhile, which ranks 7th in its output of core papers, ranks 3rd by the measure of citing papers. In terms of citing institutions, China-based institutions have actively pursued research in this area. The Chinese Academy of Sciences and the University of Hong Kong constitute the top two in their prolific follow-up research, contributing 5% and 3.9% of the citing papers. Meanwhile, the National Institutes of Health in the USA ranks 3rd.

Table 3: Top countries and institutions producing citing papers in the Research Front "Infection and transmission of SARS-CoV-2 in domestic animals"

Country Ranking	Country	Citing Papers	Proportion
1	USA	948	43.7%
2	China	552	22.7%
3	UK	223	12.2%
4	Germany	170	9.6%
5	France	145	7.4%
6	India	121	5.9%
6	Italy	121	4.7%
8	Canada	120	4.7%
9	Netherlands	104	4.3%
10	Australia	100	2.9%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	119	5.0%
2	University of Hong Kong	China	94	3.9%
3	National Institutes of Health (NIH) - USA	USA	82	3.4%
4	Harvard University	USA	80	3.4%
5	Chinese Academy of Medical Sciences - Peking Union Medical College	China	75	3.1%
6	National Institute of Health and Medical Research (INSERM)	France	62	2.6%
7	National Center for Scientific Research of France (CNRS)	France	58	2.4%
8	National Institute of Allergy and Infectious Diseases	USA	50	2.1%
9	Washington University in St. Louis	USA	46	1.9%
10	Icahn Sch Med Mount Sinai	USA	45	1.9%



1.3 KEY HOT RESEARCH FRONT – "Research and application of plant pan-genome"

Plant pan-genome research appeared in the Top 10 hot Research Fronts list in 2021. The concept of "pan-genome" was first proposed in the field of microbiomics in 2005 by Herve Tettelin and his colleagues, and was quickly applied to the field of animal and plant genomics, leading genome research into the new era of pan-genomics. The aim of pan-genome research is to collect all genome sequences existing in the whole species or population, then to understand the unique genetic traits and related genes of each individual. Therefore, pan-genome research is of great significance to fully tap biological genetic variation resources, identify regulatory genes for unique traits of strains, and cultivate the most promising agricultural animal and plant varieties. In recent years, new progress has been made in this Research Front. In 2018, 3,010 cultivated rice genomes were sequenced, and the first nearly complete pan genome of Asian cultivated rice was constructed by researchers based in China, together with scientists from 16 institutions worldwide. In 2020, an international team led by Canada drew the most complete wheat genome map in history by using 15 wheat varieties from around the world. In the same year, China-based scientists re-sequenced the genome of 2,898 soybean samples and completed the construction of plant pan genome based on graphical structure for the first time.

Of the 18 core papers in this hot Research Front this year, 14 papers appeared previously in the core (then comprising 16 papers) of the comparable hot front last year, mainly studying the pan-genome of tomato, rice, sunflower and other crops, and the functional gene mining based on pan-genome research. The other two different core papers in last year's front investigated the whole-genome sequencing of rapeseed germplasm resources and the genetic basis of their ecotype differences, as well as the assembly and comparison of the genomes of two closely related species of *Brassica napus*, focusing more on the research of sequencing and assembly methods. This year, the four new papers mainly examine how the pan-genome has gradually changed crop genomics; how super pan-genome is accelerating crop improvement by integrating the wild side of a species; and, the population genetics of structural variants in grapevine domestication; highlighting the application of pan-genome in another instance of crop improvement.

Among the 18 core papers this year, the most-cited paper is the same as last year, now cited more than 440 times (Figure 3), far ahead of other papers, and nearly twice as many as last year's count of 252. This paper was published jointly in *Nature* in 2018 by researchers at the Chinese Academy of Agricultural Sciences, the International Rice Research Institute, Shanghai Jiaotong University, Shenzhen BGI, the University of Arizona, and other institutions. The paper details the genetic variation, population structure and diversity among 3,010 diverse Asian-cultivated rice genomes.

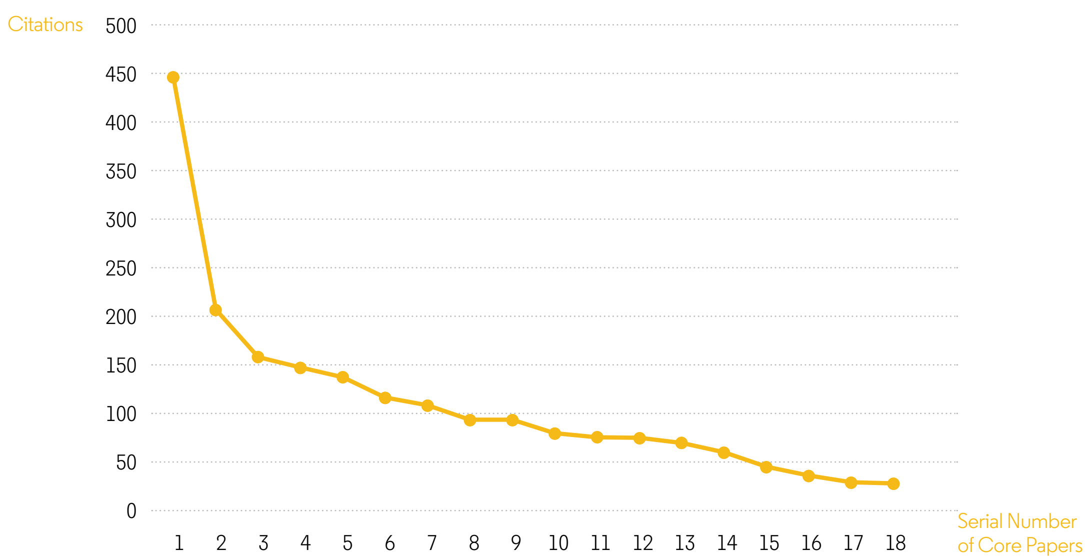


Figure 3: Citating frequency distribution curve of core papers in the Research Front "Research and application of plant pan-genome"

Among the countries and institutions producing core papers (Table 4), Australia can boast the highest contribution rate, surpassing 50%, followed by the USA with about 44%. China ranks 3rd, accounting for half of Australia's contribution. Among the top contributing institutions, the University of Western Australia, the University of Queensland, and the University of Melbourne in Australia rank in the top three in turn, with respective contribution rates of 44.4%, 22.2%, and 22.2%. In particular, the University of Western Australia performs outstandingly, contributing eight of the 10 core papers published by Australia-based authors. Meanwhile, the University of Georgia, the Chinese Academy of Agricultural Sciences, the Chinese Academy of Sciences, and the National Research Institute for Agriculture, Food and Environment (France) are tied for 4th place with 16.7% of global contribution to the core literature.

Table 4: Top countries and institutions producing core papers in the Research Front "Research and application of plant pan-genome"

Country Ranking	Country	Core Papers	Proportion
1	Australia	10	55.6%
2	USA	8	44.4%
3	China	5	27.8%
4	France	4	22.2%
5	Israel	3	16.7%
6	Germany	2	11.1%
6	Canada	2	11.1%
8	Switzerland	1	5.6%
8	India	1	5.6%
8	South Africa	1	5.6%
8	Philippines	1	5.6%
8	Spain	1	5.6%
8	Czech Republic	1	5.6%
8	Republic of Georgia	1	5.6%

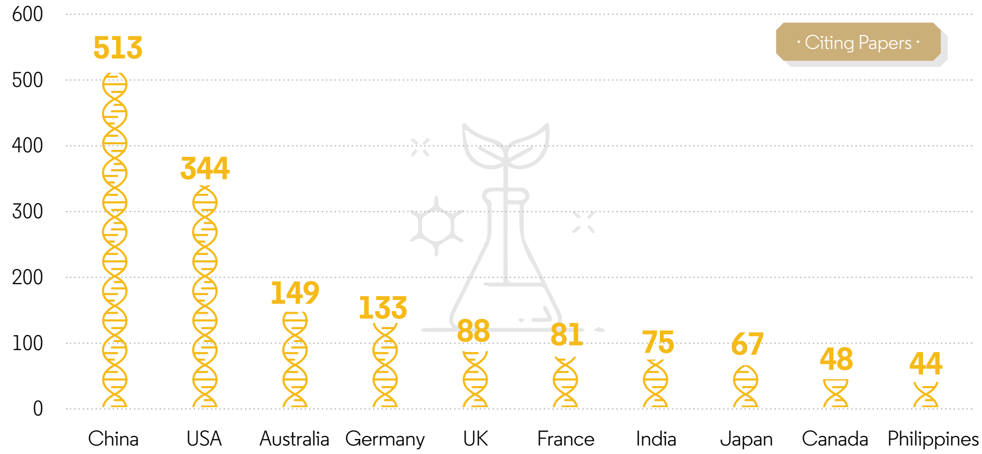
Institution Ranking	Institution	Affiliated Countries	Core Papers	Proportion
1	University of Western Australia	Australia	8	44.4%
2	University of Queensland	Australia	4	22.2%
2	University of Melbourne	Australia	4	22.2%
4	University of Georgia	USA	3	16.7%
4	Chinese Academy of Agricultural Sciences	China	3	16.7%
4	Chinese Academy of Sciences	China	3	16.7%
4	National Research Institute for Agriculture, Food and Environment	France	3	16.7%
8	University of Paris Saclay	France	2	11.1%
8	University of Florida	USA	2	11.1%
8	Cold Spring Harbor Laboratory	USA	2	11.1%
8	Shanghai Normal University	China	2	11.1%
8	Cornell University	USA	2	11.1%
8	National Center for Scientific Research of France (CNRS)	France	2	11.1%

In terms of countries and institutions that cite the core papers of this hot front (Table 5), China has become the top contributor, accounting for 44.3%. The USA ranks 2nd, matching its ranking in core papers, accounting for 29.7%. Australia, which ranks 1st in the number of core papers, ranks 3rd with 12.9% of citing papers. China, the USA, and Australia all rank in the top three countries in both terms of core papers and citing papers. The top three citing institutions, in turn are the Chinese Academy of Agricultural Sciences, the Chinese Academy of Sciences, and Huazhong Agricultural University.

Table 5: Top countries and institutions producing citing papers in the Research Front "Research and application of plant pan-genome"

Country Ranking	Country	Citing Papers	Proportion
1	China	513	44.3%
2	USA	344	29.7%
3	Australia	149	12.9%
4	Germany	133	11.5%
5	UK	88	7.6%
6	France	81	7.0%
7	India	75	6.5%
8	Japan	67	5.8%
9	Canada	48	4.1%
10	Philippines	44	3.8%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Agricultural Sciences	China	153	13.2%
2	Chinese Academy of Sciences	China	114	9.8%
3	Huazhong Agricultural University	China	101	8.7%
4	University of Western Australia	Australia	65	5.6%
5	National Research Institute for Agriculture, Food and Environment	France	57	4.9%
5	United States Department of Agriculture (USDA)	USA	57	4.9%
7	International Rice Research Institute - Philippines	Philippines	44	3.8%
8	National Center for Scientific Research of France (CNRS)	France	39	3.4%
9	China Agricultural University	China	37	3.2%
9	Cornell University	USA	37	3.2%
9	Max Planck Society	Germany	37	3.2%



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, two emerging Research Fronts have been identified: "The COVID-19 impacts on agriculture and food system" and "The mechanism and methods of alleviating arsenic poisoning in crops" (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	The COVID-19 impacts on agriculture and food system	17	486	2020.6
2	The mechanism and methods of alleviating arsenic poisoning in crops	7	191	2020.6

2.2 KEY EMERGING RESEARCH FRONT – "The mechanism and methods of alleviating arsenic poisoning in crops"

Arsenic (As) is a toxic metalloid, which can adversely affect plant growth and poses a serious threat to human health. It interferes with many physiological and metabolic pathways, such as the imbalance of nutrient, water and redox; abnormal photosynthesis and ATP synthesis; and loss of membrane integrity. In recent years, the accumulation of arsenic in soil has been increasing, resulting in the higher toxicity of arsenic in various crops.

Therefore, it is urgent to study the regulation mechanism of arsenic stress tolerance in crops and to introduce some novel modifiers to improve the tolerance. This area has become a new Research Front in the field of agricultural science.

The seven core papers in this emerging Research Front focus on the regulation mechanism of the enhancement of arsenic stress tolerance of crops and the use of modifiers to alleviate the toxicity of arsenic to crops. The main research contents of arsenic tolerance regulation mechanism include: the study of how salicylic acid-induced nitric oxide enhances arsenic toxicity tolerance in maize plants by upregulating the ascorbate-glutathione cycle and glyoxalase system; and how melatonin-mediated regulation of anthocyanin biosynthesis and antioxidant defense confer tolerance to arsenic stress in tea plants. In terms of using modifiers to reduce arsenic toxicity, the roles of Zinc Oxide nanoparticles, TiO_2 nanoparticles, melatonin, and calcium are chiefly studied as modifiers in reducing arsenic toxicity in soybean and rice.

2022 RESEARCH FRONTS

ECOLOGY AND ENVIRONMENTAL SCIENCES

2022 RESEARCH FRONTS

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, as the name implies, are mainly distributed in two sub-areas: ecological sciences and environmental sciences. Throughout the Top 10 hot Research Fronts, the predominant themes involve global ecological and environmental challenges, as well as environmental issues related to COVID-19.

The Hot Research Fronts in the environmental-science subfield mainly focus on COVID-19-related research, along with the environmental character, risk, and control of organic pollutants, microplastic and heavy metals. In the wake of COVID-19's global spread from 2020, four hot fronts focus on the scientific questions about COVID-19 and environmental issues. These fronts are "Environmental consequences and management of solid waste and medical waste caused by COVID-19", "Detection of SARS-CoV-2 in wastewater and COVID-19 epidemiological surveillance based on wastewater", "Impact of the lockdown on air quality during the COVID-19 pandemic", and "Impact of weather and ambient factors on the COVID-19 pandemic". Among these specialty areas, "Impact of the lockdown on air quality during the COVID-19 pandemic" was listed in last year's survey as one of the Top 10 hot Research Fronts of 2021. Meanwhile, "Impact of weather and ambient factors on the COVID-19 pandemic" was listed in Emerging Research Fronts of 2021.

The hot Research Fronts related to the environmental character, risk, and control of organic pollutants include "Degradation of organic pollutants by persulfate activation with catalyst", "Ecological and environmental risks of interaction and combination between microplastics and microorganisms in aquatic environment", and "Spatial distribution, source identification and health risk assessment of heavy metals in soils". The problem of microplastics is also a significant presence in the hot Research Front "Environmental consequences and management of solid waste and medical waste caused by COVID-19". Research on these pollutants has been central to hot fronts in environmental sciences for years. For example, microplastics-related research was selected among the Top 10 hot Research Fronts of 2015, 2016, 2017, 2020, and 2021, while degradation of organic pollutants by persulfate-related studies emerged in the 2017 and 2018 surveys, and heavy-metals-related studies emerged in the 2016 survey.

The three hot Research Fronts in the ecological science subfield mainly emphasize biodiversity, forest habitat, and soil ecology, as examined in "The trend, extinctions, and drivers of insect declines", "Global patterns of forest habitat fragmentation and the impact on biodiversity", and "Formation mechanisms of humus and the role of microorganisms during composting with different materials". Biodiversity-related research has been a hot topic for multiple years, and "The trend, extinctions, and drivers of insect declines" has been listed as a hot front for the second consecutive year.

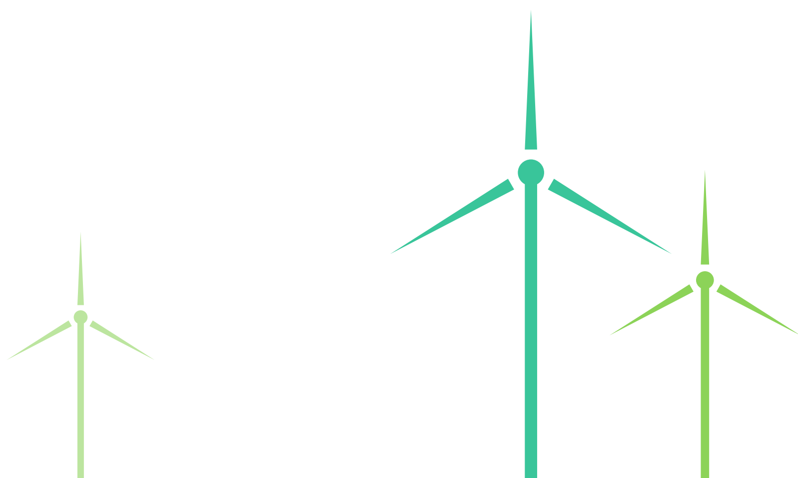


Table 7: Top 10 Research Fronts in ecology and environmental sciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Environmental consequences and management of solid waste and medical waste caused by COVID-19	40	1970	2020.7
2	Detection of SARS-CoV-2 in wastewater and COVID-19 epidemiological surveillance based on wastewater	16	2798	2020.1
3	Impact of the lockdown on air quality during the COVID-19 pandemic	18	3631	2020
4	Impact of weather and ambient factors on the COVID-19 pandemic	19	2638	2020
5	Degradation of organic pollutants by persulfate activation with catalyst	17	1420	2020
6	The trend, extinctions, and drivers of insect declines	18	3435	2019.7
7	Formation mechanisms of humus and the role of microorganisms during composting with different materials	22	2186	2018.8
8	Ecological and environmental risks of interaction and combination between microplastics and microorganisms in aquatic environment	16	1849	2018.8
9	Global patterns of forest habitat fragmentation and the impact on biodiversity	10	1419	2018.8
10	Spatial distribution, source identification and health risk assessment of heavy metals in soils	38	4518	2018.7

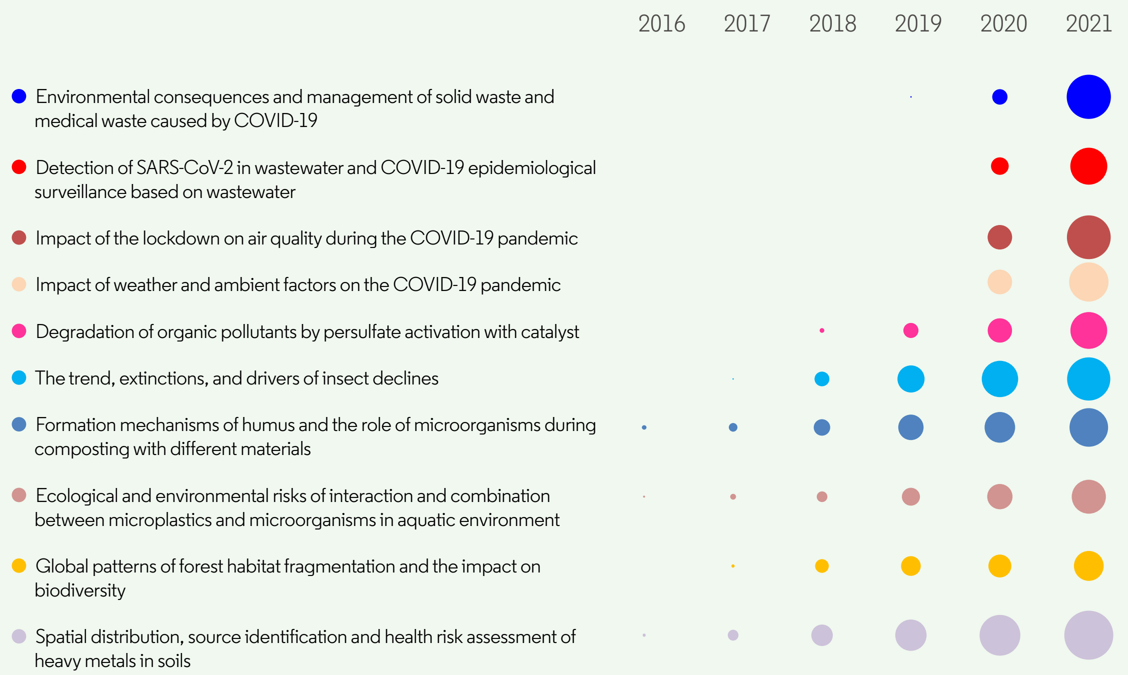


Figure 4: Citing papers for the Top 10 Research Fronts in ecology and environmental sciences

1.2 KEY HOT RESEARCH FRONT – "Environmental consequences and management of solid waste and medical waste caused by COVID-19"

In addition to COVID-19's immediate effects on public health, the global emergency provoked by the pandemic has also raised social and economic concerns that have spilled over into environmental issues. In response to COVID-19, the use of Personal protective appliances and medical supplies in hospitals surged greatly. It is estimated that 129 billion face masks and 65 billion gloves are used globally each month. The explosive growth of medical wastes and solid wastes is resulting in widespread environmental contamination and negative impacts on environmental and human health. The main components of personal protective equipment are plastics, on which SARS-CoV-2 can survive for up to three days. These medical wastes and their residual pathogens pose a risk of disease transmission and threaten public health.

People are increasingly opting for single-use plastic medical products rather than reusing them, due to concerns that plastic can serve as a vector for disease. As a result, the outbreak has also made the implementation of single-use-plastic bans difficult, which has directly led to a significant increase in the risk of plastic pollution. Relevant research has prompted deep concerns from environmental researchers since the outbreak of the epidemic in 2020.

Forty core papers identify this Research Front, covering two themes. The first theme centers on ecological and environmental risks to land and marine environments, as well as the management challenges arising from personal protective equipment. The front focuses on the global environmental proliferation of personal protective equipment as a new source of microplastics pollution and its impact and challenges on waste management. One of the most frequently cited core papers in this front specified and emphasized the environmental consequences related to plastic use and follow-up waste owing to COVID-19, proposed the concept of Plastic Waste Footprint (PWF), and discussed the emerging challenges in waste management during and after the COVID-19 pandemic from the perspective of research and environmental policies. This article comes from Brno University of Technology, Czech Republic, and its collaborating institutions and was published by J.J. Klemes and colleagues in *Renewable & Sustainable Energy Reviews* in 2020. The article has now been cited nearly 200 times.

The second theme is pollution-control technology, harmless disposal measures, and management measures for personal protective equipment produced during the COVID-19 pandemic. This area focuses on new strategic and policy-based solutions for balancing public health, environmental security, and industrial and supply-chain requirements. Multinational researchers from the University of Aveiro in Portugal and other institutions published a highly cited paper in the *Chemical Engineering Journal* in 2021. The paper discussed the potential strategies to overcome the challenge of plastic pollution associated with COVID-19, and emphasized that future measures should balance public health and environmental safety and turn to sustainable plastic alternatives. The authors urged that the issue of plastic pollution be placed at top the global and regional political agenda, given the need for prompt, coordinated action by the scientific community, industry, and politicians.

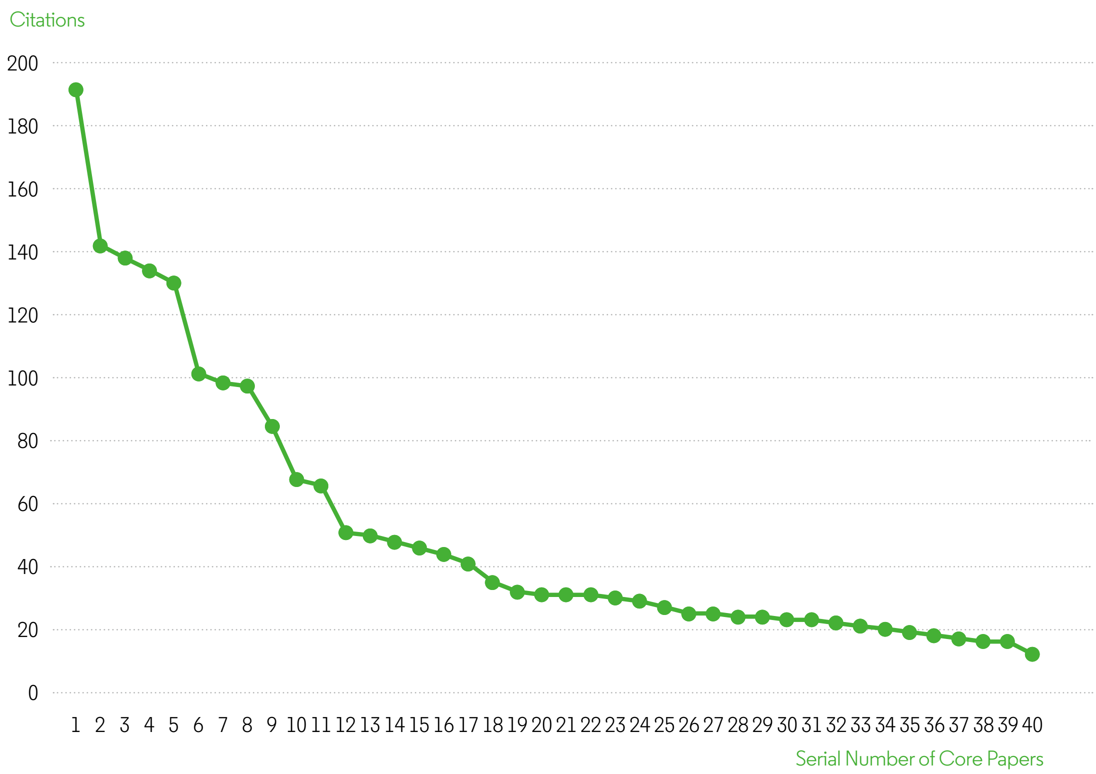


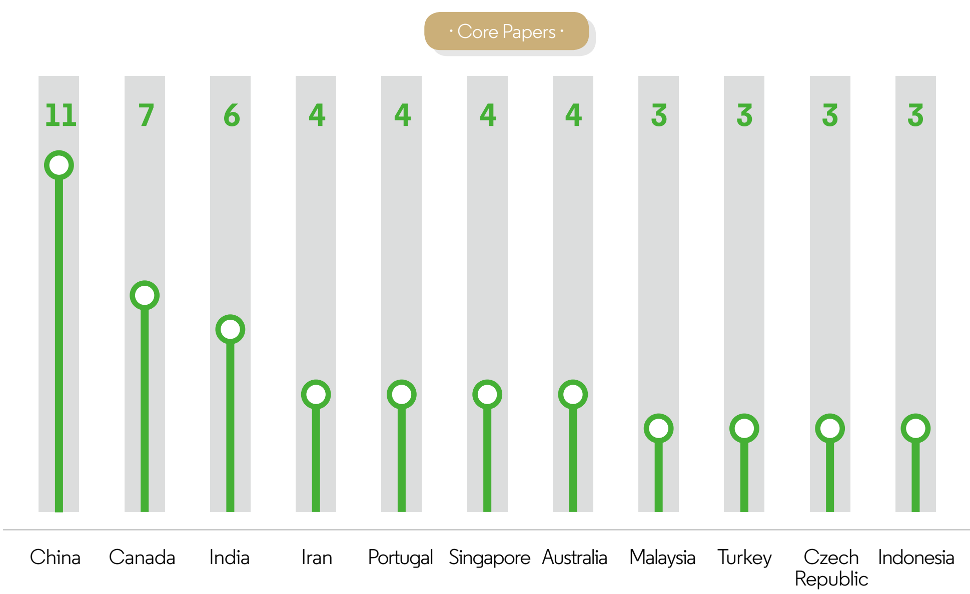
Figure 5: Citation frequency distribution curve of core papers in the Research Front "Environmental consequences and management of solid waste and medical waste caused by COVID-19"

According to the statistics on the top countries and institutions in this front (Table 8), China, Canada and India are the three countries with the most core papers. China has 11 core papers, exceeding a quarter of the total. In terms of the most prolific institutions: five schools or agencies -- Dalhousie University in Canada, the University of Aveiro in Portugal, the Agency for Science, Technology and Research in Singapore, the Institute of High Performance Computing in Singapore, and Brno University of Technology in the Czech Republic -- all contributed three foundational papers.

Table 8: Top countries and institutions producing core papers in the Research Front "Environmental consequences and management of solid waste and medical waste caused by COVID-19"

Country Ranking	Country	Core Papers	Proportion
1	China	11	27.5%
2	Canada	7	17.5%
3	India	6	15.0%
4	Iran	4	10.0%
4	Portugal	4	10.0%
4	Singapore	4	10.0%
4	Australia	4	10.0%
8	Malaysia	3	7.5%
8	Turkey	3	7.5%
8	Czech Republic	3	7.5%
8	Indonesia	3	7.5%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Dalhousie University	Canada	3	7.5%
1	University of Aveiro	Portugal	3	7.5%
1	Agency for Science, Technology and Research (A*STAR)	Singapore	3	7.5%
1	Inst High Performance Comp (IHPC)	Singapore	3	7.5%
1	Brno University of Technology	Czech Republic	3	7.5%
6	Middle East Technical University	Turkey	2	5.0%
6	Chulalongkorn University	Thailand	2	5.0%
6	Istinye University	Turkey	2	5.0%
6	Instituto de Diagnostico Ambientaly Estudios del Agua (IDAEA)	Spain	2	5.0%
6	University of San Ignacio Loyola	Peru	2	5.0%
6	Institut Catala de Recerca de l'Aigua (ICRA)	Spain	2	5.0%
6	Indian Institute of Technology (IIT)	India	2	5.0%
6	University of Girona	Spain	2	5.0%
6	Memorial University of Newfoundland	Canada	2	5.0%
6	Spanish National Research Council (CSIC)	Spain	2	5.0%
6	Poznan University of Technology	Poland	2	5.0%

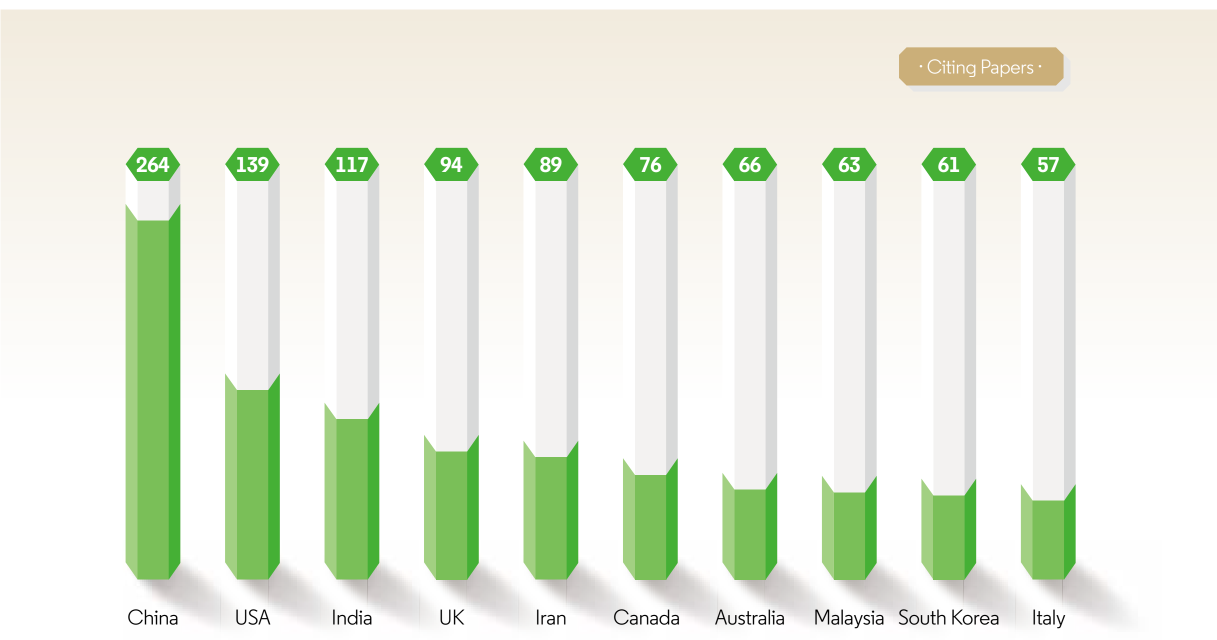


In terms of the countries and institutions citing the core papers (Table 9), China is still the largest national source of citing papers in this field, with 264 articles in total, accounting for nearly a quarter. The USA and India rank 2nd and 3rd with 139 and 117 citing papers respectively, accounting for more than 10%. The main institutional sources of citing papers include Brno University of Technology in the Czech Republic, the Chinese Academy of Sciences, the Indian Institute of Technology, and Islamic Azad University Karaj in Iran. The Chinese Academy of Sciences ranks 2nd with 24 citing papers.

Table 9: Top countries and institutions producing citing papers in the Research Front "Environmental consequences and management of solid waste and medical waste caused by COVID-19"

Country Ranking	Country	Citing Papers	Proportion
1	China	264	24.1%
2	USA	139	12.7%
3	India	117	10.7%
4	UK	94	8.6%
5	Iran	89	8.1%
6	Canada	76	6.9%
7	Australia	66	6.0%
8	Malaysia	63	5.7%
9	South Korea	61	5.6%
10	Italy	57	5.2%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Brno University of Technology	Czech Republic	28	2.6%
2	Chinese Academy of Sciences	China	24	2.2%
3	Indian Institute of Technology (IIT)	India	23	2.1%
3	Islamic Azad University Karaj	Iran	23	2.1%
5	Egyptian Knowledge Bank	Egypt	18	1.6%
5	National University of Singapore	Singapore	18	1.6%
7	Agency for Science, Technology and Research (A*STAR)	Singapore	16	1.5%
7	Dalhousie University	Canada	16	1.5%
7	University of Tehran	Iran	16	1.5%
10	National Center for Scientific Research of France (CNRS)	France	15	1.4%
10	Tsinghua University	China	15	1.4%



1.3 KEY HOT RESEARCH FRONT – "Detection of SARS-CoV-2 in wastewater and COVID-19 epidemiological surveillance based on wastewater"

Currently available evidence demonstrates that viral RNA has been present in raw wastewater in communities during the COVID-19 pandemic. On one hand, evidence suggests that wastewater might be one possible route for exposure and infection of SARS-CoV-2, which has aroused concern about the spread of the virus in untreated wastewater in communities. On the other hand, the SARS-CoV-2 detected in the wastewater also reflects the existence of virus in the community. The data can be used to monitor the prevalence of infection. Wastewater-based monitoring of the spread of the SARS-CoV-2, also referred to as wastewater-based epidemiology (WBE), has been suggested as a tool to augment other epidemiological measures. Sixteen core papers anchor this Research Front, largely focusing on three aspects: (1) Content in media, environmental characteristics, and monitoring methods of SARS-CoV-2 in wastewater; (2) The exposure pathways of SARS-CoV-2 in wastewater, the impact on virus transmission, and the assessment of ecological risk and health risk; (3) Epidemiological surveillance and early warning through the detection of SARS-CoV-2 in wastewater before the situation becomes a large-scale outbreak.

The most-cited core paper comes from the Commonwealth Scientific & Industrial Research Organisation in Australia and other institutions. The authors estimated viral RNA copy numbers observed in the wastewater and then calculate the number of infected individuals in the catchment via Monte Carlo simulation, which is in reasonable agreement with clinical observations. The paper was published in *Science of the Total Environment* in 2020, and its citation total currently reach to 441.

In another 2020 publication, researchers from KWR Water Research Institute, Netherlands, found that the RNA signal detected in wastewater correlated significantly with the increase of reported COVID-19 prevalence. The article was published in *Environmental Science & Technology Letters*, and has achieved the second-highest citation in this Research Front, exceeding 350. These works highlight the viability of wastewater-based epidemiology for monitoring infectious diseases, such as COVID-19, in communities.

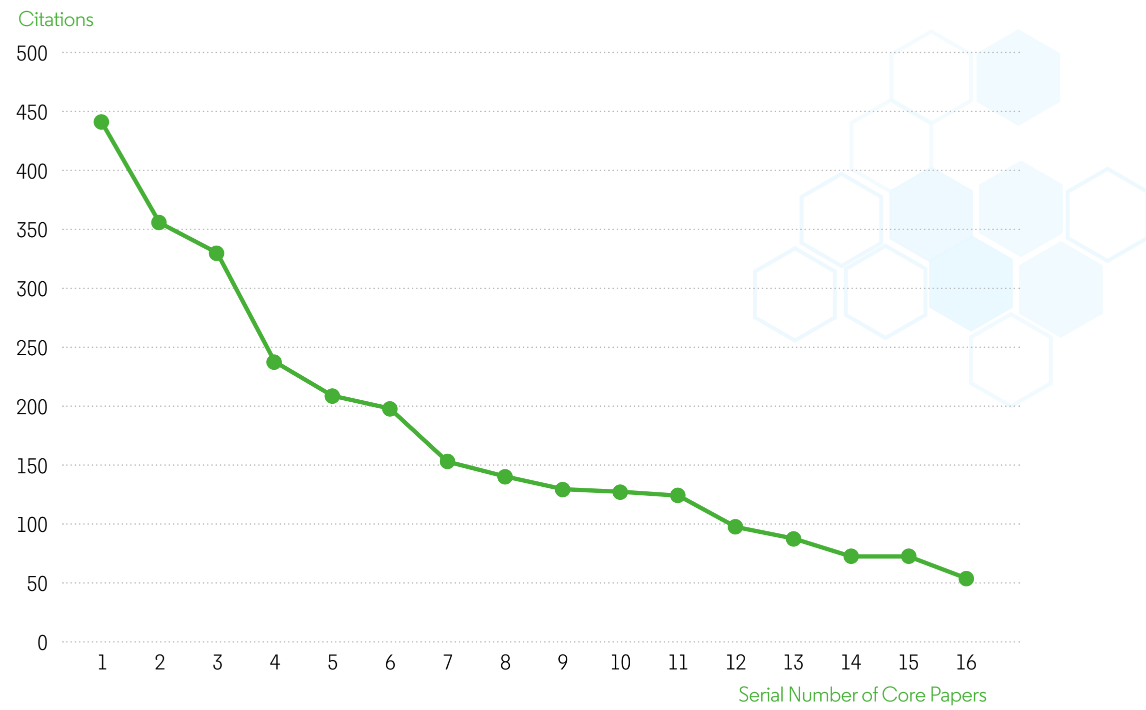


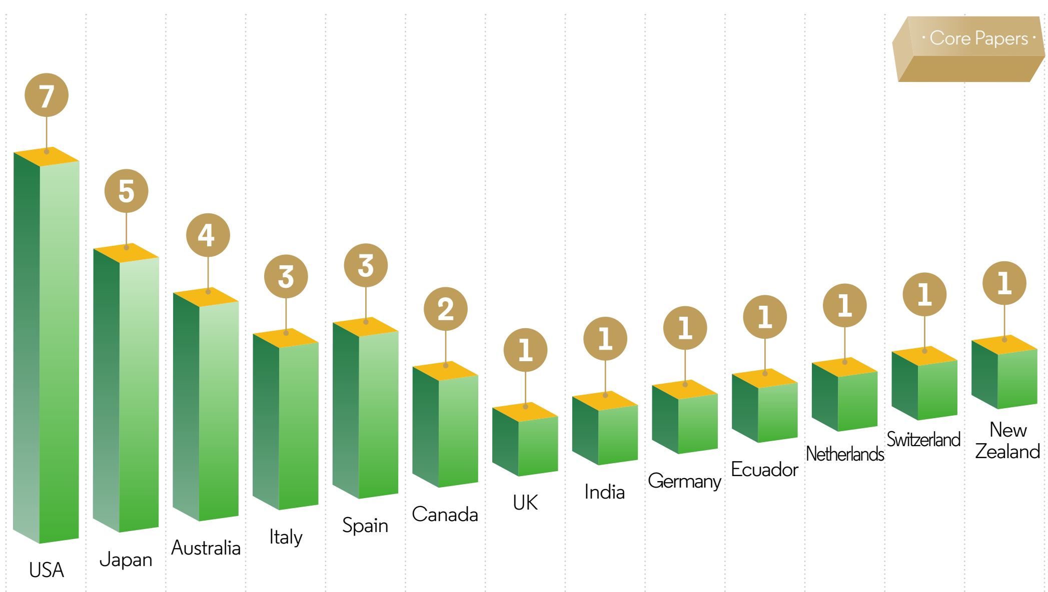
Figure 6: Citation frequency distribution curve of core papers in Research Front "Detection of SARS-CoV-2 in wastewater and COVID-19 epidemiological surveillance based on wastewater"

Statistics on the countries and institutions in this front (Table 10) indicates that the USA, Japan, and a selection of European countries and institutions are the most prolific by this measure. Seven of the core papers list contributing authors based in the USA, accounting for 43.8% of the total core of 16 papers. Japan and Australia account for five and four core papers, earning the two nations 2nd and 3rd places, respectively. Hokkaido University in Japan is the most prolific institution with 5 core papers. Commonwealth Scientific & Industrial Research Organization in Australia, University of Yamanashi in Japan, and University of Notre Dame in USA tie for 2nd with four core papers respectively.

Table 10: Top countries and institutions producing core papers in the Research Front "Detection of SARS-CoV-2 in wastewater and COVID-19 epidemiological surveillance based on wastewater"

Country Ranking	Country	Core Papers	Proportion
1	USA	7	43.8%
2	Japan	5	31.3%
3	Australia	4	25.0%
4	Italy	3	18.8%
4	Spain	3	18.8%
6	Canada	2	12.5%
7	UK	1	6.3%
7	India	1	6.3%
7	Germany	1	6.3%
7	Ecuador	1	6.3%
7	Netherlands	1	6.3%
7	Switzerland	1	6.3%
7	New Zealand	1	6.3%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Hokkaido University	Japan	5	31.3%
2	Commonwealth Scientific & Industrial Research Organisation (CSIRO)	Australia	4	25.0%
2	University of Yamanashi	Japan	4	25.0%
2	University of Notre Dame	USA	4	25.0%
5	Spanish National Research Council (CSIC)	Spain	2	12.5%
5	Ecoscience Precinct	Australia	2	12.5%
5	University of Valencia	Spain	2	12.5%
5	University of Queensland	Australia	2	12.5%

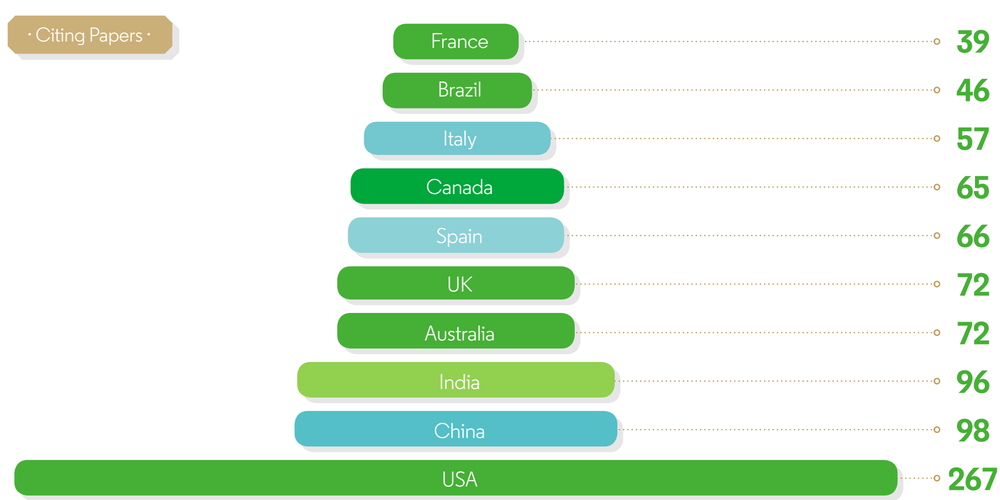


By the measure of citing papers (Table 11), the USA is still the most prolific source of research that cites the core literature of this front, with 267 citing papers contributing about one-third of the total citing papers. China ranks 2nd with 98 citing papers and India ranks 3rd, with 96. In terms of institutions, the Indian Institute of Technology published 36 citing papers, accounting for 4.3% of the total. The University of Notre Dame in the USA ranks 2nd with 27 citing papers (3.2%), and the National Center for Scientific Research of France and Spanish National Research Council tie for 3rd with 22 citing papers (2.6%) respectively. The Chinese Academy of Sciences ranks 6th with 20 citing papers.

Table 11: Top countries and institutions producing citing papers in the Research Front "Detection of SARS-CoV-2 in wastewater and COVID-19 epidemiological surveillance based on wastewater"

Country Ranking	Country	Citing Papers	Proportion
1	USA	267	32.0%
2	China	98	11.7%
3	India	96	11.5%
4	Australia	72	8.6%
5	UK	72	8.6%
6	Spain	66	7.9%
7	Canada	65	7.8%
8	Italy	57	6.8%
9	Brazil	46	5.5%
10	France	39	4.7%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Indian Institute of Technology (IIT)	India	36	4.3%
2	University of Notre Dame	USA	27	3.2%
3	National Center for Scientific Research of France (CNRS)	France	22	2.6%
3	Spanish National Research Council (CSIC)	Spain	22	2.6%
5	University of North Carolina	USA	21	2.5%
6	Chinese Academy of Sciences	China	20	2.4%
7	Commonwealth Scientific & Industrial Research Organisation (CSIRO)	Australia	19	2.3%
8	Stanford University	USA	18	2.2%
8	University of Queensland	Australia	18	2.2%
10	Hokkaido University	Japan	16	1.9%
10	Tulane University	USA	16	1.9%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ECOLOGY AND ENVIRONMENTAL SCIENCES

The area of ecology and environmental sciences features two emerging Research Fronts: "Impacts of social factors such as economy, policy, energy, and globalization on environmental sustainability" and "The impact of the 2019/2020 megafires on Australian forest ecosystem and the climate change and variability drivers".

Table 12: Emerging Research Fronts in ecology and environmental sciences

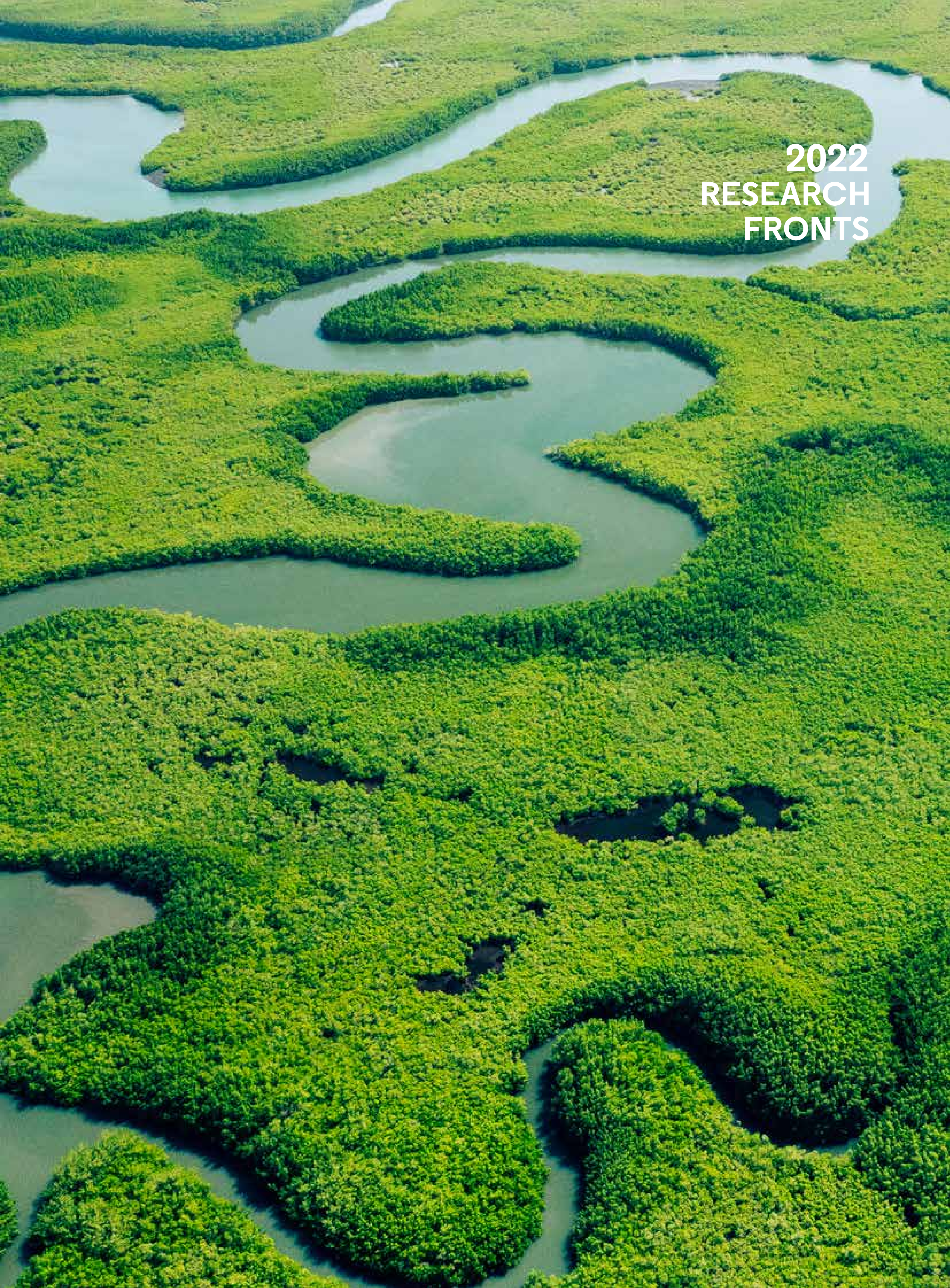
Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Impacts of social factors such as economy, policy, energy, and globalization on environmental sustainability	39	1181	2020.9
2	The impact of the 2019/2020 megafires on Australian forest ecosystem and the climate related drivers	6	173	2020.8

2.2 KEY EMERGING RESARCH FRONT – "The impact of the 2019/2020 megafires on Australian forest ecosystem and the climate related drivers"

The megafires in Australia, which started at the end of 2019 and lasted until the beginning of 2020, constitute one of the most serious forest fires ever recorded. The fire spread to large areas of the continent, burning 115,000 square kilometers of forest, and destroying more than 3,500 houses. Nearly 3 billion animals died or lost their habitat in this fire.

The research in this emerging front focuses on two topics. Firstly, the main research emphasis is to assess quantitatively the destructive impact of the 2019-2020 megafires on the Australian forest ecosystem, habitat and diversity of animals and plants, and to assess the effects of fire on the recovery potential of populations. The study calls for strengthening the research on species fire response and post-fire population persistence.

The second prominent research topic is the relationship between climate change and the mega forest fires in Australia. The year 2019 was the hottest and driest on record in Australia. Persistent drought and record temperatures are the main driving forces for fire spread. The data on long-term observations of heat and drought, along with climate models, show that, due to the long-term warming trend, heat extremes have become more likely by at least a factor of 2, increasing the risk of extreme fire caused by weather. The megafires in Australia warns people that continuous drought and climate change may lead to forest fires lasting longer and occurring more frequently, becoming a new normal in the future. The need is urgent for humanity to control carbon dioxide emissions, prevent catastrophic global warming, and reduce extreme weather events.



2022 RESEARCH FRONTS

GEOSCIENCES

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN GEOSCIENCES

Six of the Top 10 Research Fronts in geosciences focus on geology, while three pertain to geography and one concerns atmospheric science. Radiocarbon dating technology has been highlighted for the first time in this annual survey, underscoring significant progress in geoscience research and testing technology. The topics related to the in-situ detection and sampling return analysis of extraterrestrial objects by spacecraft have been selected as hot Research Fronts for six consecutive years since 2017, reflecting the continuous research attention and enthusiasm of the academic community for planetary science. It is worth noting that, based on 2022 data, asteroids have replaced Mars as the most actively researched objects.

Climate change related research from the perspective of earth-system science continues to heat up. Climate sensitivity assessment based on multiple earth-system models, and research on the impact of ice loss in Antarctica and Greenland on sea level change, have been selected as hot frontiers for several years. Research on the spatiotemporal distribution and tectonic settings of the North China Craton gold deposits, research progress on gas hydrate accumulation and mining technology have also been on the list for many years, confirming that geosciences research has made profound contributions to our understanding and utilization of the Earth.

Table 13: Top 10 Research Fronts in geosciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Radiocarbon age calibration curves, data sets, and applications	10	1742	2019.3
2	Analysis of asteroid surface characteristics and composition	12	1378	2019.3
3	Climate sensitivity based on various Earth system models	42	6337	2019.1
4	Research on Archean Earth geological changes and plate tectonics	13	1239	2019
5	Gold deposits of the north China craton: spatiotemporal distribution and tectonic settings	14	1257	2018.8
6	Contribution of Antarctic and Greenland ice-volume loss to sea-level change	32	4562	2018.7
7	Optimization of seismic data analysis using machine learning methods	35	3256	2018.7
8	Research progress on gas hydrate accumulation and mining technology	23	2616	2018.7
9	Hydrological response to the glacier mass change in high Asia	18	2612	2018.7
10	Effects of permafrost thaw in the Northern Hemisphere on tundra hydrology and carbon storage	15	1972	2018.5

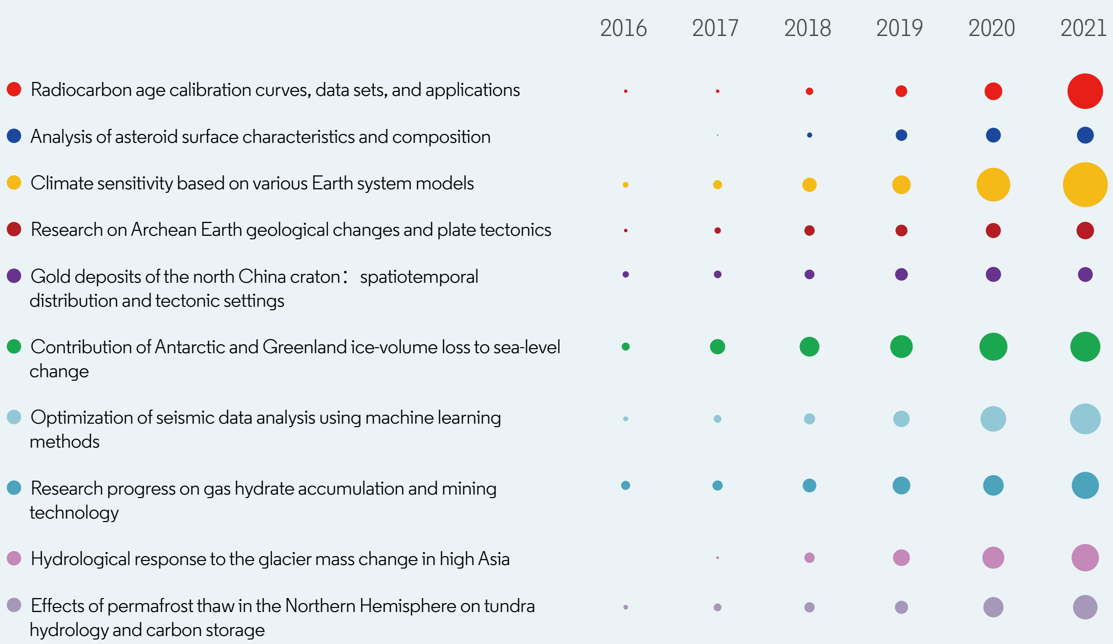


Figure 7: Citing papers for the Top 10 Research Fronts in geosciences

1.2 KEY HOT RESEARCH FRONT – "Radiocarbon age calibration curves, data sets, and applications"

Radiocarbon dating, also known as Carbon-14 dating, is a radioactive decay-based method using natural Carbon-14 isotopes for determining the age of organic remains. Willard Frank Libby, who won the Nobel Prize in Chemistry in 1960, invented the method. For more than half a century, as a powerful and reliable scientific research method, radiocarbon dating has been widely used for age determination in archaeology, geology, geophysics, and other disciplines. Radiocarbon dating continues to evolve as scientists acquire new data and our understanding of the Earth system grows.

The latest version of radiocarbon age calibration curves was released in 2020, and has attracted much attention worldwide. In the future, ongoing and active research based on this method is expected to lead to a more accurate understanding of the evolution of the Earth and the history of human beings.

The Research Front "Radiocarbon age calibration curves, data sets, and applications" consists of 10 core papers, focusing on the latest revision of radiocarbon age calibration curves, continuously updated radiocarbon data sets, and certain current applications of radiocarbon dating method in several fields. The most salient topic is the new generation of radiocarbon age calibration curves. In August 2020, the highly anticipated new revision of radiocarbon age calibration curves was published in a special issue of *Radiocarbon*, including the IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0-55 cal kBP); MARINE20-the Marine Radiocarbon Age Calibration Curve (0-55 cal kBP); and SHCal20 Southern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP).

Core papers discussing the above three curves were published by a team led by P.J. Reimer at Queens University of Belfast (UK), a team led by T.J. Heaton at the University of Sheffield (UK), and a team led by A.G. Hogg, affiliated with both University of New South Wales (Australia) and University of Waikato (New Zealand).The relevant research has been updated to include a wealth of fresh data and the extension to 55,000 cal BP. The use of Bayesian spline methodology improves the curve construction significantly. The convergence and agreement between data sets are stronger, and the total uncertainties smaller. The publication of the latest revision of radiocarbon age calibration curves has exerted a high impact on the research community, and subsequent work based on the new curves is expected to achieve more breakthroughs.

The development of a range of new statistical and computational techniques has prompted the upgrade of analysis of radiocarbon data sets. In one report, C.B. Ramsey at the University of Oxford (UK) compares three different approaches of Bayesian models, concluding that kernel density analysis is a powerful method that could be much more widely applied in a broad range of dating applications. E.R. Crema at the University of Cambridge (UK) and A. Bevan A at University College London (UK) developed an open-source software package for the R statistical computing language; this tool is expected to improve the large sets of radiocarbon dates.

Recent advances in the constantly updated data sets and the latest revision of calibration curves further promote groundbreaking research on population and climate change, including population dynamics and climatic trends, marine reservoir correction, prehistoric demography, agriculture, and population growth.

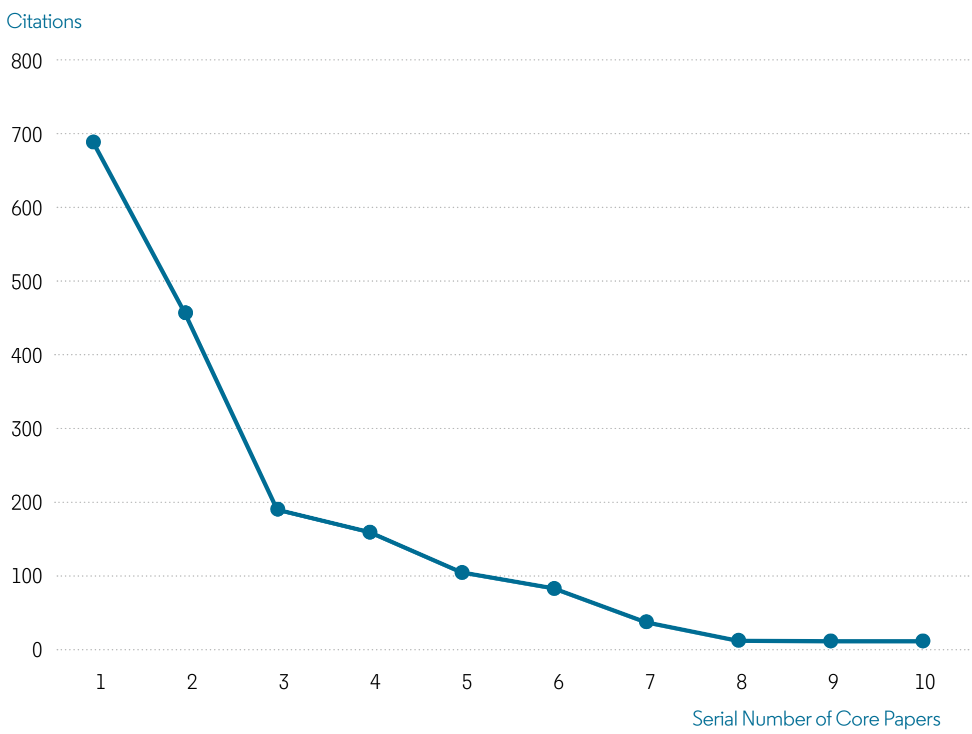


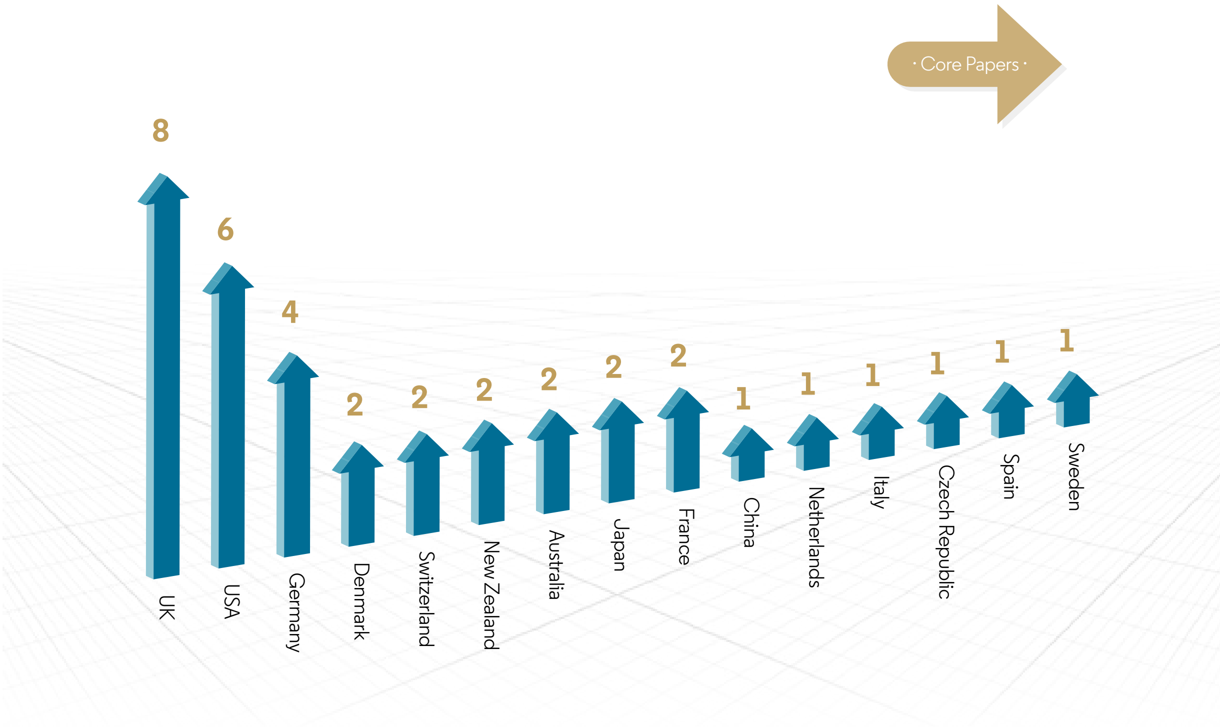
Figure 8: Citation frequency distribution curve of core papers in the Research Front "Radiocarbon age calibration curves, data sets, and applications"

The most prolific countries producing core papers include many technology powers such as the UK, the USA, Germany, Japan, and France. The UK ranks 1st (80% of the total core literature) with substantial contributions from the University of Oxford, the University of Cambridge, the University of Sheffield, University College London, Queens University of Belfast, and others. Researchers from Xi'an Jiaotong University in China participated in one core paper.

Table 14: Top countries and institutions producing core papers in the Research Front "Radiocarbon age calibration curves, data sets, and applications"

Country Ranking	Country	Core Papers	Proportion
1	UK	8	80.0%
2	USA	6	60.0%
3	Germany	4	40.0%
4	Denmark	2	20.0%
4	Switzerland	2	20.0%
4	New Zealand	2	20.0%
4	Australia	2	20.0%
4	Japan	2	20.0%
4	France	2	20.0%
10	China	1	10.0%
10	Netherlands	1	10.0%
10	Italy	1	10.0%
10	Czech Republic	1	10.0%
10	Spain	1	10.0%
10	Sweden	1	10.0%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	University of Oxford	UK	4	40.0%
1	University of Cambridge	UK	4	40.0%
3	University of Sheffield	UK	3	30.0%
3	University College London	UK	3	30.0%
3	Queens University of Belfast	UK	3	30.0%
6	National Research Institute for Agriculture, Food and Environment	France	2	20.0%
6	University of Munich	Germany	2	20.0%
6	University of St Andrews	UK	2	20.0%
6	University of Waikato	New Zealand	2	20.0%
6	English Heritage	UK	2	20.0%
6	University of Aix-Marseille	France	2	20.0%
6	University of Kiel	Germany	2	20.0%
6	Woods Hole Oceanographic Institution	USA	2	20.0%
6	College France	France	2	20.0%
6	French National Research Institute for Sustainable Development (IRD)	France	2	20.0%
6	UHI Millennium Institute	UK	2	20.0%
6	University of New South Wales	Australia	2	20.0%
6	Alfred Wegener Institute for Polar and Marine Research	Germany	2	20.0%
6	University of California Irvine	USA	2	20.0%
6	Smithsonian Institution	USA	2	20.0%
6	Universite PSL	France	2	20.0%
6	Helmholtz Association	Germany	2	20.0%
6	National Center for Scientific Research of France (CNRS)	France	2	20.0%
6	Durham University	UK	2	20.0%
6	Ruprecht-Karls—Universitaet Heidelberg	Germany	2	20.0%
6	University of Arizona	USA	2	20.0%
6	Aarhus University	Denmark	2	20.0%

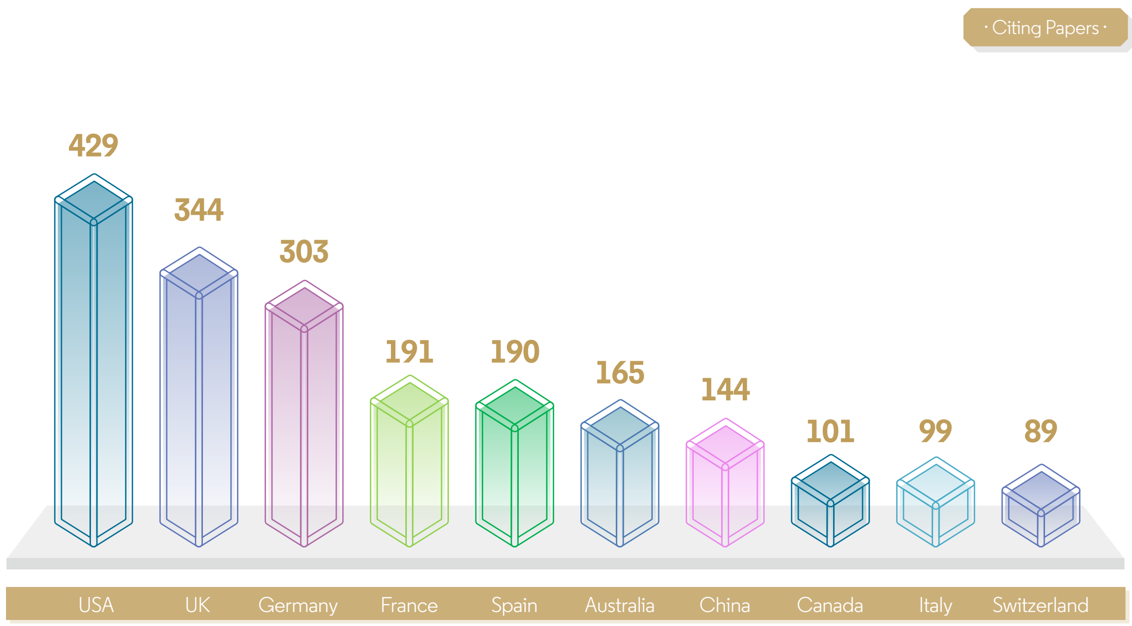


In terms of countries producing the citing papers, the USA ranks 1st with 429, while the UK ranks 2nd with 344 and Germany 3rd with 303. As for institutions producing the most citing papers: the National Center for Scientific Research of France ranks 1st, followed by the Russian Academy of Sciences, the University of Cambridge, and various European entities. The Chinese Academy of Sciences ranks 5th.

Table 15: Top countries and institutions producing citing papers in the Research Front "Radiocarbon age calibration curves, data sets, and applications"

Country Ranking	Country	Citing Papers	Proportion
1	USA	429	27.6%
2	UK	344	22.1%
3	Germany	303	19.5%
4	France	191	12.3%
5	Spain	190	12.2%
6	Australia	165	10.6%
7	China	144	9.3%
8	Canada	101	6.5%
9	Italy	99	6.4%
10	Switzerland	89	5.7%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	National Center for Scientific Research of France (CNRS)	France	150	9.6%
2	Russian Academy of Sciences	Russia	69	4.4%
3	University of Cambridge	UK	68	4.4%
4	University of Oxford	UK	67	4.3%
5	Chinese Academy of Sciences	China	61	3.9%
6	Australian National University	Australia	59	3.8%
6	Helmholtz Association	Germany	59	3.8%
8	Spanish National Research Council (CSIC)	Spain	52	3.3%
9	Max Planck Society	Germany	51	3.3%
10	University College London	UK	50	3.2%



1.3 KEY HOT RESARCH FRONT – "Analysis of asteroid surface characteristics and composition"

Asteroids are rocky objects revolving around the sun that are too tiny to be called planets. At present, upwards of 30,000 near-Earth asteroids have been detected in our Solar System, and they are believed to hold key information about the formation and evolution of our system. The most extensive geomorphic feature on the asteroid surface is the impact crater. Since most asteroids have "rubble pile" structures, we can get information on asteroid density and impact age by analyzing the sputtering blanket of the impact crater. Studying the weathering layer and exposed rocks on the surface of asteroids helps to obtain primordial information about the properties of the materials inside asteroids and their parent-bodies. Rocks of different colors and shapes can also represent different sources or evolutionary processes of the materials on the surface of asteroids.

In the early days of research, asteroid exploration mainly focused on flyby detection. New scientific and technological development brought in-situ observations and sampling detection of asteroids. Hayabusa2, a Japanese spacecraft that explored asteroid Ryugu, was launched in 2014 and, four years later, successfully touched down on Ryugu to collect a sample from the surface, departing the asteroid in 2019. In December 2020, Hayabusa2's sample-return capsule landed in Australia.

Another spacecraft, OSIRIS-Rex, was developed by the USA and launched in 2016. It traveled to a near-Earth asteroid called Bennu, and collected a sample of surface rocks and material that it will return to Earth in 2023. It is the first US mission to return samples from an asteroid to Earth.

The 12 core papers of this hot Research Front focus on the preliminary detection results of the two spacecraft on Ryugu and Bennu, reporting the analysis of their geomorphic characteristics, surface composition and thermal characteristics, and revealing detailed information about the crater and terrain of the two asteroids. "OSIRIS-REx: sample return from asteroid (101955) Bennu", published in 2017 in

Space Science Reviews, from a team led by Dante Lauretta, principal investigator of the mission and professor of planetary science, University of Arizona, and colleagues. The paper described the scientific objective, instrumental payload, ground system, and operation principle of the mission."The unexpected surface of asteroid (101955) Bennu" is another paper authored by Lauretta and colleagues, published in *Nature* in 2019. It introduces the preliminary detection results of Bennu's surface, which will help to select the landing site."Hayabusa2 arrives at the carbonaceous asteroid 162173 Ryugu-A spinning top-shaped rubble pile", published in *Science* by a team led by Nagoya University and JAXA, presented Hayabusa2 observations of Ryugu's shape, mass, and geomorphology. Ryugu has an oblate "spinning top" shape, with a prominent circular equatorial ridge. Large surface boulders suggest a rubble-pile structure. Surface slope analysis shows Ryugu's shape may have been produced from having once spun at twice its current rate.

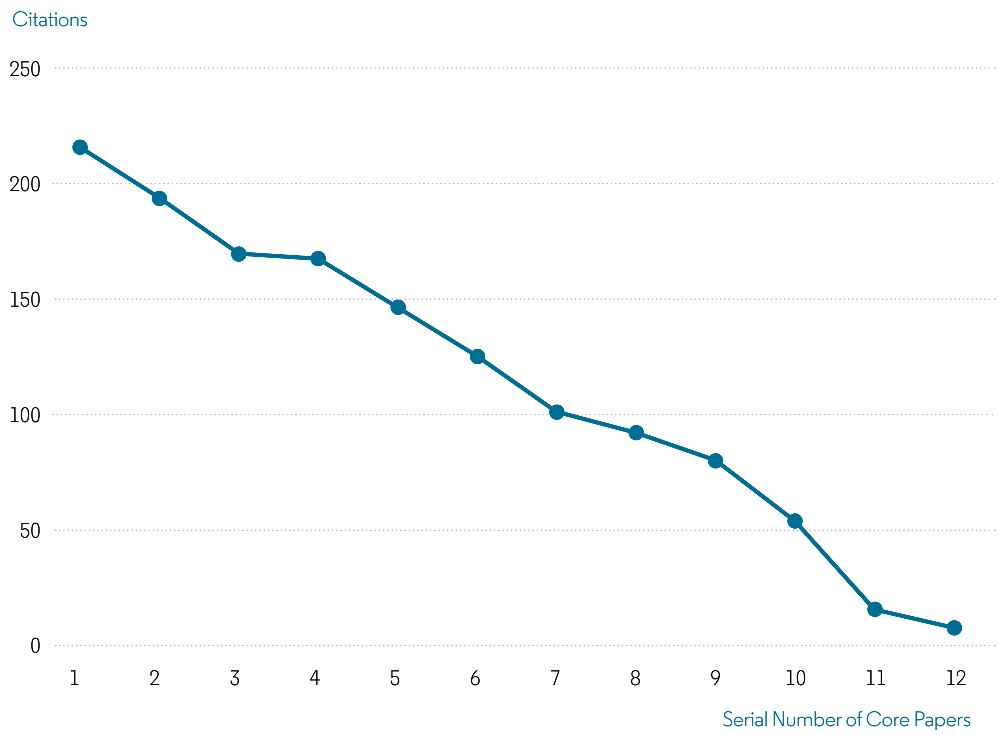


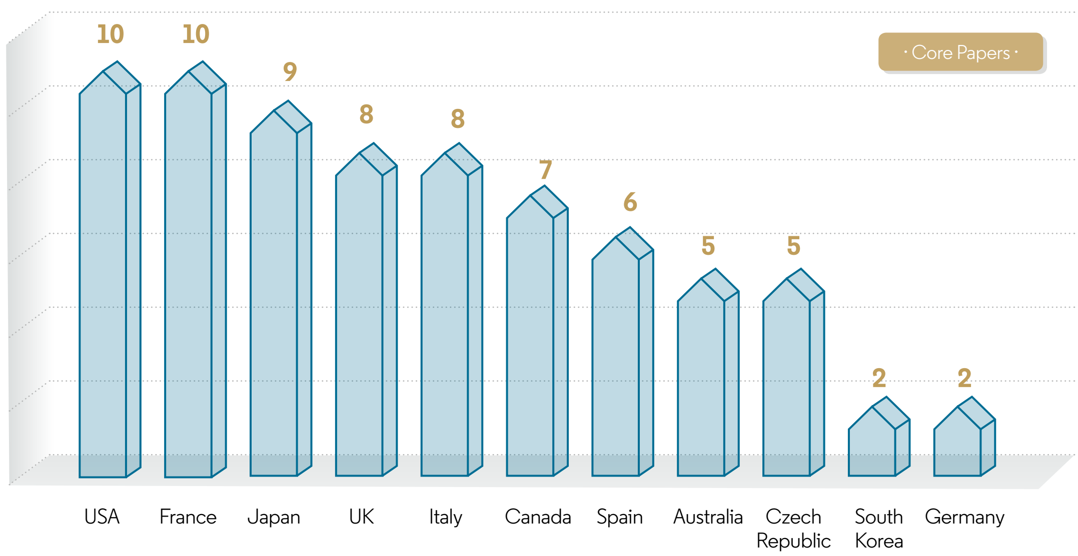
Figure 9: Citation frequency distribution curve of core papers in Research Front "Analysis of asteroid surface characteristics and composition"

In terms of top countries producing core papers, the USA, France, and Japan occupy the top rungs. The USA led the research and development of OSIRIS-Rex, and Japan led Hayabusa2. According to the disclosure of the CNES, France is the only cooperative country participating in the Ryugu sample analysis. Not coincidentally, the top institutions producing core papers are based within these three countries, including Johns Hopkins University, CNRS, Nagoya University, NASA, and JAXA. These institutions cooperate closely with each other, highlighting the advantages and possibilities for task leading countries, main participating countries and relevant institutions to lead conceptual design, master first-hand data, and make major original innovation achievements.

Table 16: Top countries and institutions producing core papers in the Research Front "Analysis of asteroid surface characteristics and composition"

Country Ranking	Country	Core Papers	Proportion
1	USA	10	83.3%
1	France	10	83.3%
3	Japan	9	75.0%
4	UK	8	66.7%
4	Italy	8	66.7%
6	Canada	7	58.3%
7	Spain	6	50.0%
8	Australia	5	41.7%
8	Czech Republic	5	41.7%
10	South Korea	2	16.7%
10	Germany	2	16.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Johns Hopkins University	USA	9	75.0%
1	National Center for Scientific Research of France (CNRS)	France	9	75.0%
1	Nagoya University	Japan	9	75.0%
1	Japan Aerospace Exploration Agency (Jaxa)	Japan	9	75.0%
1	National Aeronautics & Space Administration (NASA)	USA	9	75.0%
6	University of Arizona	USA	8	66.7%
6	Sorbonne University	France	8	66.7%
6	Université Côted'Azur	France	8	66.7%
6	Observatoire de Paris	France	8	66.7%
6	Universite PSL	France	8	66.7%

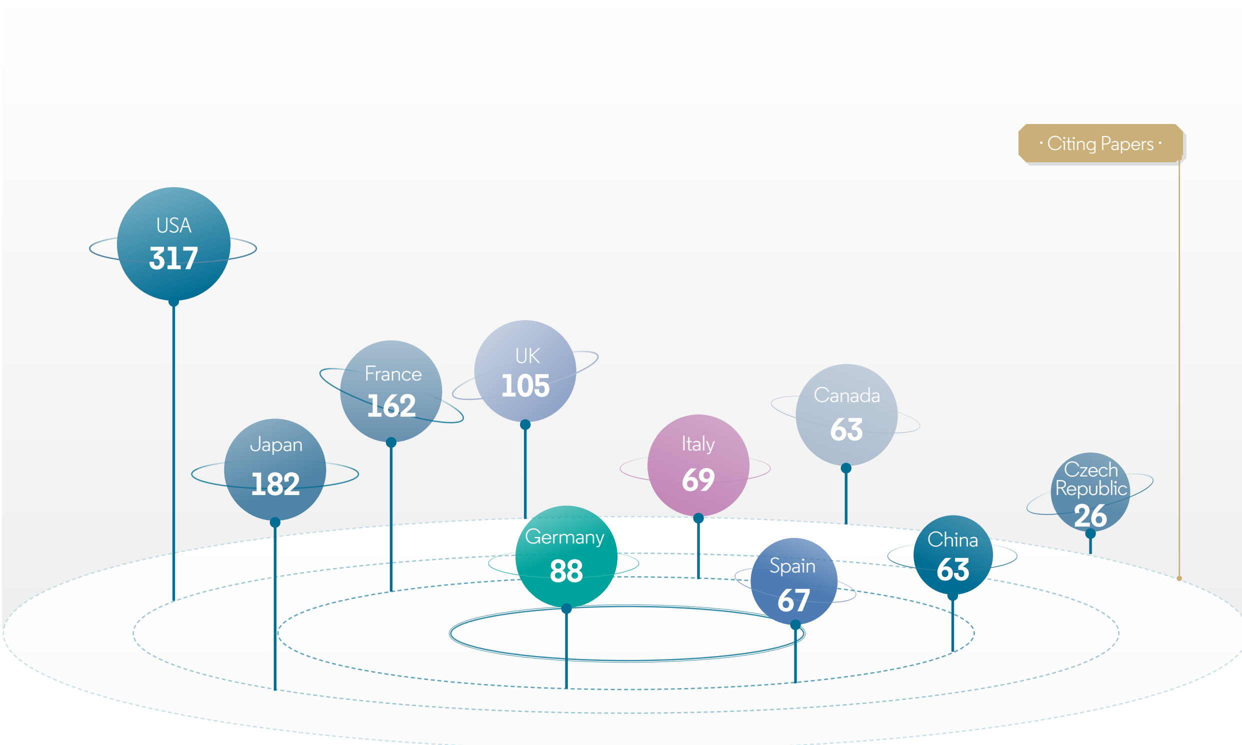


As for countries producing the most citing papers: the USA ranks 1st with 317, followed by Japan and France. The Top 10 citing institutions are also exclusively dominated by these three countries.

Table 17: Top countries and institutions producing citing papers in the Research Front "Analysis of asteroid surface characteristics and composition"

Country Ranking	Country	Citing Paper	Proportion
1	USA	317	55.1%
2	Japan	182	31.7%
3	France	162	28.2%
4	UK	105	18.3%
5	Germany	88	15.3%
6	Italy	69	12.0%
7	Spain	67	11.7%
8	Canada	63	11.0%
8	China	63	11.0%
10	Czech Republic	26	4.5%

Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	National Aeronautics & Space Administration (NASA)	USA	151	26.3%
2	National Center for Scientific Research of France (CNRS)	France	132	23.0%
3	Japan Aerospace Exploration Agency (Jaxa)	Japan	124	21.6%
4	University of Arizona	USA	123	21.4%
5	University of Tokyo	Japan	87	15.1%
6	Université Côte d' Azur	France	75	13.0%
7	Planetary Science Institute	USA	74	12.9%
7	Sorbonne University	France	74	12.9%
9	Chiba Institute of Technology	Japan	59	10.3%
10	Johns Hopkins University	USA	57	9.9%
10	Universite PSL	France	57	9.9%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN GEOSCIENCES

"Multi-scale characterization of reservoir, insights from oil fields, Gulf of Suez, Egypt" was selected as the emerging Research Front in geosciences for 2022.

Table 18: Emerging Research Front in geosciences

Rank	Emerging Research Front	Core papers	Citations	Mean Year of Core Papers
1	Multi-scale characterization of reservoir, insights from oil fields, Gulf of Suez, Egypt	9	127	2021

2.2 KEY EMERGING RESARCH FRONT – "Multi-scale characterization of reservoir, insights from oil fields, Gulf of Suez, Egypt"

The Gulf of Suez is the northwestern extension of the Red Sea located between the east coast of Africa and the Sinai Peninsula in Egypt. It is one of the two main oil producing areas in Egypt. According to statistics, there are hundreds of oil fields in the Gulf of Suez, accounting for 70% of Egypt's oil and gas resources. The Belayim oil field and the El Morgan oil field are located offshore, while the Abu Rudeis field is on land. In February 2022, a 100-million-barrel oil reserve was discovered in Egypt's Gulf of Suez, becoming the biggest oil discovery in the area in more than two decades.

Reservoir characterization is a process of quantifying reservoir attributes, and identifying geological information and spatial variation uncertainty. By studying the reservoir petrological characteristics, reservoir physical properties, main controlling factors of high-quality reservoir development and development potential, researchers can find oil and gas enrichment areas and determine the distribution of remaining oil.

The nine core papers of this emerging Research Front in geosciences focus on the characterization of unconventional tight reservoirs in October field of Suez Bay and El Morgan oil field. Studying the reservoir pore pressure and fracture pressure simulation has great value to sustainable oil-field development.

Jagiellonian University, Krakow, Poland, and Gulf of Suez Petroleum, Cairo, Egypt, jointly produced eight papers. The most-cited report, "Multi-scale characterization of unconventional tight carbonate reservoir: Insights from October oil field, Gulf of Suez rift basin, Egypt" was published in 2021 by A.E. Radwan and colleagues in the *Journal of Petroleum Science and Engineering* and has collected 19 citations. Thirteen sidewall core samples and 60 thin sections from OCT-X well were studied to investigate the petrophysical characteristic, pore system and formation potentiality as a reservoir rock.


2022
RESEARCH
FRONTS

CLINICAL MEDICINE

2022 RESEARCH FRONTS

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN CLINICAL MEDICINE

The Top 10 Research Fronts in clinical medicine focus mainly on COVID-19, with the exception of one front pertaining to research on non-alcoholic fatty liver disease. The COVID-19 pandemic remains a major challenge for modern medicine and international public health. Since the breakout of COVID 19 at the end of 2019, the virus has caused more than 600 million infections and 6 million deaths worldwide. COVID-19-related research – including clinical features of COVID-19 patients with underlying medical conditions, the clinical features of COVID-19 in women and children, complications of COVID-19, vaccine safety, and drug therapy – continues its high visibility in 2022, occupying nine seats in the Top 10 Research Fronts in clinical medicine. Non-alcoholic fatty liver disease (NAFLD), the most common liver disease worldwide, also becomes the focus of research in clinical medicine for its heterogeneity in disease pathogenesis and progression.

Table 19: Top 10 Research Fronts in clinical medicine

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Safety and efficacy of COVID-19 vaccine	4	6085	2020.8
2	Effect of tocilizumab in critically ill COVID-19 patients	11	2363	2020.6
3	Clinical features, outcome, and vaccine efficacy of COVID-19-infected cancer patients	37	5141	2020.3
4	COVID-19-associated acute kidney injury	21	4015	2020.3
5	Role of complement in pathogenesis of COVID-19 and therapeutic effects of complement inhibitors	43	6022	2020.2
6	Clinical features and obstetric and neonatal outcomes of pregnant patients with COVID-19	13	3383	2020.1
7	Risk for venous thromboembolic events in COVID-19 patients	7	8547	2020
8	COVID-19 associated multisystem inflammatory syndrome in children	14	4210	2020
9	Genetics and renaming of NAFLD	30	3172	2020
10	Impaired interferon activity in COVID-19 patients	2	2288	2020

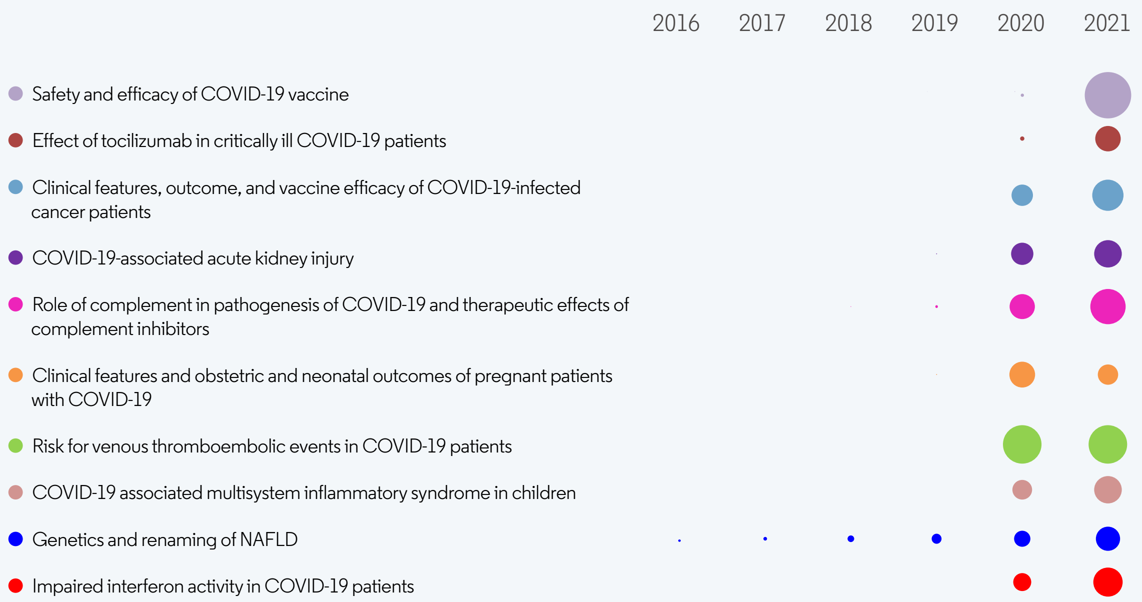


Figure 10: Citing papers for the Top 10 Research Fronts in clinical medicine

1.2 KEY HOT RESEARCH FRONT – "Genetics and renaming of NAFLD"

NAFLD, the most common manifestation of metabolic liver disease, affecting a quarter of the global population, is characterized by liver steatosis exceeding 5% of the liver weight not attributable to alcohol consumption or any other identifiable cause. NAFLD may develop into cirrhosis, hepatocellular carcinoma, or liver failure, also increasing the risk of diabetes and cardiovascular diseases, thus causing huge social and economic burdens. The pathogenesis of NAFLD is complex, and there is currently no approved drug therapy for the condition. As obesity and diabetes become increasingly serious, the incidence of NAFLD grows rapidly as well. Hence, NAFLD has become a global health concern and a hot research topic.

The revolution in precision medicine has changed the diagnosis and treatment of NAFLD. Genes related to the condition, such as PNPLA3, TM6SF2, MBOAT7, GCKR, ApoC3 and HSD17B13 have been identified. Epigenetic changes such as N6-methyladenosine (m6A) modification have also been confirmed to play a vital role in NAFLD. These studies have laid the foundation for the discovery of potential drug targets and biomarkers for NAFLD and have provided the direction for precision diagnosis and treatment.

At the same time, the heterogeneous pathogenesis, along with inaccuracies in terminology and definitions for NAFLD, necessitate a reappraisal of nomenclature to better inform clinical trial design and drug development. In 2020, an international expert panel controversially proposed to rename NAFLD, a term used for 40 years, as MAFLD (metabolic associated fatty liver disease). This caused much dispute and discussion – for example, the controversy featured in a "year in review" roundup published in *Nature Reviews Endocrinology* in November 2020. The expert consensus aims to emphasize metabolic disorder in MAFLD pathogenesis, and to change the phenomenon involving the absence of "positive" diagnostic criteria, thus promoting change in the mode of diagnosis and treatment.

The 30 core papers that anchor the key hot Research Front "Genetics and renaming of NAFLD" mainly focus on susceptibility gene research and disease renaming. NAFLD susceptibility gene research principally involves HSD17B13, MBOAT7/TMC4 and PNPLA3. For example, a report published in *Gastroenterology* in May 2016 by authors from University of Gothenburg, with 337 citations at this writing, provides evidence for an association between the MBOAT7 rs641738 variant and the development and severity of NAFLD in individuals of European descent. This association seems to be mediated by changes in the hepatic phosphatidylinositol acyl chain remodeling.

Research on renaming NAFLD is much hotter. The consensus authored by more than 30 experts from more than 10 countries/regions was published in *Gastroenterology* in May 2020 and has now collected nearly 500 citations. The proposed nomenclature MAFLD received 72.4% support among other suggestions. The new diagnosis criteria for MAFLD, published in *Journal of Hepatology* in July 2020 and subsequently garnering more than 500 citations, proposed evidence of metabolic dysregulation and other criteria for positive diagnosis of MAFLD. Renaming a condition and assigning new diagnostic criteria inevitably cause concerns and confusion, such as the possible inadequacy of evidence for new diagnosis and treatment, the question of how to grade and stage previous steatohepatitis, and concern whether there is intervention for patients with fibrosis who are not included in the new definition.

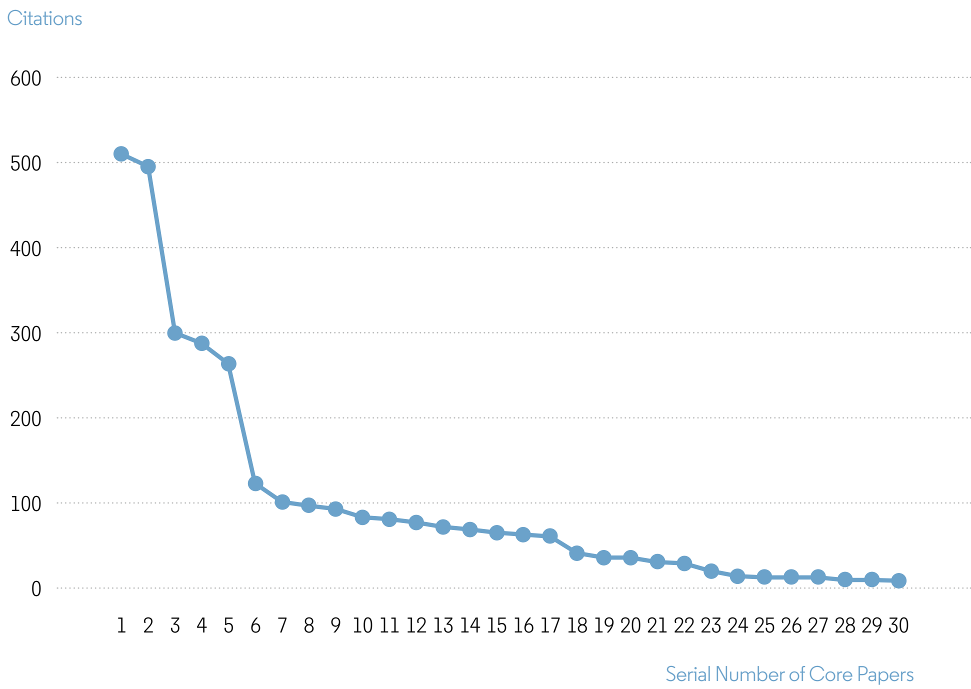


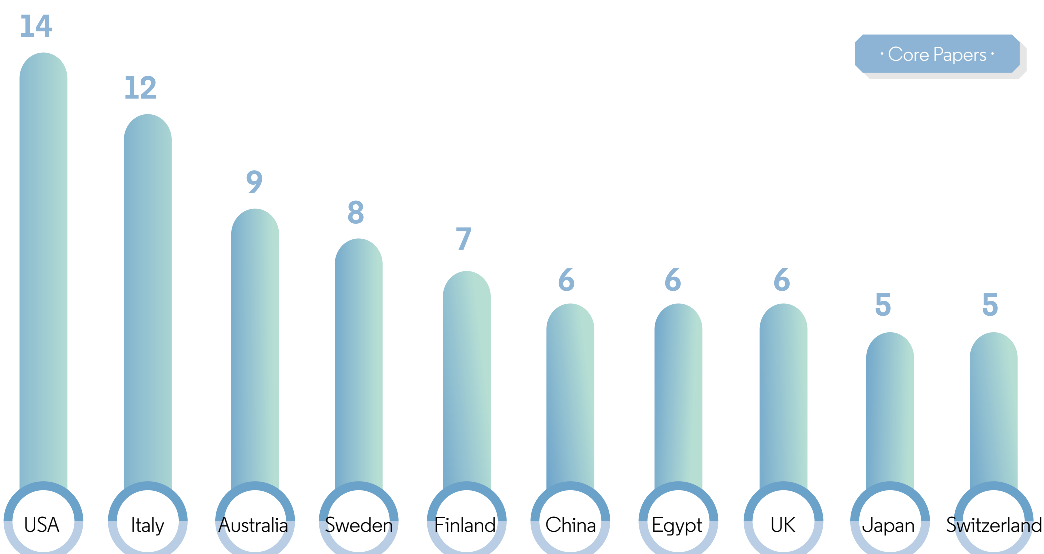
Figure 11: Citation frequency distribution curve of core papers in the Research Front "Genetics and renaming of NAFLD"

As for the top countries producing core papers in this key hot front, the USA, Italy, and Australia take the lead. The USA stands out, contributing 46.7% of the core papers, reflecting the nation's high impact in NAFLD genetic research, disease diagnosis, and treatment standardization. Among the top institutions producing core papers, Ca'Granda Ospedale Maggiore Policlinico and the University of Milan both contributed one-third of the core papers, followed by the University of Gothenburg, the University of Sydney, Magna Græcia University of Catanzaro, the Egyptian Knowledge Bank, and the University of Texas Southwestern Medical Center in Dallas.

Table 20: Top countries and institutions producing core papers in the Research Front "Genetics and renaming of NAFLD"

Country Ranking	Country	Core Papers	Proportion
1	USA	14	46.7%
2	Italy	12	40.0%
3	Australia	9	30.0%
4	Sweden	8	26.7%
5	Finland	7	23.3%
6	China	6	20.0%
6	Egypt	6	20.0%
6	UK	6	20.0%
9	Japan	5	16.7%
9	Switzerland	5	16.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Ca'Granda Ospedale Maggiore Policlinico	Italy	10	33.3%
1	University of Milan	Italy	10	33.3%
3	University of Gothenburg	Sweden	8	26.7%
4	University of Sydney	Australia	7	23.3%
4	Magna Graecia University of Catanzaro	Italy	7	23.3%
6	Egyptian Knowledge Bank	Egypt	6	20.0%
6	Univ Texas SW Med Ctr Dallas	USA	6	20.0%
8	University of Palermo	Italy	4	13.3%
8	Helsinki University	Finland	4	13.3%
8	Menia University	Egypt	4	13.3%
8	Kuopio Univ Hosp	Finland	4	13.3%
8	Minerva Fdn	Finland	4	13.3%
8	Mansoura University	Egypt	4	13.3%
8	University of East Finland	Finland	4	13.3%

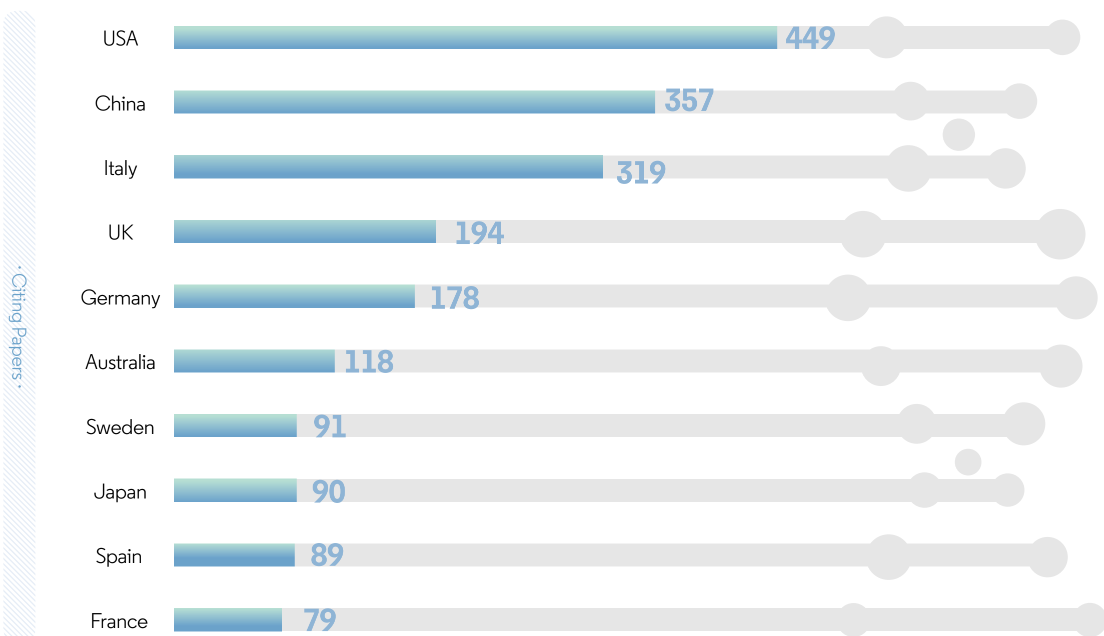


In terms of the citing papers, the USA is the most prolific, demonstrating a heightened research interest in NAFLD genetics and the renaming debates – attention that might be closely related to the increasing incidence rate in the USA. China, Italy, the UK, and Germany, all of which are also high-incidence areas of NAFLD, have actively followed up on this front. The University of Milan, Ca'Granda Ospedale Maggiore Policlinico, and the University of Sydney are the top three institutions producing citing papers.

Table 21: Top countries and institutions producing citing papers in the Research Front "Genetics and renaming of NAFLD"

Country Ranking	Country	Citing Papers	Proportion
1	USA	449	26.7%
2	China	357	21.2%
3	Italy	319	19.0%
4	UK	194	11.5%
5	Germany	178	10.6%
6	Australia	118	7.0%
7	Sweden	91	5.4%
8	Japan	90	5.4%
9	Spain	89	5.3%
10	France	79	4.7%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	University of Milan	Italy	95	5.7%
2	Ca'Granda Ospedale Maggiore Policlinico	Italy	86	5.1%
3	University of Sydney	Australia	79	4.7%
4	Harvard University	USA	56	3.3%
5	University of Gothenburg	Sweden	53	3.2%
6	CIBER	Spain	51	3.0%
7	National Institute of Health and Medical Research (INSERM)	France	48	2.9%
8	University of Verona	Italy	47	2.8%
9	Magna Graecia University of Catanzaro	Italy	45	2.7%
10	Shanghai Jiao Tong University	China	44	2.6%



1.3 KEY HOT RESEARCH FRONT – "Impaired interferon activity in COVID-19 patients"

COVID-19 research has yet to produce a wonder drug. Interferons are broad-spectrum antiviral agents which can rapidly activate multiple antiviral proteins, inhibit viral replication, and activate immune cells to eliminate viruses. Interferon response has been found to be impaired after SARS-CoV-2 infection, mainly by mechanisms such as inhibiting interferon production, signal transduction and protein production, thereby enabling massive virus replication, overwhelming inflammatory response, and precipitating multiple organ failure.

Some early studies found that interferons may control COVID-19 progression. Interferon treatment was then recommended by COVID-19 guidelines in some countries. However, further clinical trials found that interferons were unable to alleviate COVID-19 progression, and that the improper use of interferons could even aggravate disease by promoting inflammatory cytokine secretion and immune cells infiltration. Discussion and concerns about the suitable patients, therapeutic effects, timing of administration, and optimal dosage have made interferons in COVID-19 a hot research topic.

The key hot Research Front "Impaired interferon activity in COVID-19 patients" includes two core papers – one published in *Cell*, the other in *Science* -- in 2020, with 1,394 and 894 citations respectively. Both reports examined the imbalance of host transcriptional response to SARS-CoV-2 infection and virus replication, as well as immune response -- i.e., the low IFN-I/III expression with high chemokines/IL-6 expression. The paper published in *Cell* on May 28, 2020, by Daniel Blanco Melo from Icahn School of Medicine at Mount Sinai and colleagues, showed that host IFN-I/III response failed after SARS-CoV-2 infection and that chemokines accumulation might weaken immune response and aggravate inflammation. This result suggests that immunomodulatory drugs should be a direction for COVID-19 treatment.

The other paper, published online in *Science*, on July 13, 2020 by Jérôme Hadjadj from the University of Paris and colleagues, found that impaired interferon activity together with aggravated inflammation response might be one of the manifestations of severe COVID-19. Moreover, interferon deficiency is presumed to be relieved by the administration of interferon drugs, and the duration, timing, and location of interferon drug exposure to the virus appear to be critical to the success of treatment.

Both studies pointed out that using interferon in the treatment of COVID-19 might be effective, but the findings require further verification. Subsequent research has recommended that interferon should be given as early as possible, as delayed administration might aggravate the overwhelming inflammation. However, distinct findings from other research have questioned benefits of interferon treatment, and even questioned whether low interferon was the cause or a consequence of disease deterioration. Interferon treatment has thus been removed from previous COVID-19 guidelines in some regions due to insufficient clinical evidence. With these unsettled matters regarding the mechanisms of interferon in SARS-CoV-2 infection, the question of whether interferon agents can be useful in COVID-19 treatment and its therapeutic mechanism remains open.

In terms of citing papers, the USA takes the lead, indicating a considerable scale of activity in this research front. The nation is followed by China, the UK, France, Germany, Italy, India, and Canada, which have also demonstrated strong performance. Half of the top institutions producing citing papers are based France. The National Institute of Health and Medicine of France, the University of Paris, the Paris Public Aid Hospital, and Harvard University are the top four institutions contributing citing papers.

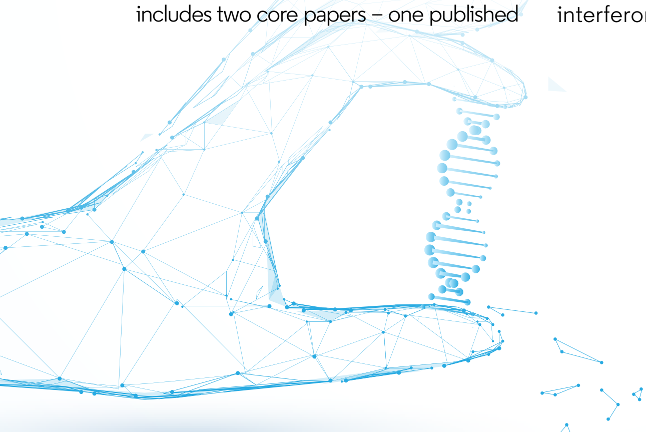
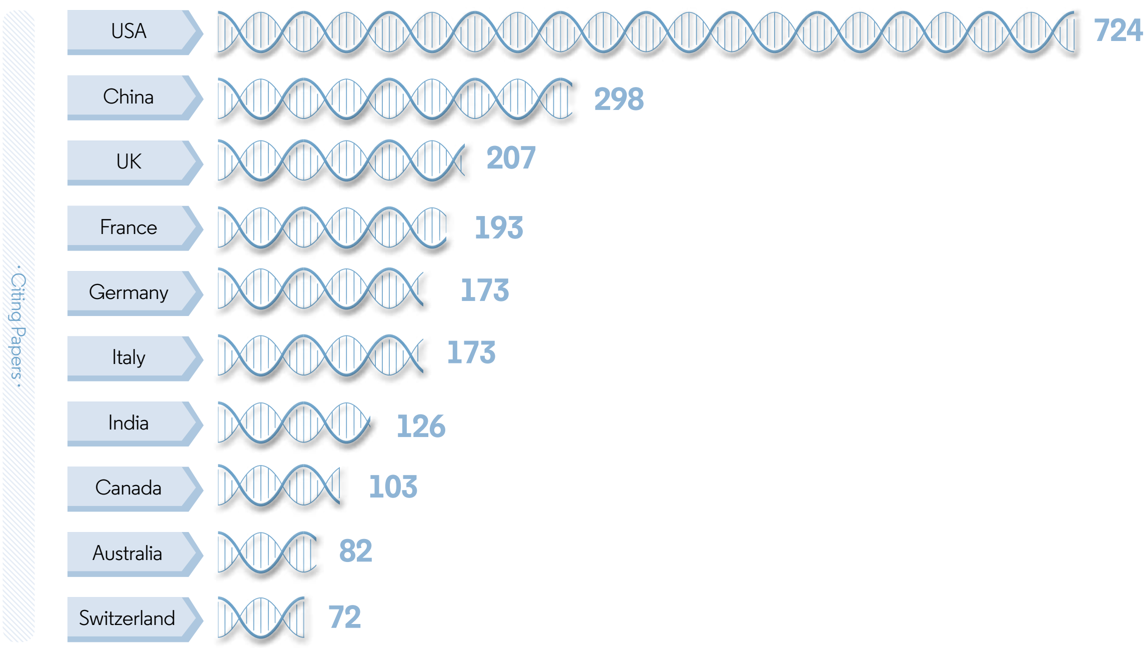


Table 22: Top countries and institutions producing citing papers in the Research Front "Impaired interferon activity in COVID-19 patients"

Country Ranking	Country	Citing Papers	Proportion
1	USA	724	36.9%
2	China	298	15.2%
3	UK	207	10.5%
4	France	193	9.8%
5	Germany	173	8.8%
5	Italy	173	8.8%
7	India	126	6.4%
8	Canada	103	5.2%
9	Australia	82	4.2%
10	Switzerland	72	3.7%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	National Institute of Health and Medical Research (INSERM)	France	127	6.5%
2	University of Paris	France	87	4.4%
3	Assistance Public Hospital Paris	France	84	4.3%
4	Harvard University	USA	82	4.2%
5	National Center for Scientific Research of France (CNRS)	France	77	3.9%
6	Chinese Academy of Sciences	China	57	2.9%
7	National Institutes of Health (NIH) - USA	USA	52	2.6%
8	Icahn Sch Med Mount Sinai	USA	50	2.5%
9	Sorbonne University	France	46	2.3%
10	Yale University	USA	45	2.3%



2. EMERGING RESEARCH FRONT

2.1 SUMMARY OF EMERGING RESEARCH FRONTS IN CLINICAL MEDICINE

Among the 17 emerging Research Fronts in clinical medicine, 15 focus on COVID-19, tackling topics that include the side effects and effectiveness of COVID-19 vaccines; sequela and complications; drug therapy; and rapid detection of SARS-CoV-2. Meanwhile, the other two fronts focus on drug therapies for obesity and diabetes. "Side effects and effectiveness of COVID-19 vaccines against variants" was selected as the key emerging Research Front Group. This front group was also a continuation of the 2021 emerging Research Front group "SARS-CoV-2 vaccine research and development".

Table 23: Emerging Research Fronts in clinical medicine

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Neutralizing antibody LY-CoV555 for COVID-19 patients	4	1001	2021
2	Effectiveness of COVID -19 vaccines against SARS-CoV-2 variant Delta	4	639	2021
3	SARS-CoV-2 reinfections	4	604	2021
4	Efficacy of ChAdOx1 nCoV-19 vaccine against SARS-CoV-2 B.1.1.7 and B.1.351 variant	3	541	2021
5	Long COVID-19	7	299	2021
6	Antithrombotic strategies in COVID-19	5	289	2021
7	Effect of semaglutide in adults with overweight or obesity	9	437	2020.9
8	Repurposed antidepressant used to treat COVID-19	12	313	2020.9
9	Vaccine-induced thrombotic thrombocytopenia after COVID-19 vaccination	24	1896	2020.8
10	Rapid antigen test for detection of SARS-CoV-2 virus	33	1732	2020.8
11	Allergic reactions to COVID-19 mRNA vaccines	8	661	2020.8
12	Pathological features and mechanisms of COVID-19-associated myocardial injury	13	532	2020.8
13	Effect of finerenone on chronic kidney disease outcomes in Type 2 Diabetes	3	256	2020.7
14	Saliva sample for SARS-CoV-2 testing	11	1570	2020.6
15	Effects of COVID-19/SARS-CoV-2 on male reproductive function	21	1146	2020.6
16	Benefits of rehabilitation in COVID-19	11	443	2020.6
17	Androgen deprivation therapy and risk of SARS-CoV-2 infection and implication of androgen regulation of TMPRSS2 and ACE2 in COVID-19 therapy	5	356	2020.6

2.2 KEY EMERGING RESEARCH FRONT GROUP – "Side effects and effectiveness of COVID-19 vaccines against variants"

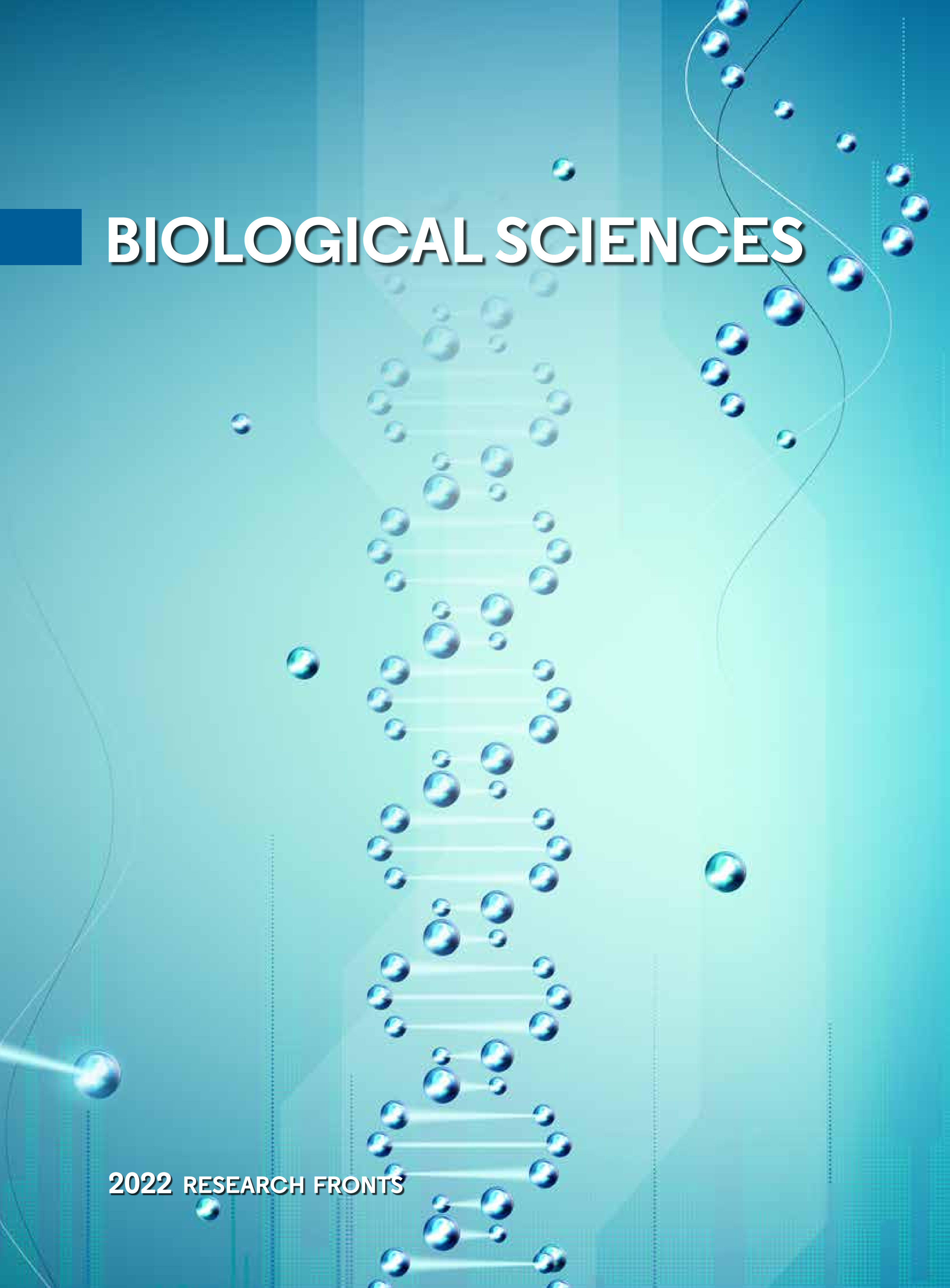
Vaccination is still one of the most effective measures to control the COVID-19 epidemic, bringing hope to millions of people during the ongoing global pandemic. Based on proven safety and effectiveness in clinical trials, many COVID-19 vaccines developed with different platforms have been approved for use. According to the World Health Organization (WHO), as of September 26, 2022, 12.7 billion doses have been administered globally, and 67.9% of the world population has received at least one dose of a COVID-19 vaccine. However, as the number of vaccinated people and the number of doses increase in the real world, side effects of COVID-19 vaccines have drawn public attention. The emergence of novel COVID-19 variants has also challenged vaccine development and future immunization policy.

The key emerging front group "Side effects and effectiveness of COVID-19 vaccines against variants" includes four emerging Research Fronts: "Vaccine-induced thrombotic thrombocytopenia after COVID-19 vaccination", "Allergic reactions to COVID-19 mRNA vaccines", "Effectiveness of COVID-19 vaccines against SARS-CoV-2 variant Delta", and "Efficacy of ChAdOx1 nCoV-19 vaccine against SARS-CoV-2 B.1.1.7 and B.1.351 variant".

The two emerging Research Fronts on side effects of COVID-19 vaccines mainly focus on vaccine-induced immune thrombotic thrombocytopenia (VITT) and severe allergic reactions. VITT is a new syndrome with devastating effects that may occur in some persons after vaccination with ChAdOx1 nCoV-19, with symptoms such as multiple thrombosis in cerebral venous sinus, lung, and artery, and usually accompanied by thrombocytopenia and D-dimer elevation. Although rare, VITT progresses rapidly, with a fatality rate of 20% to 50%, and requires a thorough risk–benefit analysis. Severe allergic reactions to COVID-19 vaccines that may occur after vaccination with mRNA nCoV-19, often attributed to various vaccine components, have also raised public concern. To guide safe COVID-19 vaccination, risk stratification schema has been recommended for individuals with different allergy histories to ensure that they can safely receive their first mRNA COVID-19 vaccine.

The other two emerging Research Fronts focus on the effectiveness of COVID-19 vaccines against variants, including seven core papers published in Nature, Lancet, and the *New England Journal of Medicine*. These reports mainly assess the safety and efficacy of ChAdOx1/NVX-CoV2373 nCoV-19 vaccine against emerging SARS-CoV-2 variants, including the B.1.1.7 (alpha), B.1.351 (beta), B.1.617.2 (delta), and P.1 (Gamma). The observation on reduced neutralization activity against some variants provides important evidence-based insights for vaccine development and future vaccination policy.

BIOLOGICAL SCIENCES



2022 RESEARCH FRONTS

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN BIOLOGICAL SCIENCES

The Top 10 Research Fronts in biological sciences all focus on research related to SARS-CoV-2, specifically the pathogenesis, key targets, immune response, neutralizing antibody, evolutionary origin and intermediate host, PCR nucleic acid detection of the virus, and the prediction model and vaccine research of COVID-19.

Among these topics, "Structure, function, and antigenicity of SARS-CoV-2 spike glycoprotein," selected as a hot Research Front in 2021, appears again in the Top 10 for 2022, reflecting recent progress against the pathogen and the disease.

"Structural analysis and inhibitor discovery of SARS-CoV-2 Main Protease" and "T cell immunity induced by SARS-CoV-2," which registered as Emerging Fronts in the 2021 survey, have now made the list of hot fronts for 2022.

As might be expected, research devoted to COVID-19 vaccines stood out as an important hot topic in 2022. Two hot Research Fronts in the field of biological sciences center on vaccines: "Research and development of various COVID-19 vaccines" and "Development of SARS-CoV-2 epitope peptide vaccine".

Two of the emerging Research Fronts in the field of biological sciences also involve neutralizing antibody immune response induced by vaccination for COVID-19. In addition, there are many fronts in the field of clinical medicine related to the safety of COVID-19 vaccine and the effectiveness of SARS-CoV-2 mutant strains.

"Discovery and drug development of neutralizing antibodies against SARS-CoV-2" and "PCR nucleic acid detection of SARS-CoV-2" have also become new hot fronts in the field of biological sciences.

Table 24: Top 10 Research Fronts in biological sciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Study on several SARS-CoV-2 receptors other than ACE2	7	1316	2020.3
2	Research and development of various COVID-19 vaccines	22	8520	2020.2
3	Structure, function, and antigenicity of SARS-CoV-2 spike glycoprotein	6	17127	2020
4	Discovery and drug development of neutralizing antibodies against SARS-CoV-2	21	6555	2020
5	T cell immunity induced by SARS-CoV-2	7	3788	2020
6	Structural analysis and inhibitor discovery of SARS-CoV-2 Main Protease	7	3290	2020
7	PCR nucleic acid detection of SARS-CoV-2	2	3202	2020
8	Prediction model of COVID-19 epidemic situation	4	2765	2020
9	The evolutionary origin and intermediate host of SARS-CoV-2	6	2025	2020
10	Development of SARS-CoV-2 epitope peptide vaccine	9	1479	2020

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

1.2 KEY HOT RESEARCH FRONT – "Discovery and drug development of neutralizing antibodies against SARS-CoV-2"

As a therapeutic antibody, neutralizing antibody of SARS-CoV-2 can protect cells from invasion by neutralizing or inhibiting the biological activity of pathogens. With its specificity and high affinity, neutralizing antibodies can preemptively bind to the spike protein (S protein) of SARS-CoV-2, thereby blocking the binding of virus to host cells. Neutralizing antibody of SARS-CoV-2 is a powerful supplement to COVID-19 vaccine, which can effectively protect people who cannot be vaccinated or have poor vaccine effect. For high-risk people who have been infected, neutralizing antibodies also have the potential to provide long-term protection against reinfection.

In 2021, "Potent SARS-CoV-2 neutralizing antibody" was selected as an emerging Research Front in the field of biological sciences. In 2022, recent progress in this area is reflected in a hot Research front titled "Discovery and drug development of neutralizing antibodies against SARS-CoV-2".

The 21 core papers that underlie this Research Front, as well as the later papers that cite the core literature, mainly involve three topics: 1) the discovery and exploration of the mechanism of neutralizing antibodies against SARS-CoV-2; 2) findings on the recognition sites and classification of features of neutralizing antibodies against SARS-CoV-2; and, 3) the escape mutation of SARS-CoV-2 and the challenges faced by neutralizing antibodies. To discuss these topics in turn:

1) In the early epidemic period of COVID-19, most studies were conducted to directly isolate human monoclonal neutralizing antibodies from the recovered patients, or to quickly obtain candidate antibodies by immunizing animals.

2) With more and more antibody structures being analyzed, many researchers have proposed that antibody classification can be carried out according to different recognition epitopes, which is of great significance for understanding antibody neutralizing activity and mechanism of action.

3) Until now, many monoclonal neutralizing antibodies have been approved for the treatment and prevention of COVID-19 worldwide. However, the SARS-CoV-2 continues to mutate, and the Omicron mutant strain, which is widely prevalent in the world, has derived a variety of subclasses and has largely escaped the neutralizing antibody reported currently. Scientists have begun to focus on developing a new generation of monoclonal broad-spectrum neutralizing antibodies.

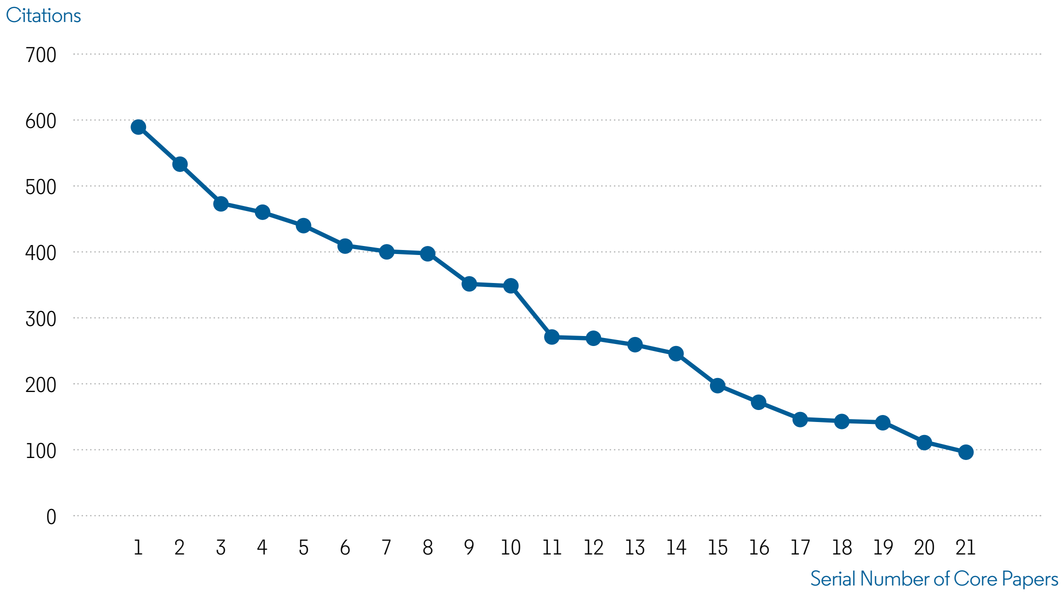


Figure 13: Citating frequency distribution curve of core papers in the Research Front "Discovery and drug development of neutralizing antibodies against SARS-CoV-2"

Among prolific nations contributing core papers, the USA is in the leading position, accounting for 61.9% of the foundational papers of this front. China and Switzerland rank 2nd and 3rd. Among the prolific contributing institutions, Lugano University (Switzerland), the University of Washington, Seattle (USA), and Scripps Research Institute (USA) constitute the top three (Table 25).

Among the core papers, the papers published in Nature by Tsinghua University and Shenzhen Third People's Hospital and other teams were cited the most for 600 times. This paper reported the isolation and characterization of 206 RBD specific monoclonal antibodies and in-depth research on the neutralization mechanism of neutralizing antibodies.

Secondly, David Veesler from the University of Washington, Seattle, and others teams published a paper in Nature, which was cited 542 times. The paper reported that antibodies isolated from SARS cured people can effectively block the infectivity of SARS CoV-2. The human SARS-CoV monoclonal antibody has cross neutralization effect on SARS CoV-2.

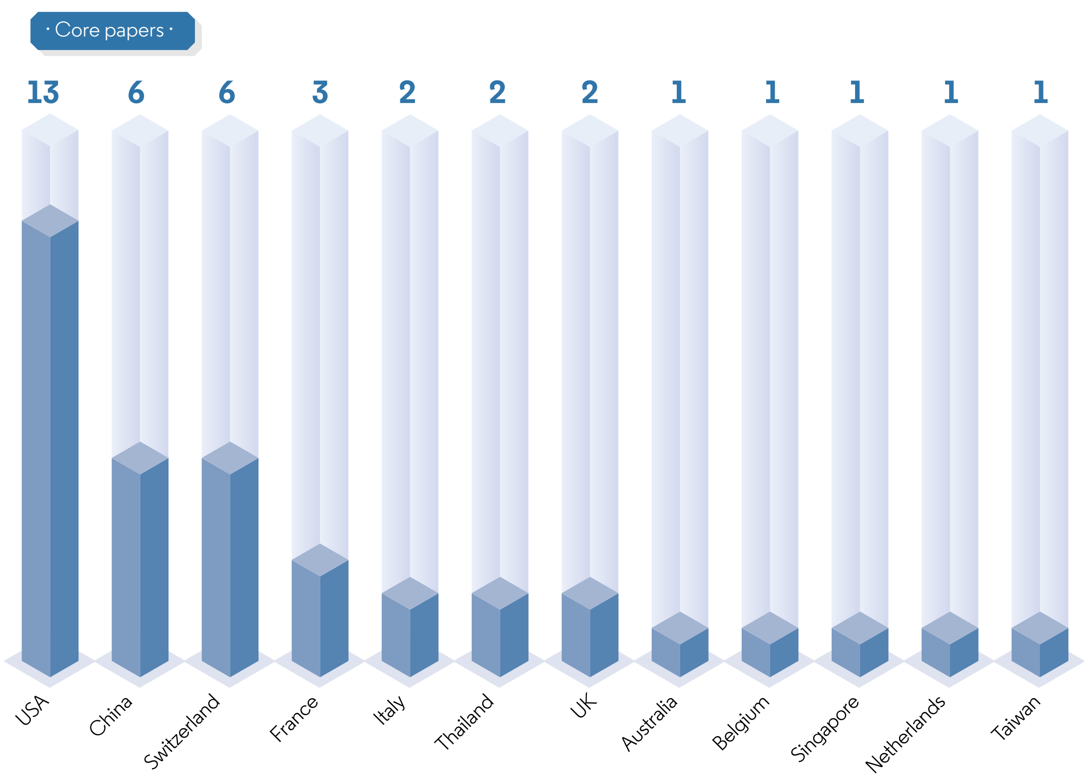
Table 25: Top countries and institutions producing core papers in the Research Front "Discovery and drug development of neutralizing antibodies against SARS-CoV-2"

Country Ranking	Country	Core Papers	Proportion
1	USA	13	61.9%
2	China	7	33.3%

Institution Ranking	Institution	Affiliated Country	Core papers	Proportion
1	University of Lugano	Switzerland	5	23.8%
2	University of Washington Seattle	USA	4	19.0%

Country Ranking	Country	Core Papers	Proportion
3	Switzerland	6	28.6%
4	France	3	14.3%
5	Italy	2	9.5%
5	Thailand	2	9.5%
5	UK	2	9.5%
8	Australia	1	4.8%
8	Belgium	1	4.8%
8	Singapore	1	4.8%
8	Netherlands	1	4.8%
8	Taiwan	1	4.8%

Institution Ranking	Institution	Affiliated Country	Core papers	Proportion
2	Scripps Research Institute	USA	4	19.0%
4	Ragon Institute	USA	3	14.3%
4	Harvard University	USA	3	14.3%
4	Humabs BioMed SA	Switzerland	3	14.3%
4	California Institute of Technology	USA	3	14.3%
4	Massachusetts Institute of Technology (MIT)	USA	3	14.3%
4	Chinese Academy of Sciences	China	3	14.3%
4	National institute for food and drug control	China	3	14.3%
4	Institute Pasteur Paris	France	3	14.3%
4	Howard Hughes Medical Institute	USA	3	14.3%
4	Massachusetts General Hospital	USA	3	14.3%
4	National Center for Scientific Research of France (CNRS)	France	3	14.3%
4	Rockefeller University	USA	3	14.3%
4	Capital Medical University	China	3	14.3%
4	Vir Biotechnology	USA	3	14.3%

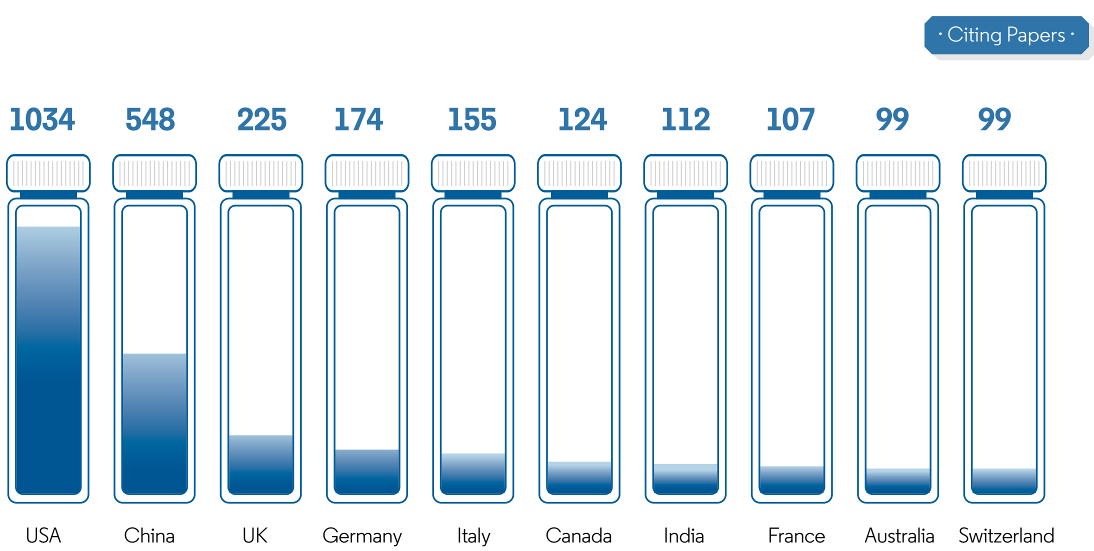


In terms of countries that cite the front's core papers, the USA has fielded the largest number of citing papers, with US-based authors contributing to 1,034 citing papers. China ranks 2nd with 548 citing papers. These numbers indicate that both China and the USA have carried out a substantial portion of follow-up research in this specialty area, but the number of citing papers in China is only half of that in the USA. Seven of the Top 10 institutions (including 11 in parallel) that published citing papers are based in the USA while three institutions are situated in China and one is in the UK. The Chinese Academy of Sciences and Harvard University rank 1st and 2nd with leading contributions of follow-up studies in this front.

Table 26: Top countries and institutions producing citing papers in the Research Front "Discovery and drug development of neutralizing antibodies against SARS-CoV-2"

Country Ranking	Country	Citing Papers	Proportion
1	USA	1034	40.3%
2	China	548	21.4%
3	UK	225	8.8%
4	Germany	174	6.8%
5	Italy	155	6.0%
6	Canada	124	4.8%
7	India	112	4.4%
8	France	107	4.2%
9	Australia	99	3.9%
10	Switzerland	99	3.9%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	148	5.8%
2	Harvard University	USA	131	5.1%
3	National Institutes of Health (NIH) - USA	USA	87	3.4%
4	University of Washington Seattle	USA	85	3.3%
5	Howard Hughes Medical Institute	USA	80	3.1%
6	Massachusetts Institute of Technology (MIT)	USA	68	2.7%
7	University of Oxford	UK	67	2.6%
8	National Institute of Allergy and nfectious Diseases	USA	63	2.5%
9	Fudan University	China	61	2.4%
10	Chinese Academy of Medical Sciences - Peking Union Medical College	China	60	2.3%
10	Scripps Research Institute	USA	60	2.3%



1.3 KEY HOT RESARCH FRONT – "PCR nucleic acid detection of SARS-CoV-2"

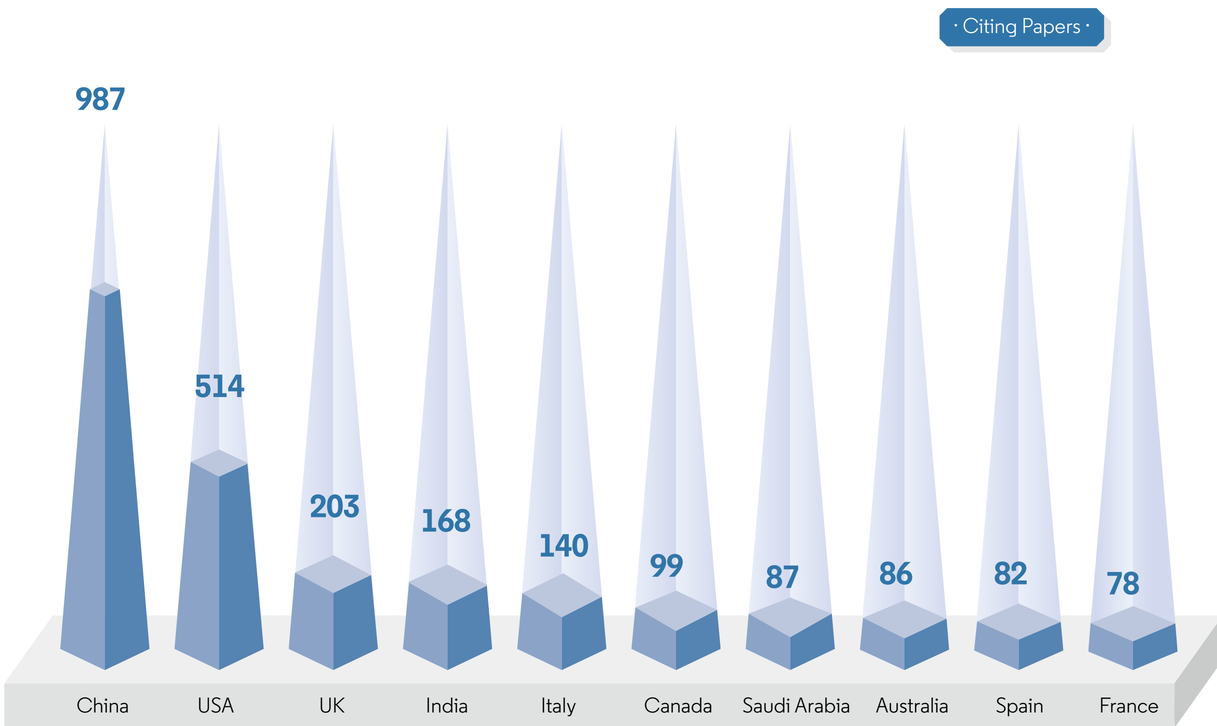
SARS-CoV-2 PCR nucleic acid detection is mainly used to detect whether the collected samples contain SARS-CoV-2 nucleic acid, and to judge whether the person being tested is infected with SARS-CoV-2. Compared with gene sequencing, PCR nucleic acid detection for viruses is simple, fast, and relatively low cost. At present it is the most important method for screening people infected with SARS-CoV-2.

The key hot Research Front consists of two core papers. A core paper with the highest citations (2,716 at this writing) was the first publication of the RT-PCR diagnostic test method for SARS-CoV-2. On January 23, 2020, Christian Drosten at the Medical School of the University of Berlin (Germany) and colleagues published a research paper entitled "Detection of 2019 SARS-CoV-2 (2019-nCoV) by real-time RT-PCR". The authors found that SARS-CoV-2 can be detected by RT-PCR and provided the detection primer sequence and determination method. This provides a theoretical basis and foundation for the detection of SARS-CoV-2.

From the distribution of citing papers, China and the USA are the most active countries, contributing 987 and 514 citing papers, respectively (Table 27). The UK ranks 3rd with 203 citing papers. Nine of the Top 10 institutions producing citing papers are based in China, demonstrating the active participation of Chinese institutions in this research topic. The only non-China based institution to make Table 27 is Harvard University in the USA. The top three institutions are the University of Hong Kong, the Chinese Academy of Sciences, and the Chinese University of Hong Kong.

Table 27: Top countries and institutions producing citing papers in the Research Front "PCR nucleic acid detection of SARS-CoV-2"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	987	42.3%	1	University of Hong Kong	China	72	3.1%
2	USA	514	22.0%	2	Chinese Academy of Sciences	China	71	3.0%
3	UK	203	8.7%	3	Chinese University of Hong Kong	China	65	2.8%
4	India	168	7.2%	4	Fudan University	China	61	2.6%
5	Italy	140	6.0%	5	Huazhong University of Science & Technology	China	55	2.4%
6	Canada	99	4.2%	6	Harvard University	USA	48	2.1%
7	Saudi Arabia	87	3.7%	6	Hong Kong Polytechnic University	China	48	2.1%
8	Australia	86	3.7%	8	Wuhan University	China	47	2.0%
9	Spain	82	3.5%	9	Shanghai Jiao Tong University	China	46	2.0%
10	France	78	3.3%	10	Zhejiang University	China	45	1.9%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN BIOLOGICAL SCIENCES

In the field biological sciences, 11 emerging Research Fronts have been identified. Although the majority focus on research related to SARS-CoV-2, other topics include "AlphaFold and other artificial intelligence predict protein structure", "Pfam and other protein family databases", "Physical and chemical properties of small molecule protein kinase inhibitors", and "Regeneration and protection of inner ear hair cells and auditory neurons".

Among the seven COVID-related fronts in these emerging areas, the reports examine related research from different perspectives, including: research on two variants SARS-CoV-2 in South Africa and Brazil; neutralizing antibody responses induced by seven COVID-19 vaccines and nanoparticle vaccines; SARS-CoV-2 main protease (Mpro), nucleocapsid protein; host factor and other virus invasion mechanisms; and drug target research.

Table 28: Emerging Research Fronts in biological sciences

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Antibody resistance of SARS-CoV-2 South African variant B.1.351	2	927	2021
2	Genomics and epidemiology of Brazilian variant P.1 of SARS-CoV-2	2	615	2021

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
3	AlphaFold and other Artificial Intelligence predict protein structure	4	587	2021
4	Pfam and other protein family databases	3	426	2021
5	Neutralizing antibody responses induced by vaccination of seven SARS-CoV-2	2	327	2021
6	Neutralizing antibody responses induced by SARS-CoV-2 nanoparticle vaccine	7	230	2020.9
7	Physicochemical properties of small molecule protein kinase inhibitors	4	301	2020.8
8	Antiviral effect of quercetin inhibitor on SARS-CoV-2 main protease (Mpro)	13	299	2020.8
9	Regeneration and protection of hair cells and auditory neurons in the inner ear	8	230	2020.8
10	Identification of host factors needed for SARS-CoV-2 infection	32	1785	2020.6
11	Structure and function of SARS-CoV-2 nucleocapsid protein	7	557	2020.6

2.2 KEY EMERGING RESEARCH FRONT – “AlphaFold and other artificial intelligence predict protein structure”

There are thousands of proteins in the human body. Prediction of these protein structures will help provide new insights for basic biology and reveal new drug targets with clinical significance – a matter of great importance for basic science and drug research and development. In the past, protein structure could only be determined by heavy laboratory analysis. In the past decades of protein structure analysis, such technologies as X-ray crystallography, nuclear magnetic resonance spectroscopy (NMR) and cryo electron microscopy (Cryo-SEM) have made great contributions, but these techniques are usually time-consuming and costly.

In his acceptance speech for the 1972 Nobel Prize, American biochemist Christian Anfinsen proposed an idea: Based on a protein’s one-dimensional amino acid sequence, the three-dimensional structure of protein can be calculated and predicted. However, before the three-dimensional structure is formed, there will be hundreds of millions of ways in which the protein might fold. Data shows that a typical protein has about $10^{\wedge 300}$ possible configurations. If we use brute force to calculate all possible configurations, it may take longer time than the age of the Universe.

More than 50 years after this idea was put forward, DeepMind, an AI company under Google, defeated other players in the 14th Critical Assessment of Structure Prediction (CASP14) in December 2020 with the new model called AlphaFold2, which was close to the human experimental results in terms of prediction accuracy, and shocked the entire biology community.

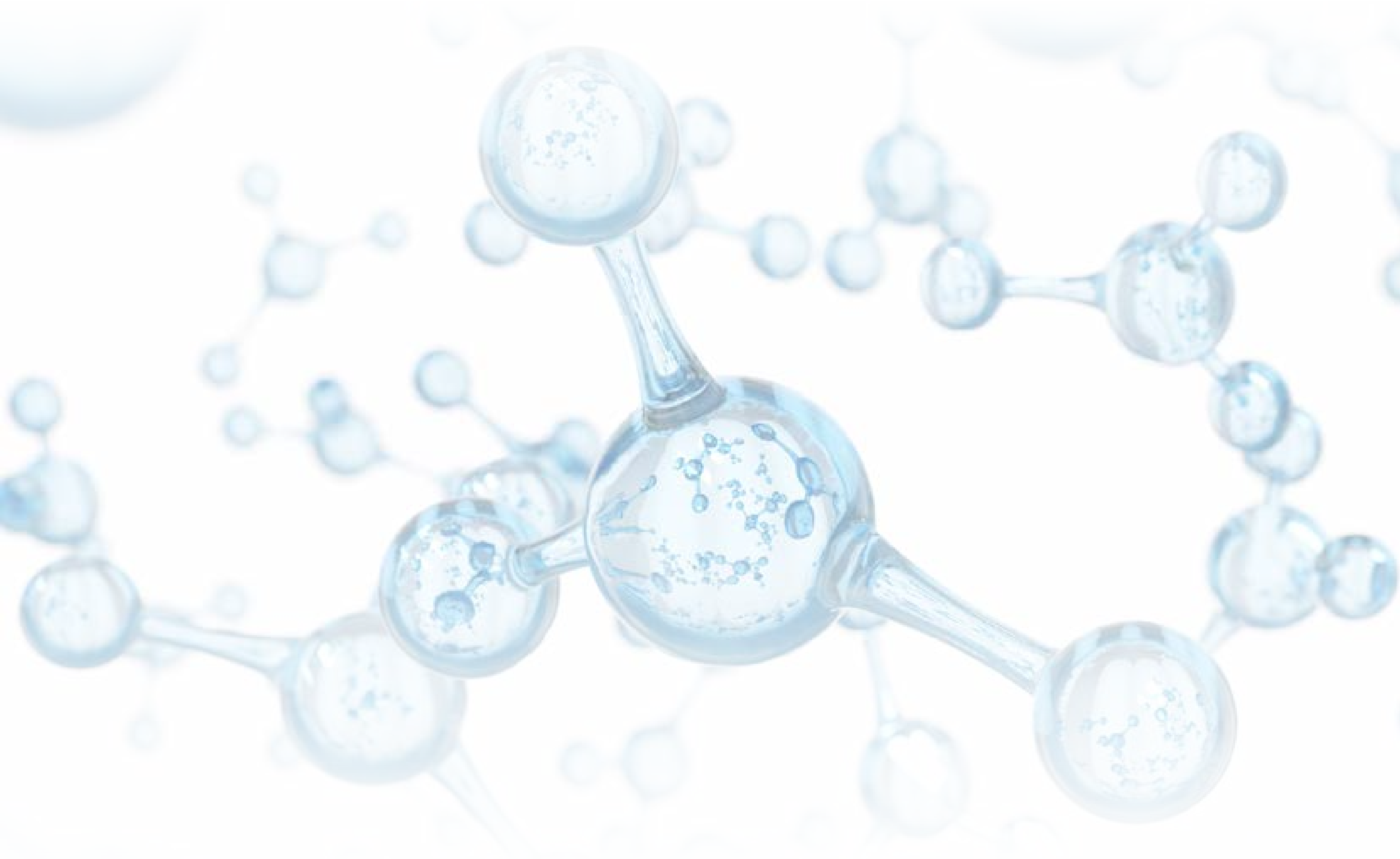
This emerging Research Front includes four core papers. On July 16 and 22, 2021, the Google DeepMind team published two papers in *Nature*, describing AlphaFold2’s accurate structural prediction of human proteome, and shared open-source code for the first time. The prediction information is also free to the public. On July 16, 2021, the team led by David Baker from Washington University and colleagues reported their development of a new Deep Learning tool, RoseTTAFold; the paper was published in *Science*. Based on a “three track” neural network, the structure of the target protein was quickly and accurately predicted according to limited information. The new tool demonstrated ultra-high accuracy compared to AlphaFold2 protein structure prediction, in addition to being faster and requiring less computer processing power. Similarly, the research team also shared open-source code.

These achievements mean that Artificial intelligence (AI) has entered the micro molecular field of life science and is open to researchers. Its significance is like AlphaGo's entry into people's lives (Go field). Its widespread application may have a significant impact on biology. This is a milestone in the development of biology. AI prediction of protein structure was also selected as one of the Top 10 breakthroughs of the year by *Science* in 2021.

Protein structure used to be determined solely only by laborious analysis in the lab. But now we can quickly calculate thousands of proteins and protein complexes.

In subsequent research, scientists from all over the world began to use open-source tools to explore unknown proteins, and constantly verified the robustness of new tools. More teams have developed a protein interaction prediction tool based on the open-source protein structure prediction tool to analyze the protein-protein interaction and assist in the research of cell metabolic pathways.

What is even more exciting is that scientists have now used open-source protein structure prediction tools to design and create original compounds that can potentially be used in industrial reactions, cancer treatment, and candidate vaccines.



CHEMISTRY AND MATERIALS SCIENCE

2022 RESEARCH FRONTS

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 2022 spotlight specialty areas as diverse as catalysis, battery materials, advanced materials, and emerging fields. In the field of catalysis, among three Research Fronts, catalytic asymmetric construction of axially chiral compounds has been selected for the second consecutive year in this annual survey, and both single-atom catalysis and nanozymes are fields in which China-based chemists undertook the earliest investigations and have made significant contributions to the growth of these areas. In the field of battery materials, research on the respective fields of aqueous Zn-ions batteries and Li-S batteries has been highlighted here in two Research Fronts. Although the former has been selected for the second time, the focus shifts from the cathode research discussed in the 2020 Research Front report to the anode in 2022. In the field of advanced materials, self-powered wearable textiles, circularly polarized thermally activated delayed fluorescence emitters, and polyoxometalates are selected as hot frontiers. The convergence between data science and chemistry has been selected for the second time as one of the Top 10 Research Fronts, while mechanochemistry also makes the list.

Table 29: Top 10 Research Fronts in chemistry and materials science

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Single-atom catalysis	31	2439	2020.3
2	Self-powered wearable textiles	35	5457	2019.4
3	Zinc metal anode for aqueous batteries	22	4462	2019.3
4	Circularly polarized thermally activated delayed fluorescence emitters	29	4304	2019.2
5	Two-dimensional MXenes for lithium-sulfur batteries	17	2909	2019.1
6	Nanozymes	4	2495	2019.0
7	Catalytic asymmetric construction of axially chiral compounds	27	2904	2018.9
8	Mechanochemistry	17	2357	2018.9
9	Machine learning-assisted chemistry synthesis	35	4788	2018.8
10	Polyoxometalates	19	2319	2018.8

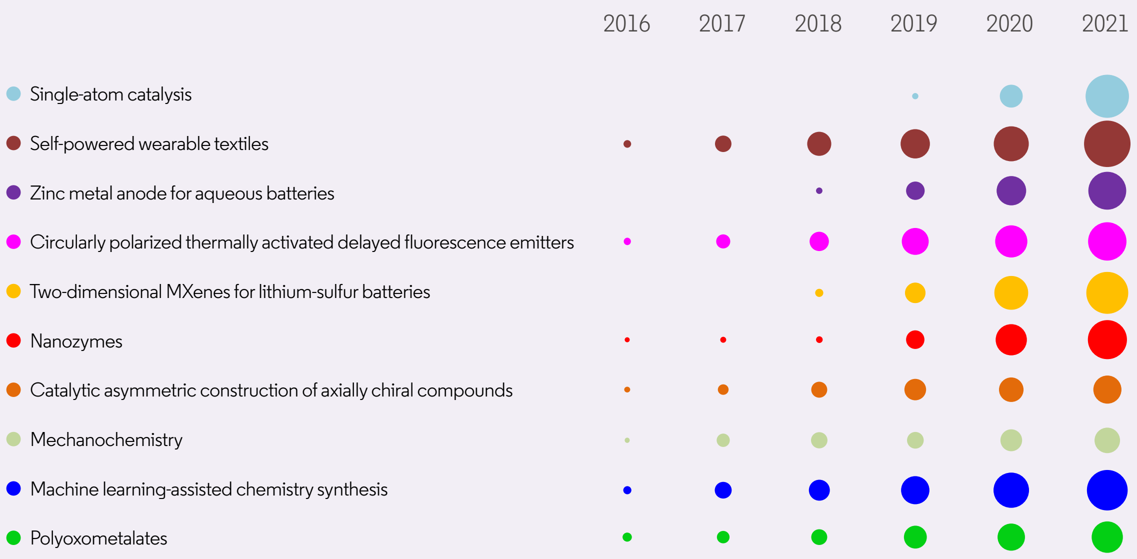


Figure 14: Citing papers of the Top 10 Research Fronts in chemistry and materials science

1.2 KEY HOT RESEARCH FRONT – "Nanozymes"

Nanozymes constitute a new concept proposed by China-based chemists. In 2007, Xiyun Yan at the Institute of Biophysics, Chinese Academy of Sciences, reported the first evidence that Fe_3O_4 nanoparticles have intrinsic horseradish peroxidase-mimicking activity. Since then, hundreds of nanomaterials have been found to mimic the catalytic activity of natural enzymes, and Yan's group defined such nanomaterials as nanozymes, meaning nanomaterials that exhibit intrinsic enzyme-like characteristics. As of 2022, more than 1,100 nanozymes have been reported and can be classified by natural enzymes' rules as oxidoreductases, hydrolases, lyases, and isomerases. Some peroxidase or superoxidedismutase nanozymes have shown catalytic activities close to or even higher than those of their natural counterparts.

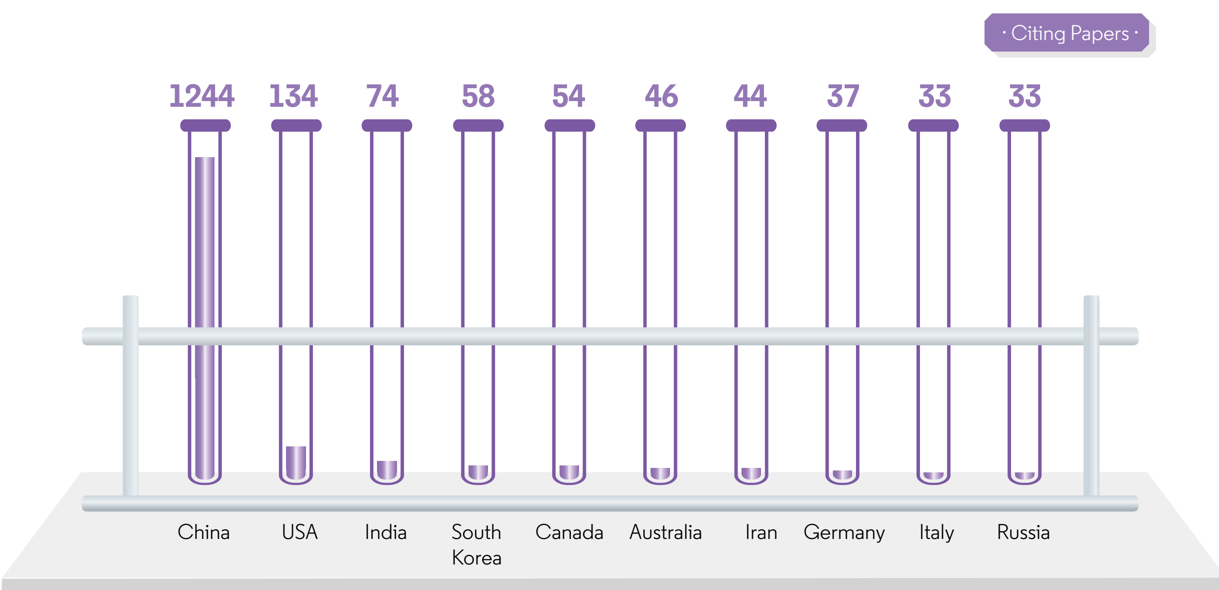
As mentioned above, Chinese scientists have played a leading role in the progress of basic research and applications in the field of nanozymes. The four highly cited papers constituting this Research Front were published in *Chemical Society Reviews*, *Chemical Reviews*, *and Accounts of Chemical Research*, which are highly regarded journals providing authoritative reviews of important recent research in chemistry. Two of the four papers are from Yan and her collaborators -- the latter based at the University of Wisconsin, Madison (USA), Shenzhen University (China), and Beijing Institute of Technology (China). These two papers review progress in the systematic design and construction of functionally specific nanozymes, the standardization of nanozymes research, and the exploration of their applications for replacing natural enzymes in biomedical science.

One of these papers, from Xiaogang Qu at Changchun Institute of Applied Chemistry, Chinese Academy of Sciences (China) and his collaborator at Nanjing Forestry University (China), introduces recent research progress on nanozymes in the fields of biosensing, environmental protection, and disease treatments. Another core paper, from Hui Wei and his colleague at Nanjing University (China) covers the broad applications of nanozymes from biomedical analysis and imaging to theranostics and environmental protection.

As shown in Table 30, China has published the greatest number of citing papers in this field, a total far exceeding that of the other listed nations. Among the Top 10 institutions producing citing papers, nine are based in China – in fact, the top six institutions are situated in the nation, demonstrating that China can boast a very active and influential group of researchers in the field of nanozymes.

Table 30: Top countries and institutions producing citing papers in the Research Front "Nanozymes"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	1244	74.2%	1	Chinese Academy of Sciences	China	244	14.5%
2	USA	134	8.0%	2	Jilin University	China	61	3.6%
3	India	74	4.4%	3	Nanjing University	China	57	3.4%
4	South Korea	58	3.5%	4	University of Science and Technology of China	China	56	3.3%
5	Canada	54	3.2%	5	Tianjin University	China	50	3.0%
6	Australia	46	2.7%	6	Zhengzhou University	China	42	2.5%
7	Iran	44	2.6%	7	Southwest University	China	37	2.2%
8	Germany	37	2.2%	7	University of Waterloo	Canada	37	2.2%
9	Italy	33	2.0%	9	Shanghai Jiao Tong University	China	36	2.1%
9	Russia	33	2.0%	10	Southeast University	China	34	2.0%



1.3 KEY HOT RESARCH FRONT – "Machine learning-assisted chemistry synthesis"

The synthesis of new molecules has always been a largely manual process, not only requiring an investment of time and effort from expert chemists but also occasionally raising concerns regarding issues of safety. The promise of a machine capable of using human-like intelligence to automatically synthesize large numbers of molecules has long been pursued by chemists. The time is now at hand, as the emergence of machine learning methods has facilitated rapid advances in many fields of science. This series of Research Fronts reports have tracked this new paradigm of synthesis in recent years, as "machine learning predictions of molecular properties" was selected as one of the Top 10 Research Fronts in chemistry and materials science in 2019. This year, the field's evolution is represented by the hot Research Front named "machine learning-assisted chemistry synthesis."

The 35 highly cited papers constituting the core of this Research Front are mainly on reaction prediction and automation. Both rules-based methods -- such as Chematica software developed by the Polish Academy of Sciences, the University of Warsaw (Poland), and Ulsan National Institute of Science and Technology (South Korea) -- and natural language processing-based methods, including the Molecular Transformer model developed by IBM Research-Europe and the University of Cambridge (UK), are highlighted in predicting synthetic routes, reactivity, and outcomes of reactions. The most-cited core paper concerns planning retrosynthetic pathways with deep neural networks and is coauthored by researchers at the University of Münster (Germany) and Shanghai University (China). Both automated synthesis machines, such as Automated Synthesizers developed by the University of Illinois (USA) and the Chemputer system developed by the University of Glasgow (UK) and autonomous laboratories, such as the robotic synthesis platform developed by MIT (USA) and the mobile robotic chemist developed by the University of Liverpool (UK) are discussed in the field of automation.

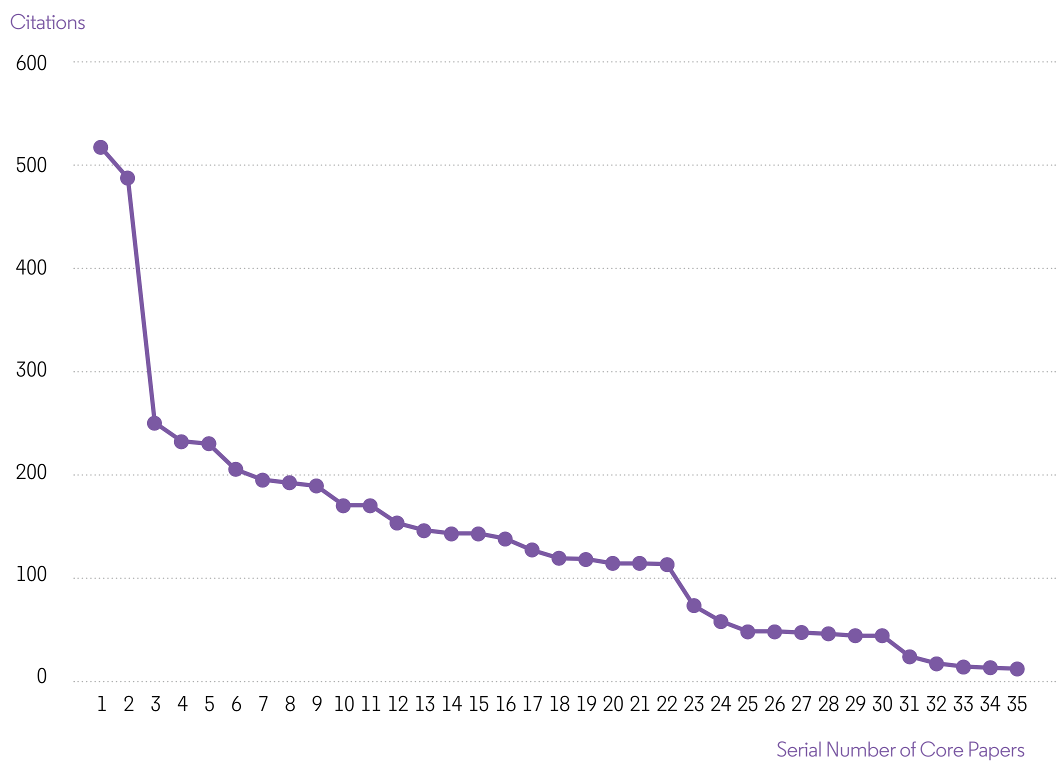


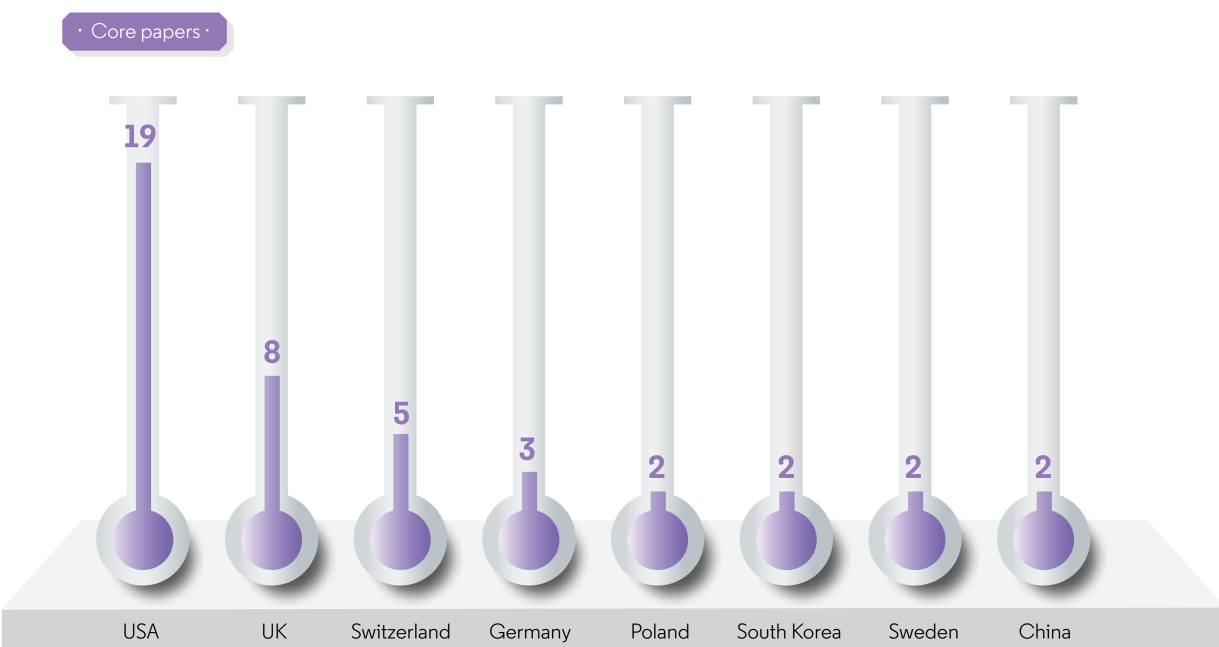
Figure15: Citation frequency distribution curve of core papers in the Research Front "Machine learning-assisted chemistry synthesis"

As shown in Table 31, more than half of the core papers are from institutions based in the USA. The UK and Switzerland have also contributed to several core papers, ranking in 2nd and 3rd place, respectively. These three countries are leaders in the field. The leading research institutions, such as MIT (USA), IBM Research-Europe (Switzerland), the University of Glasgow (UK), the University of Illinois (USA), and Ulsan National Institute of Science and Technology (South Korea), have not only published several highly cited papers but have also produced prototypes and even commercial products.

Table 31 Top countries and institutions producing core papers in the Research Front "Machine learning-assisted chemistry synthesis"

Country Ranking	Country	Core papers	Proportion
1	USA	19	54.3%
2	UK	8	22.9%
3	Switzerland	5	14.3%
4	Germany	3	8.6%
5	Poland	2	5.7%
5	South Korea	2	5.7%
5	Sweden	2	5.7%
5	China	2	5.7%

Institution Ranking	Institution	Affiliated Country	Core papers	Proportion
1	Massachusetts Institute of Technology	USA	8	22.9%
2	IBM Research – Europe	Switzerland	4	11.4%
3	University of Bern	Switzerland	3	8.6%
4	University of Illinois	USA	2	5.7%
4	University of Utah	USA	2	5.7%
4	University of Glasgow	UK	2	5.7%
4	AstraZeneca	UK/Sweden	2	5.7%
4	University of Warsaw	Poland	2	5.7%
4	Harvard University	USA	2	5.7%
4	Ulsan National Institute of Science and Technology	South Korea	2	5.7%
4	University of Münster	Germany	2	5.7%
4	Polish Academy of Sciences	Poland	2	5.7%
4	Shanghai University	China	2	5.7%

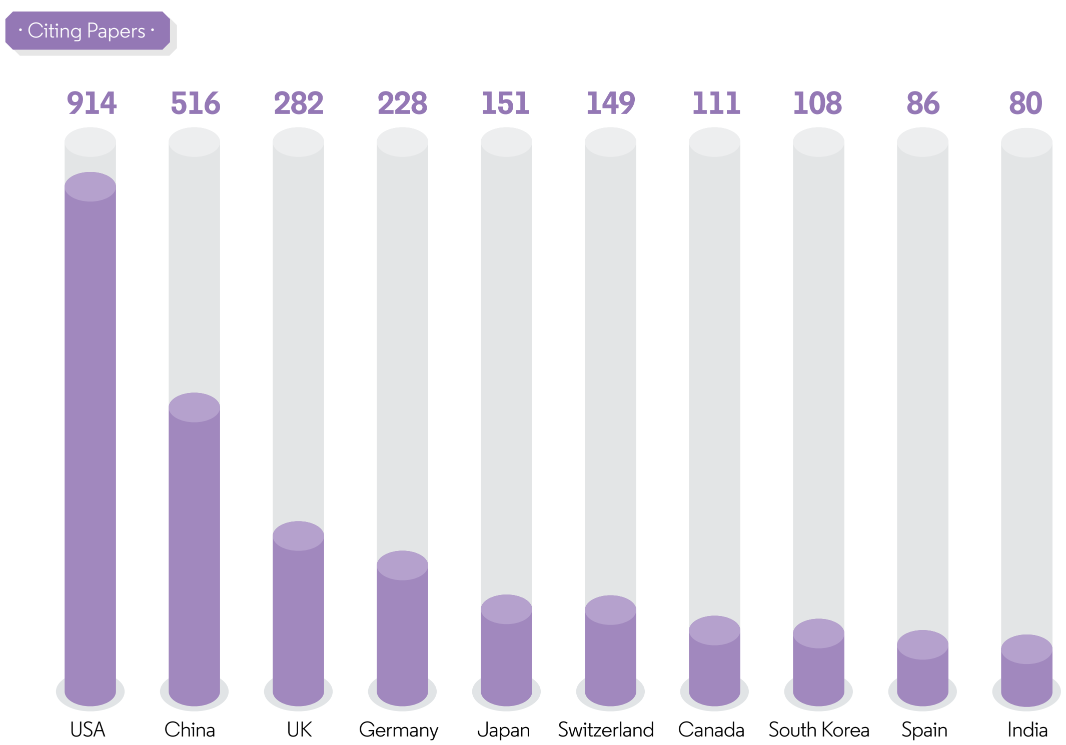


As shown in Table 32, the USA, with a cluster of leading institutionsin the field, has published the highest quantity of citing papers. China, which is ranked second, is also an active contributor. Canada, too, has advanced rapidly in recent years. Among the Top 10 institutions producing citing papers, four are based in the USA, being led in quantity in Table 32 by MIT, and two are situated in China: the Chinese Academy of Sciences and Tsinghua University.

Table 32 Top countries and institutions producing citing papers in the Research Front "Machine learning-assisted chemistry synthesis"

Country Ranking	Country	Citing Papers	Proportion
1	USA	914	36.1%
2	China	516	20.4%
3	UK	282	11.1%
4	Germany	228	9.0%
5	Japan	151	6.0%
6	Switzerland	149	5.9%
7	Canada	111	4.4%
8	South Korea	108	4.3%
9	Spain	86	3.4%
10	India	80	3.2%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Massachusetts Institute of Technology	USA	163	6.4%
2	Chinese Academy of Sciences	China	94	3.7%
3	University of Utah	USA	63	2.5%
4	Swiss Federal Institutes of Technology Domain	Switzerland	56	2.2%
5	University of Cambridge	UK	50	2.0%
6	Harvard University	USA	48	1.9%
7	French National Center for Scientific Research	France	44	1.7%
8	University of California Berkeley	USA	42	1.7%
9	Tsinghua University	China	41	1.6%
10	AstraZeneca	UK/Sweden	39	1.5%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

Three topics have been selected as the emerging Research Fronts in the field of chemistry and materials science (Table 33). These specialty areas involve energy materials, nano biomedical materials, and chemical detection technology. Research on perovskite materials has consistently figured among the hot Research Fronts of recent years. From 2013 to 2021, this research mainly focused on the solution of core fundamental problems, such as material preparation, efficiency, and stability improvement. In this latest report for 2022, a new focus on how large-scale fabrication is pushing commercialization of perovskite solar cells (PSCs) is selected as the emerging Research Front. The application of nanofibers in drug release and delivery, which is prepared by electrospinning technology, is selected as an emerging Research Front for the first time.

With the spreadof COVID-19, the rapid detection technology of the novel coronavirus was selected as the emerging Research Front in 2021, mainly focusing on virus-detection sensors using metal nanoparticles. In 2022, the emerging direction shifts to the rapid detection technology with electrochemical principle, such as by using printed electrodes to detect the by-products of immune marker enzymes to achieve rapid and intelligent detection of novel coronavirus in saliva.

Table 33: Emerging Research Fronts in chemistry and materials science

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Research on Core Fundamental Problems and Commercialization Technology of Perovskite Solar Cells	12	909	2020.8
2	Study on the Application of Nanofiber Prepared by Electrospinning Technology in Drug Release and Delivery	11	282	2020.8
3	Electrochemical Sensing Technology used in COVID-19 causative virus detection	5	321	2020.6

2.2 KEY EMERGING RESEARCH FRONT – "Research on Core Fundamental Problems and Commercialization Technology of Perovskite Solar Cells"

Compared with silicon-based solar cells, PSCs not only have a similar conversion efficiency, but also possess some special advantages, such as simple processing and manufacturing process, being being prepared into thin film shapes, low cost, and light weight. PSCs have become one of the most promising thin film photovoltaic (PV) materials, and may provide a jolt to the mature silicon solar cell market. Efficiency improvement, long-term stability and large-scale fabrication with large-area pushing commercialization are important challenges that PSCs need to face. This emerging Research Front is committed to exploring solutions to these challenges.

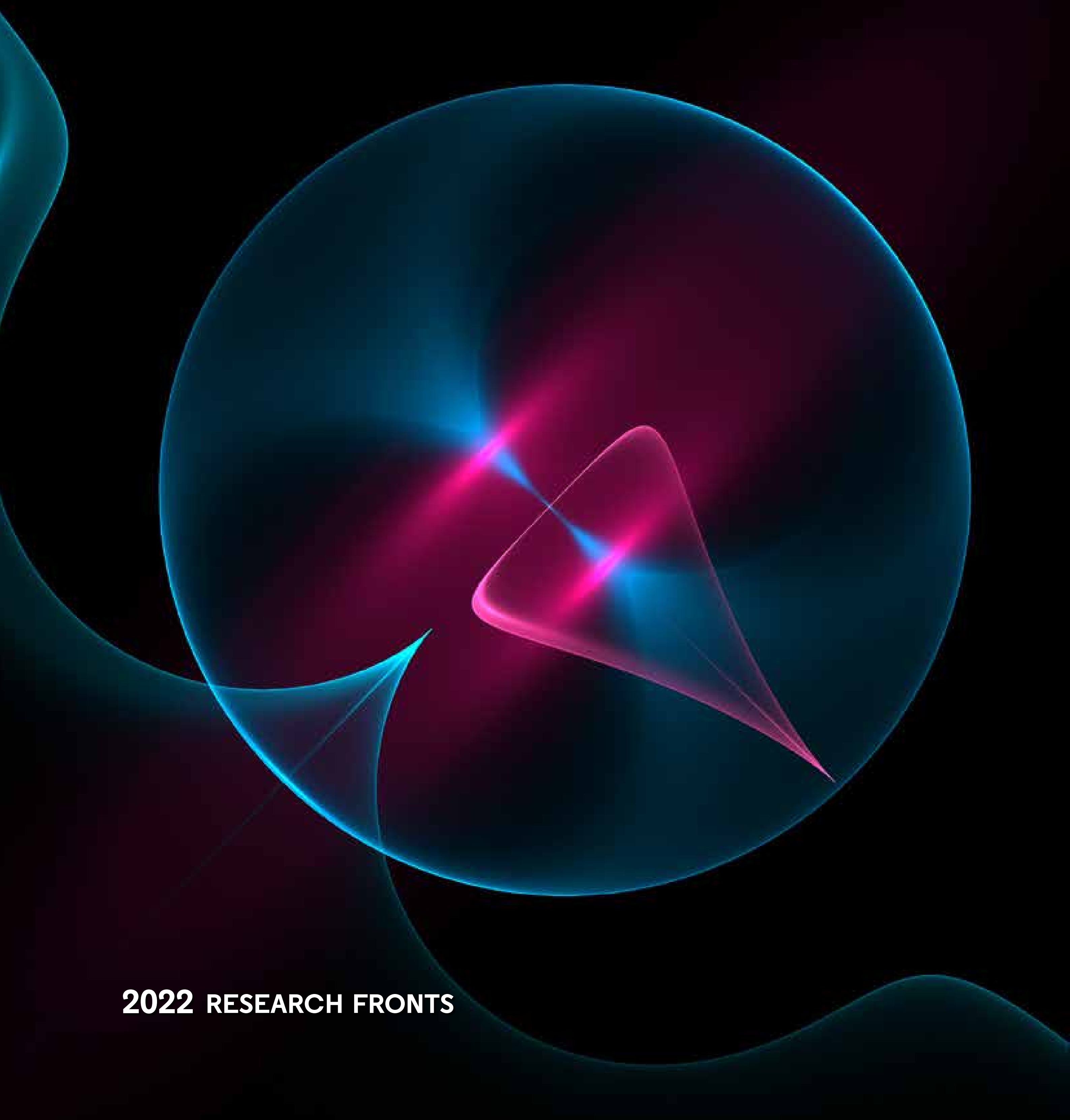
For the improvement of PSCs' efficiency, the technical solutions in this emerging Research Front mainly include: placing an electron transport layer (SnO_2) between the perovskite layer and the conductive layer and adding methylammonium lead bromide; introducing an anion engineering concept that uses the pseudo-halide anion formate (HCOO-) to suppress anion-vacancy defects that are present at grain boundaries and at the surface of the perovskite films, and to augment the crystallinity of the film.

For the improvement of the long-term stability of PSCs, the technical solutions in this emerging Research Front mainly include: employing a holistic interface stabilization strategy by modifying all the relevant layers and interfaces, namely the perovskite layer, charge transporting layers and device encapsulation, to improve the efficiency and stability of perovskite solar modules; adding slightly excessive AX (at a molar percentage of 0.25% to Pb^{2+} ions), where A is formamidinium or caesium and X is iodine, to the formamidinium-caesium mixed-cation perovskites.

The large-scale and scalable manufacturing of PSCs is the key to the cells' commercialization. The technical solutions in this emerging Research Front mainly include: using a room-temperature nonvolatile Lewis base additive, diphenyl sulfoxide (DPSO), in formamidinium-cesium (FACs) perovskite precursor solution; fabrication of inorganic $CsPbI_2Br$-based perovskite thin films with a well-defined $CsPbI_{3-x}Brx$ composition gradient in the surface region by a scalable, orthogonal processable spray-coating approach.

2022 RESEARCH FRONTS

PHYSICS



2022 RESEARCH FRONTS

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, high-energy physics, and theoretical physics. In condensed matter physics, Kagome metals, the magnetic topological insulators $MnBi_2Te_4$, and metal halide perovskite light-emitting diodes emerge as hot topics. The topological states of non-Hermitian systems have now ranked among the hot Research Fronts for three consecutive years, while high-temperature superconductivity in hydrogen-rich compounds under high pressure now extends its run the Top 10 to two years. In high-energy physics, measurement of the Muon anomalous magnetic moment has newly emerged, while flavor symmetries and lepton masses remain a hot topic. Research on tetraquark and pentaquark states has been selected as a hot front for five years, including the period from 2017 to 2020 and in 2022. In theoretical physics, scattering amplitudes in quantum field theory and teleparallel theories of gravity have attracted much attention.

Table 34: Top 10 Research Fronts in physics

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Kagome metals	34	2409	2020.2
2	Flavor symmetries and lepton masses	36	2001	2019.8
3	Studies of scattering amplitudes in quantum field theory	45	2518	2019.7
4	Measurement of the muon anomalous magnetic moment	34	3034	2019.6
5	Hidden-charm pentaquark and tetraquark states	45	4564	2019.4
6	Magnetic topological insulators $MnBi_2Te_4$	23	3449	2019.2
7	Topological states of non-Hermitian systems	34	6166	2018.9
8	Efficient metal halide perovskite light-emitting diodes	15	5398	2018.8
9	High-temperature superconductivity in hydrogen-rich compounds under high pressure	21	3221	2018.8
10	Teleparallel theories of gravity	10	1976	2018.8

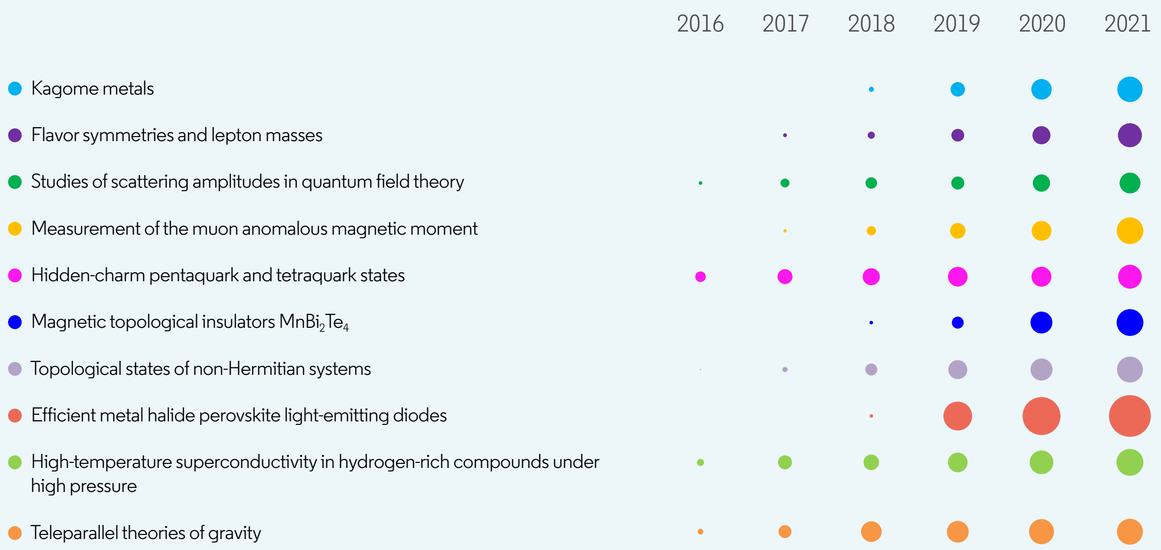


Figure 16: Citing papers for the Top 10 Research Fronts in physics

1.2 KEY HOT RESEARCH FRONT – "Magnetic topological insulators $MnBi_2Te_4$"

A topological insulator is a new state of matter discovered in recent years, whose surface is conductive, but the interior is insulative. Topological matter and topological materials constitute one of the most important and rapidly developing topics in condensed physics since the theoretical prediction of two-dimensional topological insulators in 2005 and their experimental demonstration in 2007. New forms of topological matter have been continuously discovered, such as topological semimetals, topological superconductors, and high-order topological insulators.

The interactions between topology and magnetism can generate a variety of exotic topological quantum states in materials. Therefore, magnetic topological insulators have attracted growing interest. $MnBi_2Te_4$ was experimentally demonstrated to be an intrinsic magnetic topological insulator in 2019, and the $MnBi_2Te_4$ family of materials has emerged as a hot research focus and has seen important progress, such as high-temperature quantum anomalous Hall effect and high Chern number quantum anomalous Hall effect. At present, research on magnetic topological insulators is blooming and will promote the development of next-generation electronic applications, including low-energy spintronics and topological quantum computing.

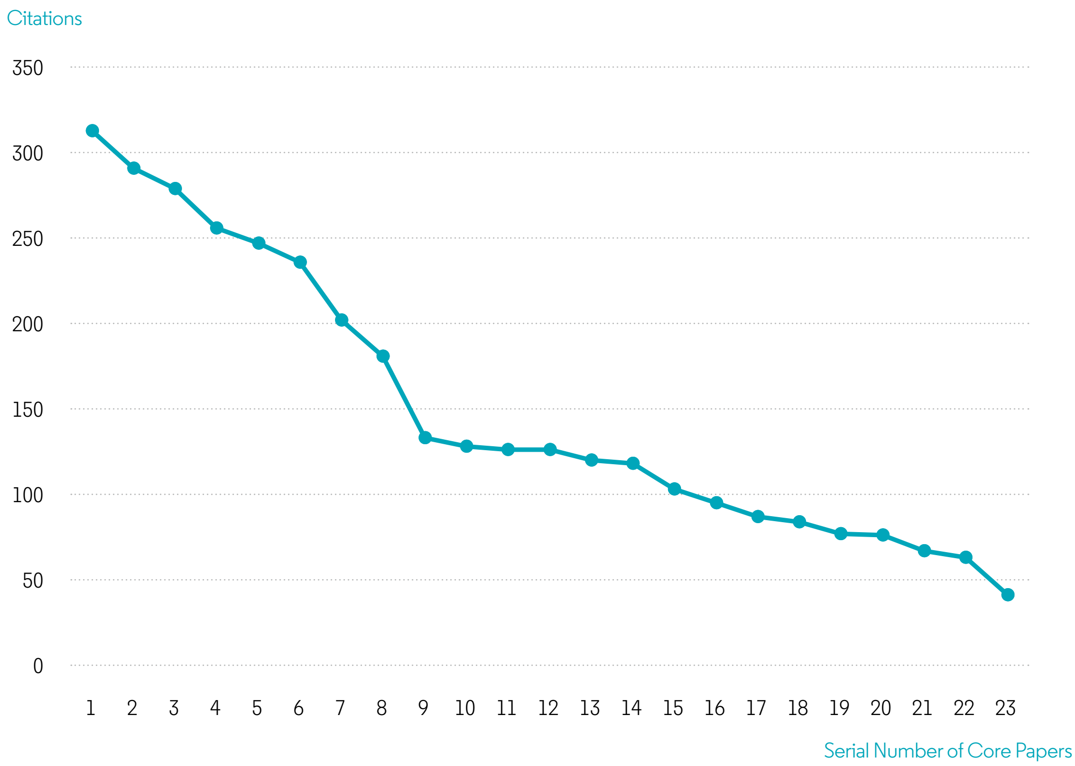


Figure 17: Citation frequency distribution curve of core papers in the Research Front "Magnetic topological insulators $MnBi_2Te_4$"

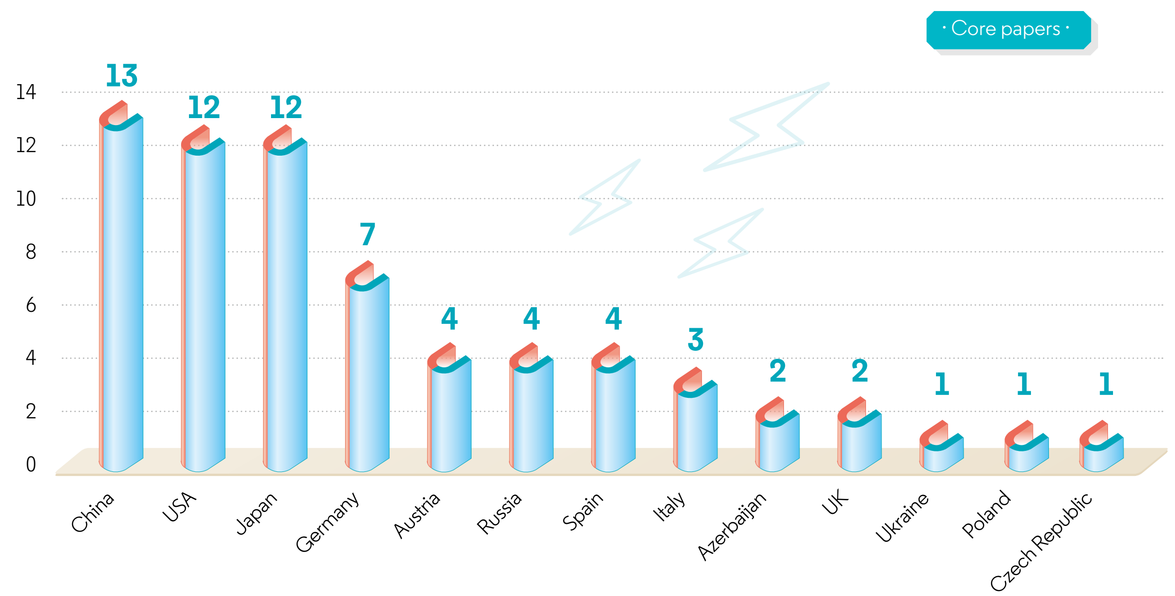
Regarding the citation frequency of individual core papers (Figure 17): a paper published by Fudan University and its collaborators reported the realization of quantum anomalous Hall effect in $MnBi_2Te_4$, and has recorded the highest citation total of all the core papers, now exceeding 300. Four 2019 papers focusing on research into topological quantum states in the $MnBi_2Te_4$ systems were published by coauthors representing Tsinghua University (China), the Centro Mixto CSIC-UPV/EHU (Spain), and Nanjing University (China), and have also attracted high rates of citation. In addition, a review published by RIKEN (Japan) on magnetic topological insulators has currently logged more than 250 citations.

China, the USA, and Japan are the most active countries in this front. Authors based in these countries participated in 13, 12, and 12 core papers, respectively (Table 35), accounting for 56.5%, 52.2%, and 52.2% of the total. Germany, Spain, Austria, and Russia also demonstrate strong performance. On the list of top institutions, Germany is host to three, while China, Russia, Spain, and the USA contain two each, and Japan and Austria each claim one. The Chinese Academy of Sciences and RIKEN contributed the highest numbers of core papers as individual organizations.

Table 35: Top countries and institutions producing core papers in the Research Front "Magnetic topological insulators $MnBi_2Te_4$"

Country Ranking	Country	Core Papers	Proportion
1	China	13	56.5%
2	USA	12	52.2%
2	Japan	12	52.2%
4	Germany	7	30.4%
5	Austria	4	17.4%
5	Russia	4	17.4%
5	Spain	4	17.4%
8	Italy	3	13.0%
9	Azerbaijan	2	8.7%
9	UK	2	8.7%
11	Ukraine	1	4.3%
11	Poland	1	4.3%
11	Czech Republic	1	4.3%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Chinese Academy of Sciences	China	7	30.4%
2	Riken	Japan	6	26.1%
3	Tsinghua University	China	5	21.7%
3	Max Planck Society	Germany	5	21.7%
5	Dresden University of Technology	Germany	4	17.4%
5	Tomsk State University	Russia	4	17.4%
5	St Petersburg State University	Russia	4	17.4%
5	Helmholtz Association	Germany	4	17.4%
5	Basque Foundation for Science	Spain	4	17.4%
5	University of the Basque Country	Spain	4	17.4%
5	Johannes Kepler University Linz	Austria	4	17.4%
5	University College London	USA	4	17.4%
5	Lawrence Berkeley National Laboratory	USA	4	17.4%

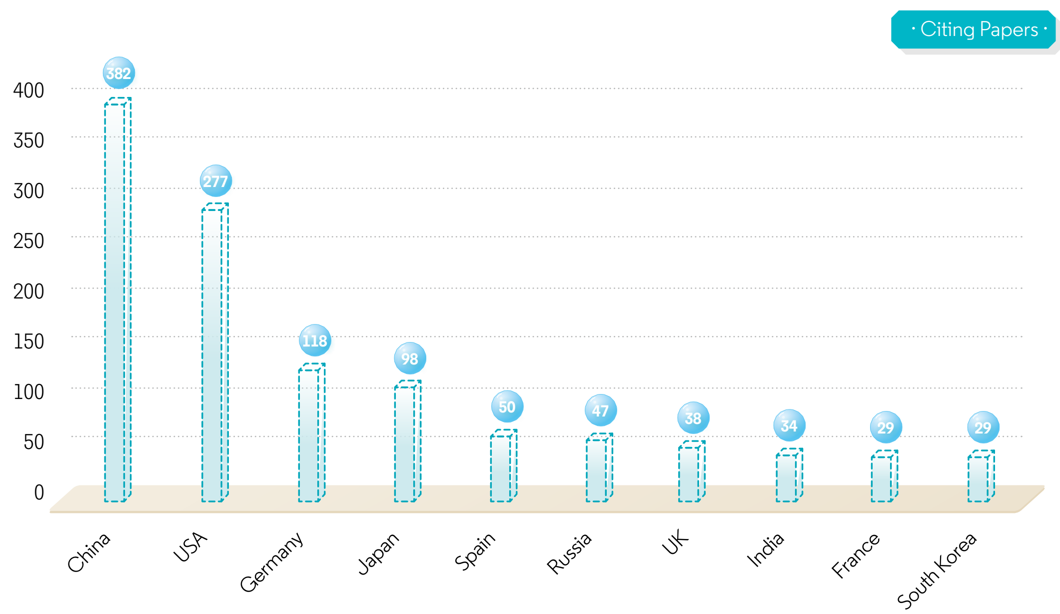


In terms of papers that cite this front's core literature (Table 36), China and the USA are again the most prolific countries, with paper counts far exceeding those of other nations. Germany, Japan, and Spain rank 3rd to 5th. Among the top institutions, the Chinese Academy of Sciences published the most citing papers, followed by the Max Planck Society, Tsinghua University, Peking University, and the Oak Ridge National Laboratory. On the list of citing institutions, five of the top entities are based in China, while the USA and Germany are host to two each, and one is located in Spain.

Table 36: Top countries and institutions producing citing papers in the Research Front "Magnetic topological insulators $MnBi_2Te_4$"

Country Ranking	Country	Citing Papers	Proportion
1	China	382	47.0%
2	USA	277	34.1%
3	Germany	118	14.5%
4	Japan	98	12.1%
5	Spain	50	6.2%
6	Russia	47	5.8%
7	UK	38	4.7%
8	India	34	4.2%
9	France	29	3.6%
9	South Korea	29	3.6%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	139	17.1%
2	Max Planck Society	Germany	47	5.8%
2	Tsinghua University	China	47	5.8%
4	Peking University	China	44	5.4%
4	Oak Ridge National Laboratory	USA	44	5.4%
6	Nanjing University	China	42	5.2%
7	University of Science & Technology of China	China	40	4.9%
8	Helmholtz Association	Germany	34	4.2%
9	Pennsylvania State University	USA	32	3.9%
10	University of the Basque Country	Spain	30	3.7%



1.3 KEY HOT RESARCH FRONT– "Efficient metal halide perovskite light-emitting diodes"

Light-emitting diodes (LEDs) are semiconductor optoelectronic devices widely used in lighting, display, and energy saving for their advantages of low energy consumption, long life, small size, high reliability, and excellent color rendering indexes. With the increasing demand in lighting and display, research and development of new light-emitting materials and devices has attracted much attention. In recent years, metal halide perovskite materials have become emerging light-emitting materials due to their excellent photoelectric properties. Consequently, metal halide perovskite

LEDs (PeLEDs) has gained prominence as a hot topic.

PeLEDs demonstrating room-temperature electroluminescence were developed by Cambridge University in 2014, attracting great attention in the research community. External quantum efficiency (EQE) is an important metric of the photoelectric conversion efficiency of LEDs. EQEs of near-infrared, red, and green PeLEDs have reached over 20% in recent years. However, the EQE of blue-emission PeLEDs needs further advancement. Recently, blue PeLEDs have been broadly studied and have shown significant progress.

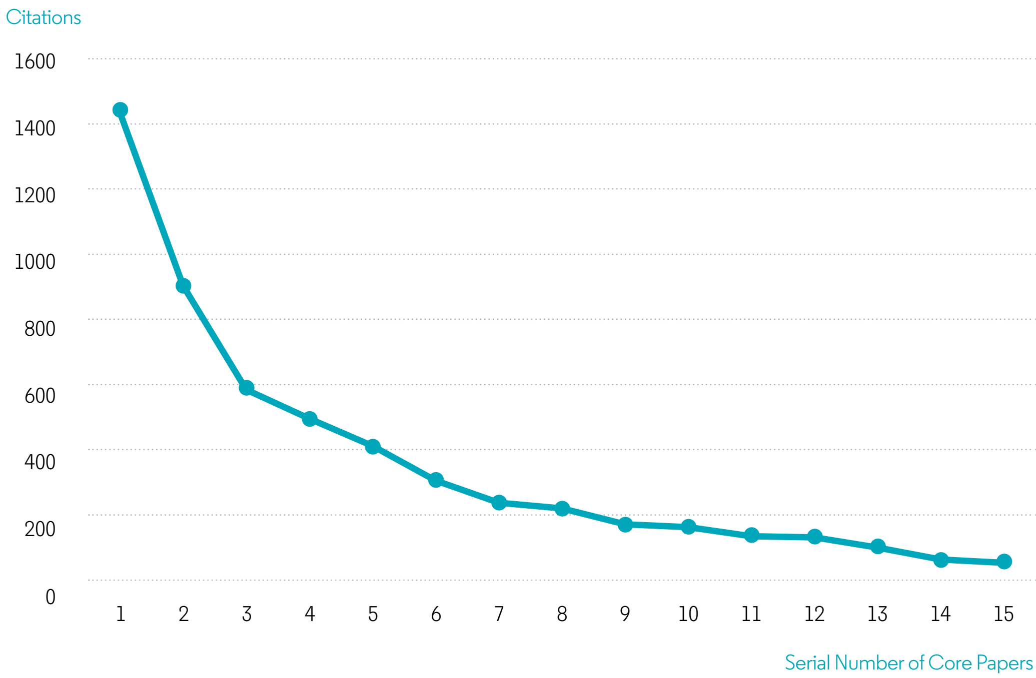


Figure 18: Citation frequency distribution curve of core papers in the Research Front "Efficient metal halide perovskite light-emitting diodes"

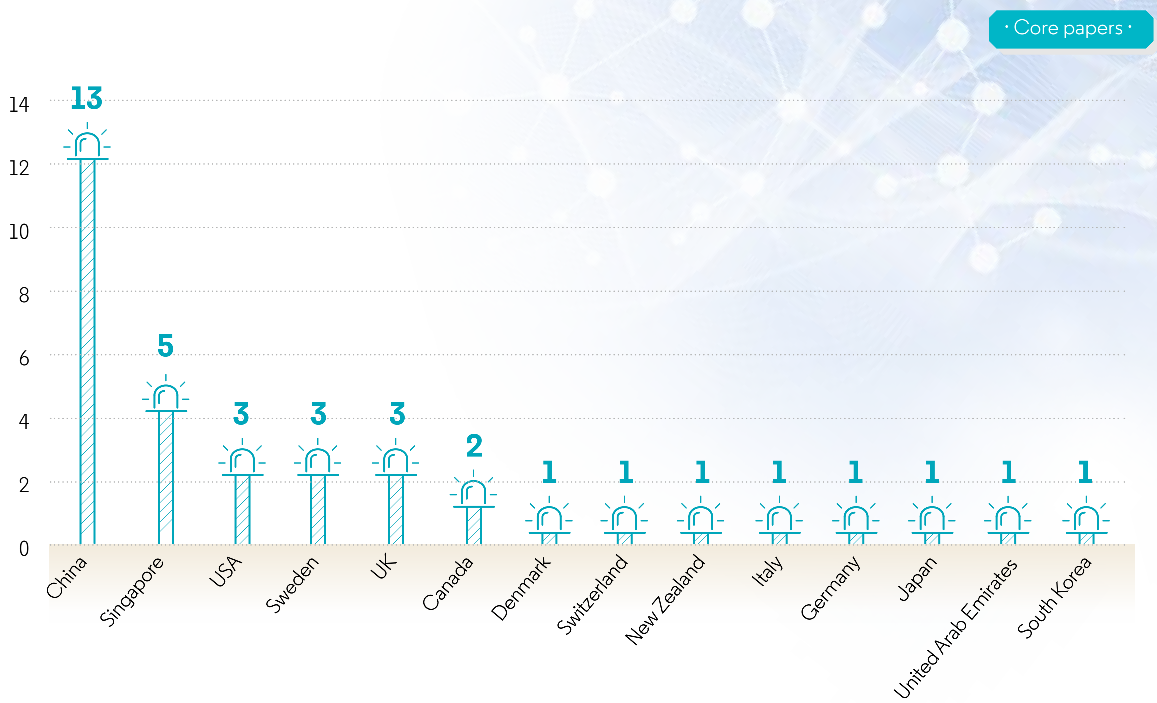
As for the citation frequency of individual core papers (Figure 18), a 2018 paper published by researchers at Huaqiao University in China and their collaborators reported green PeLEDs with an EQE of 20.3%. This paper has garnered the highest citation count of more than 1,400 -- far surpassing others in the core. In this front, the papers that reported near-infrared PeLEDs with an EQE of 20.3%, red PeLEDs with an EQE of 21.3%, and near-infrared PeLEDs with an EQE of 21.6%, have respectively earned citation counts of 903, 585 and 495 at this writing. Publications on blue PeLEDs with improving EQEs, such as 1.5% and 9.5%, and spectra stable blue PeLEDs have also been widely cited

China is the most active country in this front, participating in 13 core papers, and accounting for 86.7% of the total (Table 37). Singapore, the USA, Sweden, and the UK also demonstrate notable performance. Nanjing University of Technology in China contributes the highest number of core papers among individual organizations, followed by Nanyang Technological University in Singapore, Linköping University in Sweden, the Chinese Academy of Sciences, the University of Cambridge, and Northwestern Polytechnical University in China. Among the top institutions, five are based in China, while Singapore, Sweden, the UK, and Canada are each home to one.

Table 37: Top countries and institutions producing core papers in the Research Front "Efficient metal halide perovskite light-emitting diodes"

Country Ranking	Country	Core Papers	Proportion
1	China	13	86.7%
2	Singapore	5	33.3%
3	USA	3	20.0%
3	Sweden	3	20.0%
3	UK	3	20.0%
6	Canada	2	13.3%
7	Denmark	1	6.7%
7	Switzerland	1	6.7%
7	New Zealand	1	6.7%
7	Italy	1	6.7%
7	Germany	1	6.7%
7	Japan	1	6.7%
7	United Arab Emirates	1	6.7%
7	South Korea	1	6.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Nanjing University of Technology	China	5	33.3%
2	Nanyang Technological University	Singapore	4	26.7%
3	Linköping University	Sweden	3	20.0%
3	Chinese Academy of Sciences	China	3	20.0%
3	University of Cambridge	UK	3	20.0%
3	Northwestern Polytechnical University	China	3	20.0%
7	Nanjing University	China	2	13.3%
7	Zhejiang University	China	2	13.3%
7	University of Toronto	Canada	2	13.3%

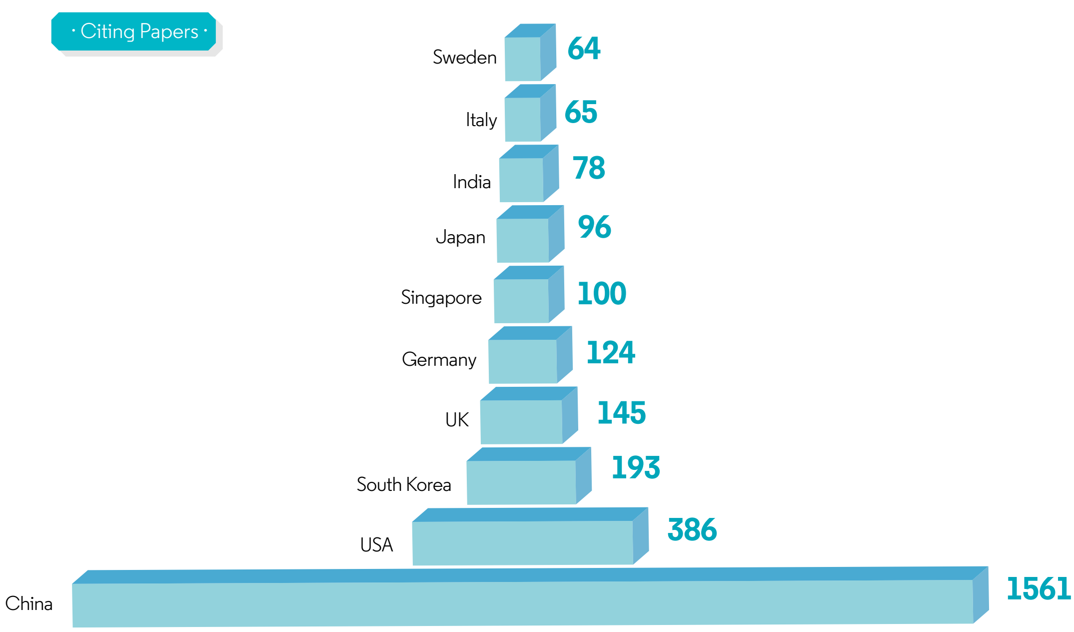


Analysis of the citing papers (Table 38) indicates that China is the most active country, participating in 1,561 papers and accounting for 64.6% of the total. The USA, South Korea, and the UK also perform well. Among the top citing institutions, eight are based in China. The Chinese Academy of Sciences published the most citing papers, accounting for 12.2% of the total, followed by Suzhou University and Jilin University in China.

Table 38: Top countries and institutions producing citing papers in the Research Front "Efficient metal halide perovskite light-emitting diodes"

Country Ranking	Country	Citing Papers	Proportion
1	China	1561	64.6%
2	USA	386	16.0%
3	South Korea	193	8.0%
4	UK	145	6.0%
5	Germany	124	5.1%
6	Singapore	100	4.1%
7	Japan	96	4.0%
8	India	78	3.2%
9	Italy	65	2.7%
10	Sweden	64	2.6%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	296	12.2%
2	Suzhou University	China	101	4.2%
3	Jilin University	China	97	4.0%
4	Huazhong University of Science & Technology	China	78	3.2%
5	Nanyang Technological University	Singapore	76	3.1%
6	University of Cambridge	UK	70	2.9%
7	Zhengzhou University	China	69	2.9%
8	Nanjing University of Technology	China	64	2.6%
9	Southern University of Science Technology	China	62	2.6%
10	Zhejiang University	China	61	2.5%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN PHYSICS

Two topics in physics are highlighted as emerging Research Fronts, namely "Two-dimensional $MoSi_2N_4$ materials" and "Black hole information paradox and entanglement entropy".

Table 39: Emerging Research Front in physics

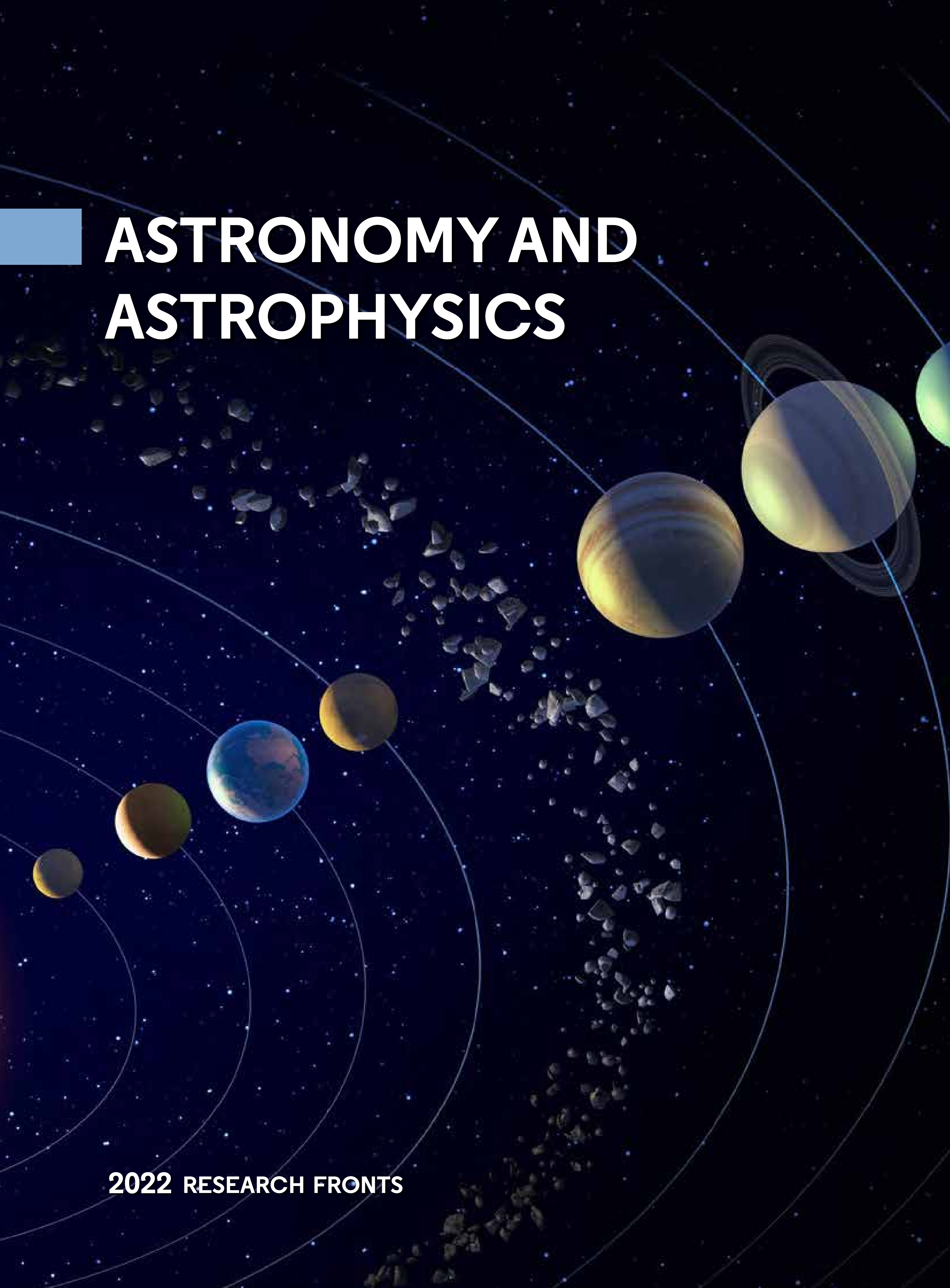
Rank	Emerging Research Front	Core papers	Citation	Mean Year of Core Papers
1	Two-dimensional $MoSi_2N_4$ materials	10	294	2020.9
2	Black hole information paradox and entanglement entropy	42	1683	2020.6

2.2 KEY EMERGING RESEARCH FRONT – "Two-dimensional $MoSi_2N_4$ materials"

In recent years, two-dimensional van der Waals materials have been widely studied for their unique optical, electrical, and mechanical properties, and have constantly been the basis for hot and emerging fronts. These specialty areas have included twisted bilayer graphenes and two-dimensional van der Waals magnets. Two-dimensional van der Waals materials, including graphene, transition metal sulfide, and phosphorene, have their own three-dimensional parent materials. Hence, the synthesis of two-dimensional van der Waals materials without parent materials in nature will expand the applications of these two-dimensional materials.

In 2020, a research team at the Institute of Metal Research, Chinese Academy of Sciences, reported a new two-dimensional van der Waals material, $MoSi_2N_4$, without known parent materials. The discovery expanded the family of these materials, opened a new approach for synthesizing two-dimensional van der Waals materials, and fascinated scientists. In this front, a paper published by researchers of the Institute of Metal Research achieved the highest citation total, currently at 101. Other core papers in this front mainly focus on research on the properties of $MoSi_2N_4$, including mechanical properties, thermal conductivity, piezoelectricity, photocatalysis, magnetism, and superconductivity.

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 this area focus on diverse topics, including gravitational waves, fast radio bursts, the relationship between black holes and dark matter, the properties of neutron stars, the map of the Milky Way, and the formation and evolution of stars, galaxies, and the universe. In general, the detection of gravitational waves and related research has had a far-reaching impact on astronomy and astrophysics. Many hot fronts pertain to this work, such as the study of the properties of black holes and neutron stars, as well as binary neutron star and binary black hole mergers. Large-scale simulations of stars, galaxies, and the universe have become a hot research topic. In addition, the observation and theoretical examination of mysterious fast radio bursts have been selected among the hot Research Fronts again for this 2022 survey. The large-scale scientific platforms continue to exert a very high influence, such as the phased and centralized outputs of the Parker Solar Probe (PSP) and Solar Orbiter missions. Research topics involving black holes, dark matter, and the formation of stars and planetary systems are still notably active and prominent.

Table 40: Top 10 Research Fronts in astronomy and astrophysics

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Early dark energy and Hubble tension	17	2291	2019.6
2	Heliophysics research using Parker Solar Probe and Solar Orbiter	28	2741	2019.3
3	Measurements of neutron stars with GW170817	45	7713	2019.1
4	Observational and characteristic research on fast radio bursts	49	6680	2018.9
5	Protoplanetary disks and their evolution	36	4563	2018.4
6	Observational and characteristic research on primordial black holes	35	5148	2018.1
7	Simulations of stars, galaxies, and the universe	35	7724	2017.8
8	Exploring the early Universe with spaceborne and ground-based observatories	26	4076	2017.8
9	Gaia building the most precise 3D map of the Milky Way	5	9284	2017.6
10	Multi-messenger observations of binary neutron star and binary black hole mergers	47	27244	2017.2

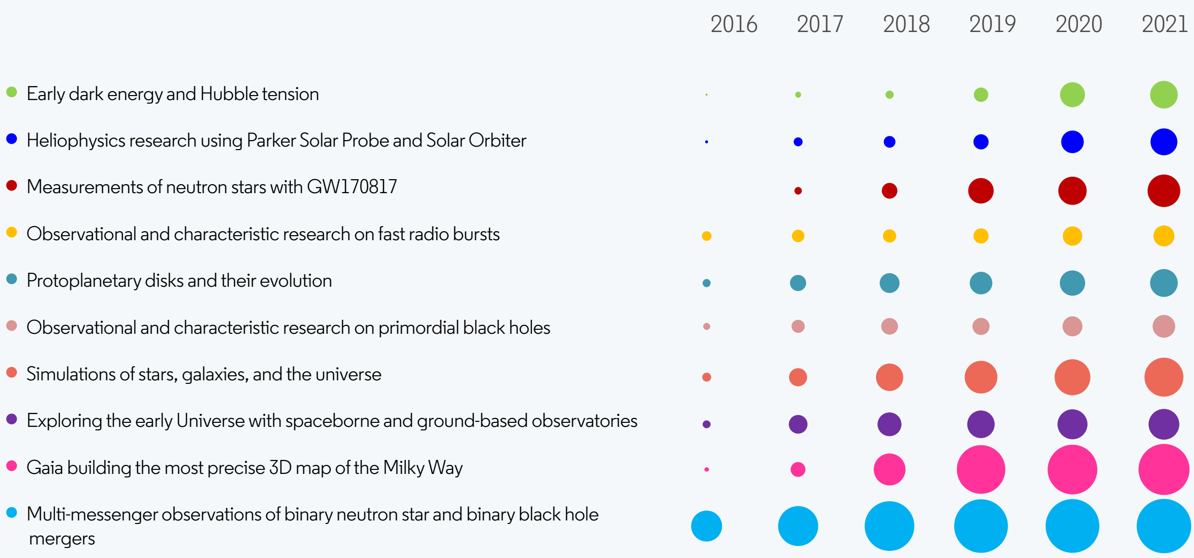


Figure 19: Citing papers for the Top 10 Research Fronts in astronomy and astrophysics

1.2 KEY HOT RESEARCH FRONT – "Heliophysics research using Parker Solar Probe and Solar Orbiter"

Through multi-band observations of the sun, solar-terrestrial space, and interplanetary space, scientists have revealed that the sun is the main source controlling and influencing the space environment of the heliosphere. Around the end of the 1990s, heliophysics research entered a period of rapid development, during which spaceborne observation dominated, and a series of solar spacecraft have achieved unprecedented improvement in both observation technologies and range of observation, opening an era of multi-band, full-time-domain, high-resolution, and high precision observation.

In August 2018, NASA successfully launched the Parker Solar Probe (PSP), whose main science goals are to change the understanding of the corona using a combination of *in situ* measurements and imaging techniques, to improve the understanding of the origin and evolution of the solar wind, and to make a significant contribution to the improvement of space weather event prediction capabilities. PSP will provide humanity with the closest-ever observations of a star. On the final three orbits of its nominal mission, PSP will pass within 6 million kilometers (8.86 solar radii) of the sun's surface. In February 2020, the European Space Agency's (ESA) Solar Orbiter, the world's first spacecraft to conduct close observations of the sun's polar regions, was successfully launched. Solar Orbiter's primary science goal is to study how the sun produces and dominates the heliosphere. Working together, Solar Orbiter's comprehensive suite of instruments and the NASA PSP's up-close view of the sun provide a never-before-seen global view of our stars.

The hot Research Front "Heliophysics research using Parker Solar Probe and Solar Orbiter " includes 28 core papers, discussing in depth the goals, objectives, and payloads of the PSP and Solar Orbiter missions, as well as a series of key findings based on their observational data. Four of the five most-cited core papers are related to the PSP, discussing the probe's overall objective, two of its science payloads -- including the FIELDS instrument suite and Solar Wind Electrons Alphas and Protons (SWEAP) -- and the discovery of low-latitude coronal holes as a key source of the slow solar wind and how it is accelerated. Other key breakthroughs from the core papers include the observation of large-scale solar energetic particle events, the detection of the solar origin of strong invisible coronal mass ejections, and the capture of transient plasma flows and jets in the solar corona.

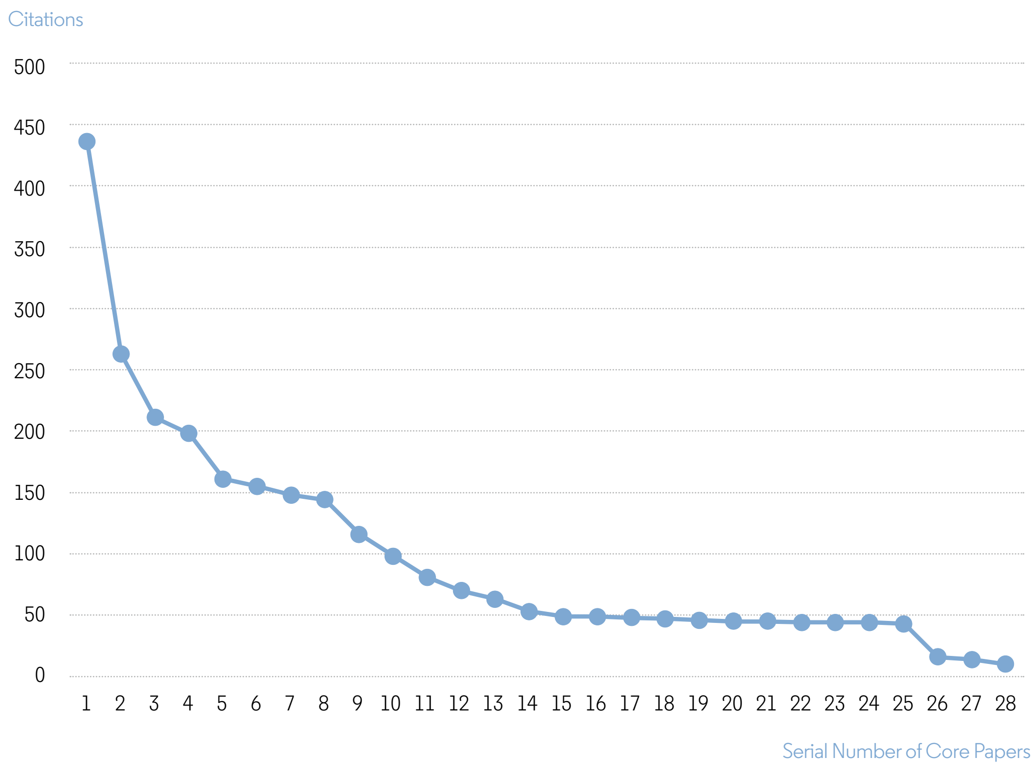


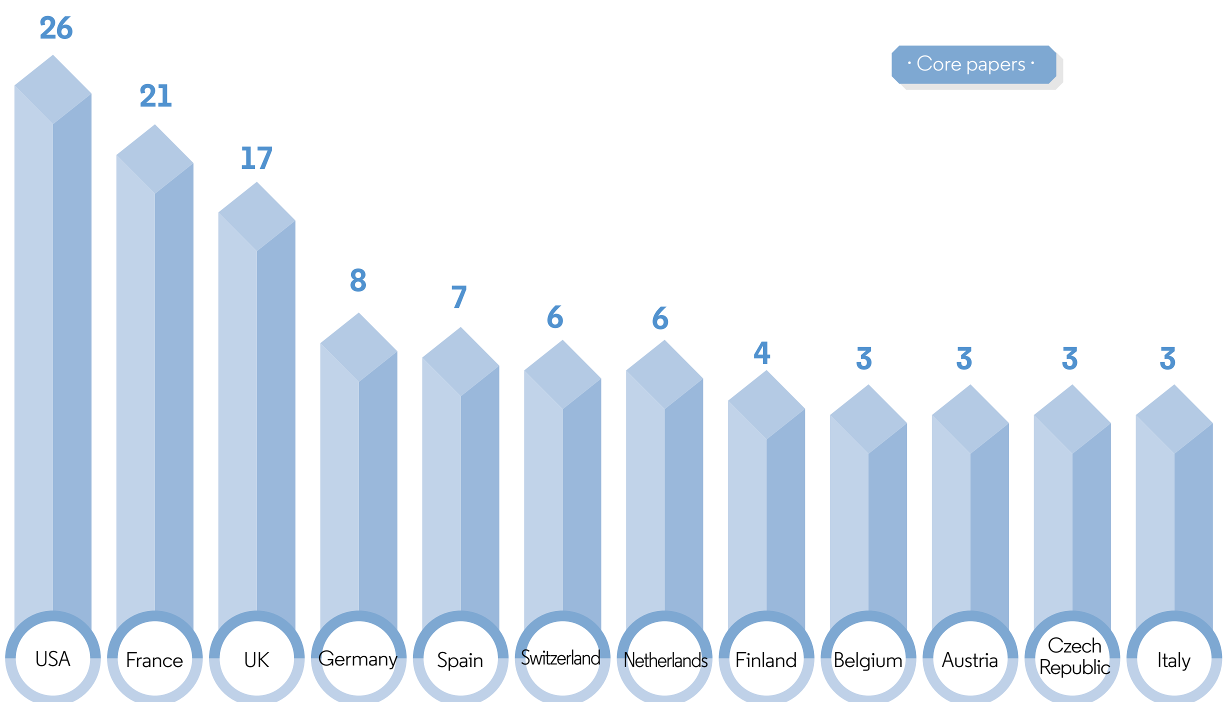
Figure 20: Citation frequency distribution curve of core papers in the Research Front "Heliophysics research using Parker Solar Probe and Solar Orbiter"

The USA, as the backer of the PSP and a participating country in the Solar Orbiter mission, contributes more than 90% of the core papers. As the lead organization behind the Solar Orbiter, the member states of the ESA are the most active contributors to this Research Front. Among the top contributing countries, all 11 are ESA member states except the USA. In terms of institutions, most top contributing institutions are the core participating institutions for both missions. NASA, as the lead agency of the PSP and the collaborative partner of the Solar Orbiter, ranks 1st in terms of the output of core papers. Since most of the core papers are the results of multi-national and multi-institutional cooperation, there is little difference in the number of core papers produced by the top contributing institutions.

Table 41: Top countries and institutions producing core papers in the Research Front "Heliophysics research using Parker Solar Probe and Solar Orbiter"

Country Ranking	Country	Core Papers	Proportion
1	USA	26	92.9%
2	France	21	75.0%
3	UK	17	60.7%
4	Germany	8	28.6%
5	Spain	7	25.0%
6	Switzerland	6	21.4%
6	Netherlands	6	21.4%
8	Finland	4	14.3%
9	Belgium	3	10.7%
9	Austria	3	10.7%
9	Czech Republic	3	10.7%
9	Italy	3	10.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	National Aeronautics & Space Administration (NASA)	USA	20	71.4%
1	University of California Berkeley	USA	20	71.4%
3	National Center for Scientific Research of France (CNRS)	France	18	64.3%
4	University of Michigan	USA	16	57.1%
5	Universite PSL	France	15	53.6%
6	Harvard University	USA	14	50.0%
6	Imperial College London	UK	14	50.0%
8	University of Colorado Boulder	USA	13	46.4%
9	University College London	UK	12	42.9%
9	Sorbonne University	France	12	42.9%

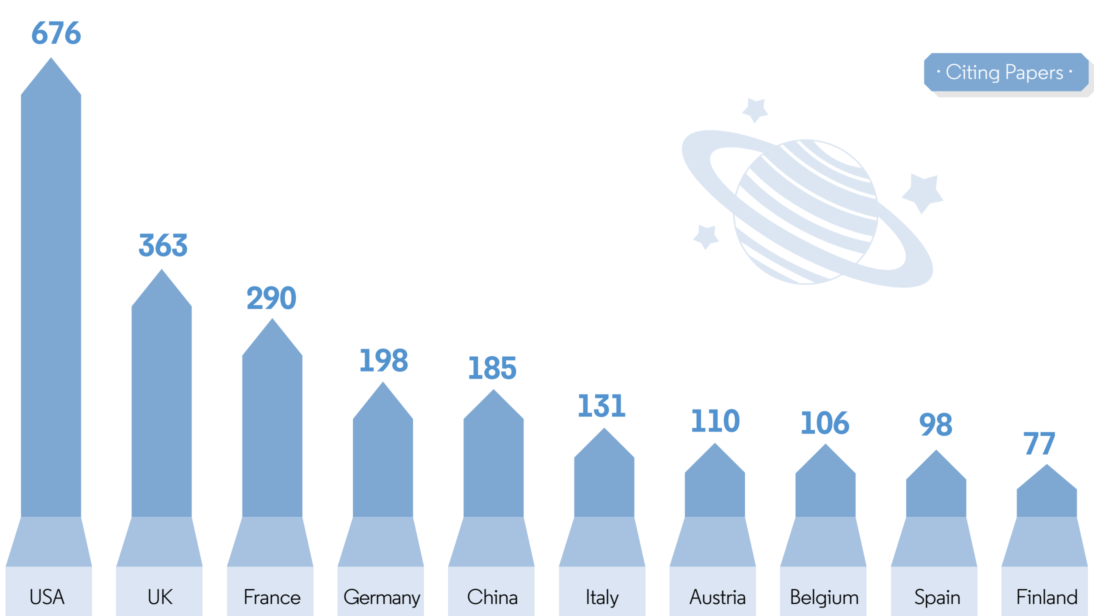


As for citing papers, the USA ranks 1st with more than half of the total citing publications. The UK, France, and Germany ranks 2nd, 3rd, and 4th, respectively. China ranks 5th with 185 citing papers, indicating that China has increasingly carried out follow-up studies in this specialty. Among the Top 10 citing institutions, US-based entities occupy four positions. Among French institutions, the National Center for Scientific Research of France, Sorbonne University, and Paris Sciences et Lettres University rank 2nd, 6th, and 8th, respectively. The Chinese Academy of Sciences contributes a considerable amount of citing papers using public data from two space missions and ranks 10th.

Table 42: Top countries and institutions producing citing papers in the Research Front "Heliophysics research using Parker Solar Probe and Solar Orbiter"

Country Ranking	Country	Citing Papers	Proportion
1	USA	676	59.2%
2	UK	363	31.8%
3	France	290	25.4%
4	Germany	198	17.3%
5	China	185	16.2%
6	Italy	131	11.5%
7	Austria	110	9.6%
8	Belgium	106	9.3%
9	Spain	98	8.6%
10	Finland	77	6.7%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	National Aeronautics & Space Administration (NASA)	USA	309	27.1%
2	National Center for Scientific Research of France (CNRS)	France	257	22.5%
3	University of California Berkeley	USA	234	20.5%
4	Imperial College London	UK	174	15.2%
5	University College London	UK	170	14.9%
6	Sorbonne University	France	169	14.8%
7	University of Michigan	USA	165	14.4%
8	Universite PSL	France	151	13.2%
9	University of Colorado Boulder	USA	144	12.6%
10	Chinese Academy of Sciences	China	137	12.0%



1.3 KEY HOT RESEARCH FRONT – "Simulations of stars, galaxies, and the universe"

The standard model of cosmology posits that the mass-energy density of the universe is dominated by unknown forms of dark matter and dark energy. Testing this extraordinary scenario requires precise predictions for the formation of structure in the visible matter, which is directly observable as stars, diffuse gas, and accreting black holes. One of the biggest challenges in the field of theoretical astrophysics is to *ab initio* simulate the variety of galaxies observed throughout cosmic time, and for this purpose, various numerical models of the universe have been constructed to test current understanding of the formation and evolution of galaxies. At the same time, the similarities and differences between simulations and observations of galaxies in the real universe have been compared to further enhance our understanding of the process of galaxy formation.

The IllustrisTNG project is currently the most influential large-scale simulation of the evolution of the universe, and the development of the TNG (i.e., "the next generation") model and simulations were started in 2014. IllustrisTNG consists of several simulations, and each varies in its physical size, mass resolution, and complexity of the physics involved. Three physical simulation box sizes are employed: cubic volumes of roughly 50, 100, and 300 Mpc (megaparsec, equal to 3.26 million light years) side length, which are respectively referred to as TNG50, TNG100, and TNG300. These variations enable the study of the structural properties of galaxies, detailed structure of gas around galaxies, and galaxy clusters from different resolution levels. Since 2016, the IllustrisTNG collaboration has published many papers detailing the results of simulations in galaxy formation, evolution, and several different topics in cosmology.

The hot Research Front "Simulations of stars, galaxies and the universe" includes 35 core papers. The main body of these reports consists of a number of research results from the IllustrisTNG project, as well as several other computational universe models (e.g., MUFASA, Simba100, and BAHAMAS). Eight of the 10 most-cited core papers, from the IllustrisTNG collaboration, describe physical galaxy-formation models and their numerical details in IllustrisTNG simulations; the use of models to investigate the nonlinear correlation functions and power spectra of baryons, dark matter, galaxies, and halos at very large scales, as well as TNG100 and TNG300 simulations on massive galaxy populations; the stellar mass content of clusters; and the optical color and the elemental distribution of galaxies. By comparison with a large number of observations, the simulations have convincingly demonstrated that hydrodynamical simulations of structure formation at kilo-parsec spatial resolution can reasonably reproduce the fundamental properties and scaling relations of observed galaxies.

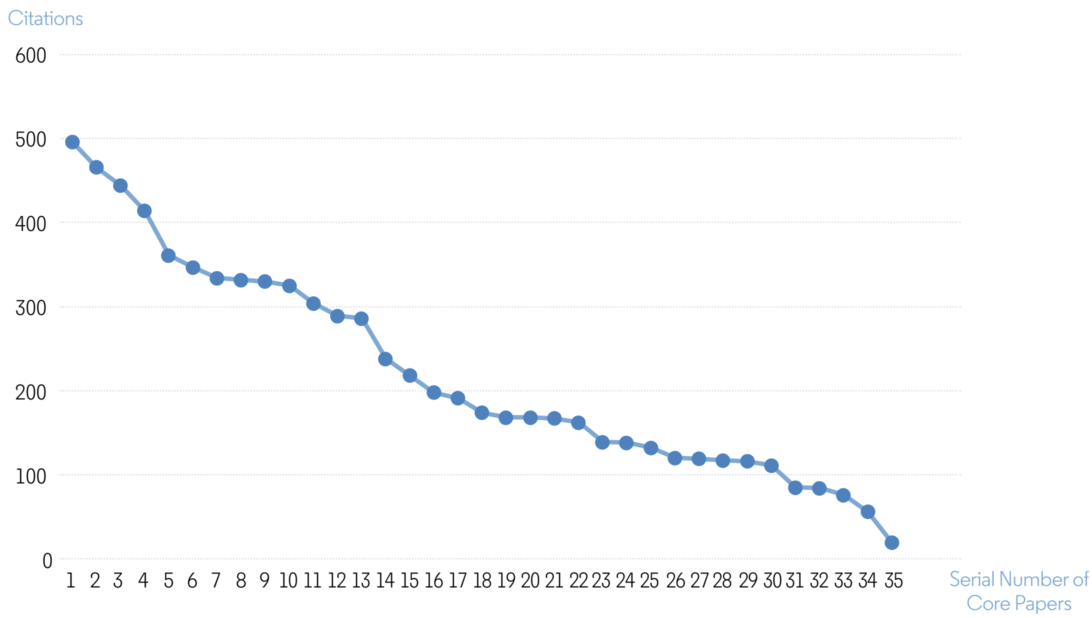


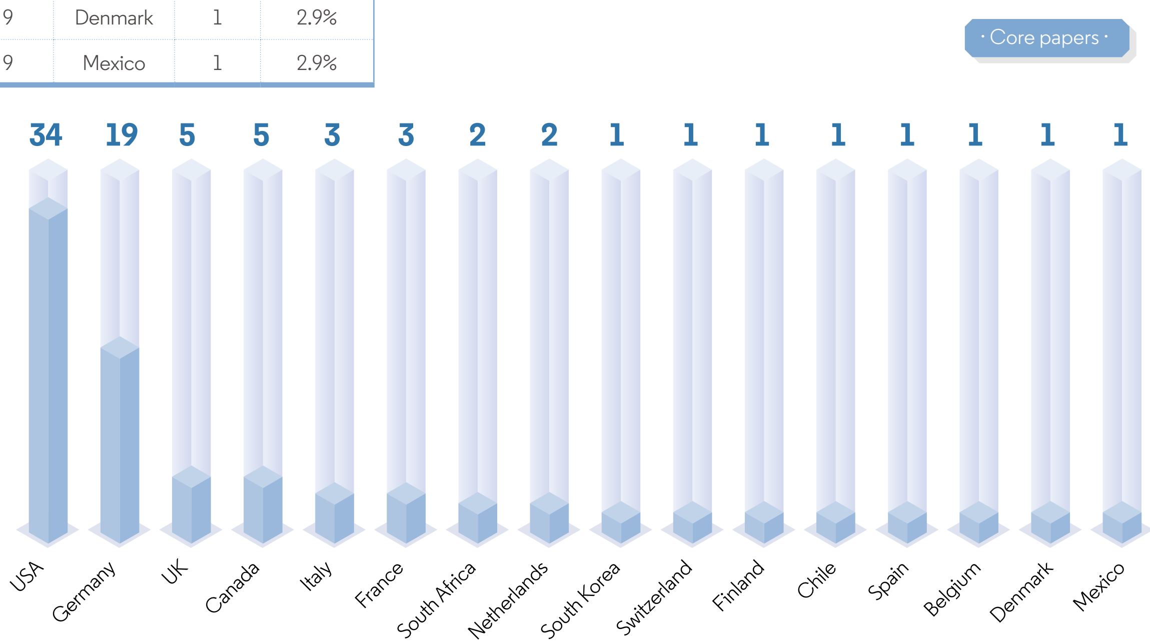
Figure 21: Citation frequency distribution curve of core papers in the Research Front "Simulations of stars, galaxies, and the Universe"

The USA and Germany, which lead the IllustrisTNG project, contribute the majority of core papers in this front, followed by the UK, Canada, Italy, and France. The top contributing institutions are all based in the USA or Germany. The Max Planck Society, where the chief scientist of the IllustrisTNG project is based, decisively contributes the most core papers (54.3%). Main participating institutions such as MIT, Harvard University, the Simons Foundation, the University of Heidelberg, and the Heidelberg Institute for Theoretical Studies are also prominent in this field.

Table 43: Top countries and institutions producing core papers in the Research Front "Simulations of stars, galaxies, and the Universe"

Country Ranking	Country	Core Papers	Proportion
1	USA	34	97.1%
2	Germany	19	54.3%
3	UK	5	14.3%
3	Canada	5	14.3%
5	Italy	3	8.6%
5	France	3	8.6%
7	South Africa	2	5.7%
7	Netherlands	2	5.7%
9	South Korea	1	2.9%
9	Switzerland	1	2.9%
9	Finland	1	2.9%
9	Chile	1	2.9%
9	Spain	1	2.9%
9	Belgium	1	2.9%
9	Denmark	1	2.9%
9	Mexico	1	2.9%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Max Planck Society	Germany	19	54.3%
2	Massachusetts Institute of Technology (MIT)	USA	16	45.7%
3	Smithsonian Astrophysical Observatory	USA	14	40.0%
3	Harvard University	USA	14	40.0%
5	Ruprecht-Karls—Universitaet Heidelberg	Germany	11	31.4%
6	Heidelberg Institute for Theoretical Studies	Germany	9	25.7%
6	Columbia University	USA	9	25.7%
8	California Institute of Technology	USA	8	22.9%
9	University of Florida	USA	6	17.1%
9	University of California Berkeley	USA	6	17.1%
9	University of California San Diego	USA	6	17.1%

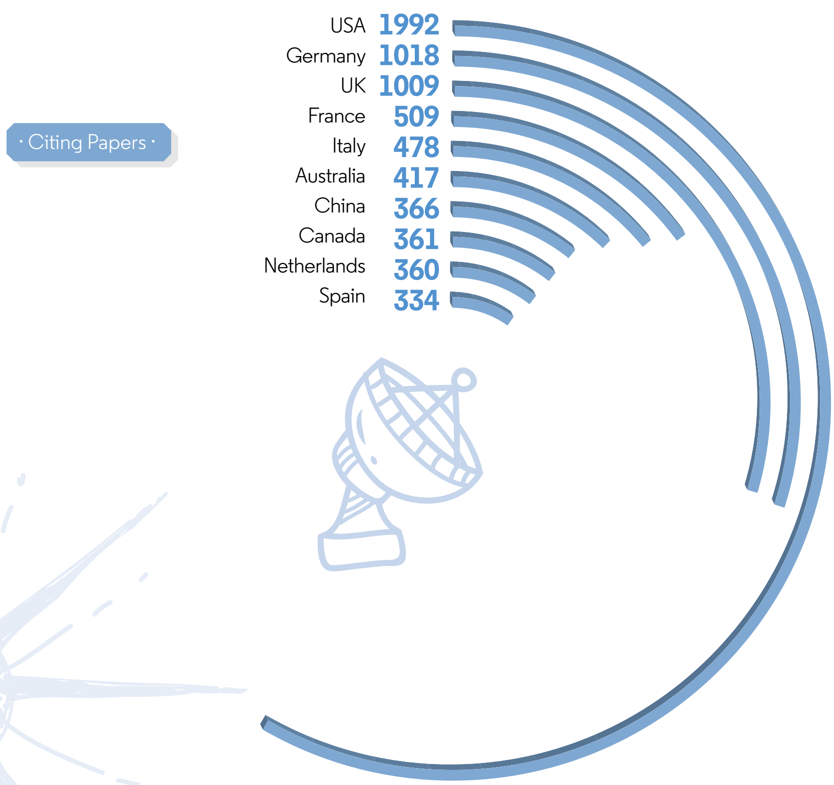


As for citing papers, the countries contributing the most numerous core papers also maintain their dominant positions in the follow-up research in the field. The USA and Germany remain dominant, with 58.3% and 29.8% of the total citing papers, respectively. The UK also produced a significant number of citing papers and ranked 3rd. China is actively pursuing follow-up research and ranked 7th. The top institutions are from the powerhouses in space science and information technology, such as Germany, France, the US, Italy, and the UK, highlighting the distinctive feature that this research front strongly relies on the close integration of space science and computer science.

Table 44: Top countries and institutions producing citing papers in the Research Front "Simulations of stars, galaxies, and the Universe"

Country Ranking	Country	Citing Papers	Proportion
1	USA	1992	58.3%
2	Germany	1018	29.8%
3	UK	1009	29.5%
4	France	509	14.9%
5	Italy	478	14.0%
6	Australia	417	12.2%
7	China	366	10.7%
8	Canada	361	10.6%
9	Netherlands	360	10.5%
10	Spain	334	9.8%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Max Planck Society	Germany	596	17.4%
2	National Center for Scientific Research of France (CNRS)	France	482	14.1%
3	National Institute for Astrophysics (INAF)	Italy	292	8.5%
4	California Institute of Technology	USA	289	8.5%
5	National Institute for Earth Sciences and Astronomy (INSU)	France	286	8.4%
6	Durham University	UK	281	8.2%
6	Harvard University	USA	281	8.2%
8	University of Paris	France	249	7.3%
9	Smithsonian Astrophysical Observatory	USA	239	7.0%
10	Leiden University	Netherlands	234	6.9%



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: "Cosmology research based on NANOGrav observation data" and "The properties of GW190814's secondary component with 2.6 solar mass".

Table 45: Emerging Research Fronts in astronomy and astrophysics

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Cosmology research based on NANOGrav observation data	14	477	2020.9
2	The properties of GW190814's secondary component with 2.6 solar mass	11	350	2020.6

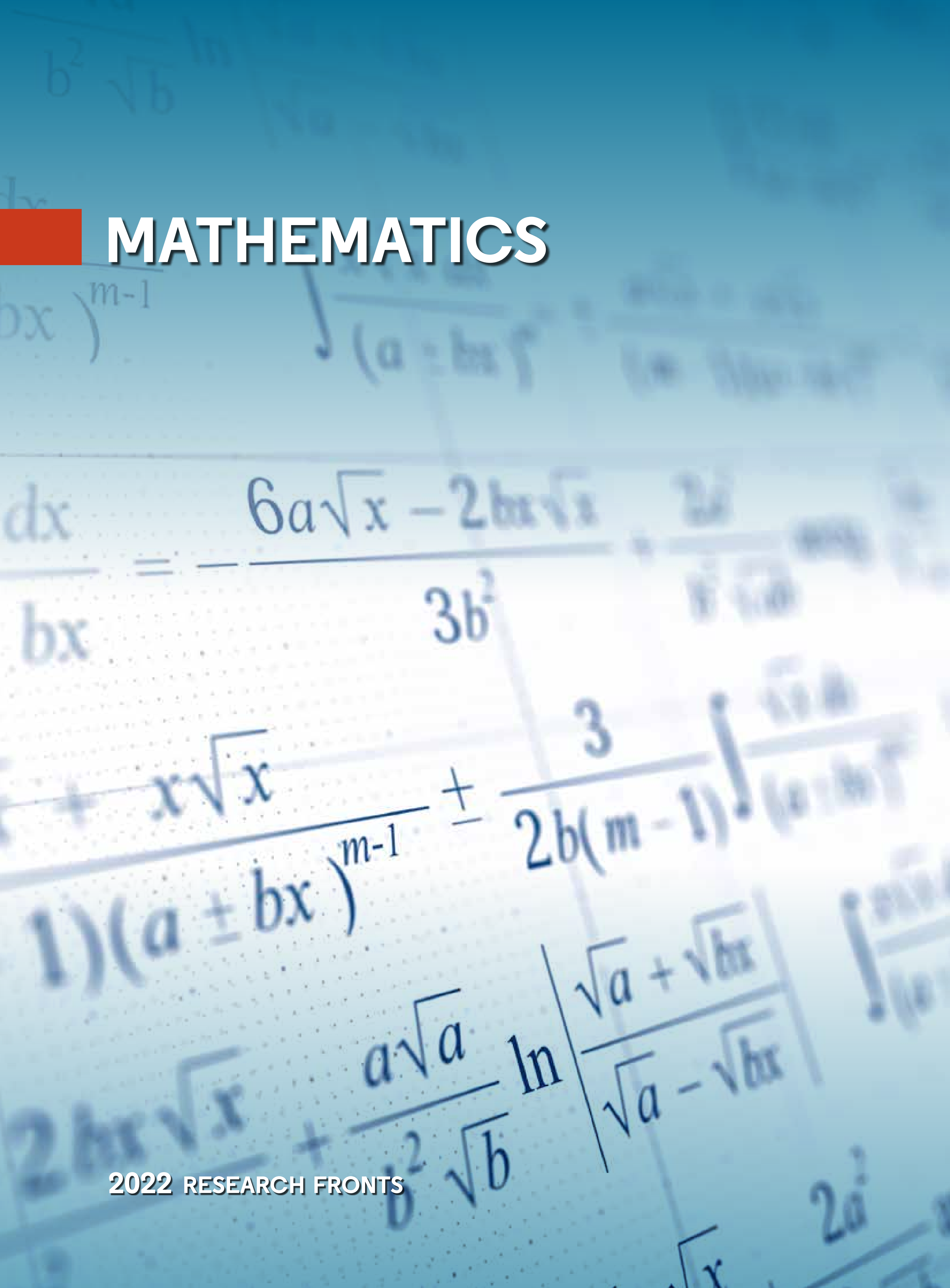
2.2 KEY EMERGING RESARCH FRONT – "The properties of GW190814's secondary component with 2.6 solar mass"

When the most massive stars die, they collapse under their own gravity and leave behind black holes. Meanwhile, when stars that are a bit less massive die, they explode in supernovas and leave behind dense, dead remnants of stars called neutron stars. For decades, astronomers have been puzzled by a gap that lies between neutron stars and black holes. The heaviest known neutron star is no more than 2.5 times the mass of our sun, or 2.5 solar masses, and the lightest known black hole is about 5 solar masses.

On 23 June 2020, the LIGO Scientific Collaboration and the Virgo Collaboration announced the discovery of a gravitational wave binary, GW190814. While one component of this binary is a 23 solar mass black hole, the other is a celestial body of 2.6 solar mass. As this smaller component happens to be in the "mass gap" between neutron stars and black holes, it provides an opportunity to answer this long outstanding question.

This emerging Research Front brings together 11 core papers focusing on the properties of GW190814's 2.6 solar mass mysterious components, including the lightest black hole ever discovered, a rapidly rotating neutron star that collapsed to a rotating black hole at some point before the merger, a massive rapidly rotating neutron star with exotic degrees of freedom, a superfast pulsar which is the fastest pulsar with the highest mass yet observed, a strange quark star, a color-flavor locked quark star, and other possibilities.

In general, uncovering the properties of the 2.6 solar mass components of GW190814 may challenge our understanding of extremely dense matter or what we know about the evolution of stars, and have far-reaching implications on neutron star equation of state and compact object formation channels. The mass gap may in fact not exist at all but may have been due to limitations in observational capabilities. Time and more observations will tell. This observation is yet another example of the transformative potential of the field of gravitational-wave astronomy, which brings novel insights with every new detection.



MATHEMATICS

2022 RESEARCH FRONTS

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: optimal subset selection; tau-tilting finite algebra; numerical algorithms for partial differential equations based on deep learning, nonlinear time fractional-order reaction-diffusion equations; derivative-free optimization methods; high-precision energy stable numerical scheme for phase-field models; optimal approximation of deep neural networks; dense packing of equal-sized spheres in high-dimensional space; regularity theory for general stable operators; and proof of the main conjecture in Vinogradov's mean value theorem.

The Top 10 Research Fronts in 2022 show both continuity and new development when 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 2022, the topic of dense packing of equal-sized spheres in 8- and 24-dimensional space in geometry has been identified as a hot Research Front for the first time.

Table 46: Top 10 Research Fronts in mathematics

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Optimal subset selection	3	217	2018.7
2	Tau-Tilting finite algebra	2	137	2018.5
3	Numerical algorithms for high-dimensional partial differential equations based on deep learning	9	1904	2018.3
4	Nonlinear time fractional-order reaction-diffusion equation	38	2690	2018.2
5	Derivative-free optimization methods	2	114	2018
6	High-precision energy stable numerical scheme for phase-field models	31	1968	2017.8
7	Optimal approximation of deep neural networks	5	375	2017.8
8	Dense packing of equal-sized spheres in 8- and 24-dimensional space	3	214	2017
9	Regularity theory for general stable operators	2	153	2016
10	Proof of the main conjecture in Vinogradov's Mean Value Theorem	2	145	2016

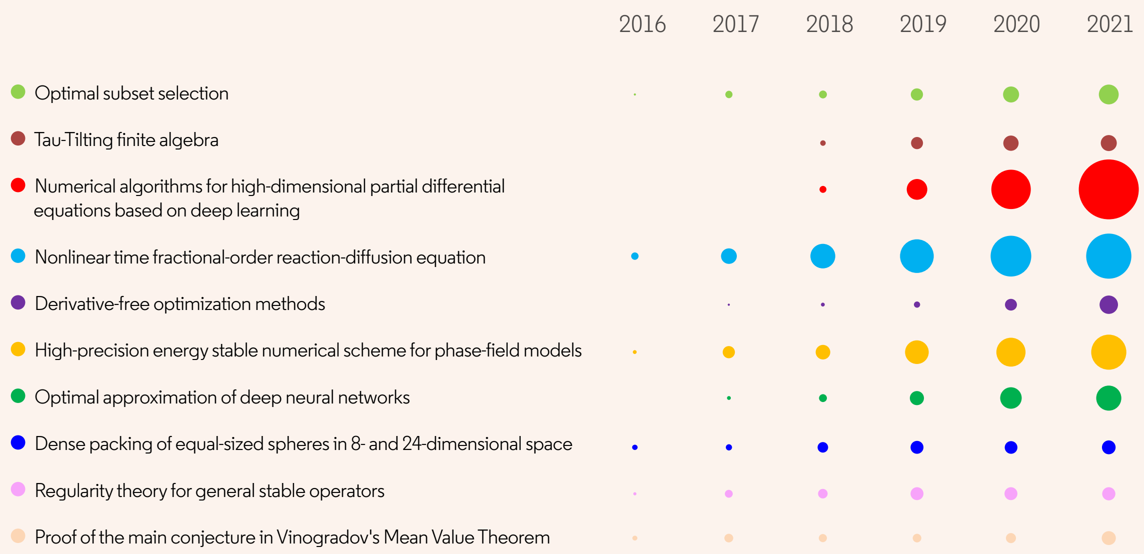


Figure 22: Citing papers for the top 10 Research Fronts in mathematics

1.2 KEY HOT RESEARCH FRONT – "Numerical algorithms for high-dimensional partial differential equations based on deep learning"

"Partial differential equation" refers to the equation of an unknown function and its partial derivative, which can be used to describe the relationship between an independent variable, an unknown function, and its partial derivative. Since the Swiss mathematician Leonhard Euler first proposed the second-order equation of string vibration in the 18th century, partial differential equations have gradually become one of the most important mathematical tools to describe the laws of the objective physical world. The tool has important applications in electromagnetics, thermodynamics, fluid mechanics, quantum mechanics, geometry, and other disciplines. Partial differential equations have become an important part of contemporary mathematics, and they now constitute an important bridge linking many branches of pure mathematics with fields such as natural science and engineering technology.

Research on partial differential equations has been continuously selected among the hot Research Fronts over the years, such as "Solving several classes of partial differential equations" in 2016, "Solutions for typical nonlinear evolution equations and their applications" in 2018, and "Methods of solving high-dimensional nonlinear partial differential equations" in 2021. At present, the development of effective numerical algorithms for higher dimensional partial differential equations remains one of the most challenging tasks in applied mathematics. This is due to the problem of "dimensional disaster", in which the cost of calculating partial differential equations increases exponentially with the increase of dimension.

The hot 2022 Research Front on "Numerical algorithms for high-dimensional partial differential equations based on deep learning" aims to cope with this challenge. Work in this area focuses on emerging deep learning methods for approximate solutions of high-dimensional partial differential equations. Compared with traditional numerical algorithms, these methods can not only save huge storage and computing costs, but also be more versatile and simple.

This hot front contains nine core papers, which are mainly reflected in the deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations; learning unknown parameters of partial differential equations from small sample data using deep learning methods; deep learning-based numerical methods for high-dimensional parabolic partial differential equations and backward stochastic differential equations; machine learning approximation algorithms for high-dimensional fully nonlinear partial differential equations and second-order backward stochastic differential equations; and deep learning-based numerical algorithm (Deep Ritz) for solving variational problems.

Among the core papers, the report with the highest number of citations came from the team of Paris Perdikaris of the University of Pennsylvania (USA). This article was published in 2019 in the authoritative *Journal of Computational Physics*, and has been cited more than 700 times. This paper first proposed the concept of Physical Information Neural Networks (PINNs). These neural networks can be used to solve forward and reverse problems of various forms of partial differential equations, which is different from the pure data-driven neural network learning method. This method does not require many measurement data as labels, imposes physical information constraints on the training process, and can learn a model with more generalization ability from fewer samples.

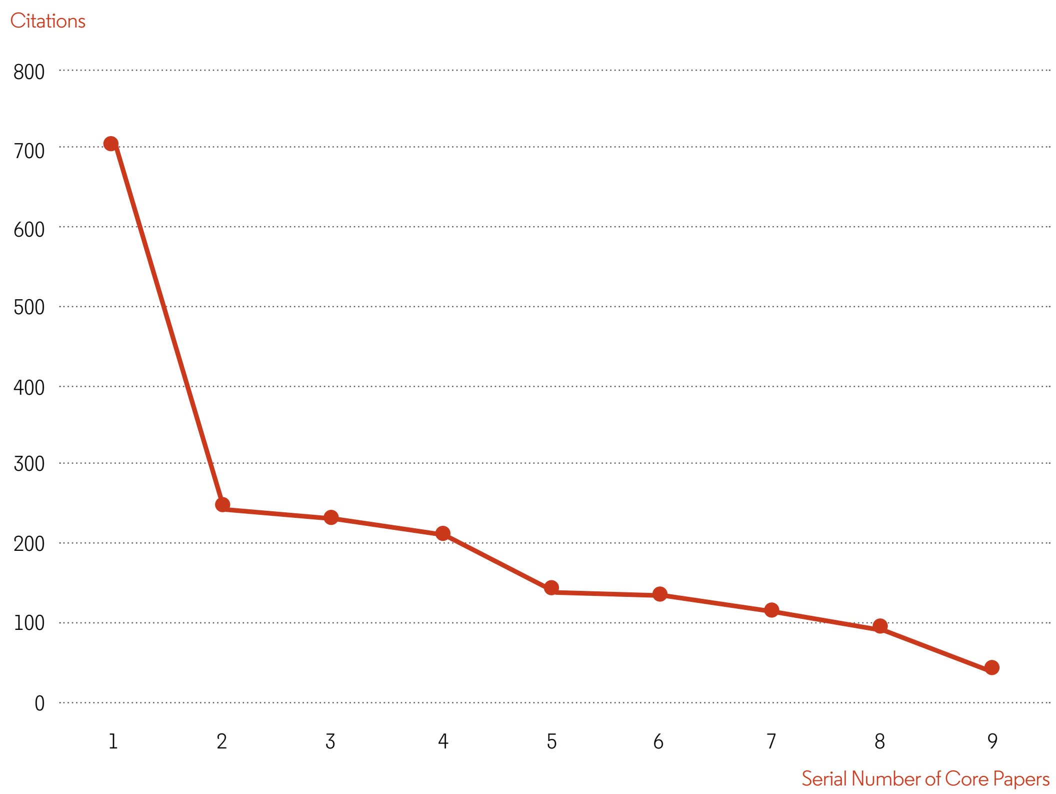


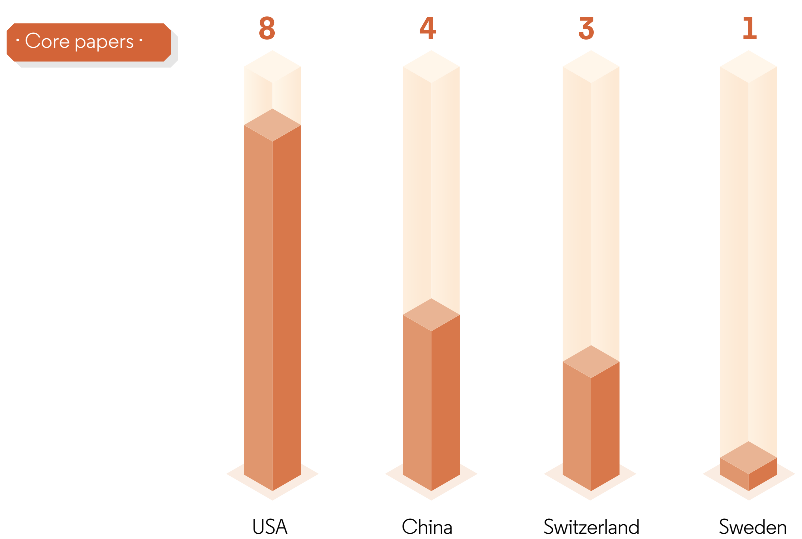
Figure 23: Citation frequency distribution curve of core papers in the Research Front "Numerical algorithms for high-dimensional partial differential equations based on deep learning"

In terms of representation among the core papers in the front (Table 47), the USA displays the most prominent performance, contributing eight core papers, representing 88.9% of the total. China ranks 2nd, contributing four core papers. It is worth noting that these four papers are all from the team of Weinan E. of the Beijing Institute of Big Data Research, and all focus on their pioneering work in applying deep learning technology to scientific calculations such as high-dimensional partial differential equations. Switzerland and Sweden rank 3rd and 4th respectively. Among the top institutions producing core papers, the USA has seven institutions on the list, far ahead of other countries. Princeton University, the Beijing Institute of Big Data Research, the Swiss Federal Institute of Technology Zurich, and Brown University each account for more than three core papers.

Table 47: Top countries and institutions producing core papers in the Research Front "Numerical algorithms for high-dimensional partial differential equations based on deep learning"

Country Ranking	Country	Core Papers	Proportion
1	USA	8	88.9%
2	China	4	44.4%
3	Switzerland	3	33.3%
4	Sweden	1	11.1%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Princeton University	USA	4	44.4%
1	Beijing Institute of Big Data Research	China	4	44.4%
3	Swiss Federal Institute of Technology Zurich	Switzerland	3	33.3%
3	Brown University	USA	3	33.3%
5	Peking University	China	2	22.2%
6	NVIDIA Corporation	USA	1	11.1%
6	Boston University	USA	1	11.1%
6	University of Colorado Boulder	USA	1	11.1%
6	University of Pennsylvania	USA	1	11.1%
6	University of Illinois Urbana-Champaign	USA	1	11.1%
6	Uppsala University	Sweden	1	11.1%

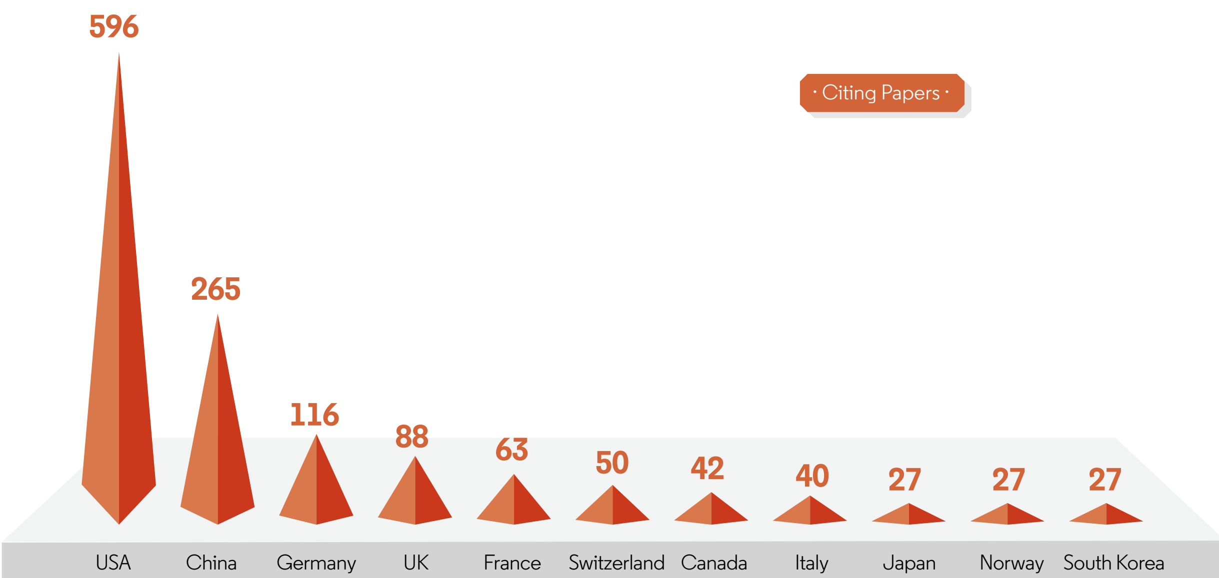


In terms of the citing papers (Table 48), the USA maintains its leading position, producing 596 citing papers, with a contribution rate of more than 50%. China and Germany are also actively following up on this front, producing 265 and 116 citing papers respectively, ranking 2nd and 3rd. Among the top-producing institutions, the USA, represented by Brown University, MIT, and other institutions, accounts for five places, while Switzerland and China both register with two. Peking University and the Chinese Academy of Sciences actively participate in China's follow-up research on this front. In addition, the National Center for Scientific Research of France also makes the list.

Table 48: Top countries and institutions producing citing papers in the Research Front "Numerical algorithms for high-dimensional partial differential equations based on deep learning"

Country Ranking	Country	Citing Papers	Proportion
1	USA	596	51.3%
2	China	265	22.8%
3	Germany	116	10.0%
4	UK	88	7.6%
5	France	63	5.4%
6	Switzerland	50	4.3%
7	Canada	42	3.6%
8	Italy	40	3.4%
9	Japan	27	2.3%
9	Norway	27	2.3%
9	South Korea	27	2.3%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Brown University	USA	56	4.8%
2	Massachusetts Institute of Technology (MIT)	USA	54	4.7%
3	Swiss Federal Institutes of Technology Domain	Switzerland	44	3.8%
4	Stanford University	USA	39	3.4%
5	Swiss Federal Institute of Technology Zurich	Switzerland	36	3.1%
6	Purdue University	USA	35	3.0%
7	National Center for Scientific Research of France (CNRS)	France	32	2.8%
8	Peking University	China	30	2.6%
9	Chinese Academy of Sciences	China	29	2.5%
10	Pacific Northwest National Laboratory	USA	27	2.3%



1.3 KEY HOT RESEARCH FRONT – “Dense packing of equal-sized spheres in 8- and 24-dimensional space”

Finding the best packing of equal-sized spheres is a challenging problem, and mathematicians have been studying sphere packing since at least 1611, when German mathematician Johannes Kepler conjectured that the densest way to pack together equal-sized spheres in space is the familiar pyramidal piling of oranges seen in grocery stores. Despite the problem’s seeming simplicity, it was not settled until 1998, when American mathematician Thomas Hales finally proved Kepler’s conjecture in 250 pages of mathematical arguments combined with extensive computer calculations.

A high-dimensional sphere is a set of points in a high-dimensional space at a fixed distance away from a given center point. Higher-dimensional sphere packings are hard to visualize, but the related research has shown various practical values including that dense sphere packings are intimately related to the error-correcting codes used by cell phones, space probes, and the internet to send signals through noisy channels. Finding the best packing of equal-sized spheres in a high-dimensional space should be even more complicated, since each added dimension means more possible packings to consider. In dimensions 8 and 24, there exist symmetric sphere stacking called E8 and Leech lattice, respectively, and these two stacking methods may be better than other known candidates for densest stacking.

The hot Research Front “Dense packing of equal-sized spheres in 8-dimensional and 24-dimensional space” includes three core papers. The most-cited core paper is the formal proof of Kepler’s conjecture by Thomas Hales, which has undergone a long review process since it was first proposed in 1998 and was only fully verified in 2014 and formally published in 2017.

The second-most-cited core paper is the formal proof of the E8 stacking method in 8-dimensional space by the Ukrainian mathematician Maryna Viazovska constructing an auxiliary function. The core paper ranking third by citations is a collaboration between Viazovska and four other mathematicians who were inspired by her proposed method to prove that the Leech stacking method is the optimal densest stacking method in 24-dimensional space. Viazovska was also awarded the 2022 Fields Medal for her pioneering contribution to the problem of dense packing of equal-sized spheres in 8- and 24-dimensional space.

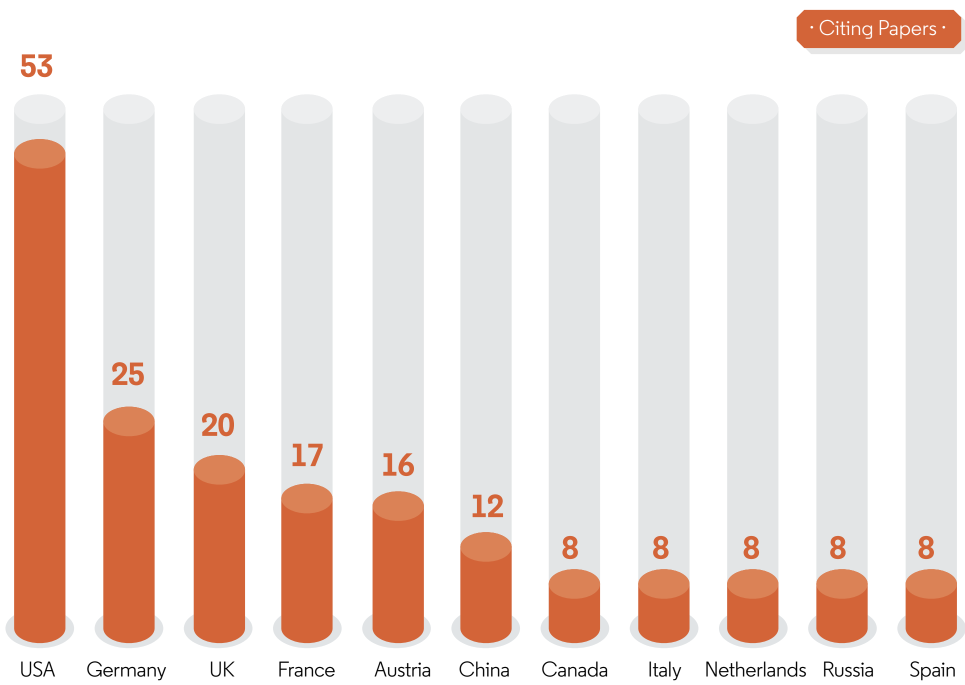
Germany and Switzerland are among the top nations in this front, represented by the Berlin Mathematical Institute, Humboldt University Berlin, and École Polytechnique Fédérale de Lausanne, where Viazovska has studied and worked. The proof of Kepler’s conjecture led by Thomas C. Hales, University of Pittsburgh (USA) is a joint effort of 18 research institutions from the USA, Italy, the Netherlands, the UK, Austria, France, Australia, China, Czech Republic, and Vietnam.

The problem of the dense packing of equal-sized spheres in high-dimensional space has attracted widespread interest in the academic community following the groundbreaking results by Hales and Viazovska. As for citing papers, the USA takes the lead, contributing more than one-third of all citing papers. Germany, the UK, France, Austria, and China are also actively following up in this front, contributing more than 10 citing papers. Among the top institutions producing citing papers, institutions from France, the UK, the USA, and Austria occupy many seats, with typical top contributors including CNRS (France), the University of Cambridge (UK), and the University of Vienna (Austria). The themes of the follow-up studies center on the science propagation of dense stacking theory and the applied research of the theory in various fields such as quantum gravity, quantum information, microbiology, materials science, and crystallography, among others.

Table 49: Top countries and institutions producing citing papers in the Research Front "Dense packing of equal-sized spheres in 8- and 24-dimensional space"

Country Ranking	Country	Citing Papers	Proportion
1	USA	53	36.8%
2	Germany	25	17.4%
3	UK	20	13.9%
4	France	17	11.8%
5	Austria	16	11.1%
6	China	12	8.3%
7	Canada	8	5.6%
7	Italy	8	5.6%
7	Netherlands	8	5.6%
7	Russia	8	5.6%
7	Spain	8	5.6%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	National Center for Scientific Research of France (CNRS)	France	11	7.6%
2	University of Cambridge	UK	7	4.9%
2	University of Vienna	Austria	7	4.9%
4	Princeton University	USA	5	3.5%
4	Sorbonne University	France	5	3.5%
4	University of Paris	France	5	3.5%
7	University of Oxford	UK	4	2.8%
7	Microsoft	USA	4	2.8%
7	State University of New York (SUNY) Stony Brook	USA	4	2.8%
7	Swiss federal Institute of Technology in Lausanne	Switzerland	4	2.8%
7	Tula State University	Russia	4	2.8%
7	University of Bonn	Germany	4	2.8%
7	University of Innsbruck	Austria	4	2.8%
7	Abdus Salam Intl Ctr Theoret Phys	Italy	4	2.8%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN MATHEMATICS

Two topics in the field of mathematics are highlighted as emerging Research Fronts: "Recurrent neural networks for time series forecasting" and "Probability learning method based on physics".

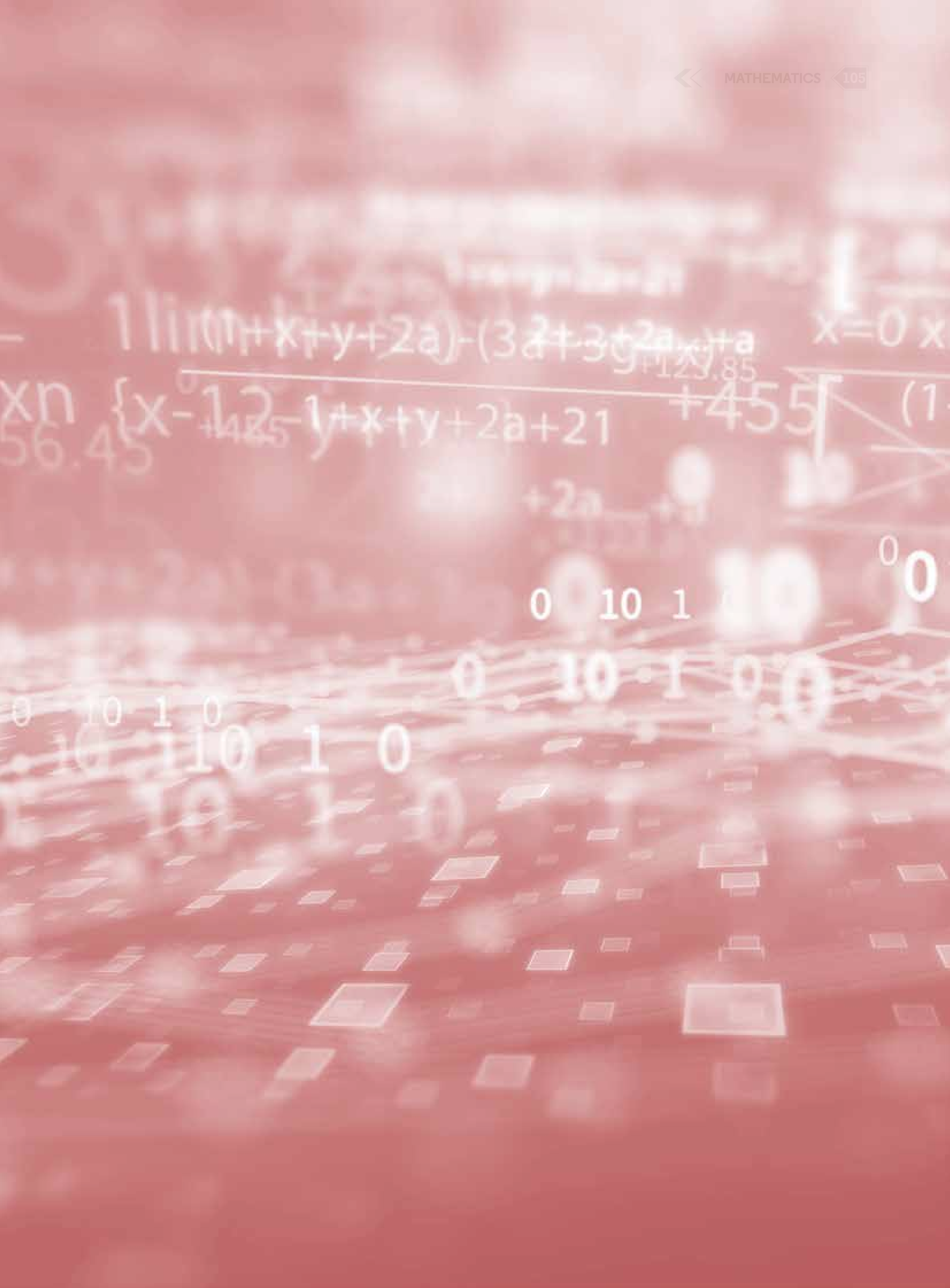
Table 50: Emerging Research Front in mathematics

Rank	Emerging Research Front	Core papers	Citations	Mean Year of Core Papers
1	Recurrent neural networks for time series forecasting	9	772	2019.4
2	Probability learning method based on physics	3	216	2019

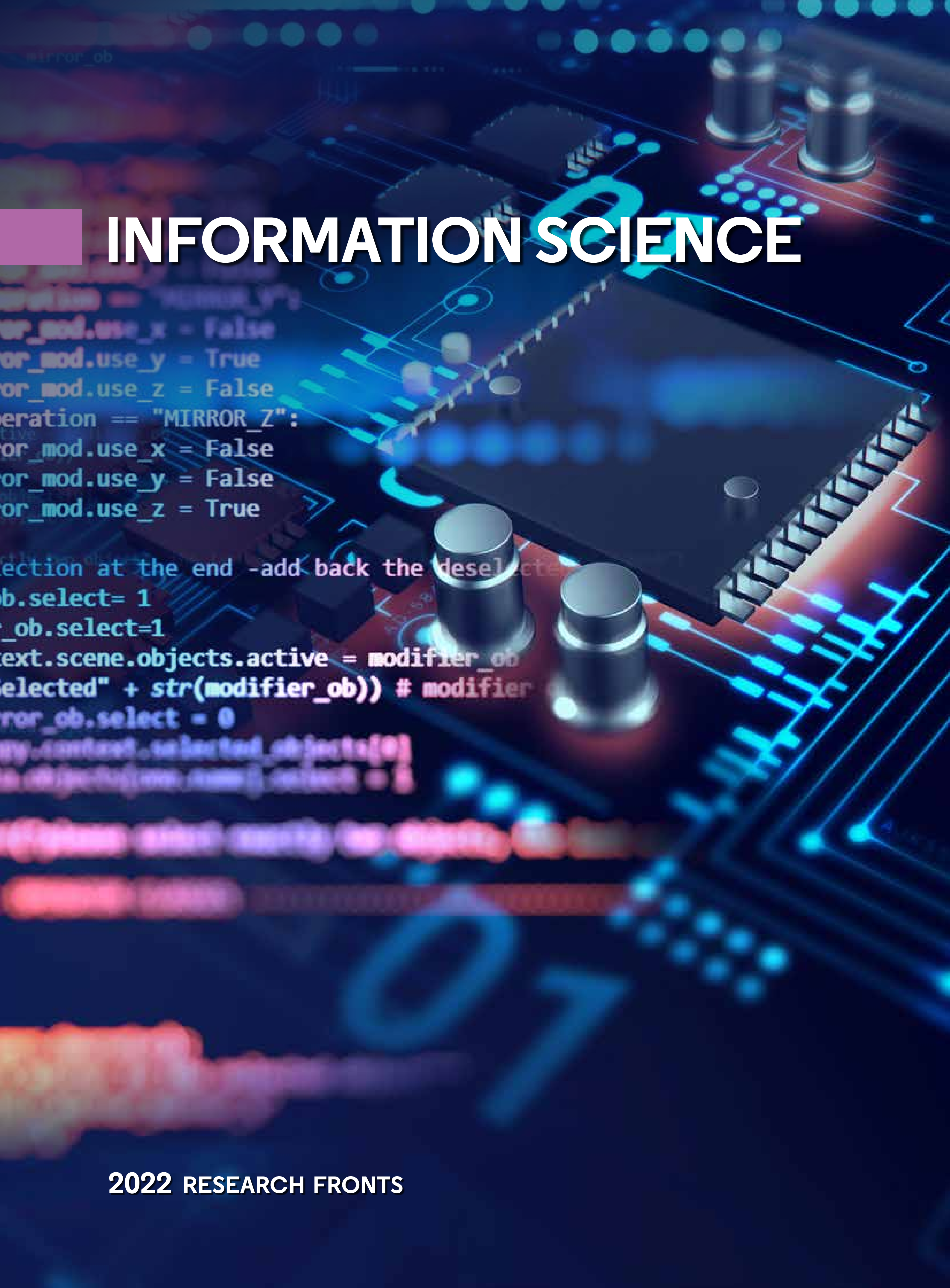
2.2 KEY EMERGING RESEARCH FRONT – "Recurrent neural networks for time series forecasting"

Time series forecasting algorithm is widely used in many fields, such as financial market forecasts, weather forecasts, and complex dynamic system analysis. Traditionally, statistical learning methods are commonly used in time series forecasting. It is necessary to combine the unique statistical analysis in the time series field, convert the data into a stationary series by difference, and then model it by linear regression. Although this method can integrate the knowledge of a large number of experts on time series, it has difficulty in facing complex situations such as nonlinear characteristics, and is not conducive to large-scale forecasting. For example, the famous autoregressive moving average model has proved its effectiveness for various real-world applications, but it can neither model nonlinear relationships nor distinguish between exogenous (driver) inputs. In order to solve this kind of problem, various nonlinear autogenetic regression models have been proposed successively, and a large number of time series forecasting have been made through kernel mode, integration mode, Gaussian process, and other methods. However, most of these methods use the pre-defined nonlinear form, which may not be able to properly capture the real potential nonlinear relationship.

In recent years, as a deep neural network method especially for sequence modeling, the recurrent neural network method has been widely concerned by scientists due to its flexibility in capturing nonlinear relationships, especially in time series forecasting of nonlinear autogenetic regression models. However, the traditional recurrent neural network method may encounter the problem of gradient disappearance due to its inability to capture long-term dependencies. In recent years, Long Short-Term Memory (LSTM) and Gated Recirculating Unit (GRU) can overcome this limitation to some extent, and have been applied in many fields such as machine translation, speech recognition, and image processing. At present, exploring more advanced recurrent neural networks for time series forecasting has become the focus of scientists. This emerging Research Front contains nine core papers. They mainly reflect validating the accuracy of a neural network as a statistical method for time series forecasting, the interpretable modular neural network regression model for large-scale time series modeling, the clustering approach of forecasting across time series databases using recurrent neural networks on groups of similar series, the autoregressive recurrent neural networks DeepAR for time series probability forecasting, the FFORMA for feature-based forecast model averaging, and the hybrid method of exponential smoothing and recurrent neural networks for time series forecasting.



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 deep learning methods for de novo drug design; human activity recognition; brain tumor image segmentation; long distance free space quantum key distribution and quantum entanglement; knowledge graph and graph embedding technology; multi-agent reinforcement learning; blockchain and the Internet of Things; and large-scale machine learning optimization methods (Table 51).

In the field of communication, the main focus can be found in unmanned aerial vehicle wireless communication and hybrid precoding technology for millimeter wave MIMO communication systems. Reflecting the evolution of specialty areas covered in previous Research Front reports, "Research on multi-agent reinforcement learning" is the continuation and expansion of a hot Research Front covered in the 2020 edition: "Reinforcement Learning Algorithm of AlphaGo Zero". Meanwhile, "Research on unmanned Aerial Vehicle Wireless Communication" continues and expands on another hot front, highlighted in 2021, covering "UAV-based Wireless Communication Technology". New in this year's survey are three fronts appearing for the first time: "Research on knowledge graph and graph embedding technology", "Large-scale machine learning optimization methods", and "Research on hybrid precoding technology for millimeter wave MIMO communication systems".

Table 51: Top 10 Research Fronts in information science

Rank	Hot Research Fronts	Core papers	Times Cited	Mean Year of Core Papers
1	Long Distance free space quantum key distribution and quantum entanglement	31	5009	2018.2
2	Research on deep learning methods for de novo drug design	12	2551	2018.2
3	Research on deep learning algorithm for human activity recognition	14	2443	2018.2
4	Research on knowledge graph and graph embedding technology	10	1804	2018.2
5	Research on multi-agent reinforcement learning	6	5303	2017.7
6	Integration of blockchain and the Internet of Things	6	2311	2017.3
7	Research on deep learning method for brain tumor segmentation	4	2588	2017
8	Large-scale machine learning optimization methods	3	652	2017
9	Research on unmanned aerial vehicle wireless communication	10	4307	2016.9
10	Research on hybrid precoding technology for millimeter wave MIMO communication systems	12	3171	2016.3

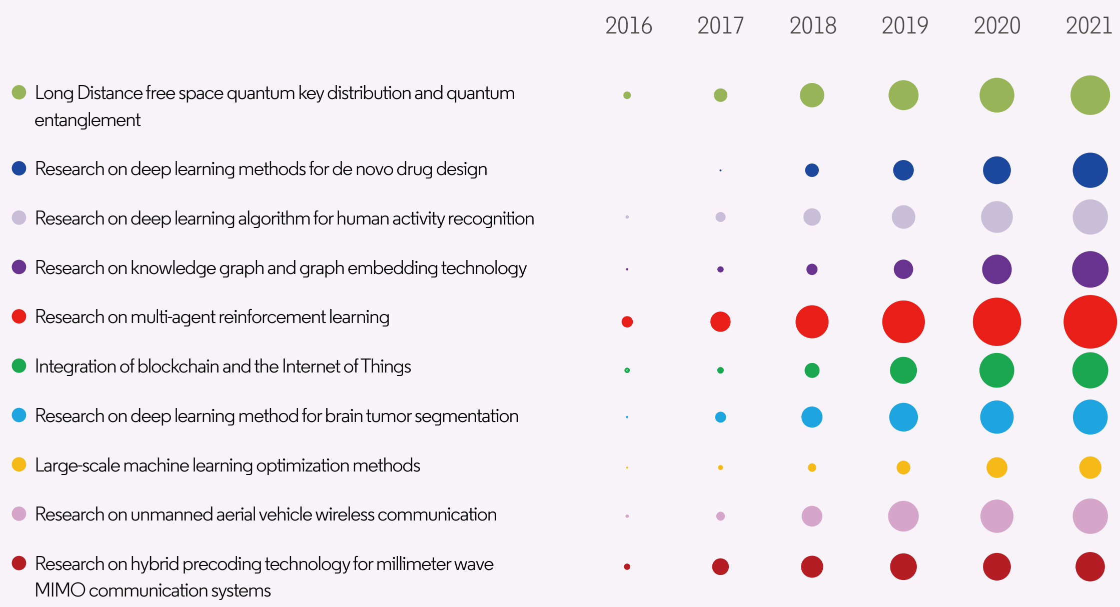


Figure 24: Citing papers for the Top 10 Research Fronts in information science

1.2 KEY HOT RESEARCH FRONT – "Research on deep learning methods for de novo drug design"

Drug discovery and development constitute a long-cycle, high-investment, and high-risk process. In recent years, computationally driven tools represented by computer-aided drug design (CADD) and artificial intelligence drug discovery (AIDD) have made remarkable progress in the fields of target discovery, precision medicine, and drug design and discovery. These advances have raised hopes for faster drug development and lower drug-development costs.

The number of drug-like molecules in the chemical realm is estimated to be in the order of 10^{23}-10^{60}. Therefore, finding specific lead compounds in the entire chemical space by computational methods has become a major challenge in drug discovery. Although high-throughput screening and virtual screening methods can effectively evaluate molecules in large compound libraries, they can only screen known compound libraries to find molecules that satisfy specific properties. Unlike de novo drug design, which targets desirable chemical properties, the latter generates completely new molecules with specific properties to explore the chemical space and complement the compound library through a deep learning-based molecule generation approach, thus breaking conventional structural barriers to drug discovery and design.

"Research on deep learning methods for de novo drug design" includes 12 core papers, covering automated design methods for continuous representation of molecules, recurrent and adversarial neural networks, druGAN autoencoder models, and MOSES, a benchmarking platform for molecular generation models. Among these foundational papers, the most cited is "Automatic chemical design using a data-driven continuous representation of molecules" published in 2018 by professor Alán Aspuru-Guzik (then at Harvard University) and colleagues in *ACS Central Science*, with nearly 800 citations to date (Figure 25). The article describes the use of neural networks to transform molecules into continuous vector representations, demonstrating gradient-based optimization of molecular properties to solve inverse design challenges in chemistry. Professor Aspuru-Guzik currently leads the "AI for Discovery and Self-Driving Labs" research group at the University of Toronto, Canada, which is dedicated to combining AI with an automated robotic platform to autonomously discover new materials in a high-throughput format, with the goal of reducing the time and the cost required to discover new functional materials or to optimize known functional materials by a factor of 10. In other words, from an estimated $10 million and 10 years of development time to $1 million and 1 year.

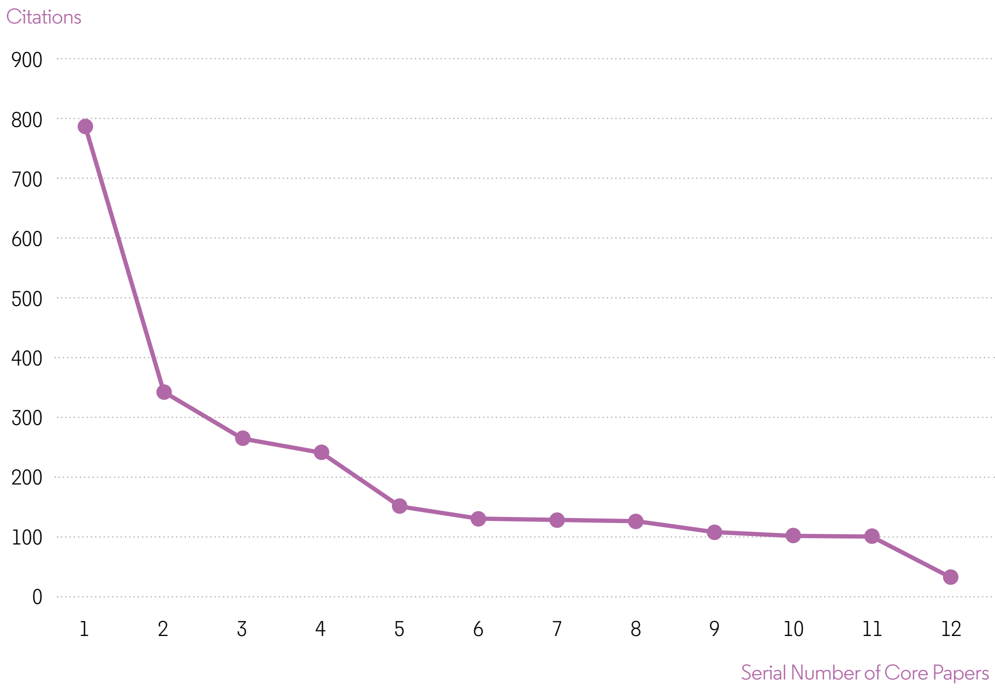


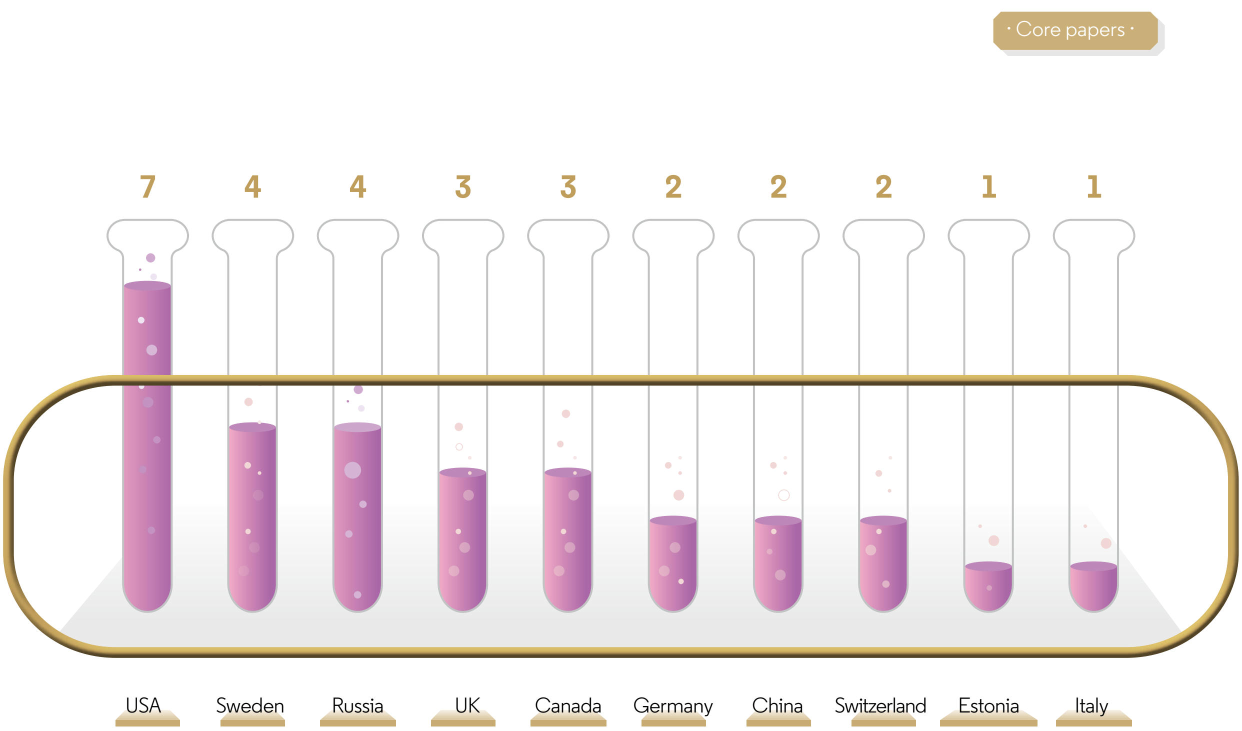
Figure 25: Citation frequency distribution curve of core papers in the Research Front "Research on deep learning methods for de novo drug design"

Looking at the distribution of countries and institutions producing the core papers for this front (Table 52), the USA contributes more than half of the core papers, while Sweden and Russia each contribute one-third, and the UK and Canada are represented in three papers each. AstraZeneca, a leading global pharmaceutical company, contributes four core papers, ranking as the core's most prolific institution. Among the AstraZeneca papers, the 2017 paper titled "Molecular de-novo design through deep reinforcement learning" (M. Olivecrona and colleagues, *Journal of Cheminformatics*), which uses reinforcement learning and recurrent neural networks to generate analogues of query structures, as well as to predict and generate compounds of practical relevance to biological targets, has garnered nearly 250 citations. Three institutions based in Russia have earned places on the most-prolific list. Two Canada-based institutions have each published two core papers, while Hong Kong's Insilico Medicine and Shanghai University from China contribute one paper each.

Table 52: Top countries and institutions producing core papers in the Research Front "Research on deep learning methods for de novo drug design"

Country Ranking	Country	Core Papers	Proportion
1	USA	7	58.3%
2	Sweden	4	33.3%
2	Russia	4	33.3%
4	UK	3	25.0%
4	Canada	3	25.0%
6	Germany	2	16.7%
6	China	2	16.7%
6	Switzerland	2	16.7%
9	Estonia	1	8.3%
9	Italy	1	8.3%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	AstraZeneca	Sweden	4	33.3%
2	Moscow Institute of Physics and Technology	Russia	3	25.0%
2	Harvard University	USA	3	25.0%
2	Canadian Institute for Advanced Research	Canada	3	25.0%
5	Swiss Federal Institute of Technology Zurich	Switzerland	2	16.7%
5	National Research University Higher School of Economics	Russia	2	16.7%
5	Russian Academy of Sciences	Russia	2	16.7%
5	University of Toronto	Canada	2	16.7%

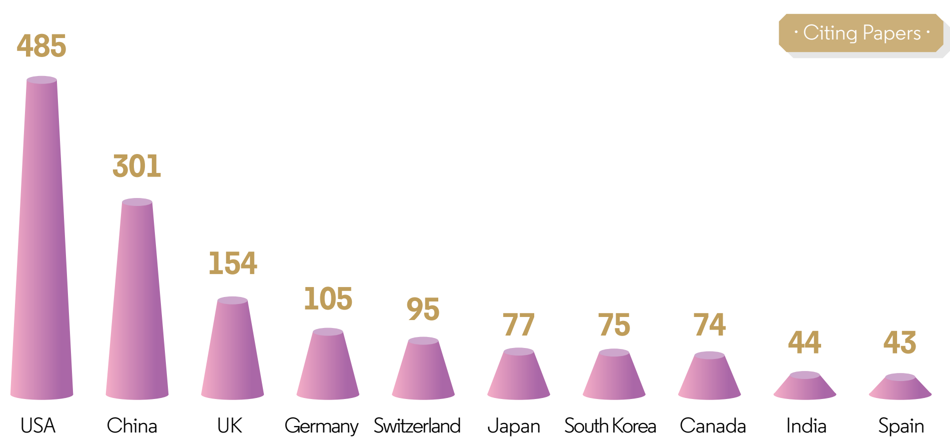


Analysis of the citing papers (Table 53) indicates that, among countries, the USA demonstrates the most active follow-up work in this Research Front, with representative institutions being MIT and Harvard University. Notably active research has also been conducted in China and the UK. The list of the top institutions ranked by citing papers shows that many strong research institutions, universities, and commercial enterprises are conducting relevant research, demonstrating the importance of this specialty area and the fierce competition within. The Chinese Academy of Sciences and the University of Cambridge represent China and the UK respectively on the list, while Canada holds three of the ranks. The University of Tokyo in Japan is ranked at 10th.

Table 53: Top countries and institutions producing citing papers in the Research Front "Research on deep learning methods for de novo drug design"

Country Ranking	Country	Citing Papers	Proportion
1	USA	485	36.2%
2	China	301	22.5%
3	UK	154	11.5%
4	Germany	105	7.8%
5	Switzerland	95	7.1%
6	Japan	77	5.7%
7	South Korea	75	5.6%
8	Canada	74	5.5%
9	India	44	3.3%
10	Spain	43	3.2%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	51	3.8%
2	Massachusetts Institute of Technology (MIT)	USA	50	3.7%
3	University of Toronto	Canada	42	3.1%
4	Harvard University	USA	41	3.1%
5	Swiss Federal Institute of Technology Zurich	Switzerland	40	3.0%
6	University of Cambridge	UK	32	2.4%
7	Vector Institute for Artificial Intelligence	Canada	31	2.3%
8	AstraZeneca	Sweden	28	2.1%
9	Canadian Institute for Advanced Research	Canada	26	1.9%
10	University of Tokyo	Japan	24	1.8%



1.3 KEY HOT RESEARCH FRONT – "Research on multi-agent reinforcement learning"

With the breakthrough of Deep Reinforcement Learning (DRL) in recent years, a large number of algorithms and applications related to DRL continue to emerge. Many recent studies have not been limited to single-agent reinforcement learning but have also begun to study DRL in multi-agent learning scenarios.

In reinforcement learning, the interaction between a single agent and the environment is a simple system view, while the extended multi-agent reinforcement learning pursues the cooperation, competition, and co-evolution of multiple agents in a complex environment, representing a complex system view.

Multi-agent reinforcement learning continuously improves the learning algorithm when different agents are rewarded with different learning strategies. At present, remarkable progress has been made in this direction in a series of advances, such as traffic signal control, robot control, unknown exploration, bus schedule optimization, and the like. An increasing number of research and applications of multi-agent reinforcement learning have emerged and have been deeply explored in communication networks, cooperative exploration, task offloading, and other applications.

"Multi-agent reinforcement learning Research" includes six core papers, including three papers published in Science and another three published in *Nature*. This hot Research Front focuses on the following aspects: (1) exploring an algorithm for dealing with information asymmetry problem by introducing DeepStack, which is a landmark breakthrough in AI in imperfect information games; (2) enhancing the tree algorithm of the AlphaGo neural network to iterate higher-quality behavior predictions without human supervised learning; and (3) using self-play ideas to solve the problem of "circular learning" of ordinary self-game methods by constantly adjusting confrontation strategies.

Three core papers in this front -- all from Google DeepMind -- have each earned more than 300 citations (Figure 26). By citations, the standout paper is "Mastering the game of Go with deep neural networks and tree search" (D. Silver and colleagues, 2016), published in *Nature* and now cited more than 3,000 times. This paper introduces an algorithm that combines Monte Carlo simulation with valuation and strategy networks, and through reinforcement learning of self-game, the AlphaGo program achieves a 99.8% chance of winning. This article marked the birth of the first generation of AlphaGo and set off a craze for reinforcement learning.

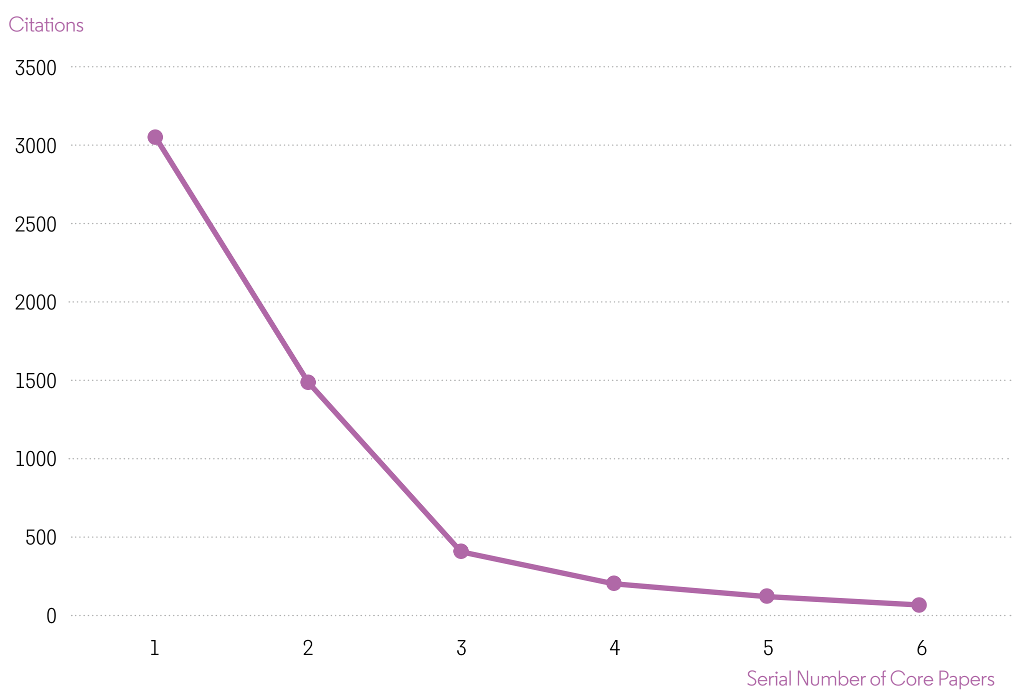


Figure 26: Citation frequency distribution curve of core papers in Research Front "Research on multi-agent reinforcement learning"

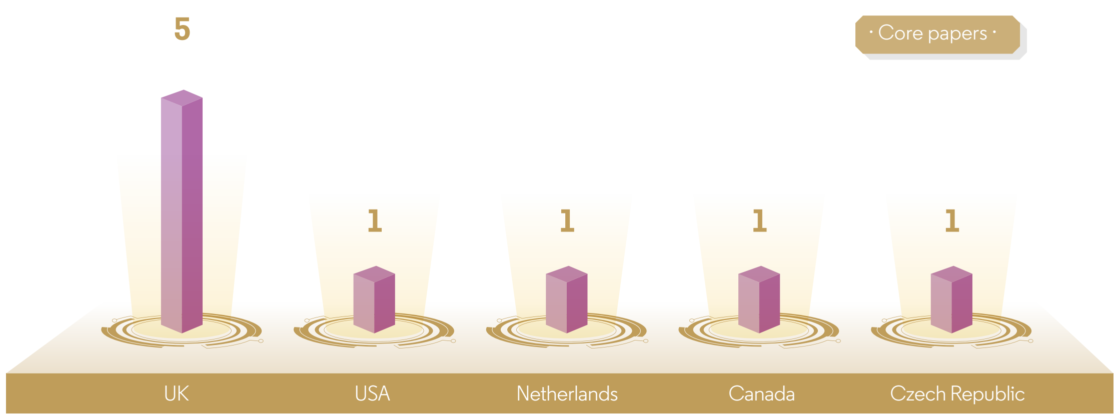
As can be seen in Table 54, the UK displays notable prominence in this front, contributing five of the six core papers. The USA, the Netherlands, Canada, and the Czech Republic each contribute one article. In terms of top-producing institutions behind the core papers, DeepMind (acquired by Google in 2014) contributed four articles, and Prague Charles University in the Czech Republic, Czech Polytechnic University, Google in the USA, and the University of Alberta in Canada contributed one paper each.

It is evident that DeepMind is far ahead in this cutting-edge topic. After Google's acquisition of DeepMind, the company now occupies an absolute leading position in the field of multi-agent reinforcement learning with Alpha series products. The Netherlands-based Team Liquid esports club was one of the contributors to the core paper via research participation with Google's DeepMind. The paper "DeepStack: expert-level artificial intelligence in heads-up no-limit poker" (M. Moravcik and colleagues, *Science*, 2017), produced by institutions in Canada, the Czech Republic, and elsewhere, has wielded slightly less influence in terms of citation impact.

Table 54: Top countries and institutions producing core papers in the Research Front "Research on multi-agent reinforcement learning"

Country Ranking	Country	Core Papers	Proportion
1	UK	5	83.3%
2	USA	1	16.7%
2	Netherlands	1	16.7%
2	Canada	1	16.7%
2	Czech Republic	1	16.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	DeepMind	UK	4	66.7%
2	Charles University Prague	Czech Republic	1	16.7%
2	University College London	UK	1	16.7%
2	Google Inc	USA	1	16.7%
2	Czech Technical University in Prague	Czech Republic	1	16.7%
2	Team Liquid	Netherlands	1	16.7%
2	University of Alberta	Canada	1	16.7%

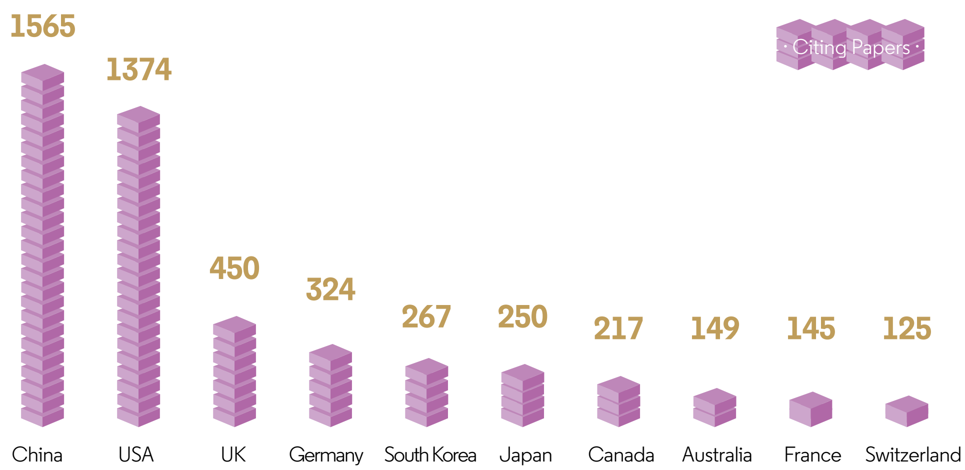


Analysis of the citing papers (Table 55) indicates that China and the USA have each produced more than 1,000 papers, accounting for 66.3% of the total number of papers that cite the front's core literature. The UK, Germany, South Korea, and Japan are also prolific by this measure. In terms of top-producing institutions, China is represented by five entries on the list. Among them, the Chinese Academy of Sciences, and Tsinghua University are the most active among the top institutions. MIT, Stanford University, and Harvard University post comparable numbers of citing papers. Single institutions based in the UK and France also earn places on the list.

Table 55: Top countries and institutions producing citing papers in the Research Front "Research on multi-agent reinforcement learning"

Country Ranking	Country	Citing Papers	Proportion
1	China	1565	35.3%
2	USA	1374	31.0%
3	UK	450	10.2%
4	Germany	324	7.3%
5	South Korea	267	6.0%
6	Japan	250	5.6%
7	Canada	217	4.9%
8	Australia	149	3.4%
9	France	145	3.3%
10	Switzerland	125	2.8%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	198	4.5%
2	Tsinghua University	China	147	3.3%
3	Massachusetts Institute of Technology (MIT)	USA	86	1.9%
4	Stanford University	USA	79	1.8%
5	National Center for Scientific Research of France (CNRS)	France	78	1.8%
6	Harvard University	USA	74	1.7%
7	Zhejiang University	China	69	1.6%
8	University College London	UK	63	1.4%
9	University of Electronic Science & Technology of China	China	59	1.3%
10	Peking University	China	57	1.3%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN INFORMATION SCIENCE

"Research on reconfigurable intelligent surface for MISO and MIMO communication" and "Explainable Artificial Intelligence (XAI)" were selected as the emerging Research Fronts in information science for 2022.

Table 56: Emerging Research Fronts in information science

Rank	Emerging Research Front	Core papers	Citations	Mean Year of Core Papers
1	Research on reconfigurable intelligent surface for MISO and MIMO communication	45	5653	2019.7
2	Explainable Artificial Intelligence (XAI)	3	1111	2019

2.2 KEY EMERGING RESARCH FRONT – "Explainable Artificial Intelligence (XAI)"

Explainable Artificial Intelligence (XAI) is a method and technology that allows experts to understand the results of artificial intelligence, and makes deep neural networks present a certain degree of comprehensibility through machine learning technology. This comprehensibility, in turn, will meet the information demands of relevant users for models and application services (such as causal or background information), so as to establish cognitive trust for human users of artificial intelligence services – for example, in health care.

Faced with the "black box" of deep neural network models, XAI intervenes from all aspects of the algorithm model life cycle, solves the problem of opaque technical details under the deep learning mechanism through the interpretation of data, models, and results. This increased clarity helps users troubleshoot models or improve performance. Compared with traditional AI, XAI pays more attention to trustworthiness, causality, fairness, transparency, and privacy awareness, and so has broad prospects for future application pro key fields such as medical care, justice, security.

"Explainable Artificial Intelligence (XAI)" includes three core papers, which focus on the development of explainable artificial intelligence technology. Among them, the article "Explainable Artificial Intelligence (XAI): Concepts, taxonomies, opportunities and challenges toward responsible AI" (A.B. Arrieta and colleagues, *Information Fusion*, 2020), published by researchers from the Basque Country Center for Applied Mathematics in Spain, the University of Granada, and other research institutions, systematically reviews the concepts, categories, and future development opportunities of XAI from a theoretical viewpoint. Scholars from the University of Pisa in Italy analyzed the interpretation method of the black box model (R.Guidotti, *ACM Computing Surverys*, 2019).

ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

2022 RESEARCH FRONTS

1. HOT RESEARCH FRONT

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

Among the Top 10 Research Fronts in economics, psychology and other social sciences in 2022, research in psychology accounts for half. This portion contains fronts pertaining to COVID-19, with topics that include health risk behaviors; the psychological and physical health of special populations; physical and mental health and preventive measures; and adaptation and evaluation of fear scales. Another front in the field of psychology examines how positive psychology can enhance the enjoyment and reduce the anxiety of learning a foreign language in a classroom setting.

Seven of these Top 10 hot fronts pertain to the COVID-19 pandemic, highlighting the impact of the global outbreak on economics, psychology and other social sciences. Among these fronts, except psychology and sociology, there are two fronts falling within the specialty of economic management, including "The impact and restructuring of the epidemic outbreak on the supply chain" and "Financial market volatility amid the COVID-19 global pandemic".

The Top 10 hot Research Fronts in 2022 also reflect the application of bibliometric methods in economic management research, as well as research on digital or "smart" agriculture from the perspective of social sciences.

Table 57: Top 10 Research Fronts in economics, psychology and other social sciences

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Health risk behaviors such as alcohol consumption during the COVID-19 pandemic	35	1266	2020.7
2	The impact and care of COVID-19 on the mental and physical health of special populations such as children	44	1836	2020.6
3	The impact and restructuring of the epidemic outbreak on the supply chain	21	1522	2020.5
4	Financial market volatility amid the COVID-19 global pandemic	19	2359	2020.3
5	Physical and mental health and precautions during the COVID-19 pandemic	24	11907	2020.1
6	Adaptation and assessment of local COVID-19 fear scales	23	2823	2020.1
7	Knowledge, attitudes, and practices about COVID-19	10	1595	2020
8	Foreign language enjoyment and anxiety: the role of positive psychology in foreign language classroom emotions and teaching	30	1404	2019.7
9	Research on the scientific mapping of economic management based on bibliometrics	42	3136	2019.3
10	Social science research in digital agriculture, smart agriculture, and agriculture 4.0	16	1283	2019.3

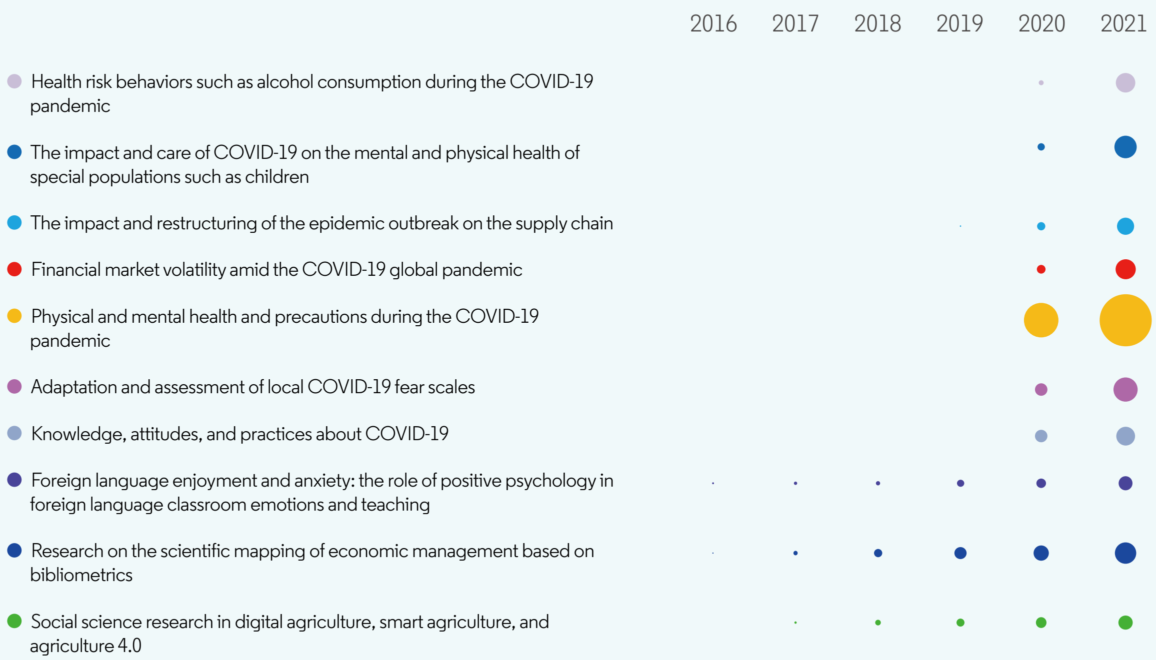


Figure 27: Citing papers for the Top 10 Research Fronts in economics, psychology and other social sciences

1.2 KEY HOT RESEARCH FRONT: "Financial market volatility amid the COVID-19 global pandemic"

The ongoing spread of COVID-19 has had a dramatic impact on global financial markets, bringing an unprecedented level of risk and resulting in significant losses for investors in a very short period. This hot front mainly covers two aspects of research. One area seeks to measure the impact of COVID-19 on financial markets, while the other evaluates how investors have hedged different assets in periods of COVID-19 related volatility.

Within the core of this front, 12 papers empirically analyzed or reviewed the impact of the COVID-19 outbreak on financial markets, demonstrating that infectious diseases can have a severe negative impact on the stock market. Firstly, with the increase in the number of confirmed COVID-19 cases, stock market returns declined. Compared with the increase in the number of deaths, the stock market has responded more strongly to the increase in the number of confirmed cases. Secondly, by analyzing the differences in the impact of epidemic prevention and control policies on stock market volatility in different countries, research demonstrated that non-pharmaceutical interventions significantly increased stock market volatility. Thirdly, the relationship between sentiment generated by coronavirus-related news and stock market volatility was studied, confirming that distress or panic generated by news media was associated with increased stock market volatility.

As far as hedging assets: Faced with unprecedented risks in the market, investors increasingly need to find safe havens for investments, and are therefore compelled to re-evaluate the suitability of some traditional asset types (gold, cryptocurrencies, foreign exchange, and commodities, etc.) for this purpose. Research shows that Bitcoin, Ethereum, etc., have not proved themselves suitable for a reliable safe-haven role, and their addition increases the downside risk of an investment portfolio. TETHER, the world's largest stablecoin issuer, has successfully maintained its peg to the US dollar during the turmoil of the COVID-19, which has certain safe-haven attributes. Meanwhile, during the pandemic, gold and soybean commodity futures have remained strong as safe-haven assets.

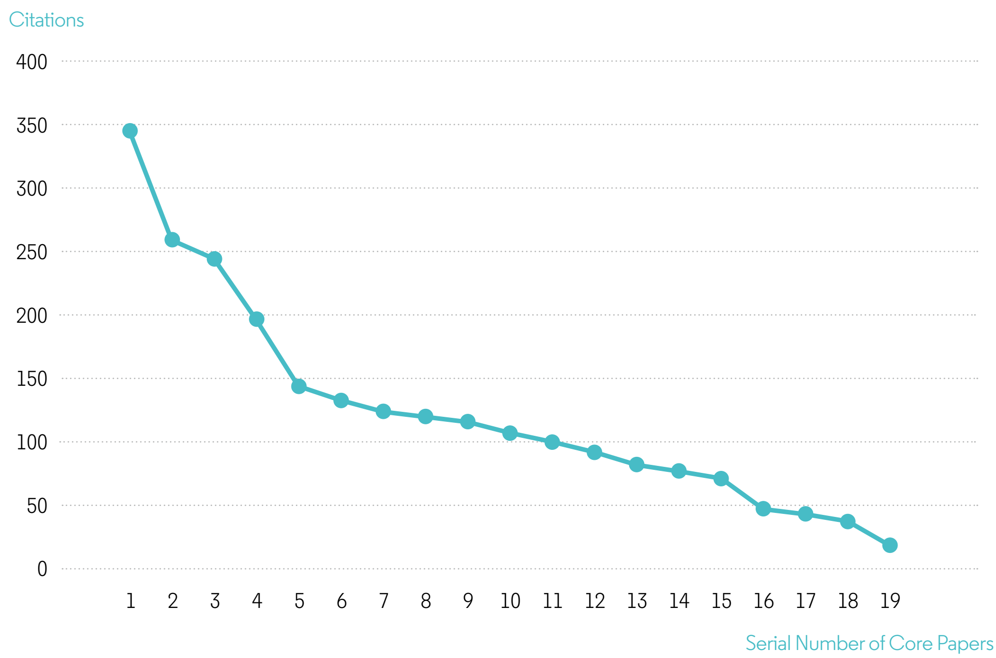


Figure 28: Citation frequency distribution curve of core papers in the Research Front "Financial market volatility amid the COVID-19 global pandemic"

Among the 19 core papers in this hot front (Figure 28), most were published in 2020, with two published in 2021. Three papers have each collected more than 200 citations. The most-cited paper (with a citation count of 346 at this writing) was published in *Finance Research Letters* in October 2020 by Zhang Dayong at Southwestern University of Finance and Economics in China and Ji Qiang at the Insitutes of Science and Development, Chinese Academy of Sciences. This paper focuses on the impact of the rapid spread of COVID-19 on global financial markets, mapping general patterns of country-specific and systemic risk in global financial markets, and analyzing the potential impact of policy interventions.

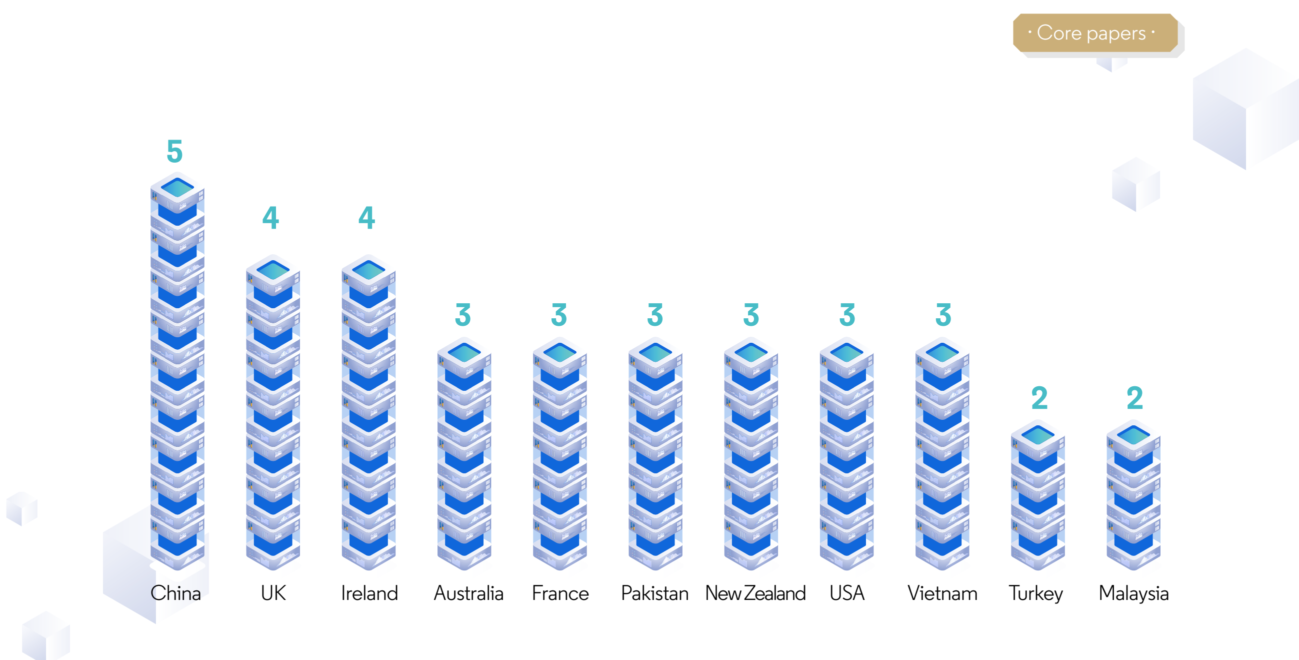
Two other core papers with citation counts now exceeding 200 were published in *Finance Research Letters and International Review of Financial Analysis*. These papers assess the impact of the epidemic on financial market analysis pertaining to safe-haven assets such as Bitcoin and other cryptocurrencies.

The contributions of various countries in this specialty area are relatively balanced. China contributed the most core papers in this hot Research Front, with five foundational papers, accounting for 26.3% of the core (Table 58). Next are the UK and Ireland, which both contributed four papers, accounting for 21.1% of the foundational literature. Among the top institutions, the University of Akron in the USA, Dublin City University in Ireland, and the University of Waikato in New Zealand all contributed three core papers, tying for the 1st rank. The Chinese Academy of Sciences and Southwestern University of Finance and Economics are also among the top institutions, with the contribution of two core papers each.

Table 58: Top countries and institutions producing core papers in the Research Front "Financial market volatility amid the COVID-19 global pandemic"

Country Ranking	Country	Core Papers	Proportion
1	China	5	26.3%
2	UK	4	21.1%
2	Ireland	4	21.1%
4	Australia	3	15.8%
4	France	3	15.8%
4	Pakistan	3	15.8%
4	New Zealand	3	15.8%
4	USA	3	15.8%
4	Vietnam	3	15.8%
10	Turkey	2	10.5%
10	Malaysia	2	10.5%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	University of Akron	USA	3	15.8%
1	Dublin City University	Ireland	3	15.8%
1	University of Waikato	New Zealand	3	15.8%
4	University College Dublin	Ireland	2	10.5%
4	Lahore University of Management Sciences	Pakistan	2	10.5%
4	Chinese Academy of Sciences	China	2	10.5%
4	Trinity College Dublin	Ireland	2	10.5%
4	Paris Business School	France	2	10.5%
4	Paris-Saclay University	France	2	10.5%
4	Southwestern University of Finance and Economics	China	2	10.5%
4	Southampton Solent University	UK	2	10.5%
4	Ho Chi Minh City University of Economics	Vietnam	2	10.5%
4	University of Sydney	Australia	2	10.5%
4	University of Southampton	UK	2	10.5%

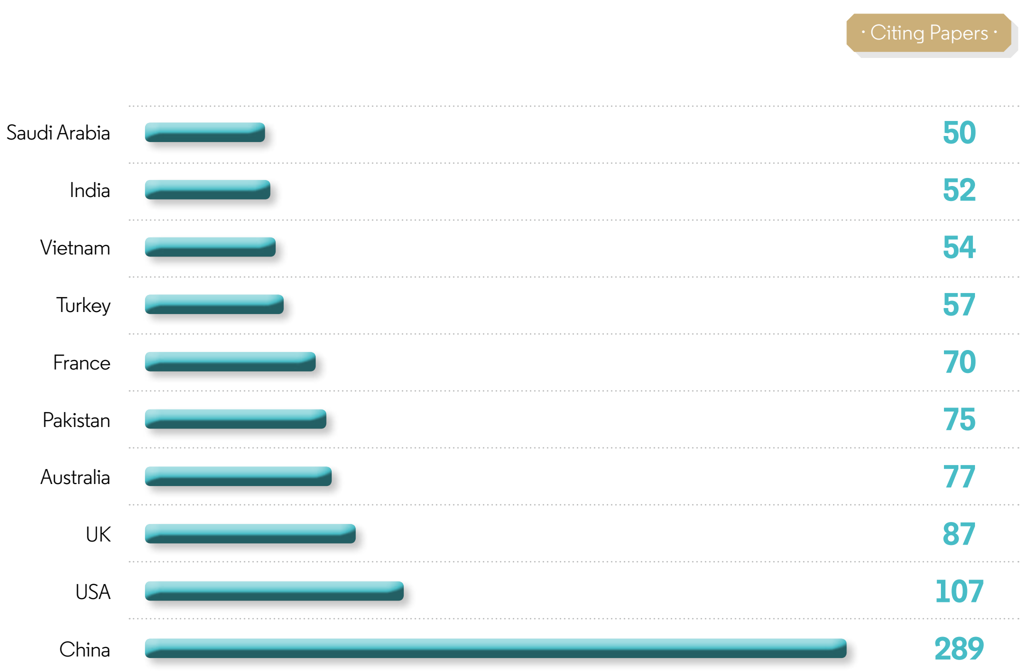


In terms of citing literature, China ranks 1st with 289 citing papers, far ahead of the USA, the UK, and Australia. As for institutions, Ho Chi Minh City University of Economics in Vietnam fielded the most citing papers, followed by South Ural State University in Russia. Central South University in China and the Chinese Academy of Sciences rank 5th and 8th respectively.

Table 59: Top countries and institutions producing citing papers in the Research Front "Financial Markets Under the COVID-19 Global Pandemic"

Country Ranking	Country	Citing Paper	Proportion
1	China	289	30.3%
2	USA	107	11.2%
3	UK	87	9.1%
4	Australia	77	8.1%
5	Pakistan	75	7.9%
6	France	70	7.3%
7	Turkey	57	6.0%
8	Vietnam	54	5.7%
9	India	52	5.5%
10	Saudi Arabia	50	5.2%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Ho Chi Minh City University of Economics	Vietnam	34	3.6%
2	South Ural State University	Russia	28	2.9%
3	Montpellier Business School	France	19	2.0%
3	Zayed University	Saudi Arabia	19	2.0%
5	Central South University	China	18	1.9%
5	University of Ibadan	Nigerian	18	1.9%
7	University of Waikato	New Zealand	17	1.8%
8	Chinese Academy of Sciences	China	16	1.7%
8	Dublin City University	Ireland	16	1.7%
8	Southampton Solent University	UK	16	1.7%



1.3 KEY HOT RESEARCH FRONT – "Research on scientific mapping in the field of economic management based on bibliometric analysis"

Bibliometric analysis is an established and scientific method for exploring and analyzing a large amount of scientific literature data. This form of analysis can help researchers track the process of intellectual evolution in a specific area, including subtle changes, and at the same time reveal a specialty's emerging research topics. Although bibliometric analysis is widely used in many fields, its application in economic management and business research is relatively new and has grown rapidly in recent years. This hot Research Front mainly reflects the use of methods such as bibliometric analysis, meta-analysis, and systematic literature review to analyze the research context, research progress, and development trend in the field of economic management and business research. Another goal is to depict the scientific knowledge map of different subfields within economic management.

From the perspective of research methods, the 42 core papers are all based on literature analysis, and 26 of them employ bibliometric analysis. In addition, they involve methods such as literature-based content analysis, meta-analysis, systematic literature review, and literature review. Two of those describe the principles of bibliometric analysis and related methods, to provide steps and applicable scenarios for bibliometric analysis and to compare the method with similar techniques (such as meta-analysis and systematic literature review) in order to shed light on the application of bibliometric analysis in the field of economic management.

From the perspective of analysis content, except for one paper that introduces bibliometric analysis methods, 28 of the remaining 42 papers pertain to conducting a search strategy and constructing a knowledge map of a certain field from a global perspective. Moreover, 13 papers analyze the development profile of the field based on the top journals in the specialty of economic management and business research.

In terms of research areas, 17 of the 42 core papers belong to the field of marketing, with the remaining fields including international investment and operation, finance, innovation (open innovation), entrepreneurship, e-commerce, knowledge management, and management science.

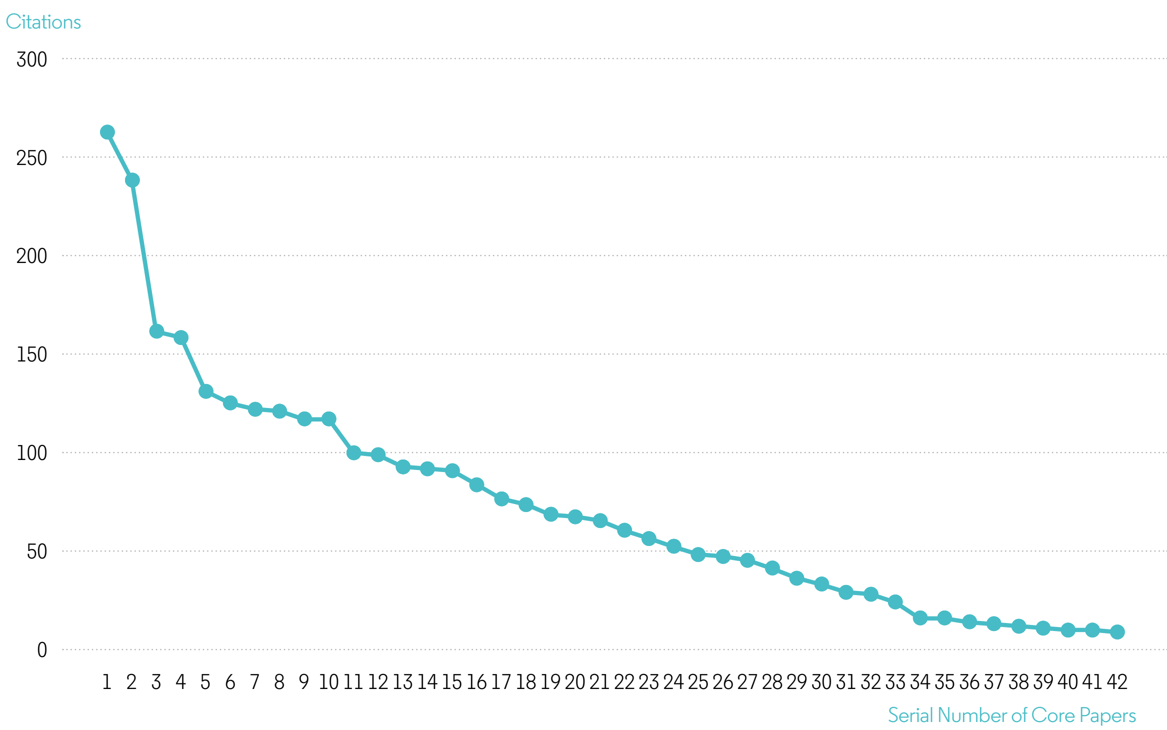


Figure 29: Citation frequency distribution curve of core papers in the Research Front "Research on the scientific map of economic management based on bibliometrics"

This hot Research Front's 42 core papers have publication dates spanning 2016 to 2021, indicating that this hot front emerged comparatively early and has been developing continuously. Among the 42 core papers, two papers have more than 200 citations each. One was published in the *Journal of Product Innovation Management* in 2012 by Krithika Randhawa at the University of Technology Sydney and colleagues; the other paper was authored by Marcel Bogers at University of Copenhagen and colleagues in *Industry and Innovation*, describing the development of open innovation from different perspectives. The agenda of open innovation was proposed from the perspective of bibliometrics, and the existing research themes and emerging topics of open innovation were depicted from different levels. Of the top three to five core papers with the highest citations, two were published in 2017, using bibliometric analysis methods to summarize the research on fuzzy decision-making and SME development challenges. In addition, a literature review on foreign direct investment in emerging countries was published in 2018.

The country that contributed the most to this hot Research Front is the USA, with 24 core papers, accounting for more than half (57.1%), followed by India, with 17 core papers, or 40.5% of the core. At the institutional level, institutions with more contributions are concentrated in India, Chile, Australia and the USA, and the distribution is relatively balanced. The National Polytechnic Institute of Malawi Jaipur, India, contributed nine core papers, accounting for the largest proportion (21.4%), followed by the University of Chile.

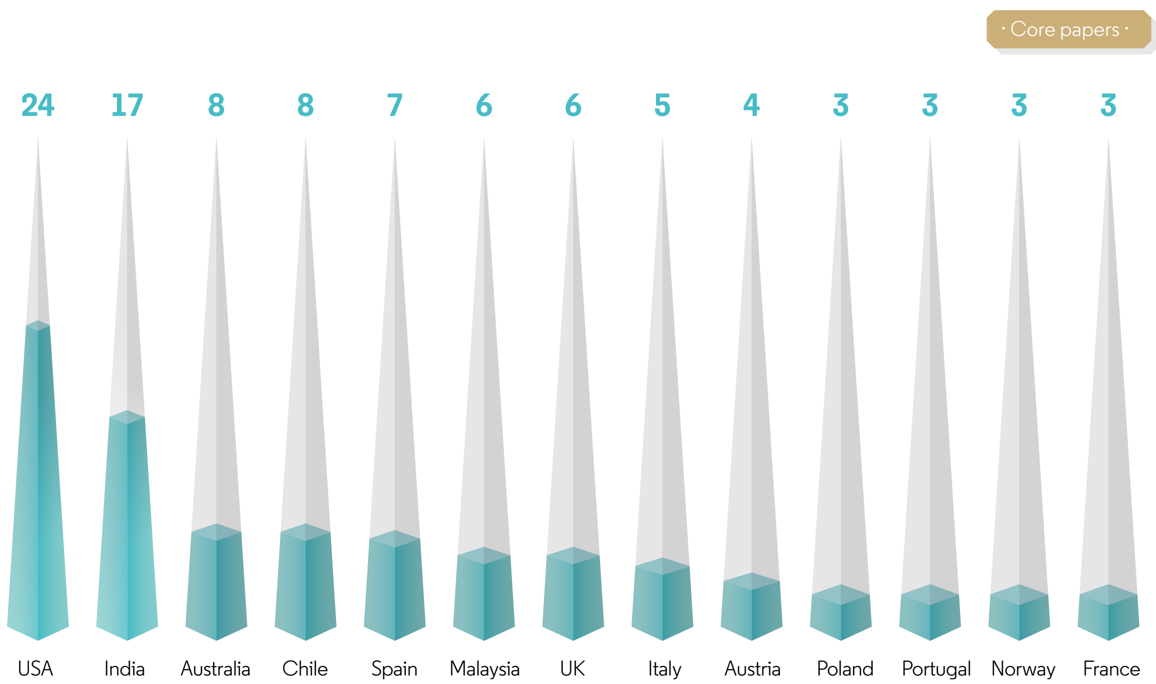
Table 60: Top countries and institutions producing the core papers in the Research Front "Research on the scientific map of economic management based on bibliometrics"

Country Ranking	Country	Core Paper	Proportion
1	USA	24	57.1%
2	India	17	40.5%
3	Australia	8	19.0%
3	Chile	8	19.0%
5	Spain	7	16.7%
6	Malaysia	6	14.3%
6	UK	6	14.3%
8	Italy	5	11.9%
9	Austria	4	9.5%
10	Poland	3	7.1%
10	Portugal	3	7.1%
10	Norway	3	7.1%
10	France	3	7.1%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	National Polytechnic Institute of Malawi Jaipur	India	9	21.4%
2	University of Chile	Chile	8	19.0%
3	Swinburne University of Technology	Australia	6	14.3%
3	Swinburne University of Technology Sarawak Campus	Malaysia	6	14.3%
5	Georgia State University	USA	5	11.9%
5	Rollins College	USA	5	11.9%
7	Indian Institute of Management Kozhikode Branch	India	4	9.5%
8	Norwegian University of Science and Technology	Norway	2	4.8%
8	American University	USA	2	4.8%
8	University of St. Thomas San Diego	Chile	2	4.8%
8	Indian Institute of Management Development	India	2	4.8%
8	American University of Puerto Rico	USA	2	4.8%
8	University of Hartford	USA	2	4.8%
8	Nottingham Trent University, UK	UK	2	4.8%

Country Ranking	Country	Core Paper	Proportion

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
8	University of Vienna	Austria	2	4.8%
8	Autonomous University of Barcelona	Spain	2	4.8%
8	University of Copenhagen	Denmark	2	4.8%
8	University of Washington Seattle	USA	2	4.8%
8	Catholic University of Portugal	Portugal	2	4.8%
8	University of Barcelona	Spain	2	4.8%
8	University of Nottingham	UK	2	4.8%
8	University of Zagreb	Croatia	2	4.8%

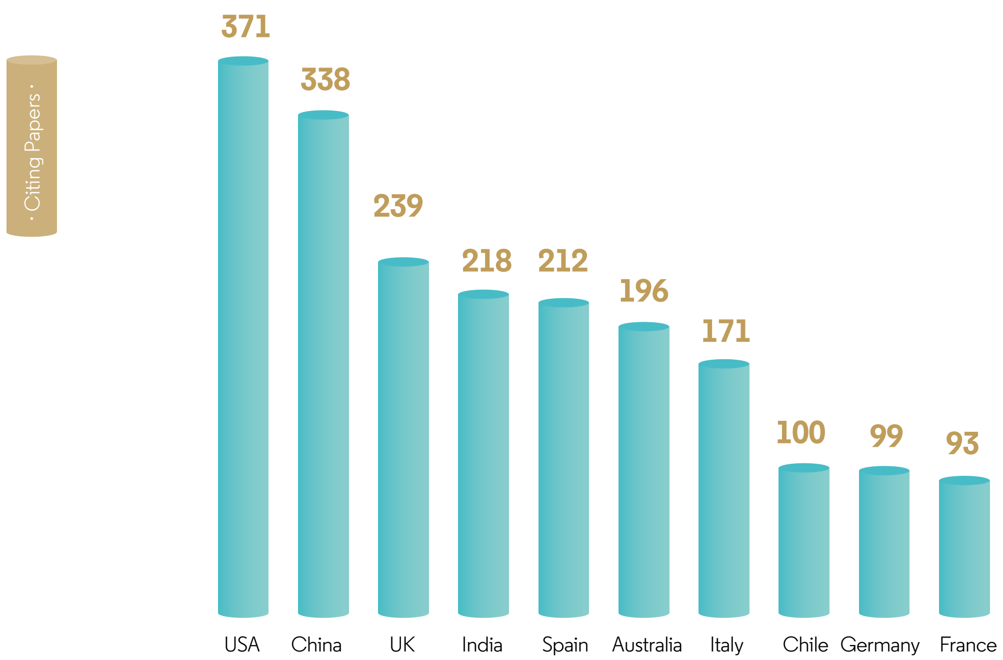


In terms of citing papers, the USA ranks 1st with 371 papers, while China, the UK, India, and Spain all contribute more than 200 citing papers. China's attention to this front has been gradually increasing. At the institutional level, the University of Chile has the most citing papers, while the University of Technology Sydney in Australia ranks 2nd and Sichuan University in China ranks 5th.

Table 61: Top countries and institutions producing citing papers in the Research Front "Research on the scientific map of economic management based on bibliometrics"

Country Ranking	Country	Citing Paper	Proportion
1	USA	371	20.1%
2	China	338	18.3%
3	UK	239	13.0%
4	India	218	11.8%
5	Spain	212	11.5%
6	Australia	196	10.6%
7	Italy	171	9.3%
8	Chile	100	5.4%
9	Germany	99	5.4%
10	France	93	5.0%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	University of Chile	Chile	80	4.3%
2	University of Technology Sydney	Australia	70	3.8%
3	National Polytechnic Institute of Malawi, Jaipur	India	55	3.0%
4	University of Copenhagen	Denmark	38	2.1%
5	Sichuan University	China	37	2.0%
6	University of California Berkeley	USA	29	1.6%
7	Swinburne University of Technology Sarawak Campus	Malaysia	28	1.5%
8	University of Barcelona	Spain	25	1.4%
9	University of Granada	Spain	23	1.2%
10	Georgia State University	USA	22	1.2%
10	Macquarie University	Australia	22	1.2%
10	Concepcion Cattolica - University of San Tisima	Chile	22	1.2%
10	University of Valencia	Spain	22	1.2%



2. EMERGING RESEARCH FRONT

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

Eleven topics in economics, psychology and other social sciences have been selected as emerging Research Fronts, of which six are relevant to the COVID-19 outbreak. Specifically, these topics pertain to loneliness and mental health among older adults during the pandemic; examination of public acceptance of digital contact tracing; the correlation between personality traits and perceived stress, risk perception, and protective behavior during the outbreak; geopolitical risk versus Bitcoin impact on financial markets such as cryptocurrencies; and research on COVID-19 vaccination intentions. The following selects the "Studies of COVID-19 vaccination hesitancy and related issue" as a key interpretation.

Table 62: Emerging Research Fronts in economics, psychology and other social sciences

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Technological innovation, energy consumption and carbon emissions	22	560	2021
2	Loneliness and mental health among older adults during the COVID-19 pandemic	5	453	2020.8
3	Energy consumption, economic policy uncertainty and carbon emissions	10	304	2020.8
4	Changes and causes of retail consumer buying behavior	10	278	2020.8
5	Double-difference study of treatment effect	4	207	2020.8
6	Mental health and behavioral manifestations of depression, anxiety, or obsessive-compulsive disorder in the context of COVID-19	12	417	2020.7
7	Internet of Things and Smart City Construction Based on Blockchain	21	954	2020.6
8	Studies of COVID-19 vaccination hesitancy and related issue	7	894	2020.6
9	Public Acceptance of Digital Contact Tracing During the COVID-19 Pandemic	14	747	2020.6
10	Research on Personality Traits and Psychological Traits During the COVID-19 Pandemic	16	684	2020.6
11	The impact of COVID-19 and geopolitical risks on financial markets such as Bitcoin	18	679	2020.6

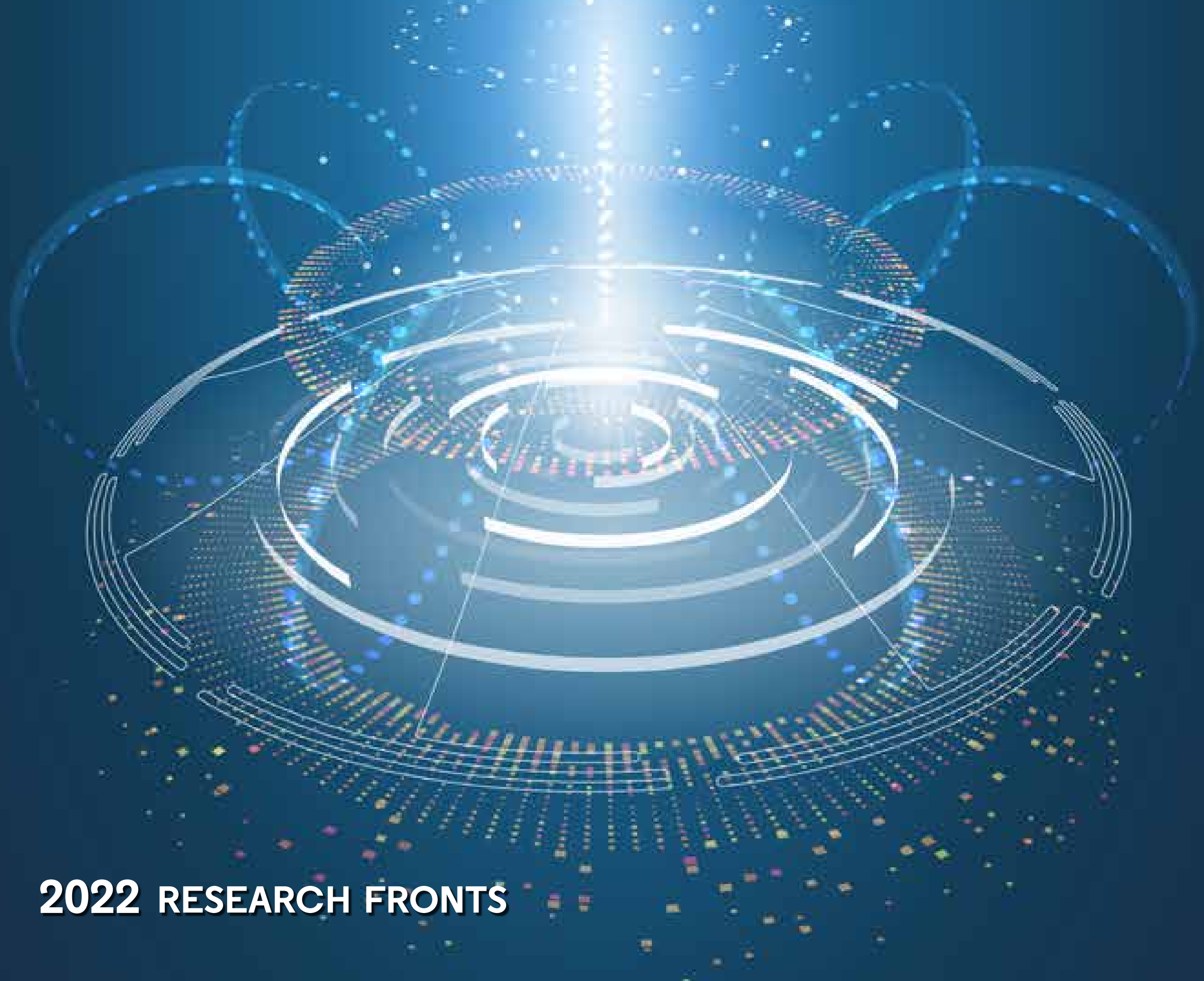
2.2 KEY EMERGING RESARCH FRONT – "Studies of COVID-19 vaccination hesitancy and related issues"

The COVID-19 epidemic continues to spread around the world. Vaccination is very important to preventing the spread of COVID-19. However, due to the short development time of the COVID-19 vaccine and public concerns about the safety of the vaccine, the phenomenon of "vaccine hesitancy" has been observed in many places. The phenomenon has also become an obstacle to vaccination against highly infectious diseases worldwide, a development highly detrimental to epidemic prevention and control. Therefore, investigating and analyzing the status quo of vaccine hesitancy around the world, and identifying which groups are the most severely hesitant, is of great significance to carry out targeted policy intervention and education in the face of the pandemic. Hence, research in the area has registered as one of the emerging Research Fronts in the main area of economics, psychology and other social sciences.

Seven core papers of this emerging front conducted an anonymous survey on the willingness of medical staff and the general public to be vaccinated, with respondents in France, Belgium, French-speaking Canada, Israel, Hong Kong region of China, and other places. One finding demonstrated that healthcare personnel working closely with virus-positive patients, and individuals who believe they are at risk, are more likely to be vaccinated. Meanwhile, parents, nurses and healthcare workers who do not care for COVID-19 positive patients are more hesitant to become vaccinated. The second finding is that older, male, white or Asian respondents were more likely than other groups to be vaccinated, and females, Blacks, Latinos, and rural people were less likely to be vaccinated as soon as vaccines became available. Third, the COVID-19 pandemic has not had a positive impact on the acceptance rate of influenza vaccines. Fourth, safety, efficacy, and the speed of development and approval are considered to be the main factors influencing COVID-19 vaccination hesitancy. These concerns should be addressed before or during a vaccination campaign.

APPENDIX RESEARCH FRONTS: IN SEARCH OF THE STRUCTURE OF SCIENCE

David Pendlebury



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.

REFERENCES

[1] Eugene Garfield. Citation indexes for science: a new dimension in documentation through association of ideas. Science, 122 (3159): 108-111, 1955.

[2] Eugene Garfield. Citation Indexing: its Theory and Application in Science, Technology, and Humanities. NewYork: John Wiley & Sons, 1979, 3.

[3] Genetics Citation Index. Philadelphia: Institute for Scientific Information, 1963.

[4] Eugene Garfield. Citation indexes in sociological and historic research. American Documentation, 14 (4): 289-291, 1963.

[5] Eugene Garfield, Irving H. Sher, Richard J. Torpie. The Use of Citation Data in Writing the History of Science. Philadelphia: Institute for Scientific Information, 1964.

[6] Derek J. de Solla Price. Science Since Babylon. New Haven:Yale University Press, 1961. [See also the enlarged edition of1975]

[7] Derek J. de Solla Price. Little Science, Big Science. NewYork: Columbia University Press, 1963. [See also the edition Little Science, Big Science…and Beyond, 1986, including nine influential papers by Price in addition to the original book]

[8] Derek J. de Solla Price. Foreword.in Eugene Garfield, Essays of an Information Scientist, Volume 3, 1977-1978,Philadelphia: Institute For Scientific Information, 1979,v-ix.

[9] Derek J. de Solla Price. Networks of scientific papers: the pattern of bibliographic references indicates the nature of thescientific research front. Science, 149 (3683): 510-515, 1965.

[10] ibid.

[11] Henry Small. Co-citation in scientific literature: a new measure of the relationship between two documents. Journal ofthe American Society for Information Science, 24 (4): 265-269,1973.

[12] Irena V. Marshakova-Shaikevich. System of document connections based on references. Nauchno Tekhnicheskaya, Informatsiza Seriya 2, SSR, [Scientific and Technical Information Serial of VINITI], 6: 3-8, 1973.

[13] Robert K. Merton. Singletons and multiples in scientific discovery: a chapter in the sociology of science. Proceedings of the American Philosophical Society, 105 (5): 470-486, 1961.

[14] Robert K. Merton. Resistance to the systematic study of multiple discoveries in science. Archives Européennes de Sociologie, 4 (2): 237-282, 1963.

[15] Myer M. Kessler. Bibliographic coupling between scientific papers. American Documentation, 14 (1): 10-25, 1963.

[16] Henry Small. Cogitations on co-citations. Current Contents, 10: 20, march 9, 1992.

[17] Henry Small, Belver C. Griffith. The structure of scientific literatures i: Identifying and graphing specialties. Science Studies, 4 (1):17-40, 1974.

[18] Belver C. Griffith, Henry g. Small, Judith A. stonehill, sandra Dey. The structure of scientific literatures II: Toward a macro- and microstructure for science. Science Studies, 4 (4):339-365, 1974.

[19] ibid.

[20] See note 8 above.

[21] Eugene Garfield. Introducing the ISI Atlas of Science: Biochemistry and Molecular Biology, 1978/80. Current Contents, 42, 5-13, October 19, 1981 [reprinted in Eugene Garfield, Essays of an Information Scientist, Vol. 5, 1981-1982, Philadelphia: Institute for Scientific Information, 1983,279-287]

[22] ISI Atlas of Science: Biochemistry and Molecular Biology,1978/80, Philadelphia: Institute for Scientific Information,1981.

[23] ISI Atlas of Science: Biotechnology and Molecular Genetics, 1981/82, Philadelphia: Institute for Scientific Information, 1984.

[24] Eugene Garfield. Launching the ISI Atlas of Science: for the new year, a new generation of reviews. Current Contents, 1: 3-8, January 5, 1987. [reprinted in Eugene Garfield, Essays of an Information Scientist, vol. 10,1987, Philadelphia: Institute for Scientific Information,1988, 1-6]

[25] Henry Small, ED Sweeney. Clustering the Science Citation Index using co-citations. I. A comparison of methods. Scientometrics, 7 (3-6): 391-409, 1985.

[26] Henry Small, ED Sweeney, Edward Greenlee. Clustering the Science Citation Index using co-citations. II. Mapping science. Scientometrics, 8 (5-6): 321-340, 1985.

[27] Henry Small, Eugene Garfield. The geography of science: disciplinary and national mappings. Journal of Information Science, 11 (4): 147-159, 1985.

[28] Eugene Garfield, Alexander I. Pudovkin, Vladimir S. Istomin. Why do we need algorithmic historiography?. Journal of the American Society for Information Science and Technology, 54(5): 400-412, 2003.

[29] Eugene Garfield. Historiographic mapping of knowledge domains literature. Journal of Information Science, 30(2):119-145, 2004.

[30] Henry Small. The synthesis of specialty narratives from co-citation clusters. Journal of the American Society for Information Science, 37 (3): 97-110, 1986.

[31] Henry Small. Macro-level changes in the structure of cocitation clusters: 1983-1989. Scientometrics, 26 (1): 5-20, 1993.

[32] Henry Small. A passage through science: crossing disciplinary boundaries. Library Trends, 48 (1): 72-108, 1999.

[33] Henry Small. Charting pathways through science: exploring Garfield's vision of a unified index to science. In Blaise Cronin and Helen Barsky Atkins, editors, The Web of Knowledge: A Festschrift in Honor of Eugene Garfield, Medford, NJ: American Society for Information Science, 2000, 449-473.

[34] Edward O. Wilson. Consilience: The Unity of Knowledge, New York: Alfred A. Knopf, 1998.

[35] Henry small. A Sci-MAP case study: building a map of AIDs Research. Scientometrics, 30 (1): 229-241, 1994.

[36] Henry Small. Update on science mapping: creating large document spaces. Scientometrics, 38 (2): 275-293, 1997.

[37] Henry Small. Visualizing science by citation mapping.Journal of the American Society for Information Science, 50 (9):799-813, 1999.

[38] George S. Davidson, Bruce Hendrickson, David K.Johnson, Charles E. Meyers, Brian N. Wylie. Knowledge mining with Vxinsight®: discovery through interaction. Journal of Intelligent Information Systems, 11 (3): 259-285, 1998.

[39] Kevin W. Boyack, Brian N. Wylie, George S. Davidson. Domain visualization using Vxinsight for science and technology Management. Journal of the American Society for Information Science and Technology, 53 (9): 764-774, 2002.

[40] Katy Börner. Atlas of Science: Visualizing What We Know, Cambridge, MA: MIT Press, 2010.

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WORKING COMMITTEE

General Plan Team (methodology, data analysis and drafting)

Clarivate	David PENDLEBURY, Weiping YUE, Na WANG, Yang GUO, Tingying HUANG, Yapeng MA, Min SUN, Yang XIONG, Qingwen YUAN, Zhen WANG
Institutes of Science and Development, Chinese Academy of Sciences	Fuhai LENG, Qiuju ZHOU, Fan YANG

Research Front Interpretation Team (analysis and interpretation of Research Fronts)

Agriculture, plant and animal sciences	Jianxia YUAN
Ecology and environmental sciences	Ying XING
Geosciences	Weiwei FAN, Fan YANG
Clinical medicine	Zanmei LI, Junlian LI, Yujing JI
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Clarivate	
Institutes of Science and Development, Chinese Academy of Sciences	Xiaomei WANG, Guopeng LI

Translation Team

Jianxia YUAN, Ying XING, Qiuju ZHOU, Weiwei FAN, Haiming WANG, Fan YANG, Zanmei LI, Junlian LI, Yujing JI, Wenyue BIAN, Chaoxing ZHANG, Longguang HUANG, Lin HAN, Haixia WANG, Zhen SUN, Rujiang BAI, Ruimin PEI, Weiping YUE, Na WANG, Christopher M. KING, Yang GUO, Tingying HUANG, Yapeng MA, Min SUN, Yang XIONG, Qingwen YUAN, Zhen WANG

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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
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