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2021
RESEARCH FRONTS

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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, and 2020, 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, and Research Fronts 2020.* These reports have gained widespread attention from around the world.

This year, the same methodology was employed. For the newest edition, Research Fronts 2021, 110 hot Research Fronts and 61 emerging Research Fronts were identified based on co-citation analysis that generated 12,147 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 171 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 171 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 2021 update, the Research Fronts drew on ESI data from 2015 to 2020, which were obtained in March 2021.

2.1 RESEARCH FRONTS SELECTION AND NAMING

Research Fronts 2021 presents a total of 171 Research Fronts, including 110 hot and 61 emerging ones. In 2021, the Research Fronts are classified into 11* broad research areas in the sciences and social sciences. Starting from 12,147 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 171 Research Fronts is described as follows.

2.1.1 SELECTING THE HOT RESEARCH FRONTS

First, Research Fronts in each ESI field were ranked by total citations, and the Top 10% of the fronts in each ESI field were extracted. These Research Fronts were then merged into 11 broad areas and re-ranked according to the average (mean) year of their core papers to produce the "youngest" ones in each broad area. Based on these data, the strategic information professionals with domain knowledge adjusted and merged some Research Fronts, resulting in a total of 110 hot Research Fronts. 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 andcitation behaviors in various disciplines, some fronts are much smaller than others in terms of number of core and citing papers.

2.1.2 SELECTING THE EMERGING RESEARCH FRONTS

A Research Front with core papers of recent vintage indicates a specialty with a young foundation that is rapidly growing. To identify emerging specialties, the immediacy of the core papers is a priority, and that is why it is characterized as "emerging." 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 2019 or more recently were considered. Then these were sorted in descending order by their total citations in each ESI field. 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 11 broader fields. Sixty-one fronts were selected as emerging, and the earliest mean year of the emerging fronts was 2019.5. Because the selection was not limited to any research area, the 61 fronts are distributed unevenly in the 11 fields. For example, there is no emerging Research Front in Mathematics, while there are 29 emerging Research Fronts in "Clinical Medicine", but only one in "Physics", "Geosciences", and

* The field of Engineering is no longer covered.

"Information Science."

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 61 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 171 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 171 Research Fronts provided by Clarivate, information professionals at the Institute of Strategic Information, conducted a detailed analysis and interpretation to highlight 31 key Research Fronts and 2 key Research Front groups (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 2020 and the earliest citing paper was published in 2016, the age of citing articles(T) equals 4.

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

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 2021, for each of the 11 broad research areas, one key hot Research Front was selected based on the number of core papers (P) in combination with the professional judgment of analysts from the Institute of Strategic Information. Another key hot Research Front was chosen by the indicator CPT. Based on their knowledge, the analysts assessed the significance of the key hot Research Fronts in addressing major issues in the given area. Firstly, the Research Front with the greatest number of core papers (P) in a broad research area was selected. If the front with the greatest P had been interpreted in previous years and there was no significant change of the core papers, then the Research Front with the second highest P would be selected as the key hot Research Front, and so on. Furthermore, another key hot front was selected based on the integration of CPT and professional judgement.

By taking advantage of the above two indicators as well as our domain experts' judgment, we selected 22 key hot Research Fronts from the 110 hot Research Fronts in the 11 broad research areas. Moreover, based on CPT and experts' judgment, nine key emerging Research Fronts and two key emerging Research Front groups were selected from the emerging Research Fronts. Thus, we interpret in detail the selected 31 key Research Fronts and two key Research Front groups from the 171 Research Fronts.

2.2.2 ANALYSIS AND INTEPRETATION OF KEY RESEARCH FRONTS

Based on the data of the selected 171 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 Top10 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.

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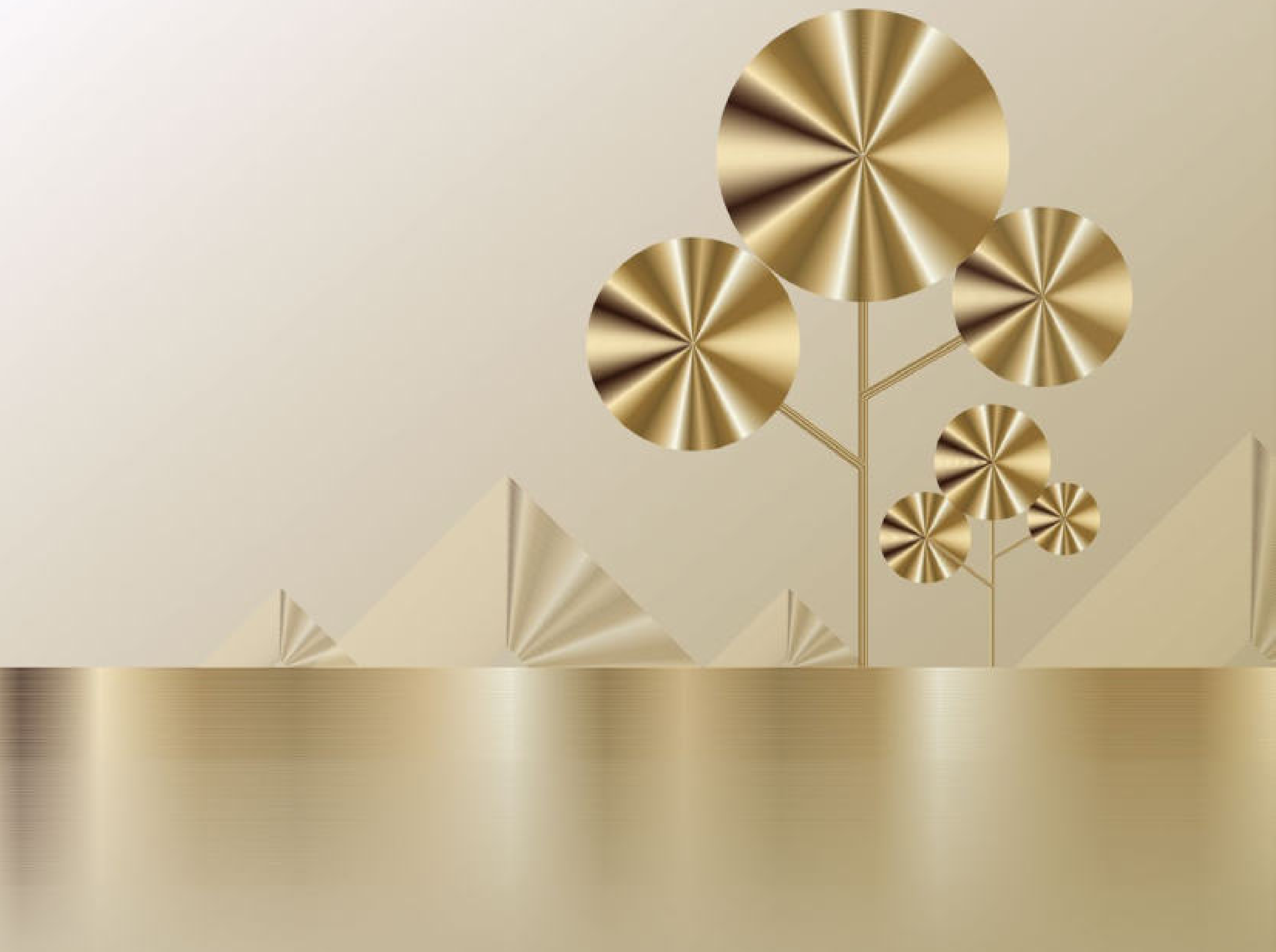
AGRICULTURAL, PLANT AND ANIMAL SCIENCES



1. HOT RESEARCH FRONT

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

The Top 10 hot Research Fronts in agricultural, plant and animal sciences mainly involve six subfields, consisting of food science and engineering, plant genomes and their editing, animal infectious diseases, healthy eating, plant evolution, and plant disease resistance (Table 1). The subfield of food science and engineering accounts for three hot Research Fronts, pertaining respectively to plant antioxidants application in meat products, multifunctional intelligent food packaging film, and melatonin application in fruit storage. There are also three hot Research Fronts on plant genomes and their editing; these fronts focus, in turn, on tea plant genome, plant pan-genome, and base editing technology for animals and plants. One hot Research Front on animal infectious diseases involves epidemiological and virological research on African swine fever. One front occupies the subfield of healthy eating, studying time-restricted feeding effects. Another front on plant evolution is devoted to the evolution of early terrestrial plants. The Research Front related to plant disease resistance investigates the plant immune receptor NLR and its mediated disease resistance mechanism.

Compared with previous surveys, the subfield of food science and engineering has registered a higher number of hot fronts in the last two years. A key Research Front in this area, on the topic of "smart" packaging for food, appears again in the Top 10 list as the field evolves: Its appearance in the 2020 Research Front roundup highlighted the preparation and characterization of intelligent food packaging, while the pertinent Research Front in 2021 concerns the development of multifunctional, intelligent food-packaging film. The subfield of animal infectious diseases also appears for the second consecutive year, having focused on porcine circovirus in 2020, and, in 2021, on African swine fever. Additionally, the subfield of healthy eating marks its first appearance on the Top 10 hot Research Front list in 2021, examining the effects of time-restricted feeding on health, aging and disease progression.

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

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Application of plant extracts as antioxidants in meat products	22	841	2019
2	The tea plant genome and its molecular mechanism of quality traits formation	25	1131	2018.8
3	Plant pan-genome research	16	900	2018.8
4	Development of multifunctional intelligent food packaging film	34	1757	2018.5
5	Epidemiological and virological research and prevention and control of African swine fever	19	962	2018.5
6	Effects of time-restricted feeding on health, aging and disease progression	17	1553	2018.4
7	Study on the evolution of early terrestrial plants	23	1522	2018.4
8	Research on the base editor of animals and plants	46	7308	2018.2
9	Influence of melatonin treatment on fruit storage quality and its function mechanism	16	905	2018.2
10	Plant immune receptor NLR and its mediated disease resistance mechanism	36	2509	2018.1

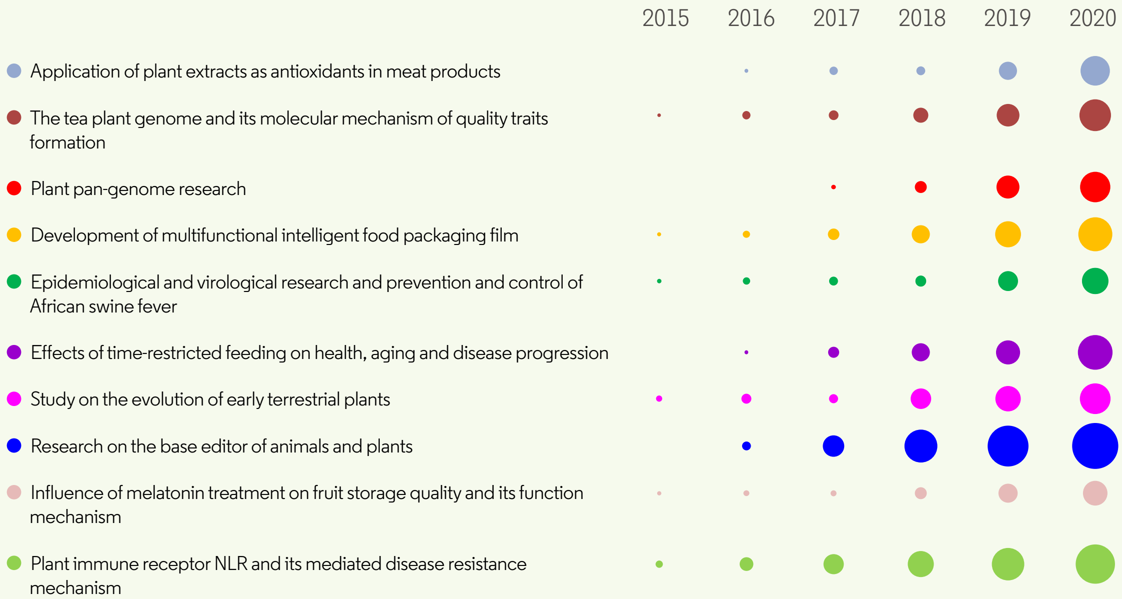


Figure 1: Citing papers for the Top 10 Research Fronts in agricultural, plant and animal sciences

1.2 KEY HOT RESEARCH FRONT – "Plant pan-genome research"

The term "pan-genome" refers to the collection of all genome sequences existing in the whole species or population rather than in a single individual. It is divided into core genome and accessory genome. The sequence of the core genome exists in all individuals, and the sequence of the accessory genome only exists in one or some individuals. In recent years, with the publication of reference genomes of different species and the comparative genome study of different individuals in the same species, researchers have gradually realized that each individual has genetic traits with great personality characteristics, and a single reference genome can't represent the diversity within the species. Therefore, the concept of pan-genome appears.

This concept was first proposed in the field of microbiomics in 2005, mainly by Herve Tettelin of University of Maryland. The concept was then quickly applied to the field of animal and plant genomics. A 2018 review pointed out that since the application of pan-genome was extended from bacteria to plants and animals, genome research has entered the era of pan-genomics. Pan-genome research is of great significance to fully tap biological genetic variation resources, identify regulatory genes for unique traits of strains, and cultivate agricultural animal and plant varieties that are best suited to demonstrating high quality and high yield in a given environment.

Sixteen core papers underlie this hot Research Front, including 13 research papers and three reviews. The 13 research papers involve *Brassica napus* (also referred to as rapeseed or oilseed rape), tomato, rice, wheat and sunflower. The main research contents include: architecture and ecotype differentiation, assembly and comparison, and the identification of disease resistance genes of *Brassica napus*'s pan-genome; the mining of tomato fruit flavor genes; the domestication history of cultivated tomato in Latin America; the genomic variation of cultivated rice and wild rice; and, last, the genetic diversity of the sunflower and the genetic relationship between the plant's cultivated and wild species. The three review papers mainly summarize the research methods, application, and research progress of plant pan genomics in crop improvement. The reviews also explore the origins of gene presence and absence variation, and the impacts of pan-genomes on plant biology, breeding and evolutionary studies.

Among the 16 core papers, the most frequently cited is a research article, cited 252 times at this writing (Figure 2). It was published in *Nature* by researchers from the Chinese Academy of Agricultural Sciences, International Rice Research Institute, Shanghai Jiao Tong University, BGI Shenzhen, the University of Arizona, and other institutions. The report details the genetic variation, population structure and diversity among 3,010 diverse Asian cultivated rice genomes, providing an important resource for rice genomics research and breeding.

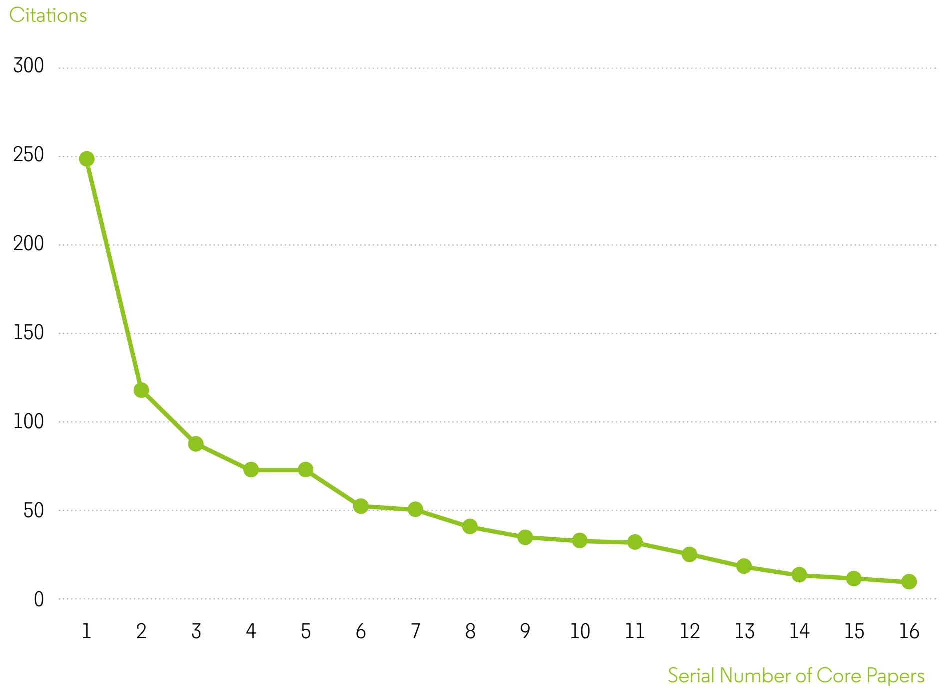
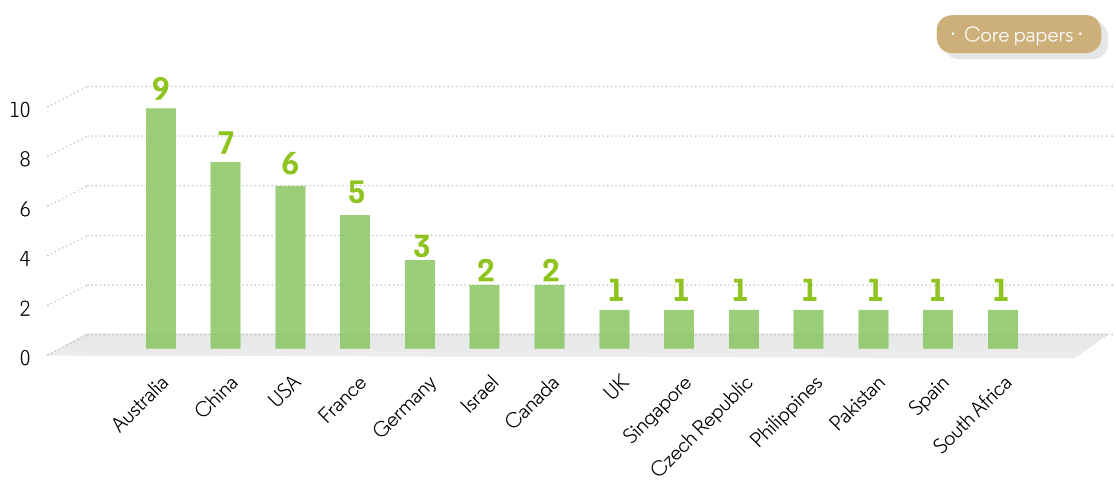


Figure 2: Citating frequency distribution curve of core papers in Research Front "Plant pan-genome research"

Among the top 10 countries and institutions producing this front's core papers (Table 2), Australia can boast the highest contribution, with its nine papers surpassing 50% of the total. China[1] ranks 2nd, accounting for 43.8% of the core literature. The USA ranks 3rd, with 37.5%. Among the prolific contributing institutions, the University of Western Australia in Australia ranks 1st, with a contribution rate of 43.8%, followed by Chinese Academy of Agricultural Sciences in China, with a contribution rate of 31.3%.

Table 2: Top countries and institutions producing core papers in the Research Front "Plant pan-genome research"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core papers	Proportion
1	Australia	9	56.3%	1	University of Western Australia	Australia	7	43.8%
2	China	7	43.8%	2	Chinese Academy of Agricultural Sciences	China	5	31.3%
3	USA	6	37.5%	3	University of Melbourne	Australia	4	25.0%
4	France	5	31.3%	3	University of Queensland	Australia	4	25.0%
5	Germany	3	18.8%	3	National Research Institute for Agriculture, Food and Environment	France	4	25.0%
6	Israel	2	12.5%	6	University of Georgia	USA	3	18.8%
6	Canada	2	12.5%	6	Huazhong Agricultural University	China	3	18.8%
8	UK	1	6.3%	6	National Center for Scientific Research of France (CNRS)	France	3	18.8%
8	Singapore	1	6.3%	6	University of Paris Saclay	France	3	18.8%
8	Czech Republic	1	6.3%	10	University of Florida	USA	2	12.5%
8	Philippines	1	6.3%	10	Chinese Academy of Sciences	China	2	12.5%
8	Pakistan	1	6.3%	10	Southern Cross University	Australia	2	12.5%
8	Spain	1	6.3%					
8	South Africa	1	6.3%					

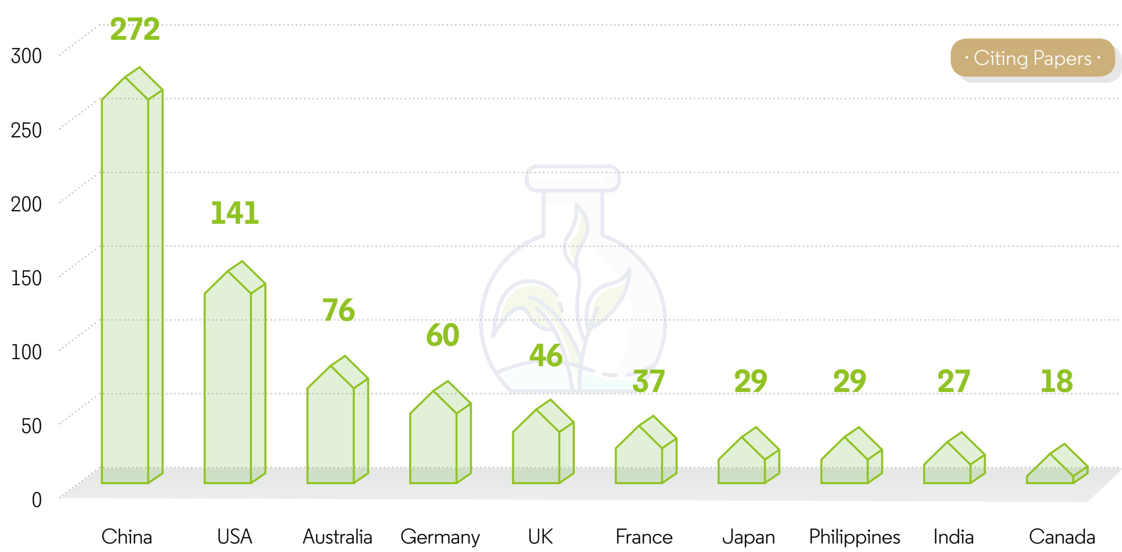


[1] In this report, data for China does not include that in Chinese Taiwan.

In terms of countries that cite the core papers in this hot front (Table 3), China, which ranks 2nd in the number of core papers, is the most prolific contributing country in terms of papers that cite the core literature, accounting for nearly 44%. The USA, which ranks 3rd in output of core papers, ranks 2nd by the measure of citing papers, accounting for nearly 23%. Australia, meanwhile, which ranks 1st in output of core papers, ranks 3rd in citing papers, representing about 12%. Clearly, China, the USA, and Australia are in the lead in this hot Research Front. In terms of citing institutions, the Chinese Academy of Agricultural Sciences, the Chinese Academy of Sciences and Huazhong Agricultural University in China constitute the top three in their prolific follow-up research in this area.

Table 3: Top countries and institutions producing citing papers in the Research Front "Plant pan-genome research"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	272	43.7%	1	Chinese Academy of Agricultural Sciences	China	93	15.0%
2	USA	141	22.7%	2	Chinese Academy of Sciences	China	55	8.8%
3	Australia	76	12.2%	3	Huazhong Agricultural University	China	49	7.9%
4	Germany	60	9.6%	4	Consultative Group on International Agricultural Research	Philippines	29	4.7%
5	UK	46	7.4%	5	National Research Institute for Agriculture, Food and Environment	France	27	4.3%
6	France	37	5.9%	6	University of Western Australia	Australia	26	4.2%
7	Japan	29	4.7%	7	United States Department of Agriculture (USDA)	USA	19	3.1%
7	Philippines	29	4.7%	8	China Agricultural University	China	18	2.9%
9	India	27	4.3%	8	National Center for Scientific Research of France (CNRS)	France	18	2.9%
10	Canada	18	2.9%	10	Justus-Liebig-Universität Gießen	Germany	17	2.7%



1.3 KEY HOT RESEARCH FRONT – "Research on the base editor of animals and plants"

Base editing is a new target gene-modification technology developed based on the CRISPR/Cas gene editing system. It can realize single nucleotide site mutation without cutting off the nucleic acid skeleton and can directly and chemically modify target nuclear bases in the process of genome and transcriptome editing. Some experts believe that if CRISPR is regarded as the crown of gene editing, then the base editor is the pearl on the crown. In 2017, the new base editor technology created by David Liu at Harvard University was selected among *Science* magazine's top 10 "breakthroughs of the year", and Liu was named in *Nature* as one of its "10 people who mattered this year".

Forty-six core papers identify this hot front. Of those papers, 42 were published in *Nature*, *Science* or their sub-journals. These papers mainly focus on DNA base editor, with more papers on cytosine base editor and fewer on adenine base editor. The research objects modified by base editing methods include mice, zebrafish, *Arabidopsis*, rice, wheat, corn, tomato, *Brassica napus*, and potato. The gene editing of mice, zebrafish, and *Arabidopsis* has mainly served to advance the use of model animals and plants, in order to generally improve base-editing technology or build a human disease model.

The gene editing of rice, wheat, corn, tomato and other crops is mainly to establish corresponding editing technology and improve crop genetic traits. Of these crops, rice is the most prominent. Among the 46 papers, the two most cited, at this writing, have respectively garnered 1,174 and 786 citations; both are authored by Liu and his colleagues. The most-cited paper is the first to report the construction of a new base editor. The paper was published in *Nature* in 2016, entitled "Programmable editing of a target base in genomic DNA without double stranded DNA cleavage", and discusses the development of cytosine base editors (CBEs) to transit from C.G to T.A base pairs. The second-highest cited paper, published in *Nature* in 2017, entitled "Programmable base editing of A.T to G.C in genomic DNA without DNA cleavage", developed adenine base editors (ABEs) which can mediate the conversion of A.T to G.C. These results show that free conversion between bases can be realized by using base editor.

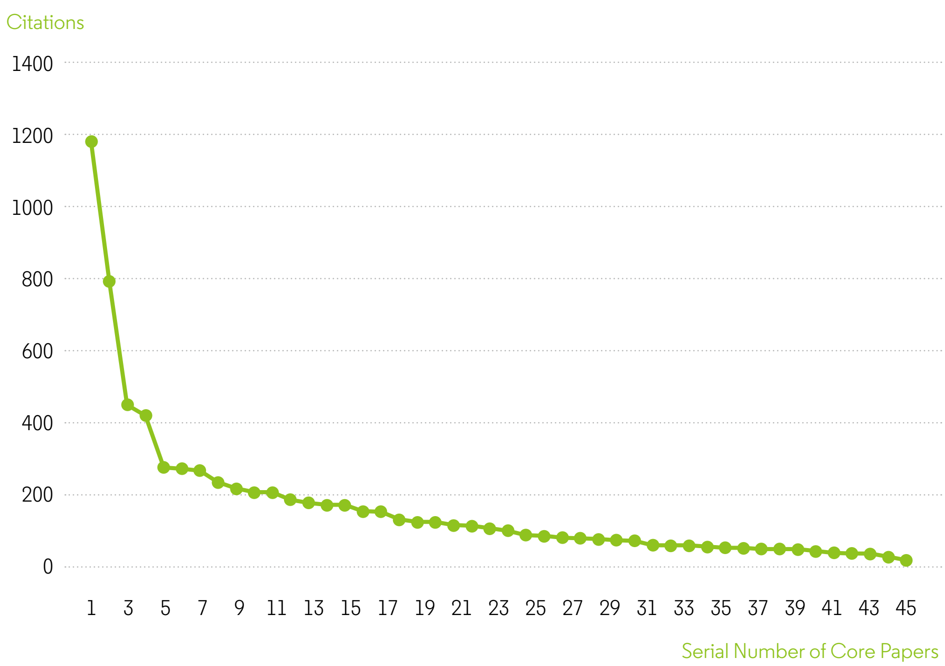


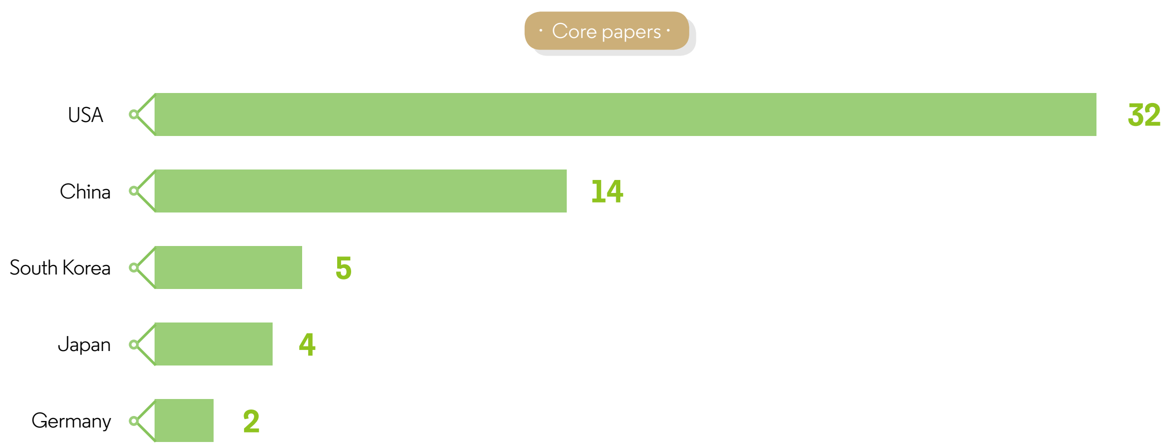
Figure 3: Citating frequency distribution curve of core papers in Research Front "Research on the base editor of animals and plants"

Among the countries and institutions producing core papers (Table 4), five countries –the USA, China, South Korea, Japan, and Germany – contribute most prolifically to the core literature. The USA has the highest contribution rate of nearly 70%, followed by China with about 30%. The other three countries contribute five papers or less. Among the top contributing institutions, Harvard University, MIT, and Bode Research Institute in the USA are listed in the top three, accounting for 47.8%, 37%, and 37%, respectively. Overall, the USA performs outstandingly and has an obvious advantage.

Table 4: Top countries and institutions producing core papers in the Research Front "Research on the base editor of animals and plants"

Country Ranking	Country	Core Papers	Proportion
1	USA	32	69.6%
2	China	14	30.4%
3	South Korea	5	10.9%
4	Japan	4	8.7%
5	Germany	2	4.3%

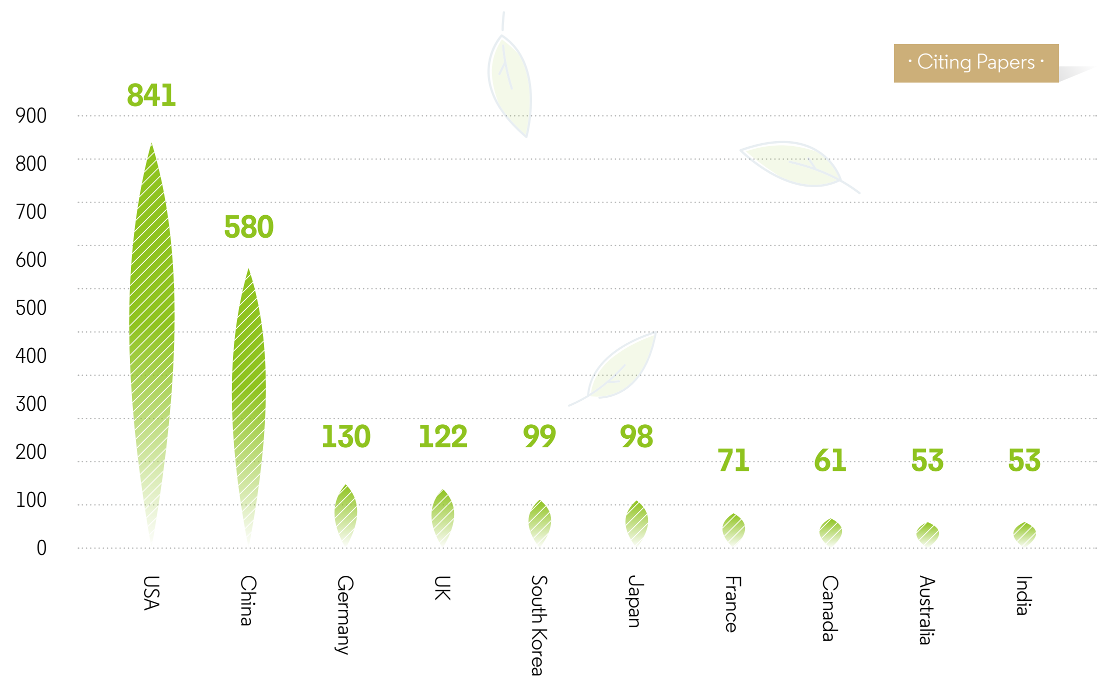
Institution Ranking	Institution	Affiliated Countries	Core Papers	Proportion
1	Harvard University	USA	22	47.8%
2	Massachusetts Institute of Technology (MIT)	USA	17	37.0%
2	Broad Institute	USA	17	37.0%
4	Chinese Academy of Sciences	China	10	21.7%
5	Institute for Basic Science	South Korea	5	10.9%
5	Seoul National University	South Korea	5	10.9%
7	Beam Therapeutics	USA	4	8.7%
7	Boston Children's Hospital	USA	4	8.7%
7	Chinese Academy of Agricultural Sciences	China	4	8.7%
7	University of California San Diego	USA	4	8.7%
7	Massachusetts General Hospital	USA	4	8.7%



In terms of countries and institutions that cite the core papers of this hot front (Table 5), the USA is the top contributor, accounting for about 41%. China ranks 2nd, matching its ranking in core papers, accounting for nearly 28%. The two countries are followed by Germany and the UK, both with roughly 6%. The top three citing institutions are the Chinese Academy of Sciences, Harvard University, and MIT, ranging from 10% to 5% of the core literature.

Table 5: Top countries and institutions producing citing papers in the Research Front "Research on the base editor of animals and plants"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	841	40.5%	1	Chinese Academy of Sciences	China	192	9.2%
2	China	580	27.9%	2	Harvard University	USA	148	7.1%
3	Germany	130	6.3%	3	Massachusetts Institute of Technology (MIT)	USA	109	5.2%
4	UK	122	5.9%	4	Broad Institute	USA	91	4.4%
5	South Korea	99	4.8%	5	Harvard Medical School	USA	77	3.7%
6	Japan	98	4.7%	6	Chinese Academy of Agricultural Sciences	China	55	2.6%
7	France	71	3.4%	7	Shanghai Tech University	China	53	2.5%
8	Canada	61	2.9%	8	Stanford University	USA	43	2.1%
9	Australia	53	2.5%	9	Shanghai Jiao Tong University	China	39	1.9%
9	India	53	2.5%	9	University of California San Diego	USA	39	1.9%



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, four emerging Research Fronts have been identified, focusing on farmland soil-pollution remediation and plant stress resistance (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	Phytoremediation of copper pollution in farmland soil	15	320	2019.8
2	Systemic signal transduction of plant stress resistance	12	230	2019.7
3	Regulatory factors for improving plant resistance to abiotic stress	7	182	2019.7
4	The alleviating effect of ACC deaminase producing PGPR on crop drought stress	6	125	2019.7

2.2 KEY EMERGING RESEARCH FRONT – "The alleviating effect of ACC deaminase producing PGPR on crop drought stress"

For many years, the beneficial interaction between plants and microorganisms, especially how plant growth promoting rhizobacteria (PGPR) regulate and affect crop drought resistance, has been one of the key topics in dryland agriculture. In this area, PGPR containing ACC (1-Aminocyclopropane-1-Carboxylate) deaminase activity currently stands as a research hotspot. The process has broad application prospects in promoting plant growth, delaying plant aging, and enhancing plant stress resistance. ACC deaminase can effectively inhibit ethylene biosynthesis and delay plant aging through degrading the ethylene precursor ACC. Inoculating plants with PGPR containing ACC deaminase can reduce ethylene content, so as to reduce the impact of abiotic stress on plant growth and development.

The core papers in this emerging Research Front focus on: the effects of ACC deaminase producing PGPR on wheat growth and yield under drought stress; how to screen ACC deaminase producing PGPR that improves the drought tolerance of maize, under sterile conditions; and the combined application effect of ACC deaminase producing PGPR and biochar in alleviating wheat drought and improving maize growth and productivity.

2021
RESEARCH FRONTS

ECOLOGY AND ENVIRONMENTAL SCIENCES

1. HOT RESEARCH FRONT

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

The Top 10 hot Research Fronts in ecology and environmental sciences, 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 the following topics: COVID-19-related research; studies on air pollution; and the environmental character, risk and control of global traditional and emerging pollutants such as Perfluorinated compounds (PFCs), mercury and microplastics.

In the wake of COVID-19's global spread in 2020, two hot fronts focus on the interaction between COVID-19 and environmental factors. These fronts are "Detection and transmission of SARS-CoV-2 in air, water and surface environment" and "Impact of the lockdown on air quality during the COVID-19 pandemic". Three air pollution-related hot fronts cover "Performance assessment of low-cost particulate matter sensors", "Estimates of global mortality and disease burden attributable to ambient air pollution", and "Aerosol and boundary-layer interactions and impact on air quality".

Among these specialty areas, the latter was listed in last year's survey as one of the Top 10 hot Research Fronts of 2020. Meanwhile, "Impact of the lockdown on air quality during the COVID-19 pandemic" also touches on air pollution.

The hot Research Fronts related to global pollutants include "Removal of mercury from coal-fired and industrial flue gas", "Exposure to microplastics in soil and the impact of microplastics on soil ecosystems", and "Distribution, exposure, toxicology, and control of perfluoroalkyl and polyfluoroalkyl substances". All the pollutants involved in these three fronts are commonly used or generated substances that cause significant and long-term ecological and environmental risks all over the world, and which have elicited global concern. Research on these pollutants has been central to hot fronts in environmental sciences for years. For example, mercury pollution-related research was selected among the Top 10 hot Research Fronts of 2016, 2017 and 2020, while microplastics-related studies emerged in the 2015, 2016, 2017 and 2020 surveys. In this latest roundup, PFCs-related studies have been listed as hot fronts for the second consecutive year.

The other two hot Research Fronts in the ecological science subfield mainly emphasize biodiversity and taxology, including "Trend, extinctions, and the drivers of insect declines" and "Improvements to the methods for species delimitation".

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

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Detection and transmission of SARS-CoV-2 in air, water, and surface environment	31	1843	2020
2	Impact of the lockdown on air quality during the COVID-19 pandemic	27	1295	2020
3	Trend, extinctions, and the drivers of insect declines	20	1828	2019.4
4	Removal of mercury from coal-fired and industrial flue gas	27	1225	2018.9
5	Exposure to microplastics in soil and the impact of microplastics on soil ecosystems	29	2657	2018.2
6	Distribution, exposure, toxicology, and control of perfluoroalkyl and polyfluoroalkyl substances	36	3008	2018.1

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
7	Performance assessment of low-cost particulate matter sensors	17	1395	2018.1
8	Aerosol and boundary-layer interactions and impact on air quality	22	1977	2018
9	Estimates of global mortality and disease burden attributable to ambient air pollution	3	1884	2018
10	Improvements to the methods for species delimitation	11	1351	2018

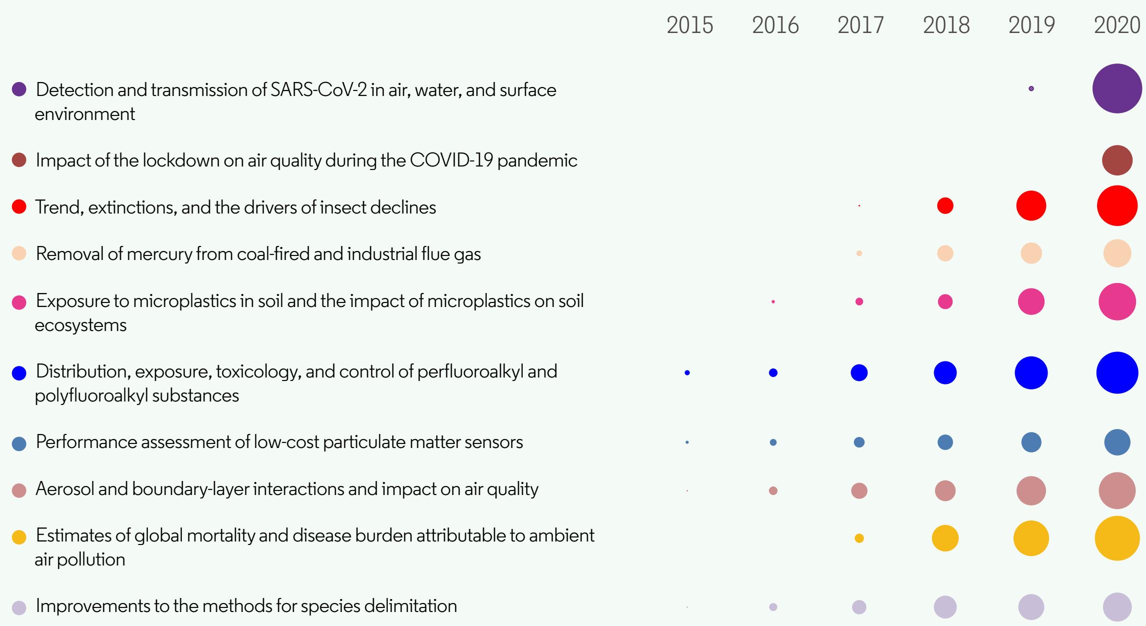


Figure 4: Citing papers for the Top 10 Research Fronts in ecology and environmental sciences

1.2 KEY HOT RESEARCH FRONT – "Trend, extinctions, and the drivers of insect declines"

Insects are an important part of the ecosystem and exert a significant impact on the whole biosphere, including humans. As decomposers, herbivores, pollinators, predators, parasites, and a food source for higher trophic levels – such as birds, mammals and amphibians – insects play a central role in a variety of ecology processes.

Loss of insect diversity and abundance is expected to cause grave effects on food webs – jeopardizing ecosystem processes and leading to huge ecological and environmental cascade effects, ultimately causing substantial social and economic losses.

Current data suggest an overall pattern of drastic decline in insect diversity and abundance owing to climate change, habitat loss and fragmentation, deterioration of habitat quality, the extensive use of chemical fertilizers and pesticides, the wide spread of toxic chemicals in the environment, and related factors. However, because the decline process of insects is in a very macro scale, it is difficult to obtain a sufficiently intuitive and detailed perception. Knowledge on the state of insect biomass and its direction over time is of broad importance to ecology and conservation. Unfortunately, historical data on insect biodiversity have been lacking, and the monitoring of insect biodiversity is extremely inadequate, leading to the severe underestimation of insect decline and its effects on biodiversity.

Twenty core papers identify this Research Front, covering multiple themes pertaining to insect biodiversity, including such areas as monitoring the status of decline in species and biomass of terrestrial and aquatic insects in North America and Europe as well as globally; the main drivers of insect declines; and the interaction between loss of insect biodiversity and ecosystem function. The core papers in this Research Front have presented substantial, and alarming, scientific evidence at the global level.

In 2017, scientists at Radboud University Nijmegen in the Netherlands and other institutions published an article in *Plos One*, showing that the total aerial insect biomass between 1989 and 2016 across 96 protected nature areas in Germany declined by 76%. This article caused a great shock to both scientists and the public. It is the most frequently cited paper in this front, with its citation total currently exceeding 660 (Figure 5). In 2019, researchers from the University of Sydney, Australia, published a review in *Biological Conservation* on the current situation and the factors driving the global loss of insects, emphasizing that nearly half of the world's insect species are rapidly decreasing and one third are endangered. The review points out that habitat loss, land-use variables, agricultural intensification, pollution, pathogens and biological invasion, and climate change are the main driving forces. This paper has been cited 446 times, making it the second-most-cited paper in this Research Front.

In 2020, the European Union (EU) issued a Biodiversity Strategy for 2030, and the Science Academies of the Group of Seven (G7) nations issued a joint statement on the global insect decline and the potential erosion of vital ecosystem functions. The fifth edition of the United Nations (UN) Global Biodiversity Outlook points out that the current rate of biodiversity loss is unprecedented in human history. In October of 2021, the UN Biodiversity Conference (COP 15) was held in China. In addition to the international actions noted above, the research findings reported in this hot front have sounded an alarm for humanity and have called on society to take urgent transformative actions to protect insect populations and biodiversity.

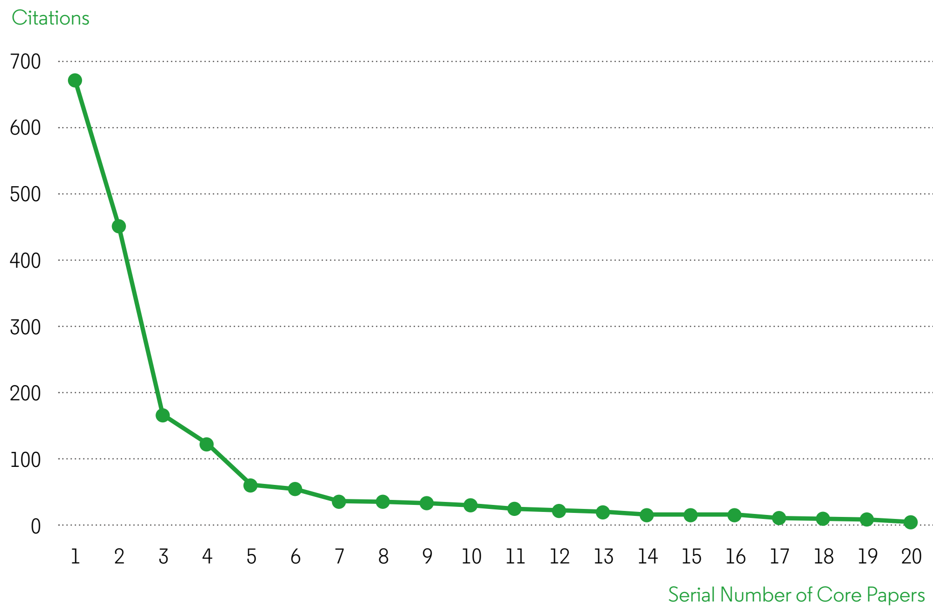


Figure 5: Citation frequency distribution curve of core papers in Research Front "Trend, extinctions, and the drivers of insect declines"

As for the top countries and institutions in this front (Table 8), the core papers reflect the output of twenty-three countries, with nine countries each publishing more than three core papers. Institutions in the USA contributed to ten core papers, accounting for half of the total core. Germany and the UK both published eight core papers, thereby sharing the #2 ranking, and the Netherlands and Australia both ranked 4th with six core papers each. The top two institutions publishing the most core papers were Radboud University Nijmegen of the Netherlands and Salzburg University in Austria.

Table 8: Top countries and institutions producing core papers in the Research Front "Trend, extinctions, and the drivers of insect declines"

Country Ranking	Country	Core Papers	Proportion
1	USA	10	50.0%
2	Germany	8	40.0%
2	UK	8	40.0%
4	Netherlands	6	30.0%
4	Australia	6	30.0%
6	Austria	4	20.0%
7	Finland	3	15.0%
7	South Africa	3	15.0%
7	Switzerland	3	15.0%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Radboud University Nijmegen	Netherlands	5	25.0%
2	Salzburg University	Austria	4	20.0%
3	German Centre for Integrative Biodiversity Research (iDiv)	Germany	3	15.0%
3	Stellenbosch University	South Africa	3	15.0%
3	Helmholtz Association	Germany	3	15.0%
3	Technical University of Munich	Germany	3	15.0%
3	University of New England	Australia	3	15.0%
3	Harper Adams University	UK	3	15.0%

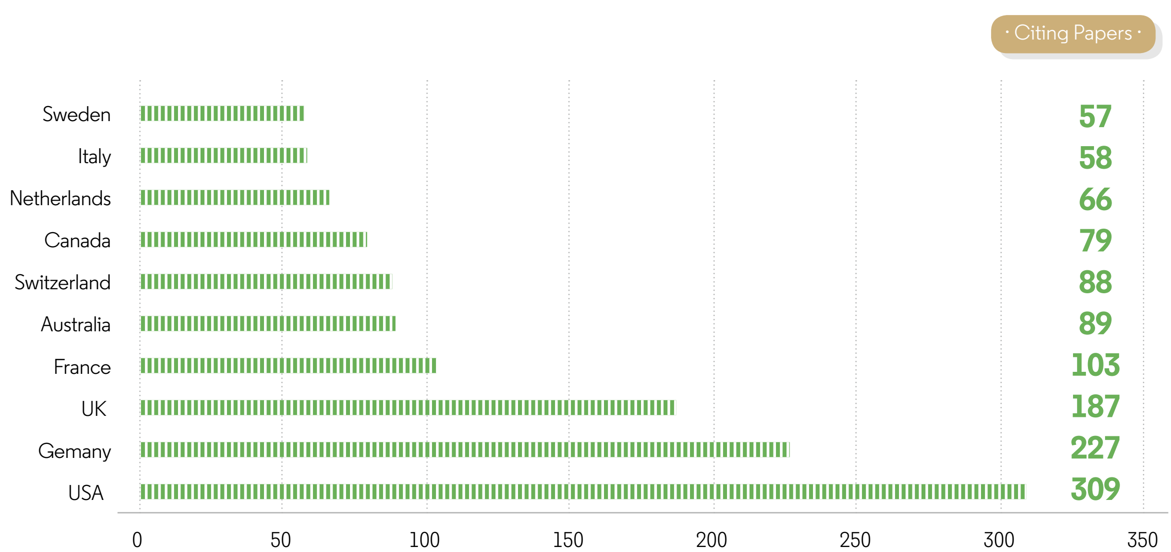
In terms of the countries and institutions citing the core papers (Table 9), the USA, Germany, and the UK are the three most prolific by this measure. Meanwhile, the most prolific citing institutions are located in Germany and France, with three German and three French institutions listed among the Top 10. The top three institutions are the CNRS in

France, the Helmholtz Association in Germany, and the National Research Institute for Agriculture, Food and Environment in France.

Based on the production of both core papers and citing papers, the USA, Germany, the UK, the Netherlands, and France are the prominent nations whose research and monitoring of insect diversity has been the most longstanding and systematic. Among all the institutions, Radboud University Nijmegen and Wageningen University & Research Center in the Netherlands, the Helmholtz Association and German Centre for Integrative Biodiversity Research in Germany, CNRS and the National Research Institute for Agriculture, Food and Environment in France, and Salzburg University in Austria contributed the most core papers or citing papers, all playing a central role in this hot front.

Table 9: Top countries and institutions producing citing papers in the Research Front "Trend, extinctions, and the drivers of insect declines"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	309	26.7%	1	National Center for Scientific Research of France (CNRS)	France	65	5.6%
2	Gemany	227	19.6%	2	Helmholtz Association	Gemany	37	3.2%
3	UK	187	16.1%	2	National Research Institute for Agriculture, Food and Environment	France	37	3.2%
4	France	103	8.9%	4	Wageningen University & Research Center	Netherlands	34	2.9%
5	Australia	89	7.7%	5	Swiss Federal Institutes of Technology Domain	Switzerland	31	2.7%
6	Switzerland	88	7.6%	6	German Centre for Integrative Biodiversity Research (iDiv)	Gemany	30	2.6%
7	Canada	79	6.8%	7	Helsinki University	Finland	29	2.5%
8	Netherlands	66	5.7%	8	Senckenberg Gesellschaftfür Naturforschung	Gemany	27	2.3%
9	Italy	58	5.0%	9	French National Research Institute for Sustainable Development (IRD)	France	26	2.2%
10	Sweden	57	4.9%	9	Swedish University of Agricultural Sciences	Sweden	26	2.2%

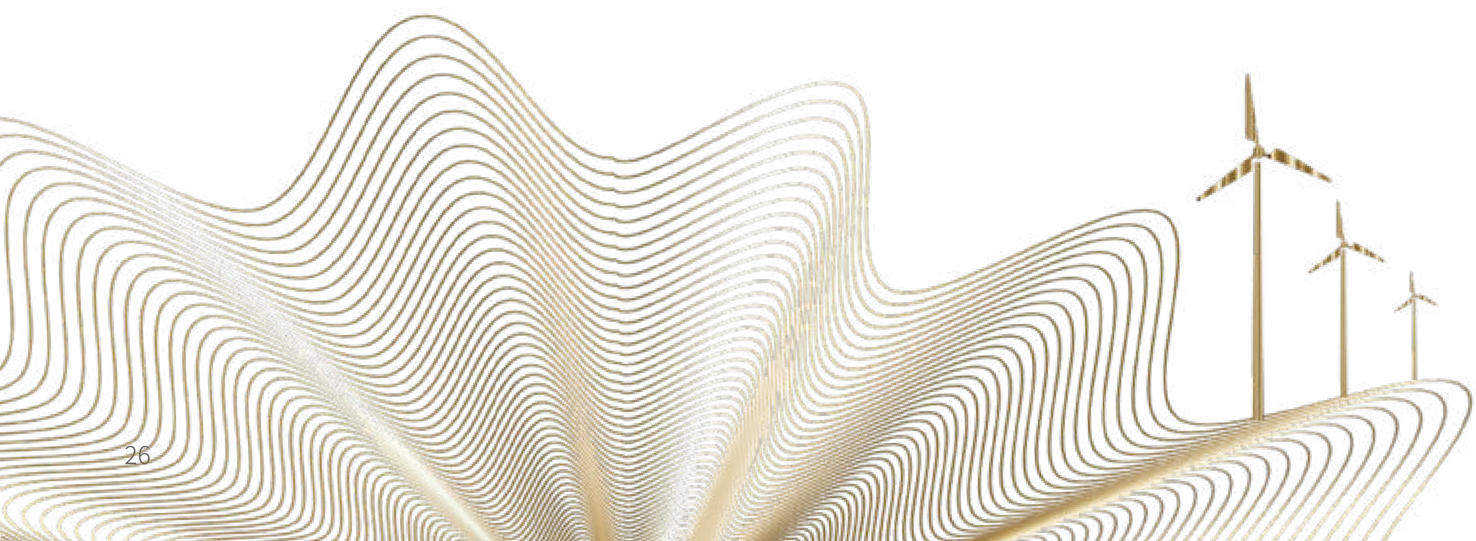


1.3 KEY HOT RESEARCH FRONT – "Distribution, exposure, toxicology, and control of perfluoroalkyl and polyfluoroalkyl substances"

Poly- and perfluoroalkyl substances (PFASs) are large groups of chemical compounds of new persistent organic pollutants (POPs), which have been utilized in a wide range of products and applications, such as surface-treatment agents for textiles, nonstick cookware, and food packaging, among other uses. They are persistent in the environment, can disperse over long distances, accumulate in organisms over time, and lead to adverse human-health effects, including organ toxicity, neurotoxicity, immune and endocrine toxicity, reproductive toxicity and tumors. Because of their environmental impact and potential health risks, they have become a global concern and the subject of international calls for control measures. Perfluorooctanesulfonate (PFOS) and Perfluorooctanoic acid (PFOA) are the most extensively investigated typical PFASs and chemicals newly added to the Stockholm Convention on Persistent Organic Pollutants.

Thirty-six core papers anchor this Research Front, largely focusing on four aspects: Pollution status and source analysis of PFASs on the global level, focusing on pollution in water environments such as surface water, groundwater and drinking water; toxicology and health risk research on PFASs, including the exposure pathway in humans, liver toxicity, effects on the growth and development of fetuses and children, and so forth; control technology for PFASs, including adsorption technology and redox technology in water; and potential alternatives to long-chain PFOS and PFOA, including the environmental and toxicological characteristics of emerging short-chain and ultrashort-chain PFASs.

The initial global concern associated with PFASs was the drinking-water pollution crisis in the USA In 2016, scientists at the Harvard T. H. Chan School of Public Health published a study in *Environmental Science & Technology Letters* on drinking water contamination with PFASs in the USA The paper reported that in the drinking-water supply for six million U.S. residents, the level of PFOS and POFA exceeds the U.S. Environmental Protection Agency's lifetime health advisory (70 ng/L). The article has been cited 267 times at this writing, making it the most-cited core paper in this front (Figure 6). Another core paper with high influence in this Research Front shows that most research and regulation pertaining to more than 3,000 per- and polyfluoroalkyl substances continues to focus on a limited selection of rather well-known long-chain PFASs, particularly PFOSs, PFOAs, and their precursors. Meanwhile, research has tended to overlook the vast majority of other PFASs, which also represent a major concern for science and society. This article was authored by researchers at Stockholm University and other institutions and was published in *Environmental Science & Technology*; it has been cited 256 times. As the study of PFASs progresses, more scientific evidence has accumulated and more PFASs have been deeply studied, attracting further global attention and prompting international actions to strengthen control measures. For example, Perfluorohexane sulfonic acid (PFHxS) and its salts have been discussed recently in many areas such as the USA and Europe and have been included in the list of candidate POPs of the Stockholm Convention.



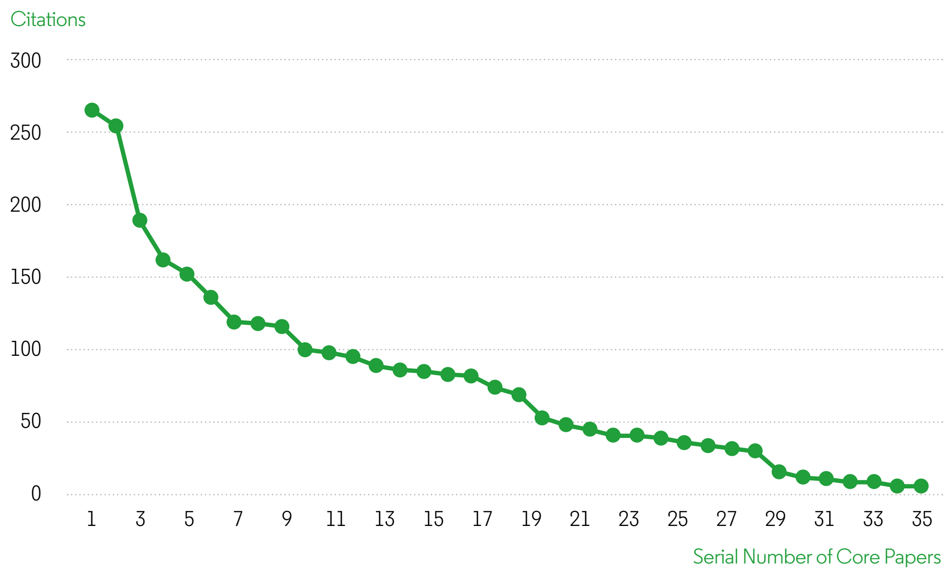


Figure 6: Citation frequency distribution curve of core papers in Research Front "Distribution, exposure, toxicology, and control of perfluoroalkyl and polyfluoroalkyl substances"

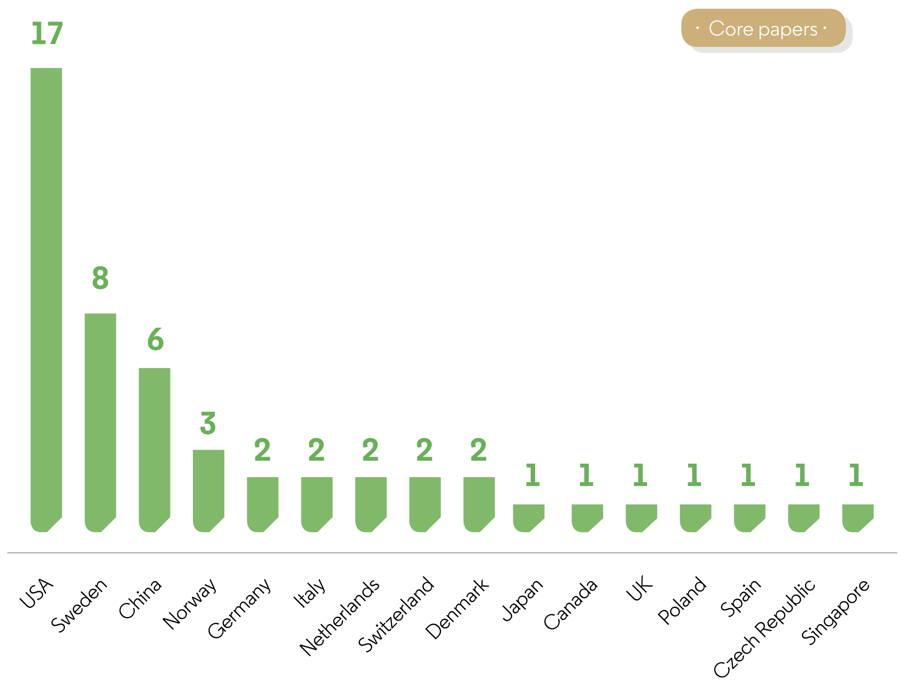
According to the statistics on top countries and institutions in this front (Table 10), most of the core papers list contributing authors based in the USA—17 such papers, accounting for 47.2% of the total core of 36 papers. Sweden and China account for eight and six core papers, earning the two nations 2nd and 3rd places, respectively. The proportions of core papers from other countries are less than 10%. The main contributing institutions to the core papers are based in the USA and Sweden. The Colorado School of Mines and the U.S. Environmental Protection Agency both published four core papers, sharing the top rank. Sixteen institutions contributed more than one core paper, among them 10 based in the USA and three in Sweden. The Chinese Academy of Sciences contributed two core papers.

Table 10: Top countries and institutions producing core papers in the Research Front "Distribution, exposure, toxicology, and control of perfluoroalkyl and polyfluoroalkyl substances"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	17	47.2%	1	Colorado School of Mines	USA	4	11.1%
2	Sweden	8	22.2%	1	US Environmental Protection Agency	USA	4	11.1%
3	China	6	16.7%	3	Stockholm University	Sweden	3	8.3%
4	Norway	3	8.3%	3	SilentSpringInstitute	USA	3	8.3%
5	Germany	2	5.6%	5	Karolinska Institute	Sweden	2	5.6%
5	Italy	2	5.6%	5	Lund University	Sweden	2	5.6%

Country Ranking	Country	Core Papers	Proportion
5	Netherlands	2	5.6%
5	Switzerland	2	5.6%
5	Denmark	2	5.6%
10	Japan	1	2.8%
10	Canada	1	2.8%
10	UK	1	2.8%
10	Poland	1	2.8%
10	Spain	1	2.8%
10	Czech Republic	1	2.8%
10	Singapore	1	2.8%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
5	GreenSciencePolicyInstitute	USA	2	5.6%
5	Chinese Academy of Sciences	China	2	5.6%
5	Clemson University	USA	2	5.6%
5	Harvard University	USA	2	5.6%
5	California Department of Toxic Substance Control	USA	2	5.6%
5	Norwegian Institute of Public Health	Norway	2	5.6%
5	University of North Carolina	USA	2	5.6%
5	Environment Working Group	USA	2	5.6%
5	University of California Berkeley	USA	2	5.6%
5	Swiss Federal Institute of Technology Zurich	Switzerland	2	5.6%

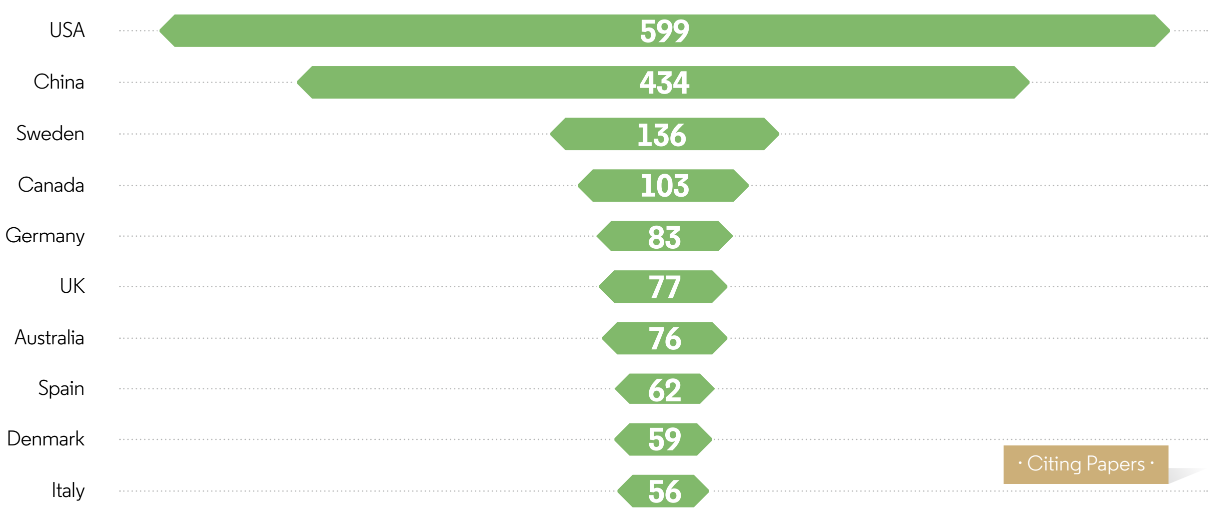


By the measure of citing papers (Table 11), the USA is still the most prolific source of research that cites the foundational papers of this front, contributing 38.8% of the total citing papers. China ranks 2nd with 28.1% of the citing reports. Other countries contributed less than 10% of citing papers. In terms of institutions, the Top 10 institutions are based in China, the USA, and Sweden, respectively. For China, the Chinese Academy of Sciences contributed 115 citing papers, ranking 1st, while Nankai University ranks 7th. Among six U.S. institutions, the U.S. Department of Health and Human Services contributed 61 citing papers and ranks 2nd, while Harvard University ranks 3rd.

Data analysis shows that the USA, China, and Sweden perform best in this Research Front in terms of representation on both core and citing papers. The USA is the leading country with the most core and citing papers, while most of the outstanding institutions are U.S. based. Sweden also registers strongly in terms of core and citing papers. China, too, is an important participant in this front, with a high number of core papers and citing papers. The Chinese Academy of Sciences has distinguished itself with increasing prominence in this front in recent years.

Table 11: Top countries and institutions producing citing papers in the Research Front "Distribution, exposure, toxicology, and control of perfluoroalkyl and polyfluoroalkyl substances"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	599	38.8%	1	Chinese Academy of Sciences	China	115	7.5%
2	China	434	28.1%	2	U.S. Department of Health and Human Services	USA	61	4.0%
3	Sweden	136	8.8%	3	Harvard University	USA	52	3.4%
4	Canada	103	6.7%	3	Stockholm University	Sweden	52	3.4%
5	Germany	83	5.4%	5	University of North Carolina	USA	49	3.2%
6	UK	77	5.0%	6	U.S. Environment Protection Agency	USA	38	2.5%
7	Australia	76	4.9%	7	Nankai University	China	37	2.4%
8	Spain	62	4.0%	8	Swedish University of Agricultural Sciences	Sweden	36	2.3%
9	Denmark	59	3.8%	9	Colorado School of Mines	USA	32	2.1%
10	Italy	56	3.6%	10	Centers for Disease Control & Prevention	USA	31	2.0%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ECOLOGY AND ENVIRONMENTAL SCIENCES

The area of ecology and environmental sciences features two emerging Research Fronts: "Impact of weather and ambient factors on COVID-19 pandemic" and "Impact of nitrogen dioxide levels on COVID-19 mortality".

Table 12: Emerging Research Fronts in ecology and environmental sciences

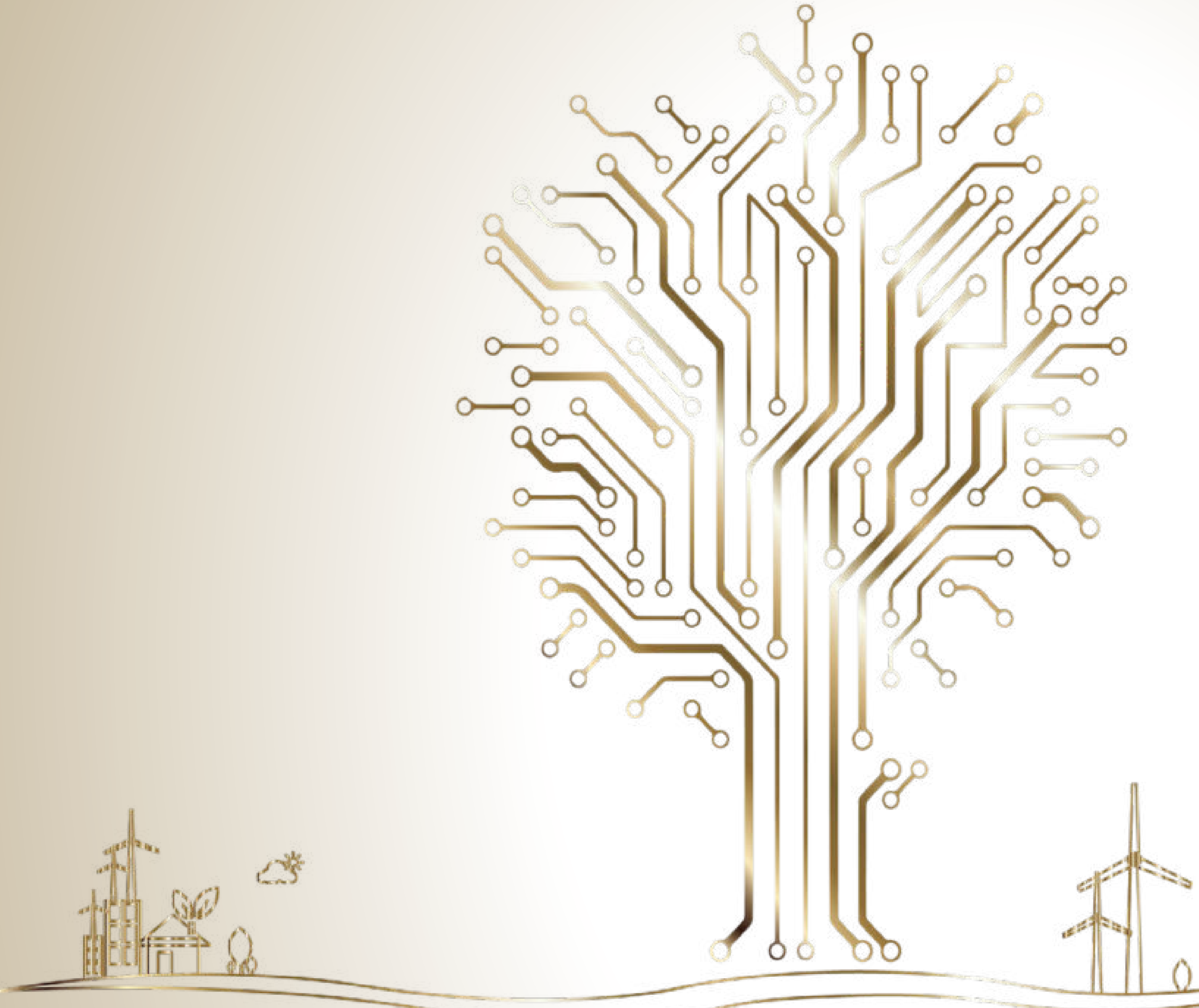
Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Impact of weather and ambient factors on COVID-19 pandemic	23	923	2020
2	Impact of nitrogen dioxide levels on COVID-19 mortality	2	263	2020

2.2 KEY EMERGING RESARCH FRONT – "Impact of nitrogen dioxide levels on COVID-19 mortality"

Air pollution, as decades of research have firmly established, has a significant impact on human health. Nitrogen dioxide is an air pollutant produced by the combustion in vehicles powered by diesel and other fossil fuels, which can damage the human respiratory system and cause hypertension, diabetes, and cardiovascular diseases. As COVID-19 continues to expand, scientists are acquiring more and more knowledge of SARS-COV-2. The extent to which the mortality of COVID-19 might tie with air pollution, such as nitrogen oxide pollution, has aroused scientists' interest.

The main study in this emerging front focuses on the correlation between long-term exposure to nitrogen dioxide and the mortality of COVID-19. Scientists at the Martin Luther University of Halle-Wittenberg, Germany, performed an analysis of air pollution data in selected outbreak centers of COVID-19, publishing the results in Science of the Total Environment. The findings indicated that out of the 4,443 fatal cases in Italy, Spain, France, and Germany, 78%, or 3,487, were recorded in five regions located in north Italy and central Spain where the nitrogen dioxide concentrations were observed to be highest. This finding indicates that long-term exposure to this pollutant may be one of the most important contributors to fatality caused by the SARS-COV-2. Similarly, a research group from Aarhus University, Denmark, also demonstrated a clear correlation between the high level of COVID-19 lethality and the atmospheric pollution in Northern Italy; this study was published in Environmental Pollution. Clearly, the causal relationship between COVID-19 mortality and air-pollution factors requires further study.

2021
RESEARCH FRONTS



2021
RESEARCH FRONTS

GEOSCIENCES

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN GEOSCIENCES

Four of the Top 10 Research Fronts in geosciences focus on geography, while three fronts pertain to geology and three concern atmospheric science. From the perspective of research topics, the Top 10 Research Fronts in geosciences are primarily focused on global climate change. Studies of climate sensitivity based on various earth-system models and global climate change have been selected as hot Research Fronts four times since 2015, showing the geoscience community's continuous attention to the study of human activities and climate change. In terms of research methods in geosciences, the reliance on using space-based detection platforms continues, once again reflecting the substantial contribution of the latest remote-sensing and information technology to the development of the field. Examples of this trend include "Research of glacier mass change in High Asia using digital elevation models", "Assessment of global fire emissions using multiple satellite data sets", "Evaluation of vegetation gross primary productivity via solar-induced chlorophyll fluorescence using satellite data", "Development and evaluation of multiple global precipitation datasets", and "Assessment and validation of satellite-observed soil moisture dataset".

Table 13: Top10 Research Fronts in geosciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Climate Sensitivity based on various Earth System Model	43	1895	2019.2
2	Research of glacier mass change in High Asia using digital elevation models	25	2076	2018.1
3	Gold deposits of the North China Craton: spatiotemporal distribution and tectonic settings	26	1985	2018
4	Assessment of global fire emissions using multiple satellite data sets	9	1163	2018
5	Contribution of Antarctic and Greenland ice-volume loss to the sea-level change	38	4211	2017.8
6	Evaluation of vegetation gross primary productivity via solar-induced chlorophyll fluorescence using satellite data	29	2272	2017.7
7	Study on the evolution and plate tectonics of the Archean continental crust	19	1475	2017.7
8	Research on geochemistry of rare earth elements	14	1257	2017.6
9	Development and evaluation of multiple global precipitation datasets	7	1254	2017.6
10	Assessment and validation of satellite-observed soil moisture dataset	25	2511	2017.5

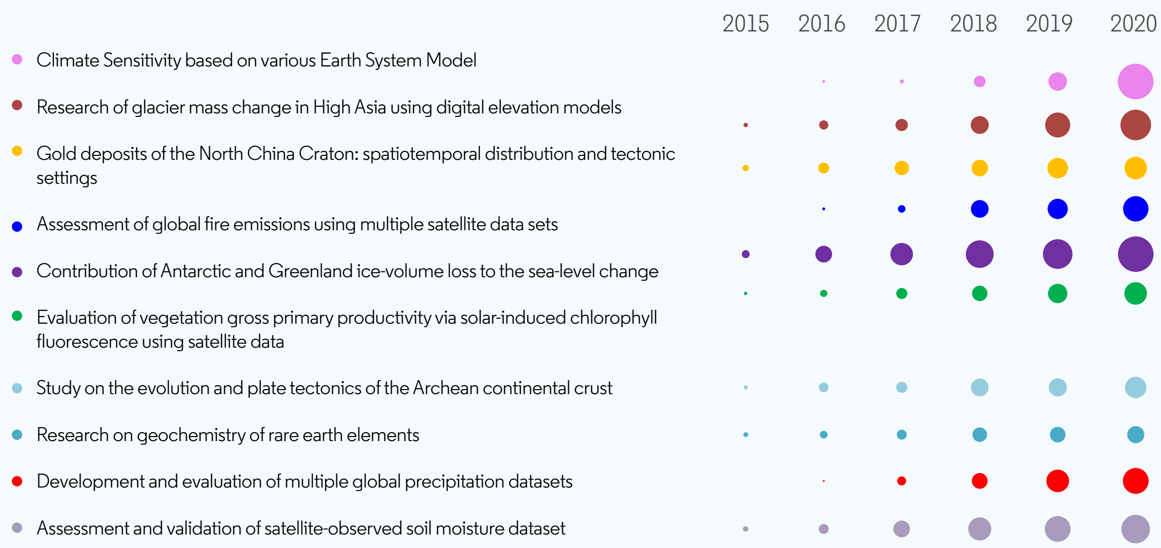
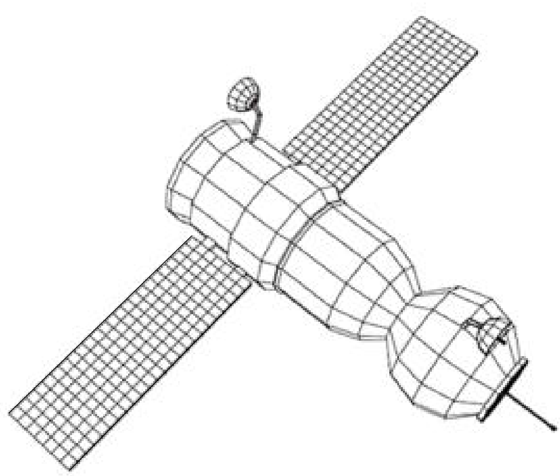


Figure 7: Citing papers for the Top 10 Research Fronts in geosciences

1.2 KEY HOT RESEARCH FRONT – "Assessment of global fire emissions using multiple satellite data sets"

The timeless element of fire is an essential Earth-system process that alters ecosystem and atmospheric composition. A large number of aerosol particles produced by fire emissions not only affect regional and global atmospheric composition along with its physical and chemical properties, but also have an important impact on the Earth-atmosphere energy balance, air quality, and human health. Fire dynamics, such as frequency and intensity, also significantly affect vegetation composition, as well as its spatial distribution, productivity, and post-fire restoration. Traditional methods such as manual lookout, patrol inspection, and aircraft observation are expensive and have limited coverage, and it is difficult to effectively monitor the combustion and emission status of fire. The technique of satellite remote sensing provides a unique way to provide observations over a long term and at large scale of the atmosphere and land surface. It is an important means for quantitatively estimating fire emissions and evaluating fire occurrence and intensity.



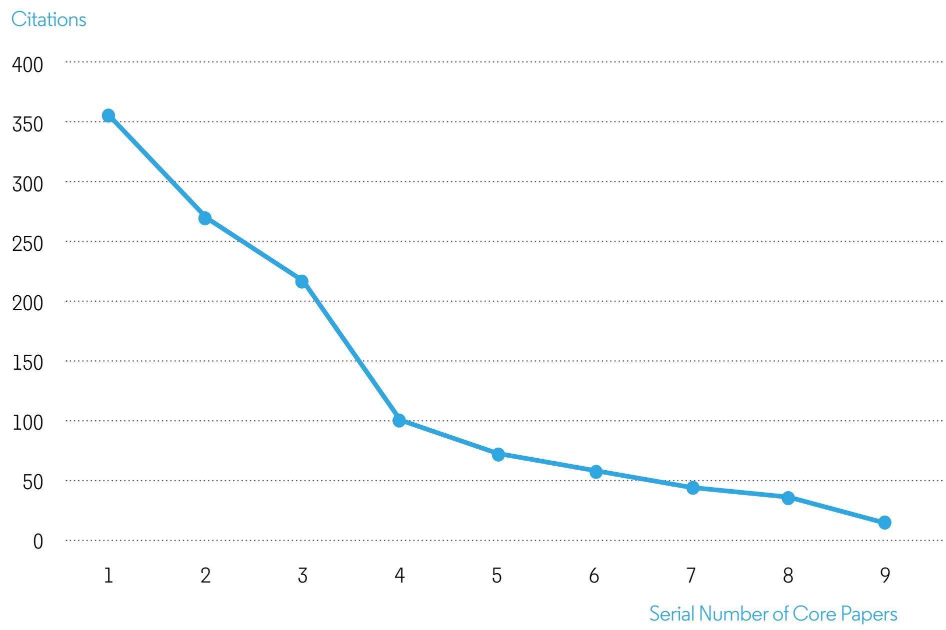


Figure 8: Citation frequency distribution curve of core papers in Research Front "Assessment of global fire emissions using multiple satellite data sets"

The Research Front "Assessment of global fire emissions using multiple satellite data sets" focuses on fire-emissions estimates, changes in global burned area, detection algorithms, and fire products. The core papers in this hot Research Front mostly use data from the Moderate Resolution Imaging Spectrometer (MODIS) onboard NASA's Terra and Aqua satellites, and the Global Fire Emissions Database (GFED), aiming to quantify global fire emissions and provide near real-time emission estimates for the tracking of ongoing fire events.

In terms of top countries and institutions producing core papers, the USA has the highest contribution rate (77.8% of the total), followed by Spain, the UK, Holland and Germany. Among institutions, the University of Maryland, College Park, is represented on six core papers, while Vrije University Amsterdam and the University of Alcalá are each represented on three core papers.

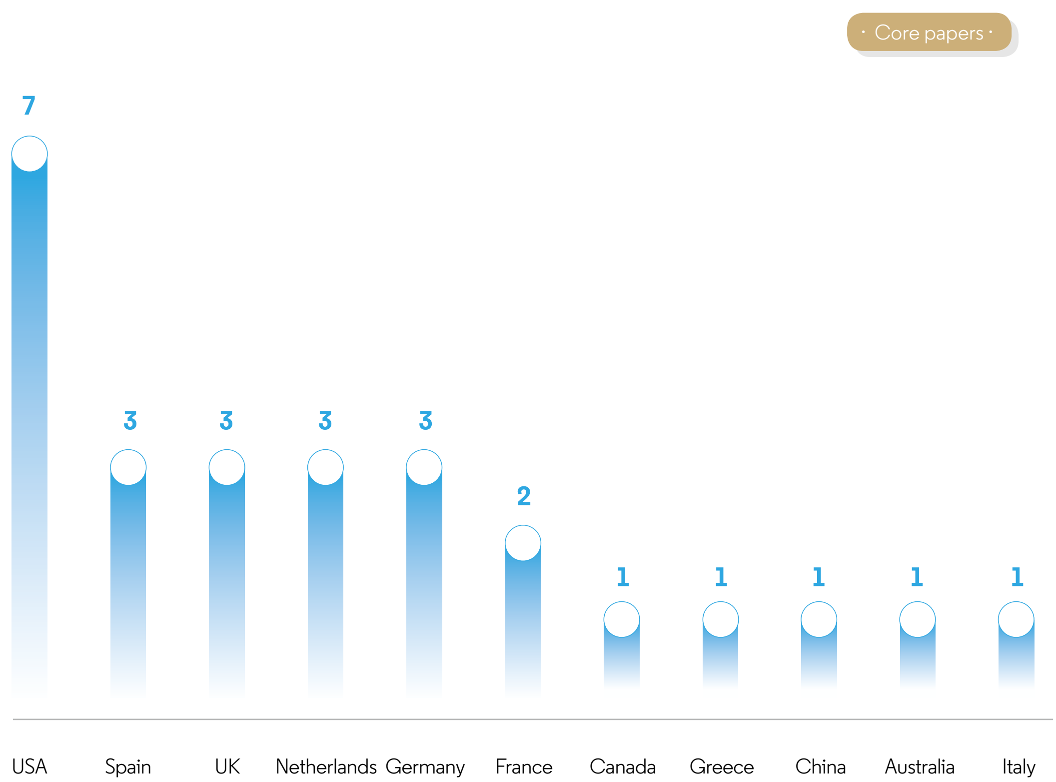
The most-cited paper in this Research Front ("Global fire emissions estimates during 1997-2016", with 354 citations at this writing) is from Vrije University Amsterdam. This paper describes the fourth version of the GFED and quantifies global fire emissions patterns during 1997–2016. The revised dataset provides an internally consistent data set on burned area and emissions that may contribute to a better understanding of multi-decadal changes in fire dynamics and their impact on the Earth system.

The second-cited paper in this Research Front ("The collection 6 MODIS active fire detection algorithm and fire products", with 269 citations at this writing) is from the University of Maryland, College Park. This paper describes improvements made to the fire-detection algorithm and swath-level product that were implemented as part of the Collection 6 MODIS land product, notably to address the occurrence of false alarms caused by small, forest-clearing blazes, and the omission of large fires obscured by thick smoke. The third-cited paper ("A human-driven decline in global burned area", with 216 citations at this writing) is from NASA. This paper assesses long-term fire trends using multiple satellite data sets, determining that global burned area declined by ~25% over the past 18 years. The decrease has been largest in savannas and grasslands because of agricultural expansion and intensification.

Table 14: Top countries and institutions producing core papers in the Research Front "Assessment of global fire emissions using multiple satellite data sets"

Country Ranking	Country	Core Papers	Proportion
1	USA	7	77.8%
2	Spain	3	33.3%
2	UK	3	33.3%
2	Netherlands	3	33.3%
2	Germany	3	33.3%
6	France	2	22.2%
7	Canada	1	11.1%
7	Greece	1	11.1%
7	China	1	11.1%
7	Australia	1	11.1%
7	Italy	1	11.1%

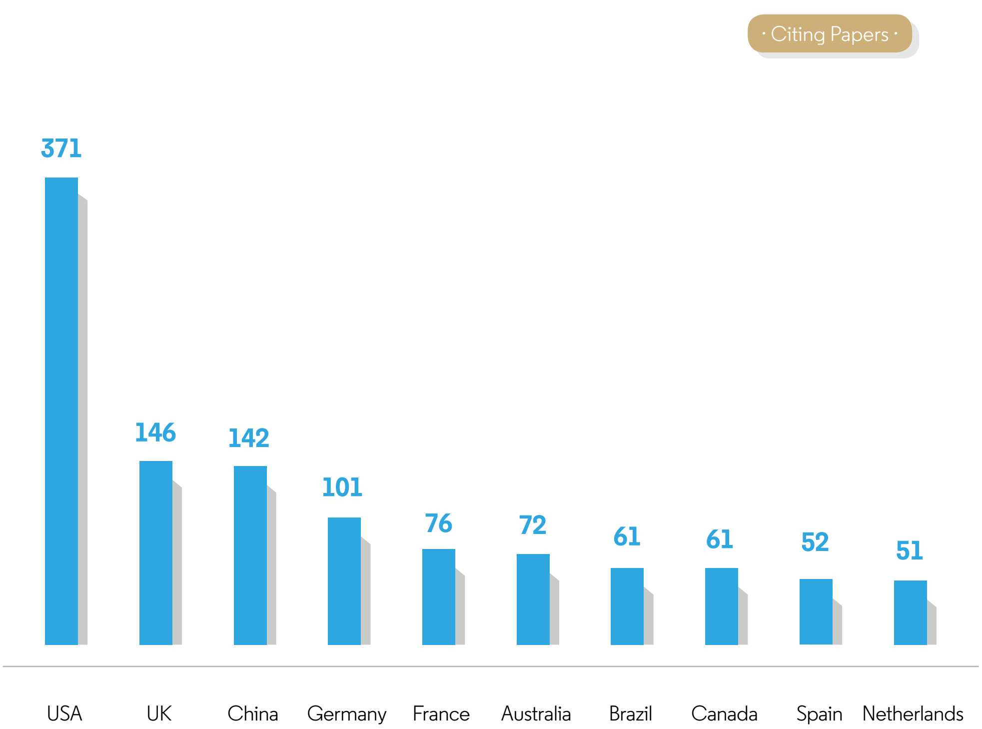
Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	University of Maryland, College Park	USA	6	66.7%
2	Vrije UniversityAmsterdam	Netherlands	3	33.3%
2	University of Alcalá	Spain	3	33.3%
4	University of Leicester	UK	2	22.2%
4	Duke University	USA	2	22.2%
4	U.S.GeologicalSurvey	USA	2	22.2%
4	University of Idaho	USA	2	22.2%
4	National Aeronautics & Space Administration (NASA)	USA	2	22.2%
4	University of California Irvine	USA	2	22.2%
4	Max Planck Society	Germany	2	22.2%
4	National Center for Scientific Research of France (CNRS)	France	2	22.2%



As for countries producing the most citing papers: the USA ranks 1st with 371. Among the Top 10 citing institutions, five are based in the USA Overall, NASA, CNRS, and the Chinese Academy of Sciences take the top three places.

Table 15: Top countries and institutions producing citing papers in the Research Front "Assessment of global fire emissions using multiple satellite data sets"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	371	45.4%	1	National Aeronautics & Space Administration (NASA)	USA	95	11.6%
2	UK	146	17.9%	2	National Center for Scientific Research of France (CNRS)	France	69	8.4%
3	China	142	17.4%	3	Chinese Academy of Sciences	China	61	7.5%
4	Germany	101	12.4%	4	National Oceanic Atmospheric Admin (NOAA)	USA	44	5.4%
5	France	76	9.3%	4	University of Paris Saclay	France	44	5.4%
6	Australia	72	8.8%	6	University of Maryland College Park	USA	41	5.0%
7	Brazil	61	7.5%	7	Helmholtz Association	Germany	40	4.9%
7	Canada	61	7.5%	8	University of California Irvine	USA	37	4.5%
9	Spain	52	6.4%	9	French Alternative Energies and Atomic Energy Commission (CEA)	France	35	4.3%
10	Netherlands	51	6.2%	9	University of Colorado Boulder	USA	35	4.3%



1.3 KEY HOT RESARCH FRONT – "Development and evaluation of multiple global precipitation datasets"

In recent years, influenced by global climate change, extreme precipitation events have increased in frequency – a trend that has attracted extensive attention. Precipitation is a crucial component of the water cycle, a key parameter of meteorology, hydrology and ecology, and the most important and active variable associated with atmospheric circulation in weather and climate studies. High-accuracy, long-time-series, and spatially contiguous precipitation records are not only essential for climate change detection and hydrological modeling, but are also one of the most important inputs for a range of studies. These include geochemistry, geophysics, meteorology and atmospheric sciences, the geologic study of water resources, and so on.

There are currently four principal measurements to determine precipitation: ground-based gauge observations, ground-based radar remote sensing, satellite remote sensing, and atmospheric retrospective-analysis models. Consequently, there are currently three types of available global precipitation data sets, including gauge-based, satellite-related, and reanalysis datasets. Many inconsistencies afflict the different measures mentioned above, such as those involving the observation principle, algorithm accuracy, spatiotemporal resolution, and coverage, resulting in great variations of different global precipitation datasets. However, there is also obvious complementarity of different global precipitation datasets. In the future, a store of global precipitation figures integrating the most advanced and accurate measurement and data is expected to support more accurate and comprehensive research.

The Research Front "Development and evaluation of multiple global precipitation datasets" consists of seven core papers, focusing on the analysis and comparison of the types, spatial resolution, temporal resolution, global/local coverage, time span, data sources, adjustment, and algorithms of various global precipitation datasets. The most-cited paper in this Research Front ("MSWEP: 3-hourly 0.25 degrees global gridded precipitation (1979-2015) by merging gauge, satellite, and reanalysis data", published in Hydrology and Earth System Sciences, with 335 citations at this writing) is from a team led by Hylke E. Beck, then associated (2017) with the Joint Research Centre of the European Commission. This paper presents the design philosophy of Multi-Source Weighted-Ensemble Precipitation (MSWEP) and the development details of MSWEP version 1.1; the report compares the quality of MSWEP against many other datasets. The paper reporting this upgrade, "MSWEP V2 Global 3-Hourly 0.1 degrees Precipitation: Methodology and Quantitative Assessment," also from Beck's team (2019), is included in this Research Front.MSWEP has merged gauge measurements, satellite products, and reanalysis data, with a 3-hourly temporal and 0.25 degrees spatial resolution from 1979 to now. Since the release of version 1.0 in 2016, the MSWEP dataset has been widely and continuously applied, with ongoing optimization of its performance. As of now, it has been upgraded to version 2.8. The second highly cited paper in this Research Front ("A Review of Global Precipitation Data Sets: Data Sources, Estimation, and Intercomparisons", published in Reviews of Geophysics, with 305 citations at this writing) is from the team of Chiyuan Miao at Beijing Normal University. The paper presents a comprehensive review of the data sources and estimation methods of 30 currently available global precipitation datasets, including gauge-based, satellite-related, and reanalysis data sets. The report focuses on analyzing the discrepancies of precipitation estimation between the datasets, as well as the influencing factors. A third paper from Beck (then at Princeton University, 2018) and team, "Global-scale evaluation of 22 precipitation datasets using gauge observations and hydrological modeling", gives a comprehensive evaluation of 22 gridded global daily precipitation datasets.

The other three core papers focus on the performance, advantages and disadvantages of merged satellite retrieved precipitation datasets, such as the American Tropical Rainfall Measuring Mission (TRMM) and the Climate Prediction Center morphing technique (CMORPH) satellite, as well as the daily evaluation of 26 precipitation datasets using Stage-IV gauge-radar data for the CONUS. All of these works will provide guidance for selecting the most suitable precipitation data et for a specific application.

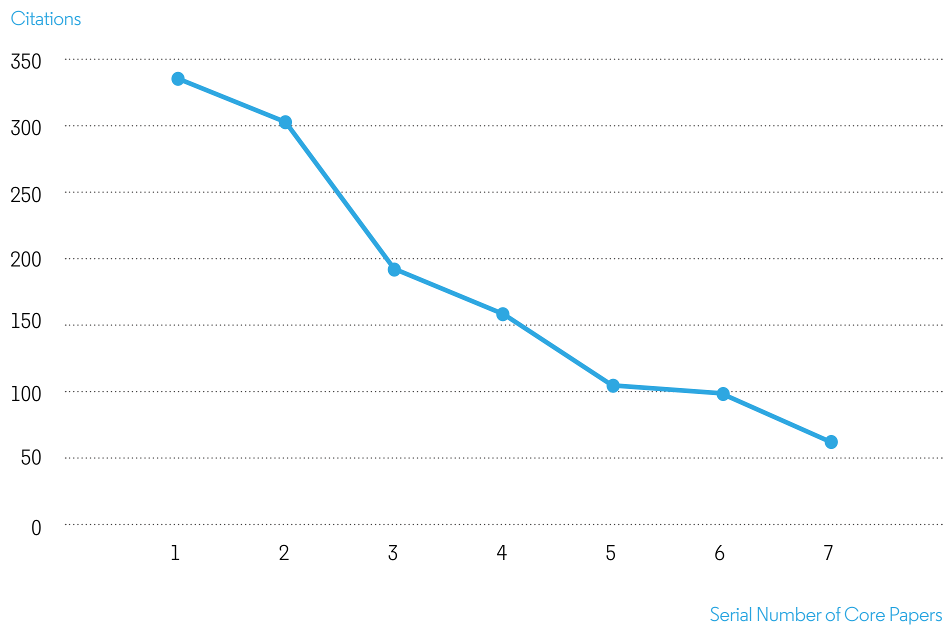


Figure 9: Citation frequency distribution curve of core papers in Research Front "Development and evaluation of multiple global precipitation datasets"

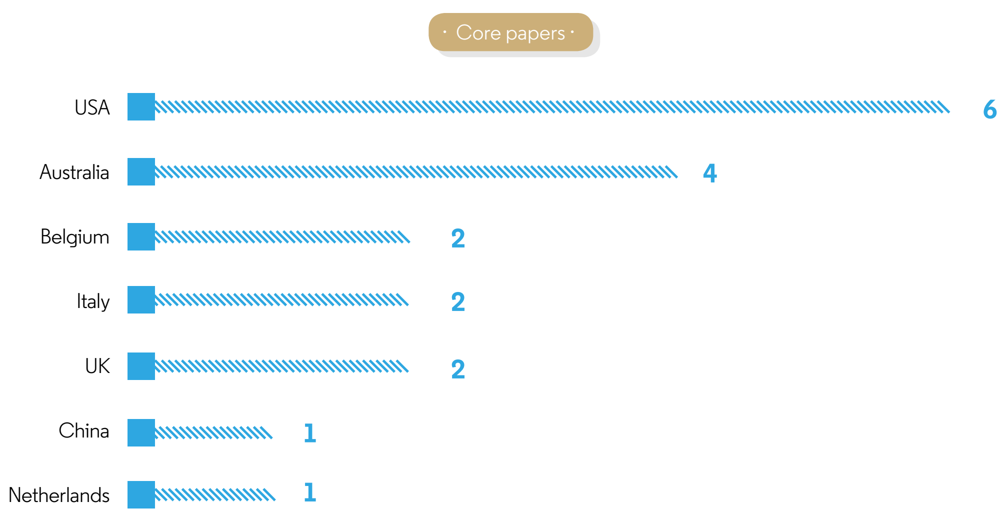
In terms of top countries and institutions producing core papers, the USA ranks 1st (85.7 % of the total) with contributions from universities that include the University of Maryland at College Park, Princeton University, George Mason University, and the University of California Irvine, as well as from information technology service enterprises, such as Innovim LLC and Wyle Inc. Australia ranks 2nd with four core papers among countries, and Australian National University ranks 1st among institutions. European researchers cooperate more frequently. The Joint Research Center of the European Commission in Italy, the European Centre for Medium-Range Weather Forecasts in the UK, and the Italian National Research Commission have participated in relevant research. China ranks 6th with the highly cited paper from Beijing Normal University, mentioned above.

Table 16: Top countries and institutions producing core papers in the Research Front "Development and evaluation of multiple global precipitation datasets"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	6	85.7%	1	Australian National University	Australia	4	57.1%
2	Australia	4	57.1%	2	University of Maryland College Park	USA	3	42.9%
3	Belgium	2	28.6%	2	Princeton University	USA	3	42.9%
3	Italy	2	28.6%	4	European Centre for Medium-RangeWeatherForecasts (ECMWF)	UK	2	28.6%

Country Ranking	Country	Core Papers	Proportion
3	UK	2	28.6%
6	China	1	14.3%
6	Netherlands	1	14.3%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
4	Italian National Research Council (CNR)	Italy	2	28.6%
4	Ghent University	Belgium	2	28.6%
4	National Aeronautics & Space Administration (NASA)	USA	2	28.6%
8	National Oceanic Atmospheric Admin (NOAA)	USA	1	14.3%
8	European commission Join tResearch Centre	Italy	1	14.3%
8	Australian Research Council	Australia	1	14.3%
8	Deltares	Netherlands	1	14.3%
8	Innovim LLC	USA	1	14.3%
8	Beijing Normal University	China	1	14.3%
8	Vrije UniversityAmsterdam	Netherlands	1	14.3%
8	George Mason University	USA	1	14.3%
8	University of California Irvine	USA	1	14.3%
8	Wyle Inc	USA	1	14.3%
8	Commonwealth Scientific & Industrial Research Organisation (CSIRO)	Australia	1	14.3%



In terms of countries producing the citing papers, the USA ranks 1st with 277, while China ranks 2nd with 233. Among the Top 10 institutions, four are based in the USA, and China and France each have three. The Chinese Academy of Sciences takes the top place, making the most prolific contribution to the continuous studies in the key research front, followed closely by the National Center for Scientific Research of France and NASA in the USA. Beijing Normal University and Tsinghua University are also among the Top 10 citing institutions.

Table 17: Top countries and institutions producing citing papers in the Research Front "Development and evaluation of multiple global precipitation datasets"

Country Ranking	Country	Citing Paper	Proportion
1	USA	277	31.9%
2	China	233	26.8%
3	UK	107	12.3%
4	France	79	9.1%
5	Germany	69	7.9%
6	Italy	65	7.5%
7	Australia	61	7.0%
8	Netherlands	59	6.8%
9	Switzerland	40	4.6%
10	Japan	39	4.5%

Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	Chinese Academy of Sciences	China	90	10.4%
2	National Center for Scientific Research of France (CNRS)	France	61	7.0%
3	National Aeronautics & Space Administration (NASA)	USA	39	4.5%
4	Princeton University	USA	36	4.1%
5	French National Research Institute for Sustainable Development (IRD)	France	35	4.0%
6	National Center for Atmospheric Research (NCAR)	USA	29	3.3%
6	National Oceanic Atmospheric Admin (NOAA)	USA	29	3.3%
8	Beijing Normal University	China	28	3.2%
8	University of Toulouse	France	28	3.2%
10	Tsinghua University	China	27	3.1%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN GEOSCIENCES

"Insight's seismic experiment on Mars" was selected as the emerging Research Front in geosciences for 2021.

Table 18: Emerging Research Front in geosciences

Rank	Emerging Research Front	Core papers	Citations	Mean Year of Core Papers
1	Insight's seismic experiment on Mars	11	290	2019.8

2.2 KEY EMERGING RESARCH FRONT – "Insight's seismic experiment on Mars"

InSight, which is one of NASA's Discovery Program missions, will place a single geophysical lander on Mars to study its deep interior. It was lunched in May 2018, and touched down on the Red Planet on November of that year. By investigating the interior structure and processes of Mars, the InSight mission will seek to understand the evolutionary formation of rocky planets, including Earth. The three science payloads will measure the planet's "vital signs" from its core, mantle, and crust. The Seismic Experiment for Interior Structure (SEIS), provided by France, the USA, Switzerland, the UK, and Germany, was designed to take the "pulse" – i.e., seismic vibrations of Mars. Its measurements provide a glimpse into the planet's internal activity. On April 6, 2019, a quiet but distinct seismic signal was detected. This first event officially kicked off a new field: Martian seismology.

The 11 core papers of this emerging front focus on InSight's seismic experiment, analysis of seismic data, the atmosphere of Mars, and other initial results. The most cited of these papers ("SEIS: Insights Seismic Experiment for Internal Structure of Mars", with 64 citations at this writing) is from SEIS development team. This paper provides the first description of the science goals and the rationale used to define the mission requirements. It also furnishes a detailed description of the hardware, from the sensors to the deployment system and associated performance, data-processing services, and outreach. In sum, the mission's contributors hope to provide key evidence to deepen our understanding of the interior of Mars and its evolution since the planet's early Noachian-Phyllosian era.

2021
RESEARCH FRONTS

2021

RESEARCH FRONTS

CLINICAL MEDICINE

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN CLINICAL MEDICINE

The Top10 Research Fronts in clinical medicine focus on two main topics: novel coronavirus pneumonia (COVID-19), along with immunotherapy and targeted therapy for tumors. The COVID-19 pandemic, of course, has been a major challenge facing modern medicine. COVID-19-related research – including clinical features, CT diagnosis, drug treatment, extrapulmonary manifestations and complications, and maternal and newborn effects – has quickly given rise to hot topics in global clinical medicine. This rise is embodied in six placements among the Top10 Research Fronts in clinical medicine in 2021. Meanwhile, the topic of immunotherapy and combined targeted therapy for tumors, which has recurred as a core theme of Research Fronts in recent years, maintains a high degree of visibility among the top fronts. This holds true even if, in Table 19, the specialty's slightly older core literature places it behind the more-current foundational literature in the COVID-19 fronts.

Table 19: Top10 Research Fronts in clinical medicine

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Clinical characteristics of COVID-19 patients	6	32799	2020
2	Chest CT in diagnosis and management of COVID-19	40	7277	2020
3	Remdesivir for the treatment of COVID-19	7	5043	2020
4	Venous thromboembolism in COVID-19 patients	9	4593	2020
5	Clinical findings and perinatal outcomes among pregnant women with COVID-19	29	2542	2020
6	Neurologic manifestations of COVID-19 patients	2	1484	2020
7	Anti-PD-1/PD-L1 combined therapy for advanced renal-cell carcinoma first-line therapy	4	2392	2018.8
8	Targeted therapy and immunotherapy in biliary tract cancers	28	2240	2018.6
9	Combined targeted therapies for chronic lymphocytic leukemia	18	1987	2018.6
10	PET/CT for assessing the clinical benefit of cancer immunotherapy	33	3762	2018.4

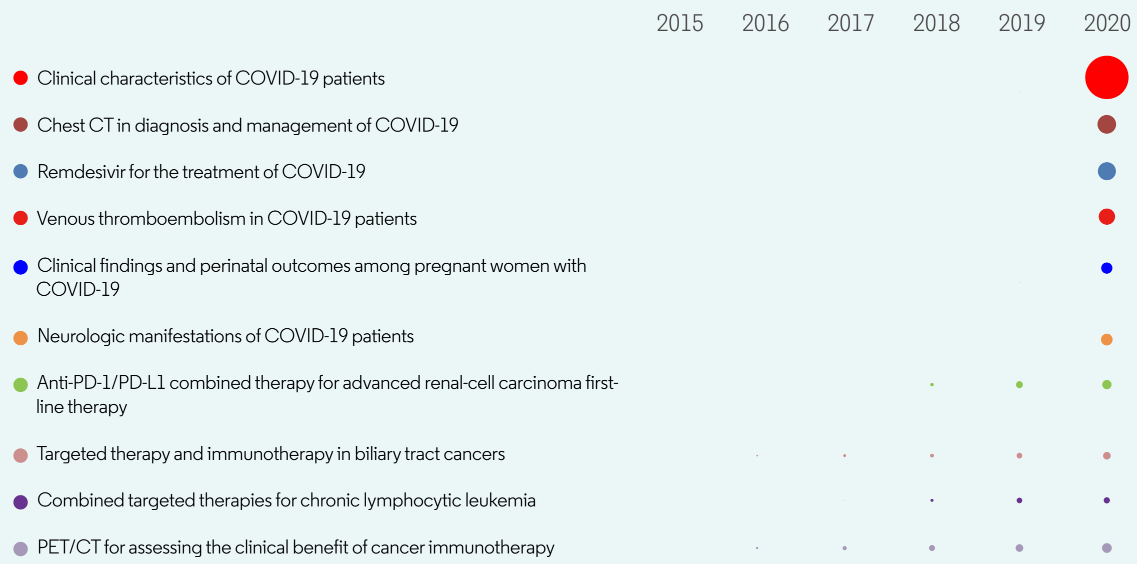


Figure 10: Citing papers for the Top10 Research Fronts in clinical medicine

1.2 KEY HOT RESEARCH FRONT – "Clinical characteristics of COVID-19 patients"

COVID-19 has been spreading around the world since 2019. Despite ongoing progress in the scientific and therapeutic spheres, effective methods for prevention and treatment have not yet become universally available, so the disease continues to pose a great threat to human health. Hence, the current status of COVID-19 research is a hot topic in recent years. This is underscored by the fact that the two key hot Research Fronts highlighted in clinical medicine in this year's report both focus on COVID-19.

The six core papers anchoring the key hot Research Front "Clinical characteristics of COVID-19 patients" had each been cited more than 6,000 times as of March 2021, having ranked as the top six most highly cited papers of 2020, according to the Web of Science™. Among these core papers, the report published in The New *England Journal of Medicine* in February 2020 by authors from the Chinese Center for Disease Control and Prevention, Wuhan Jinyintan Hospital, and their collaborators, with 7,106 citations to date, took the lead in revealing the pathogen of COVID-19 – the agent now notoriously familiar as the novel coronavirus officially named SARS-CoV-2. The other five core papers retrospectively analyzed clinical characteristics of hospitalized COVID-19 patients in China, revealing the common symptoms, imaging features, laboratory findings, and prognosis. The main findings included: 1) Fever and cough were the most typical symptoms, followed by myalgia, fatigue, expectoration, headache, hemoptysis or diarrhea, but some symptoms may not be typical; 2) Ground glass opacity was the most common finding on chest CT, but some non-severe and even a few severe patients showed no radiographic abnormality; 3) Lymphopenia was found in most patients; 4) Median duration of viral shedding was 20 days, with eight days the shortest and 37 days the longest, which partly explained the rejuvenation after discharge; 5) Complications included acute respiratory distress syndrome, viremia, myocardial injury or shock; 6) Older males with basic diseases were more likely to experience severe symptoms and fatal complications; 7) The ICU transfer rate was 5-32%, and in-hospital mortality 1.4-28%. With the continuous local outbreak of COVID-19 and the gradual deepening of related research, more clinical evidence has been revealed to provide a scientific basis for precise prevention and control of the epidemic.

The six core papers all come from China-based institutions, and all were published soon after the discovery of the COVID-19 in Wuhan. The contributing institutions include Wuhan Jinyintan Hospital, China-Japan Friendship Hospital, Beijing Union Medical College, and the Chinese Center for Disease Control and Prevention. Among them, Wuhan Jinyintan Hospital, one of the earliest hospitals for COVID-19 treatment, ranks 1st. All the institutions have played a vital role in early COVID-19 patient treatment and anti-epidemic research. Many researchers from these institutions, such as Bin Cao, Jianwei Wang, Nanshan Zhong, Fu Gao, Xinghuan Wang, Wenjie Tan, and Xinxin Zhang, made important contributions to COVID-19 control and prevention.

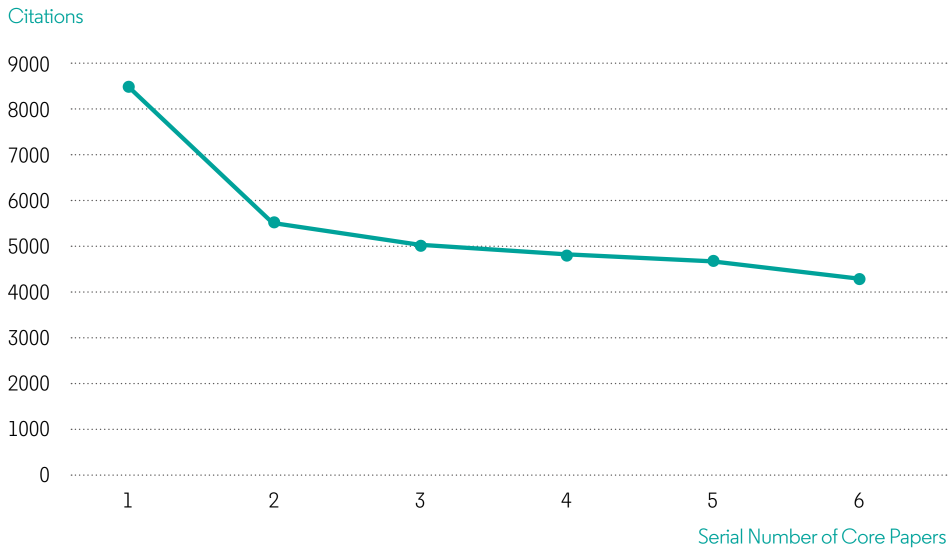


Figure 11: Citation frequency distribution curve of core papers in Research Front "Clinical characteristics of COVID-19 patients"

Table 20: Top countries and institutions producing core papers in the Research Front "Clinical characteristics of COVID-19 patients"

Country Ranking	Country	Core Papers	Proportion
1	China	6	100.0%

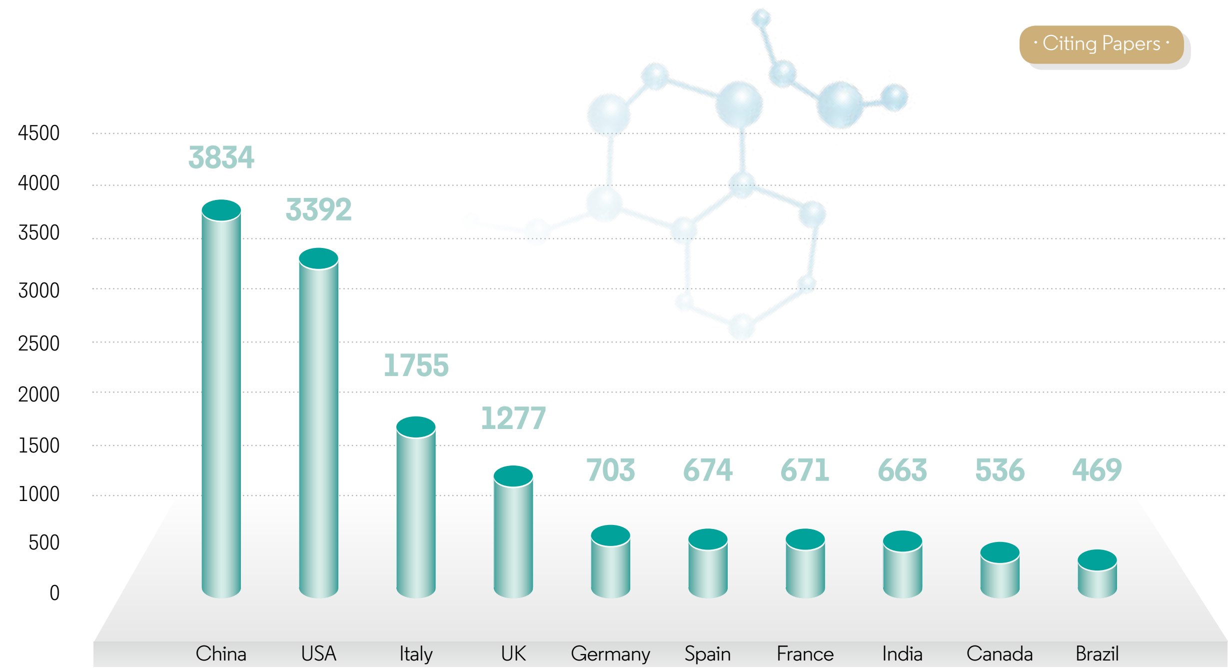
Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Wuhan Jinyintan Hospital	China	4	66.7%
2	Capital Medical University	China	3	50.0%
2	Chinese Academy of Medical Sciences - Peking Union Medical College	China	3	50.0%
4	Chinese Academy of Sciences	China	2	33.3%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
				4	Huazhong University of Science & Technology	China	2	33.3%
				4	Chinese Center for Disease Control & Prevention	China	2	33.3%
				4	Tsinghua University	China	2	33.3%
				4	China Japan Friendship Hospital	China	2	33.3%
				4	Wuhan Pulmonary Hospital	China	2	33.3%
				4	Wuhan University	China	2	33.3%

As for citing papers, the USA and China take the lead, followed by Italy, the UK, and other European countries. India and Brazil also produced hundreds of citing papers, partly associated with the severity of the COVID-19 epidemic in those countries. More than half the top institutions producing citing papers are in China, with the overall top three being Huazhong University of Science & Technology, Wuhan University, and Harvard University.

Table 21: Top countries and institutions producing citing papers in the Research Front "Clinical characteristics of COVID-19 patients"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	3834	21.5%	1	Huazhong University of Science & Technology	China	648	3.6%
2	USA	3392	19.0%	2	Wuhan University	China	413	2.3%
3	Italy	1755	9.8%	3	Harvard University	USA	408	2.3%
4	UK	1277	7.2%	4	National Institute of Health and Medical Research (INSERM)	France	273	1.5%
5	Germany	703	3.9%	5	Chinese Academy of Sciences	China	245	1.4%
6	Spain	674	3.8%	6	University of Milan	Italy	229	1.3%
7	France	671	3.8%	7	Assistance Public Hospital Paris	France	226	1.3%
8	India	663	3.7%	8	Chinese Academy of Medical Sciences - Peking Union Medical College	China	212	1.2%
9	Canada	536	3.0%	9	Fudan University	China	198	1.1%
10	Brazil	469	2.6%	10	University College London	UK	195	1.1%



1.3 KEY HOT RESEARCH FRONT – "Clinical findings and perinatal outcomes among pregnant women with COVID-19"

Pregnant women are notable in the COVID-19 infected population. Their clinical manifestations, as well as maternal and infant outcomes, have attracted much attention in COVID-19 research.

The key hot Research Front "Clinical findings and perinatal outcomes among pregnant women with COVID-19" includes 29 core papers. Most of these reports retrospectively review the clinical characteristics, pregnancy outcome, and risk of vertical transmission in pregnant women with COVID-19. Among these, the paper published in *Lancet* by researchers at Wuhan University and Peking University in March 2020 has been cited the highest (1,264 citations to at this writing). This study found that there was no significant difference between pregnant women and other adults with COVID-19 in terms of clinical characteristics, and no sufficient evidence showing that COVID-19 infection during pregnancy would lead to vertical transmission. But the paper by authors affiliated with Hubei Maternal & Child Healthcare Hospital together with Fudan University, published in *Translational* Pediatrics in February 2020, found that infection during pregnancy could have adverse effects on newborns, leading to fetal distress, premature delivery, and other complications. Other findings are included as follows: 1) Pregnancy and delivery did not aggravate the disease, and the majority of infected women experienced mild effects and had a good prognosis; 2) Common symptoms, laboratory examinations, and chest CT findings were basically the same as those of other adults patients; 3) Atypical symptoms in some women increased the difficulty of early screening, and chest CT and RT-PCR were helpful for early diagnosis; 4) Infection during pregnancy, in some cases, might have adverse effects on maternal and infant outcomes, causing spontaneous abortion, premature rupture of membranes, premature delivery, fetal distress, neonatal respiratory distress, asphyxia, fever, thrombocytopenia with abnormal liver function, or even death; 5) Some studies found that virus in vaginal secretions of the pregnant women was negative, and vertical transmission risk of vaginal delivery was very low. However, for pregnant women and their newborns, isolation and other protective measures should be followed as far as possible to reduce exposure and vertical transmission risks. Also, follow-up should be undertaken to guard against postpartum late infection of newborns.

As for the top countries producing core papers in this key hot front, China accounts for the highest contribution, far ahead in terms of the number of papers and citation frequencies, followed by the USA and Italy. Among the top institutions producing core papers, Huazhong University of Science & Technology and Wuhan University take the lead. Research institutions in Italy also registered prominently in this front.

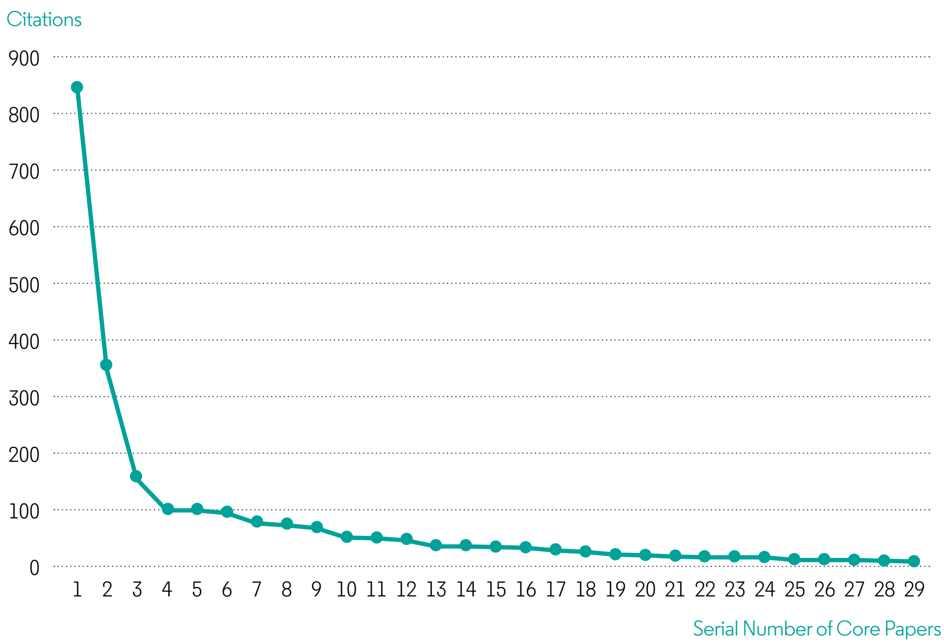
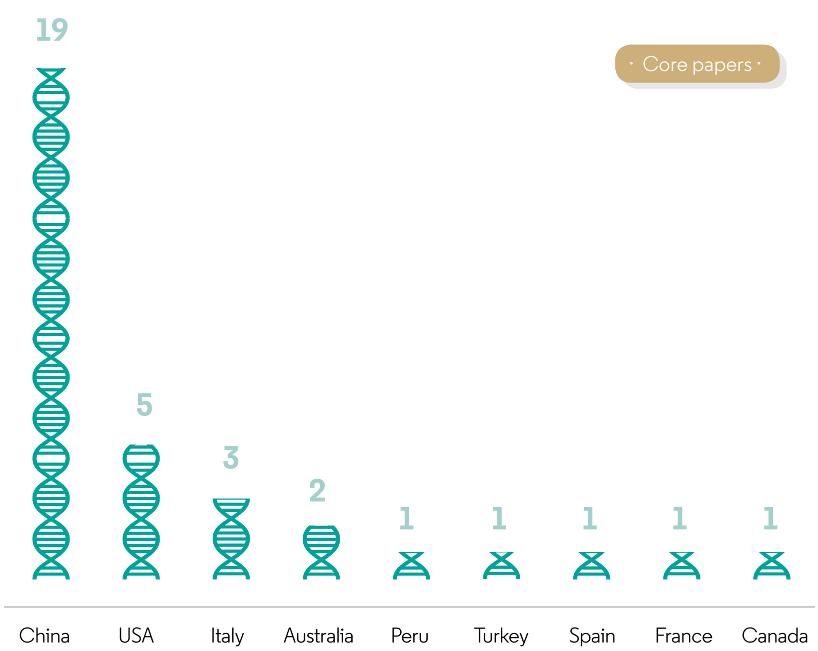


Figure 12: Citation frequency distribution curve of core papers in Research Front "Clinical findings and perinatal outcomes among pregnant women with COVID-19"

Table 22: Top countries and institutions producing core papers in the Research Front "Clinical findings and perinatal outcomes among pregnant women with COVID-19"

Country Ranking	Country	Core Papers	Proportion
1	China	19	65.5%
2	USA	5	17.2%
3	Italy	3	10.3%
4	Australia	2	6.9%
5	Peru	1	3.4%
5	Turkey	1	3.4%
5	Spain	1	3.4%
5	France	1	3.4%
5	Canada	1	3.4%

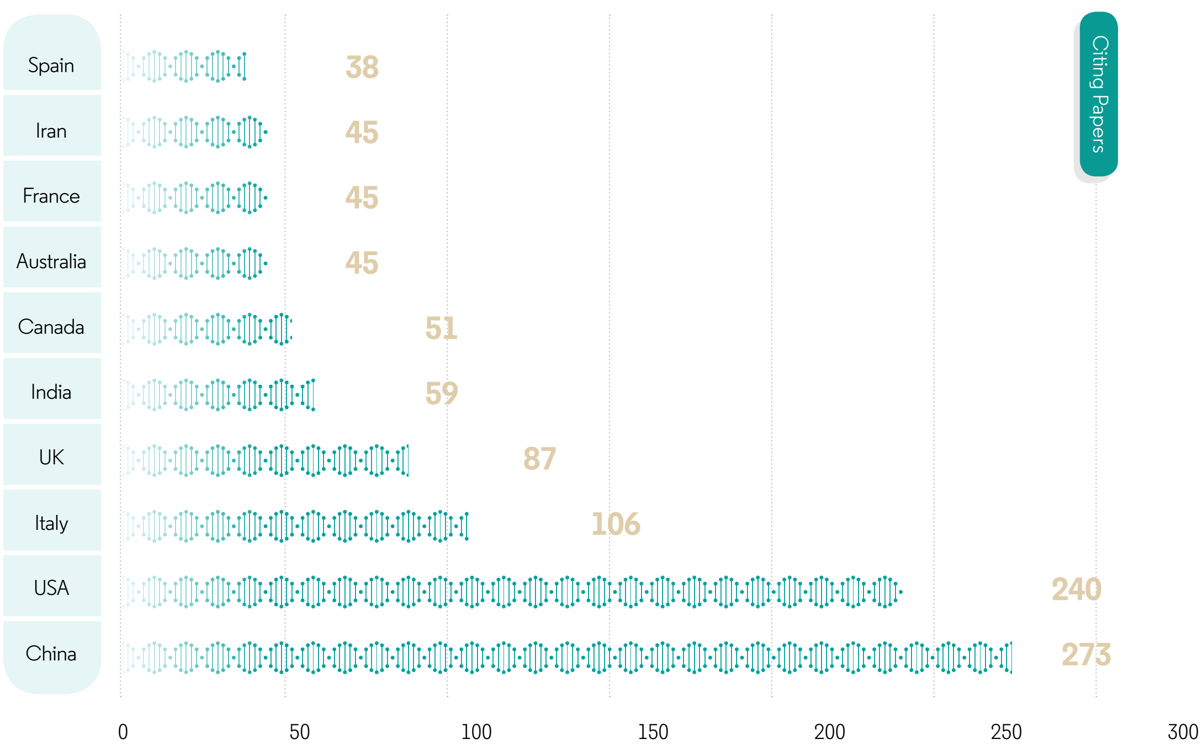
Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Huazhong University of Science & Technology	China	10	34.5%
2	Wuhan University	China	7	24.1%
3	Maternal & Child Health Hospital Hubei Province	China	3	10.3%
4	Shanghai Jiao Tong University	China	2	6.9%
4	University of Milan	Italy	2	6.9%
4	University of Padua	Italy	2	6.9%
4	Peking University	China	2	6.9%
4	Ca'Granda Ospedale MaggiorePoliclinico	Italy	2	6.9%
4	Azienda Ospedaliera Bolognini	Italy	2	6.9%
4	IRCSS Fdn San Matteo	Italy	2	6.9%
4	University of Milano-Bicocca	Italy	2	6.9%
4	ASST Papa Giovanni XXIII	Italy	2	6.9%
4	Padua Hospital	Italy	2	6.9%
4	San Gerardo Hospital	Italy	2	6.9%
4	University of Pavia	Italy	2	6.9%



In terms of citing papers, China and the USA are most prolific – demonstrating a heightened research interest in pregnancy associated with COVID-19 compared to other nations – followed by Italy and the UK. Huazhong University of Science & Technology, Wuhan University, and Assistance Publique - Hopitaux de Paris are the top three institutions producing citing papers.

Table 23: Top countries and institutions producing citing papers in the Research Front "Clinical findings and perinatal outcomes among pregnant women with COVID-19"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	273	22.9%	1	Huazhong University of Science & Technology	China	62	5.2%
2	USA	240	20.2%	2	Wuhan University	China	48	4.0%
3	Italy	106	8.9%	3	Assistance Public Hopitaux de Paris	France	26	2.2%
4	UK	87	7.3%	4	University of Sao Paulo	Brazil	20	1.7%
5	India	59	5.0%	5	Shanghai Jiao Tong University	China	19	1.6%
6	Canada	51	4.3%	6	University College London	UK	18	1.5%
7	Australia	45	3.8%	6	University of Toronto	Canada	18	1.5%
8	France	45	3.8%	8	National Institute of Health and Medical Research (INSERM)	France	17	1.4%
9	Iran	45	3.8%	8	Monash University	Australia	17	1.4%
10	Spain	38	3.2%	8	University of Paris Saclay	France	17	1.4%



2. EMERGING RESEARCH FRONT

2.1 SUMMARY OF EMERGING RESEARCH FRONTS IN CLINICAL MEDICINE

The 29 emerging Research Fronts in clinical medicine all focus on COVID-19. These specialty areas can be divided into nine groups of fronts representing clinical manifestations, organ damages and complications, impact on basic diseases, epidemiology, hospital infection prevention and control, treatments, vaccine R&D, immune characteristics, and diagnostic technologies. Specifically: the "clinical manifestations" group includes six emerging Research Fronts covering clinical manifestations of early cases, taste and smell disorders, digestive system symptoms, eye manifestations, clinical manifestations of children, and clinical manifestations of asymptomatic infections. The "organ damages and complications" group includes six fronts reporting research in heart injury, liver injury, blood-brain barrier injury, acute kidney injury, multi-system inflammatory syndrome in children, and Guillain-Barre syndrome. The "impact on basic diseases" group includes four fronts examining impact on tumors, solid organ transplantation, dementia, and hypertension medications. The "epidemiology" group includes the impact of crowd flow restriction policies, epidemic assessment models, the spread of outbreaks in Africa, and epidemiology involving children. The "hospital infection prevention and control" group also includes four fronts devoted to head and neck surgery, ENT surgery, oral surgery, and inflammatory bowel disease during the epidemic. The "treatment methods" group includes three fronts on research into vitamin D, dietary supplements, hydroxychloroquine/azithromycin combined therapy for COVID-19 treatment.

Two specialty areas, covering organ damages and complications caused by new coronavirus infection, along with SARS-CoV-2 vaccine research and development, have been selected as Emerging Research Front Groups.

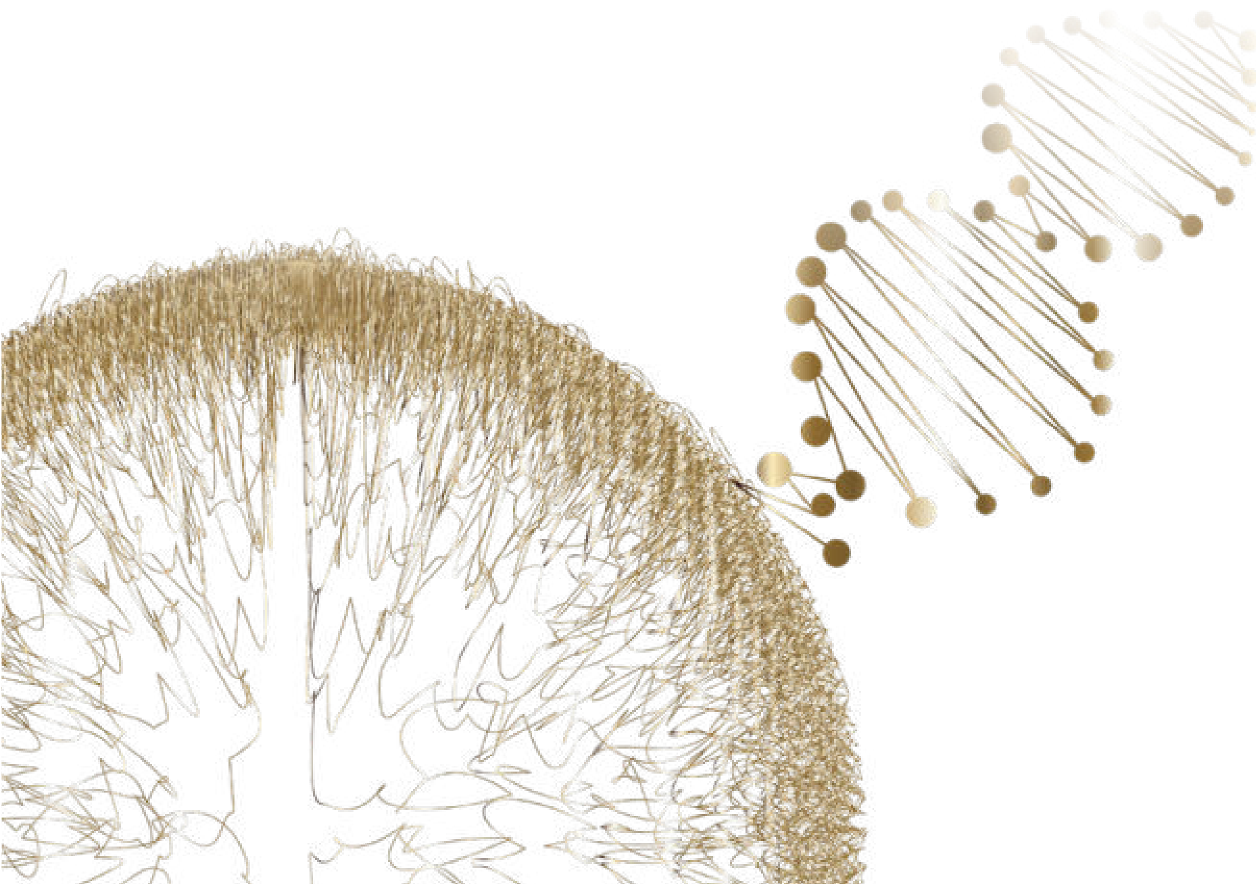


Table 24: Emerging Research Fronts in clinical medicine

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Clinical impact of COVID-19 on cancer patients	19	1528	2020
2	Immunological features of COVID-19	2	1510	2020
3	Development of vaccine against SARS-CoV-2	18	1480	2020
4	Epidemiological and clinical characteristics of early COVID-19 patients	18	1395	2020
5	Multisystem inflammatory syndrome in children associated with COVID-19	15	1370	2020
6	Association of use of angiotensin-converting enzyme inhibitors and angiotensin receptor blockers for COVID-19 patients	11	1330	2020
7	Detection of SARS-CoV-2 by RT-PCR	2	1301	2020
8	Olfactory and gustatory function impairment in COVID-19 patients	13	1293	2020
9	COVID-19 in solid organ transplant recipients	27	1226	2020
10	Association of cardiac Injury with mortality in COVID-19	2	1211	2020
11	Epidemiology of COVID-19 in children	2	1028	2020
12	Acute kidney injury in patients with COVID-19	13	974	2020
13	Gastrointestinal manifestations of COVID-19 patients	6	947	2020
14	Ocular manifestations of COVID-19 patients	12	932	2020
15	COVID-19 challenges for dental and oral medicine	13	877	2020
16	Effect of human mobility and control measures on the COVID-19 epidemic	3	835	2020
17	Management of head and neck surgery during COVID-19 pandemic	20	738	2020
18	Liver injury of COVID-19 patients	13	735	2020
19	Mathematical model to assess dynamics of transmission and control of COVID-19	2	723	2020
20	Clinical characteristics of children with COVID-19	10	665	2020
21	Cerebrovascular diseases in COVID-19	21	662	2020
22	Guillain-Barre syndrome in coronavirus disease 2019	8	400	2020
23	Clinical characteristics of asymptomatic infections with COVID-19	2	393	2020
24	COVID-19 and ENT Surgery	13	350	2020
25	Diet supplementations for COVID-19 infection	7	176	2020
26	COVID-19 pandemic on Alzheimer's disease and related dementias	6	162	2020
27	Identification of potential T cell and B cell epitopes for SARS-CoV-2 and development of epitope-based peptide vaccine	9	692	2019.9
28	Management of inflammatory bowel disease during the COVID-19 pandemic	23	995	2019.8
29	Association of vitamin D with COVID-19	21	1256	2019.6

2.2 KEY EMERGING RESEARCH FRONT GROUP – "Organ damages and complications caused by new coronavirus infection"

Respiratory symptoms are generally considered to be the main features and manifestations of infections caused by the novel SARS-CoV-2 coronavirus. But researchers have gradually discerned that the infection may also affect other organs such as the blood system, cardiovascular system, genitourinary system, digestive system, endocrine system, nervous system, skin, and eyes. Subsequent complications can include thrombosis, myocardial dysfunction, arrhythmia, acute coronary syndrome, acute kidney injury, gastrointestinal symptoms, liver injury, high blood sugar, eye diseases, and skin diseases. The pathogenic mechanism of these damages and complications may derive from direct attack of the widely distributed angiotensin converting enzyme 2 (ACE2) receptors in multiple tissues by SARS-CoV-2, or by the infection-induced endothelial damage and thrombotic inflammation, immune response imbalance, or abnormal adaptability of the ACE2 pathway. The occurrence of complications is not only associated with higher risks of death but also reduces self-care ability after discharge, resulting in a huge disease burden. Therefore, the scope of extrapulmonary damages and complications, pathogenic mechanisms, treatment methods, as well as long-term effects of these damages and complications caused by COVID-19 have all received increasing attention.

There are six emerging Research Fronts in the "Organ damages and complications caused by new coronavirus infection" key front group, including myocardial injury, liver injury, acute kidney injury, blood-brain barrier injury, Guillain-Barré syndrome, and multi-system inflammatory syndrome in children. Myocardial injury, liver injury, and acute kidney injury are the most common complications of infection with the new coronavirus, with incidences of 20-30%, 16-19%, and 20-50%, respectively. Moreover, 5-10% of new coronavirus infections may have blood-brain barrier damage and dysfunction. Also, rare and serious Guillain-Barré syndrome has been reported. Children are susceptible to COVID-19. According to epidemiological data from the U.S. Centers for Disease Control and Prevention, the morbidity, hospitalization, and mortality of children are relatively lower than adults. However, since April 2020, a rare pediatric complication named Multi-System Inflammatory Syndrome (MIS-C) has frequently been reported in areas with high COVID-19 prevalence. MIS-C shows clinical features similar to those of Kawasaki disease and toxic shock. The syndrome has increased by 30 times during the COVID-19 epidemic, and 60% of MIS-C patients require intensive care, with a fatality rate of 0.9-2.0%.

The COVID-19 epidemic has brought long-term health problems to all humankind. Although COVID-19 vaccines have achieved great success, the final outcome of the epidemic still depends on factors such as global health system response, vaccine efficacy, virus mutations, and cultural adjustments. Human beings are still facing the threat of the COVID-19 epidemic. With the accumulation of real-world evidence of the extrapulmonary effects of new coronavirus infections, understanding of the complications and sequelae caused by the new coronavirus infections has been strengthened. However, it is a long-term and complicated task to effectively resolve the complications and sequelae. Relevant research will focus on the pathogenesis of extrapulmonary organ damages and complications, the protection of extrapulmonary organs, multidisciplinary collaborative treatment, long-term sequelae assessment and response, and rehabilitation guidance.

2.3 KEY EMERGING RESEARCH FRONT GROUP – "SARS-CoV-2 vaccine research and development"

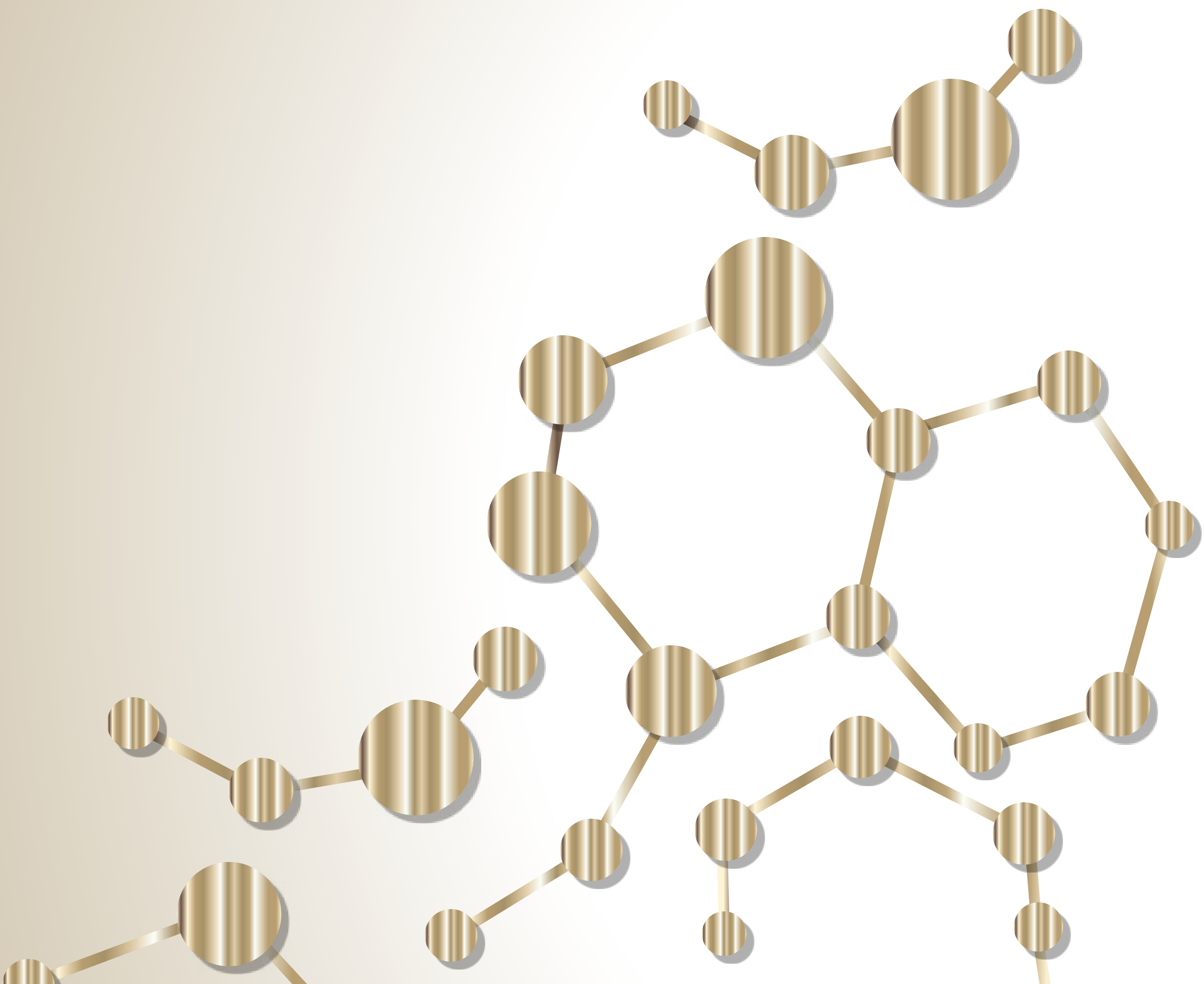
Effective herd immunity through vaccination is considered to be the most economical and effective measure to control the COVID-19 epidemic. With the joint efforts of the scientific community globally, the speed and scale of research and development of SARS-CoV-2 vaccines have reached unprecedented levels. Many SARS-CoV-2 vaccines have been approved for emergency use in just a few months, breaking the record of vaccine development, which usually takes eight to 20 years. According to the World Health Organization (WHO), as of September 24, 2021, hundreds of organizations around the world are engaged in researching and developing SARS-CoV-2 vaccines. There are currently more than 121 vaccines in clinical trials and another 194 in the preclinical stage. Science magazine, describing the effort as "Desperately needed vaccines against COVID-19, developed and tested at record speed," selected this research among the Top10 scientific breakthroughs of 2020.

The "SARS-CoV-2 vaccine research and development" key front group includes two emerging fronts: "Development of vaccine against SARS-CoV-2" and "Identification of potential T cell and B cell epitopes for SARS-CoV-2 and development of epitope-based peptide vaccine". The "Development of vaccine against SARS-CoV-2" Research Front includes 18 core papers, involving preclinical and phase 1/2 clinical trials of 15 SARS-CoV-2 vaccines from the USA, China, Russia, and the UK. These vaccine-development schemes cover all the mainstream vaccine platforms, including protein subunit, viral vector, nucleic acid, and inactivated or attenuated vaccines. Among them, there are two mRNA vaccines (Pfizer BNT162b and Moderna mRNA-1273) approved for emergency use by the FDA, along with the first Chinese inactivated vaccine (Sinopharm BBIBP-CorV) certified for emergency use by the WHO, the first adenovirus vector vaccine (Cansino Bio Ad5-nCoV) approved in China, a recombinant protein vaccine NVX-CoV2373 developed by Novavax, and a DNA vaccine INO-4800 developed by Inovio Pharmaceuticals.

The core papers in the Research Front covering "Identification of potential T cell and B cell epitopes for SARS-CoV-2 and development of epitope-based peptide vaccine" mainly focus on the prediction and identification of B cell epitopes and T cell epitopes for SARS-CoV-2 vaccine development by bioinformatics methods.

So far, numerous vaccine-development efforts R&D have made great progress. However, the COVID-19 epidemic has not yet shown a significant slowdown worldwide. In addition, uncertainty caused by incomplete data on the protection duration of existing vaccines, the health status and infection risks of different populations, the inability of single vaccine to meet global demand, and the emergence of new variants leaves the development of SARS-CoV-2 vaccines still facing major challenges. Continued research and development of multiple candidate vaccines – with higher safety, effectiveness, versatility and convenience – can provide for the control and ultimately the prevention of COVID-19.

2021
RESEARCH FRONTS



2021
RESEARCH FRONTS

BIOLOGICAL SCIENCES

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN BIOLOGICAL SCIENCES

The Top 10 Research Fronts in biological sciences mainly focus on the pathogenic mechanism of SARS-CoV-2; the inhibition mechanism of Remdesivir for coronavirus; BCG vaccine-induced training immunization; the effect of tumor-associated fibroblasts on tumor immune response; the regeneration of hippocampal neurons; the functional diversity of astrocytes; lipoprotein (a) and cardiovascular risk; depression-related loci and automatic recognition; and diagnosis of diseases based on image-based deep learning.

Given the two-year, global battle against COVID-19, it is certainly no surprise that research on the pathogenesis of SARS-CoV-2 has rapidly become a hot topic in the field of biological sciences. Through the identification of the pathogen, key targets and receptors, the research work laid a foundation for the follow-up steps of developing drugs and vaccines, with the ultimate goal being control of the pandemic and prevention of future outbreaks.

The hot Research Front "Research on the mechanism of Remdesivir inhibiting coronavirus" has confirmed that Remdesivir can effectively inhibit the replication of the coronavirus genus, including some known coronaviruses that were observed to spread from animals to humans, such as MERS and SARS. A related hot Research Front in clinical medicine is "Remdesivir for the treatment of Covid-19".

Meanwhile, in other active areas, research on brain science, oncogenesis and treatment, depression pathogenesis, and the mechanisms of drug action have been among the core topics of Research Fronts in the field of biological sciences over the years.

In brain science, two hot Research Fronts focus on "Regeneration of hippocampal neurons in adult human brain" and "Heterogeneity and functional diversity of brain astrocytes". The latter marks the development and continuation of a front identified in 2020: "Relationship between astrocytes and neurodegenerative diseases and brain aging". In addition, the hot Research Front designated "Effect of tumor associated-fibroblasts on tumor immune response" is related to the 2020 front "MicroRNA therapeutics in cancer", while the hot Research Front titled "Genome wide association study to identify depression related loci" focuses on depression, as did its 2020 predecessor, "Study on the antidepressant mechanism of ketamine".

Table 25: Top10 Research Fronts in biological sciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Identification of pathogens of COVID-19, complete genome sequence analysis of SARS-CoV-2 and recognition of ACE2 receptor	2	5280	2020
2	Structure, function and antigenicity of SARS-CoV-2 spike glycoprotein	3	5357	2020
3	Effect of tumor associated fibroblasts on tumor immune response	19	3195	2018.5
4	BCG Vaccine induced training immunization	14	2555	2018.5
5	Regeneration of hippocampal neurons in adult human brain	6	1531	2018.5
6	Lipoprotein (a) and cardiovascular risk and RNA therapy for hyperlipidemia	42	3770	2018.3
7	Genome wide association study to identify depression related loci	11	2566	2018.3
8	Research on the mechanism of Remdesivir inhibiting coronavirus	8	2470	2018.3
9	Heterogeneity and functional diversity of brain astrocytes	12	3189	2018.2
10	Research on Image-based deep learning for automatic disease diagnosis	34	7178	2018.1

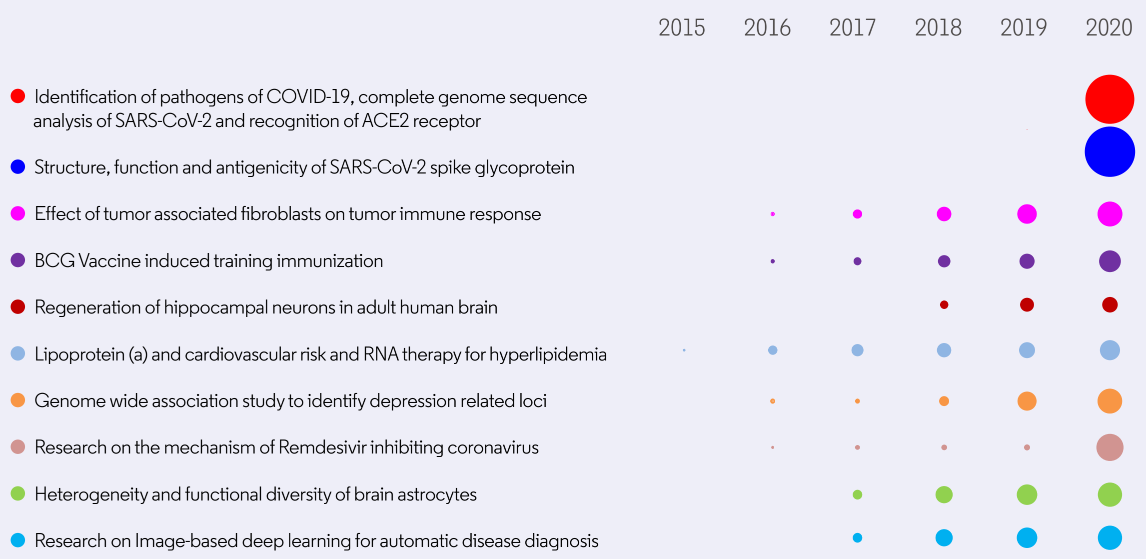


Figure 5: Citing papers for the top 10 Research Fronts in biological sciences

1.2 KEY HOT RESEARCH FRONT – “Identification of pathogens of COVID-19, complete genome sequence analysis of SARS-CoV-2 and recognition of ACE2 receptor”

COVID-19 has posed severe challenges to the global health system and socio-economic development. Scientists and medical doctors have been at the forefront of research and have published a large volume of high-quality papers, providing important guidance toward the control and prevention of COVID-19.

Rapid identification of the causative pathogens in emerging infectious diseases is the top priority of the epidemic emergency prevention and control system. The two core papers in this hot Research Front were both published on February 3, 2020, in the journal Nature; they are among the earliest papers written on the front lines of the fight against COVID-19.

The two studies provided the first detailed report on SARS-CoV-2 in the early stages of the outbreak. They confirmed that SARS-CoV-2 was the cause of the epidemic of persistent acute respiratory syndrome in Wuhan, and revealed the basic biological characteristics, the whole-genome sequence, ACE2 (angiotensin-convertingenzyme2) receptor, and the possible natural host of SARS-CoV-2. Researchers examined all those factors in terms of nucleic acid detection, serological diagnosis, virus isolation, and receptor utilization. The conclusions of the two papers corroborate each other, laying a foundation for follow-up work on vaccines and drugs to treat, contain, and prevent the disease.

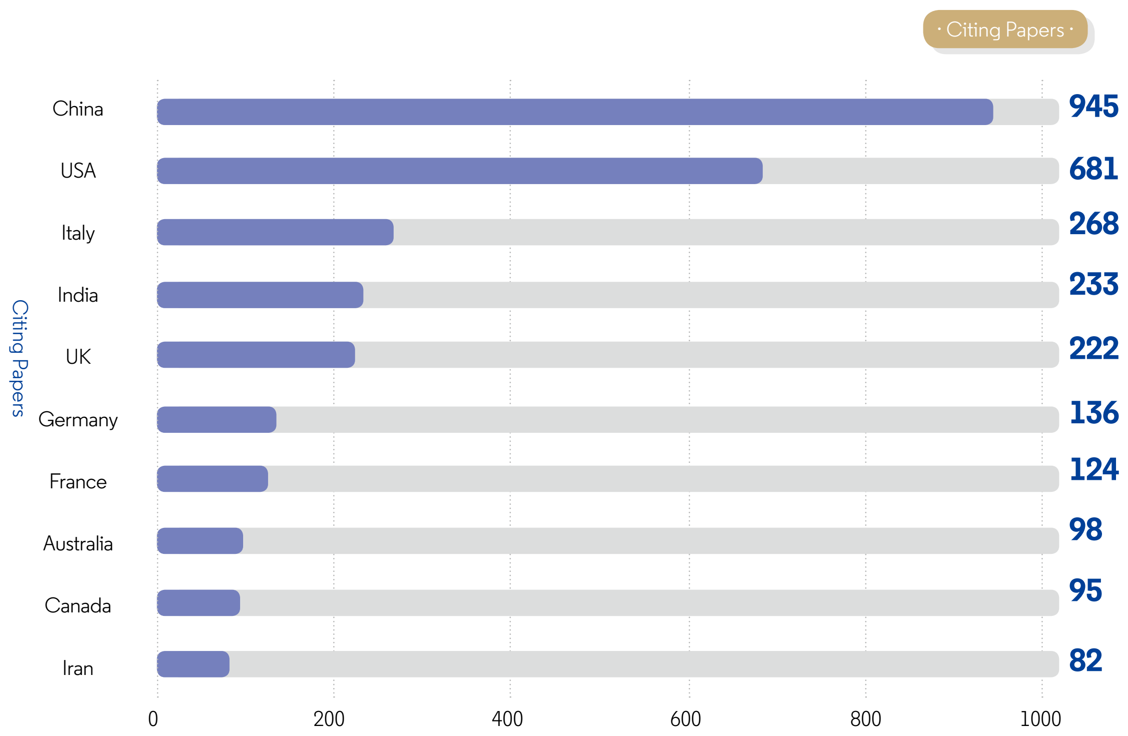
In one of the two core papers, researchers at the Wuhan Institute of Virology of the Chinese Academy of Sciences, Wuhan JinYinTan Hospital, and the Hubei Provincial Center for Disease Control and Prevention jointly identified the pathogen as SARS-CoV-2 and revealed its similarity with SARS-CoV. Meanwhile, this study provided conclusive evidence that the key receptor of SARS-CoV-2 invading human cells is ACE2.

In the other core paper, a research team composed of investigators at Shanghai Public Health Clinical Center and School of Public Health Affiliated to Fudan University, Wuhan Central Hospital of Huazhong University of Science and Technology, National Institute for Communicable Disease Control and Prevention of Chinese Center for Disease Control and Prevention, Wuhan Center for Disease Control and Prevention, and the University of Sydney in Australia, first released the whole genome sequence of SARS-CoV-2. This work has been of great significance to the subsequent, ongoing global effort aimed at the development of vaccines and therapeutics.

Citations to these two core papers, at this writing, have reached 3,655 and 1,625, respectively. In terms of countries that cite the front’s core papers, China has fielded the largest number of citing papers, participating in 945 and accounting for 62.1% of the total. The USA ranks 2nd with 681 citing papers. These numbers indicate that both China and the USAx have carried out a substantial portion of follow-up research in this specialty area. Eight of the top 10 institutions producing citing papers are based in China. The other two are Harvard University in the USA and National Institute of Health and Medical Research of France.

Table 26: Top countries and institutions producing citing papers in the Research Front "Identification of pathogens of COVID-19, complete genome sequence analysis of SARS-CoV-2 and recognition of ACE2 receptor"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	945	24.8%	1	Chinese Academy of Sciences	China	128	3.4%
2	USA	681	17.9%	2	Huazhong University of Science & Technology	China	124	3.3%
3	Italy	268	7.0%	3	Fudan University	China	77	2.0%
4	India	233	6.1%	3	Wuhan University	China	77	2.0%
5	UK	222	5.8%	5	Harvard University	USA	68	1.8%
6	Germany	136	3.6%	6	Chinese Academy of Medical Sciences - Peking Union Medical College	China	65	1.7%
7	France	124	3.3%	7	Capital Medical University	China	50	1.3%
8	Australia	98	2.6%	8	Zhejiang University	China	44	1.2%
9	Canada	95	2.5%	9	National Institute of Health and Medical Research (INSERM)	France	43	1.1%
10	Iran	82	2.2%	10	University of Hong Kong	China	42	1.1%



1.3 KEY HOT RESARCH FRONT – "Struct ure, function and antigenicity of SARS-CoV-2 spike glycoprotein"

It is now firmly established that SARS-CoV-2 is the pathogen underlying COVID-19. SARS-CoV-2, like SARS-CoV, invades human cells by combining its surface spike glycoprotein (S protein) with human ACE2 receptor. Therefore, studying the structure and function of S protein of SARS-CoV-2 and its receptors is important to further reveal the mechanism of virus invasion and to guide the development of targeted drugs and vaccines.

This hot Research Front is composed of three core papers, which were published in Science and Cell in early 2020. These reports are outstanding representatives of many SARS-CoV-2 studies and led to further innovative and important research, ultimately revealing the structure of S protein of SARS-CoV-2 and its role in the viral invasion of the human body. These key core papers and their research results establish a train of thought and a firm foundation for the research and development of SARS-CoV-2 vaccines and drugs.

Among this important work, a team at the University of Texas at Austin and their collaborators first demonstrated the structure of S protein trimer by means of cryo-electron microscopy. The researchers also pointed out that the affinity of SARS-CoV-2 and ACE2 is 10 to 20 times that of SARS-CoV, which likely explains the COVID-19 pathogen's high infectivity. A paper from the Leibniz Institute for Primate Research in Germany was cited the most frequently (4,357 times at this writing); this report points out that Transmembrane Serine Protease 2 (TMPRSS2) on the surface of host cells plays an important role in S protein activation, and TMPRSS2 inhibitors can block the process of virus invasion. This study is of great significance to understand the transmission and pathogenesis of SARS-CoV-2 and to identify potential targets for antiviral intervention.

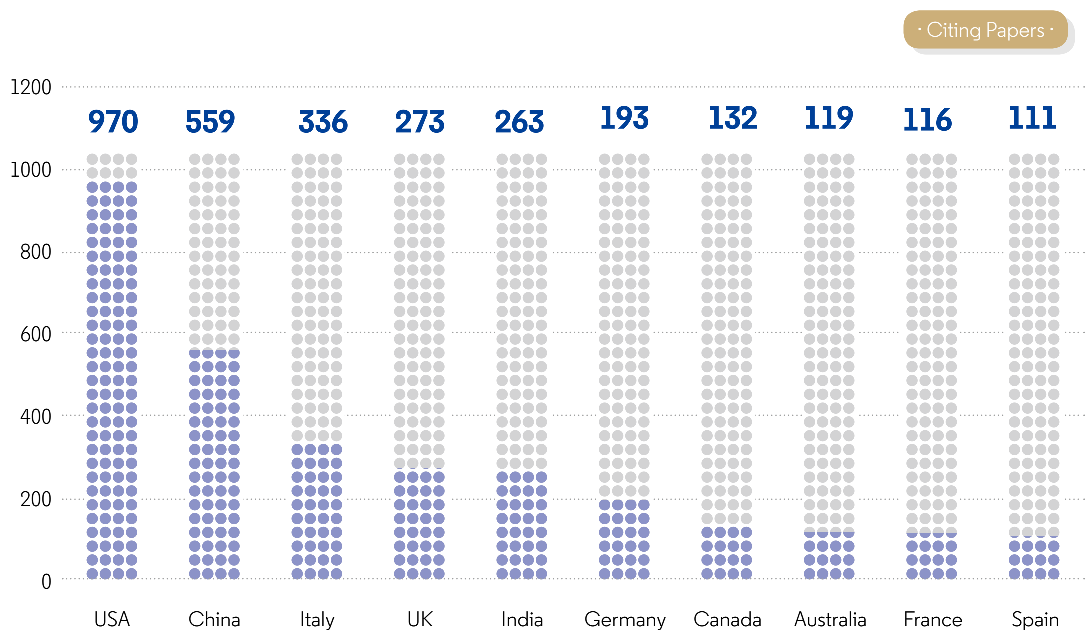
A paper published by a team at the University of Washington, Seattle, and their colleagues details the mechanism of S protein infection and membrane fusion in SARS-CoV-2, identifies the unique Furin cleavage site at the boundary of S S1/S2 subunit, and analyzes the Cryo-EM structure of S protein extracellular domain trimer. This study provides provide a blueprint for the design of vaccines and virus-invasion inhibitors.

The core papers of this Research Front have been highly cited. From the distribution of their citing papers (Table 27), the USA is the most active country, participating in 970 citing papers. The second is China, which participated in 559 citing papers. Italy ranks 3rd with 336 citing papers. Among the top 10 institutions, four are in the USA, including Harvard University, the U.S. National Institutes of Health, Mount Sinai Icahn School of Medicine, and the University of California, San Diego. Four Chinese institutions are Huazhong University of Science and Technology, the Chinese Academy of Sciences, Peking Union Medical College, and Fudan University. The other two institutions entering the top 10 are the National Institute of Health and Medical Research of France and the University of Milan, Italy.

Table 27: Top countries and institutions producing citing papers in the Research Front "Structure, function and antigenicity of SARS-CoV-2 spike glycoprotein"

Country Ranking	Country	Citing Papers	Proportion
1	USA	970	24.0%
2	China	559	13.8%
3	Italy	336	8.3%
4	UK	273	6.8%
5	India	263	6.5%
6	Germany	193	4.8%
7	Canada	132	3.3%
8	Australia	119	2.9%
9	France	116	2.9%
10	Spain	111	2.7%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Harvard University	USA	101	2.5%
2	Huazhong University of Science & Technology	China	70	1.7%
3	U.S. National Institutes of Health (NIH)	USA	62	1.5%
4	Chinese Academy of Sciences	China	61	1.5%
5	National Institute of Health and Medical Research (INSERM)	France	55	1.4%
6	Chinese Academy of Medical Sciences - Peking Union Medical College	China	45	1.1%
7	IcahnSchoolof Medicine at MountSinai	USA	42	1.0%
8	Fudan University	China	41	1.0%
9	University of Milan	Italy	40	1.0%
10	University of California San Diego	USA	39	1.0%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN BIOLOGICAL SCIENCES

Eleven specialty areas in the field of biological sciences have been selected as emerging Research Fronts. Their main research topics include SARS-CoV-2 related themes, genome wide pan cancer analysis, the mechanism of human adhesin folding genome by DNA ring extrusion, and machine intelligence in peptide therapeutics.

Among these areas, eight fronts entailing SARS-CoV-2 research from different angles occupy prominent positions among the selected emerging Research Fronts, including research on the pathogenic principle (research on the SARS-CoV-2 pathogenic mechanism with animal models; the evolutionary dynamics of interaction between SARS-CoV-2 and ACE2); research on therapeutic drug targets (SARS-CoV-2 main protease Mpro, SARS-CoV-2 RNA dependent RNA polymerase); research on potent neutralizing antibody against SARS-CoV-2; research on T cell immunity induced by the novel coronavirus; and study of the influence of SARS-CoV-2 on the female reproductive system.

Table 28: Emerging Research Fronts in biological sciences

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Potent SARS-CoV-2 neutralizing antibody	19	1681	2020
2	Study on the pathogenic mechanism of SARS-CoV-2 using model animals	19	1606	2020
3	Identification of effective antiviral drugs against major proteases from SARS-CoV-2 by molecular simulation	40	1563	2020
4	Structural elucidation and inhibitor discovery of SARS-CoV-2 major protease Mpro	6	1048	2020
5	T cell immunity induced by SARS-CoV-2	7	978	2020
6	Genome wide pan cancer analysis	8	647	2020
7	Effects of SARS-CoV-2 on reproductive system	9	314	2020
8	Structure of RNA dependent RNA polymerase of SARS-CoV-2	2	292	2020
9	Evolutionary dynamics of the interaction between SARS-CoV-2 and ACE2	5	111	2020
10	Mechanism of human adhesin folding genome by DNA ring extrusion	6	259	2019.7
11	Machine intelligence in peptide therapeutics	8	241	2019.6

2.2 KEY EMERGING RESARCH FRONT – "Structural elucidation and inhibitor discovery of SARS-CoV-2 major protease Mpro"

Since the earliest COVID-19 outbreaks, research and development for vaccines and drugs have been the focus of a great deal of energy and money. So far, great progress has been made in the development of COVID-19 vaccines, and the large-scale vaccination campaign has played a positive role in controlling the pandemic. By contrast, the research and development efforts aimed at COVID-19 drugs have made relatively slow progress.

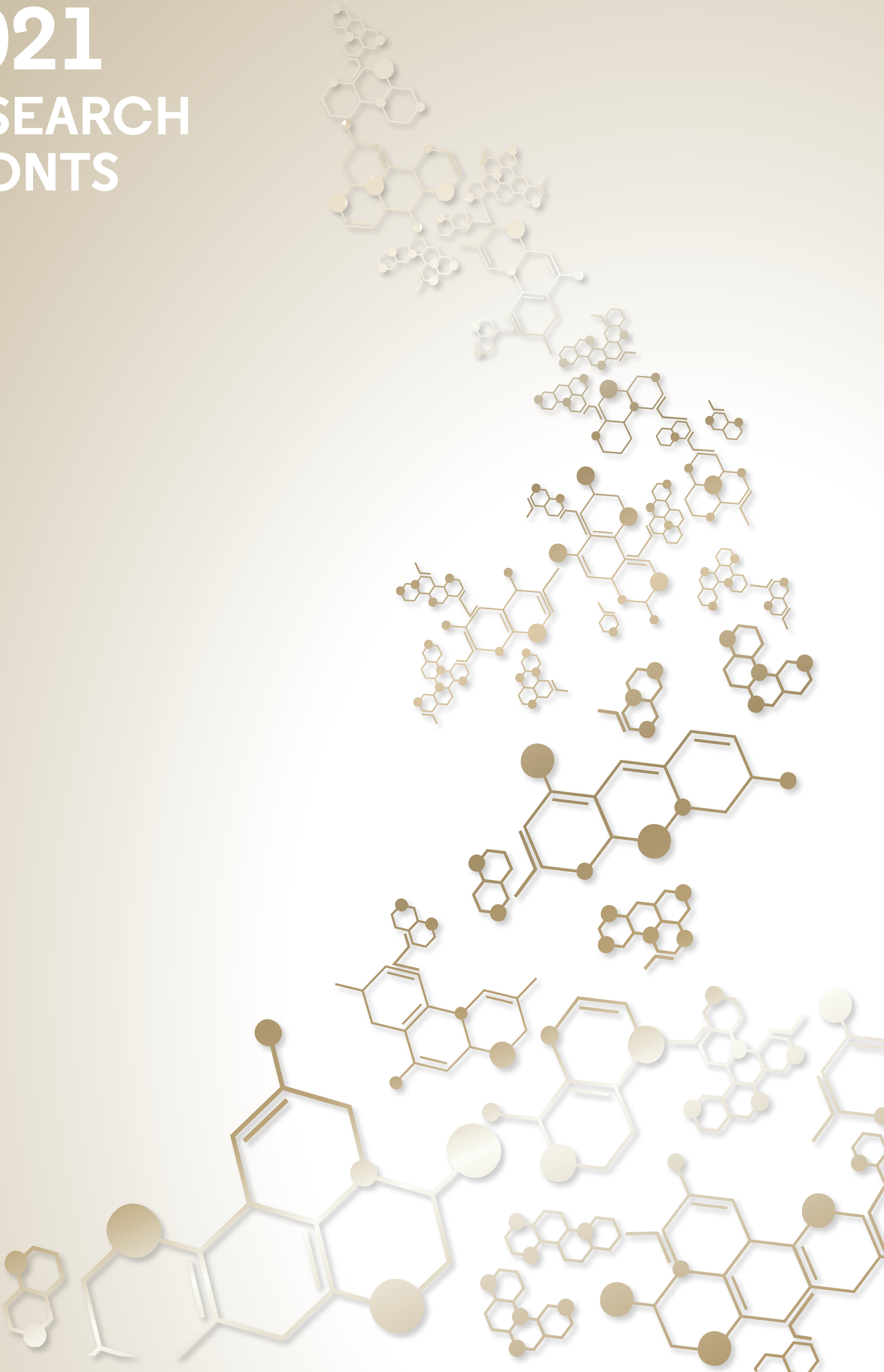
In principle, all viral enzymes and proteins related to viral replication and host cell control are potential targets for drug therapy in the search for a treatment plan for COVID-19. Based on the S protein, RNA dependent RNA polymerase (RdRp) and the main protease (Mpro, also known as 3CLpro) of SARS-COV-2, and based on host ACE2 receptor and TMPRSS2, scientists have developed various antiviral drugs. Among them, SARS-CoV-2 Mpro is highly conserved in evolution and plays a key role in mediating viral replication and transcription. Therefore, it has become an attractive drug target for SARS-COV-2.

This emerging Research Front includes six core papers, from authors based in China, the USAUSA, Australia and Germany. The research focuses on the three-dimensional structure elucidation and inhibitor discovery of SARS-CoV-2 Mpro. Researchers determined that SARS-CoV-2 Mpro is a cysteine protease with a relative molecular mass of 34,000, and its similarity with SARS-CoV Mpro is as high as 96%. The SARS-CoV-2 Mpro active molecule is composed of two monomer structures which are nearly perpendicular to each other, and each monomer contains three domains.

The research constituting this front also involves extensive screening of inhibitors by combining structural adjuvant drug design, virtual drug screening, and high-throughput screening. Results indicated that GC-376, boceprevir, Carmofur, ebselen, and other drugs have good inhibitory activity on SARS-CoV-2 Mpro and could effectively inhibit the replication of SARS-CoV-2 in host cells. At the same time, the peptide-like compounds that underwent screening, such as 11a, 11B, and α- Ketoamide inhibitor 13b, have the potential to be developed into drugs.

The research findings laid important foundations for the rapid development of new potential anti SARS-CoV-2 drugs. Meanwhile, as might be expected, this research represented by this front has attracted many scientists to carry out follow-up research. We expect that biomedical researchers will develop new specific medicines for the treatment of COVID-19 at an early date.

2021
RESEARCH FRONTS



2021
RESEARCH FRONTS

CHEMISTRY AND MATERIALS SCIENCE

1. HOT RESEARCH FRONT

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

The Top 10 Research Fronts in chemistry and materials science in 2021 are mainly distributed in organic synthesis, advanced materials, biochemistry, and other fields. Compared with previous years, more than half of the Top 10 Research Fronts in 2021 are selected for the first time. Even the research fields that have appeared in previous Top 10 roundups display a shift in direction this year. In the area of organic synthesis, N-heterocyclic carbene catalysis was selected as one of the Top 10 Research Fronts in 2020. This year, the focus shifts to N-heterocyclic carbene/photo-cocatalyzed reaction. In all, three Research Fronts are selected for the first time, including the synthesis of sulfonyl functional compounds with the insertion of sulfur dioxide; non-covalent interaction (halogen bond, sulfur bond, etc.); and asymmetric construction of axially chiral compounds.

In the field of advanced materials, research on perovskite materials has consistently figured among the hot Research Fronts of recent years. From 2013 to 2020, this research mainly focused on applications as battery materials and optical crystal materials in solar cells and photodetectors. In 2021 studies of perovskite's ferroelectric properties have become the new research topic. Similarly, the study of hydrogel-based strain sensor was a Top 10 Research Front in 2020. A year later, more studies are emerging on methods to improve the material's anti-drying performance, as well as its thermal and mechanical stability. Electromagnetic wave absorption materials constituted an Emerging Research Front in 2016, focusing on electromagnetic wave materials with core-shell structure; the field's continuation in 2021 saw much attention paid to the composite with rod, flower, and layered shape. Lead free ceramics focused on perovskite ferroelectric for energy storage ever selected as Research Front last year, and in 2021 the research on relaxor ferroelectric ceramics is featured. Meanwhile, in the field of biochemistry, chemodynamic therapy and photoelectrochemical biosensors are selected as Top 10 Research Fronts for the first time.

Table 29: Top10 Research Fronts in chemistry and materials science

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Electromagnetic wave absorber	41	3079	2019
2	Sulfonylation reactions through the insertion of sulfur dioxide	35	2450	2018.6
3	Non-covalent interactions (halogen, chalcogen, pnictogen and tetrel bond)	31	4608	2018.5
4	Lead-free energy storage ceramics	41	4005	2018.5
5	N-Heterocyclic carbene catalysis	24	2598	2018.5
6	Hydrogel-based strain sensor	29	3774	2018.3
7	Perovskite ferroelectrics	22	2543	2018.3
8	Chemodynamic therapy	12	1959	2018.3
9	Photoelectrochemical biosensors	48	7832	2018.1
10	Asymmetric construction of axially chiral compounds	30	5988	2018

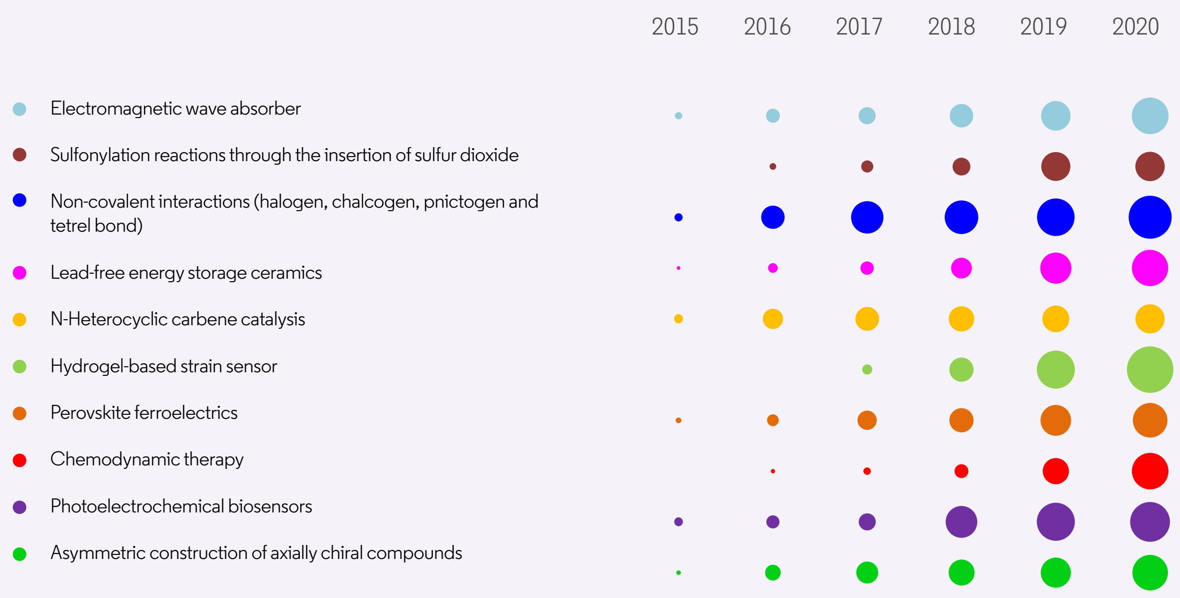


Figure 14: Citing papers of the Top 10 Research Fronts in chemistry and materials science

1.2 KEY HOT RESEARCH FRONT – "Non-covalent interactions (halogen, chalcogen, etc.)"

Halogen bond, chalcogen bond, sulfur bond and other secondary bonds are weak supramolecular interactions, which are usually regarded as competitive interactions of hydrogen bond interactions. As a new paradigm in the field of non-covalent bond research, secondary bonds such as halogen bond and sulfur bond have triggered a new direction of intermolecular interaction. The compounds based on the use of this novel intermolecular interaction exhibit unique fluorescence, phosphorescence, magnetism, liquid crystal, and other characteristics. With the potential for broad application in the fields of optical waveguides, sensing, catalysis and drug discovery, these compounds have become hot research directions in the field of chemistry and materials science.

Research on halogen bond began in 1814, when Jean Jacques Colin prepared the first blue black halogen bond complex ($I_2 \cdots NH_3$). Research on sulfur bond began in the 1960s. Nowadays, halogen bonds have been widely studied in silicon wafers and solid-state experiments. The applications in solution mainly focus on anion recognition and sensing, anion template self-assembly, and organic catalysis. In the solid phase, chalcogen bonding has been used for the construction of nano-sized structures and the self-assembly of sophisticated self-complementary arrays; in solution, until very recently, applications mostly focused on intramolecular interactions which stabilized the conformation of intermediates or reagents, which were mostly employed in anion recognition and transport as well as in organic synthesis and organocatalysis. Although these secondary non-covalent bonds have been studied for decades, research and understanding of the fundamental geometrical and physical parameters ruling these interactions is still at its infancy. The understanding of their role in supramolecular construction and their applications in synthetic transformation, crystal engineering, catalysis and synthetic or construct functional materials still needs to be deepened. This Research Front reflects some research progress in the theory and application of these secondary bonds in anion recognition, crystal engineering, non-covalent organic synthesis and organic catalysis.

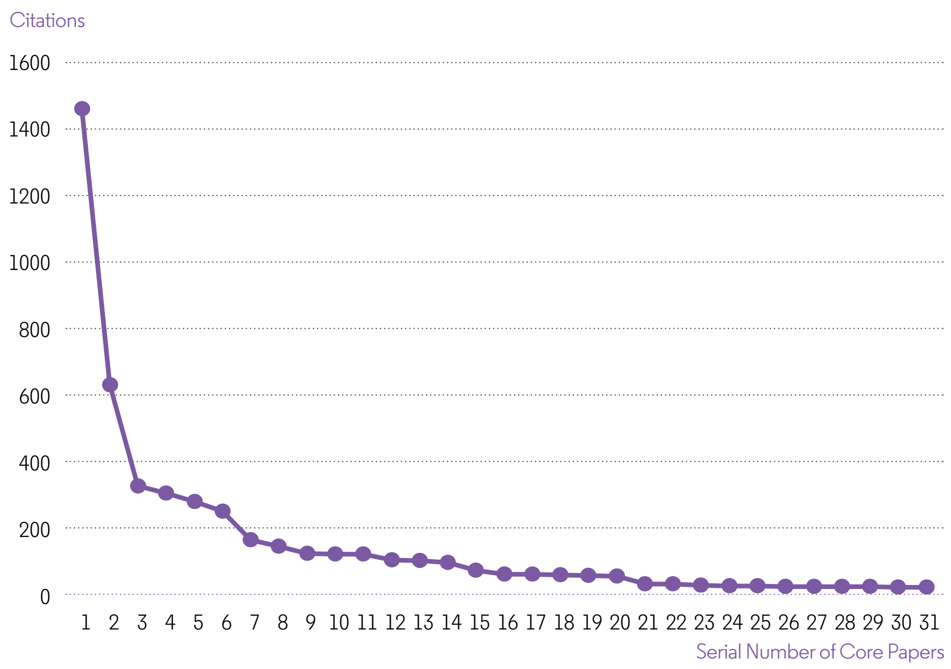


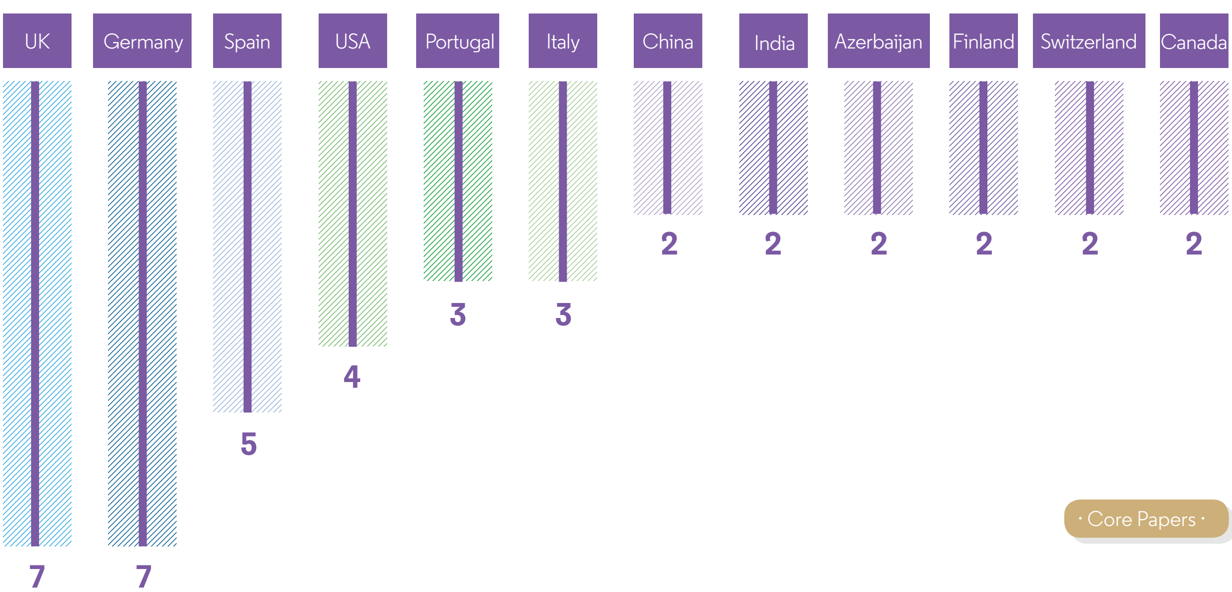
Figure15: Citation frequency distribution curve of core papers in Research Front "Non-covalent interactions (halogen, chalcogen, etc.)"

In this Research Front, the two review articles on halogen bonds and their applications in supramolecular chemistry authored by Pierangelo Metrongolo, Polytechnic University of Milan, Italy, have thus far garnered 1,462 and 625 citations, respectively (Figure 15). As shown in Table 30, the UK, Germany, Spain have published the highest numbers of core papers for this front; China has participated in producing two of the front's foundational papers. Among the top institutions, two are based in the UK, including the University Oxford and the University Edinburgh, with two each in Spain and Switzerland.

Table 30: Top countries and institutions producing core papers in the Research Front "Non-covalent interactions (halogen, chalcogen, etc.)"

Country Ranking	Country	Core Papers	Proportion
1	UK	7	22.6%
1	Germany	7	22.6%
3	Spain	5	16.1%
4	USA	4	12.9%
5	Portugal	3	9.7%
5	Italy	3	9.7%
7	China	2	6.5%
7	India	2	6.5%
7	Azerbaijan	2	6.5%
7	Finland	2	6.5%
7	Switzerland	2	6.5%
7	Canada	2	6.5%

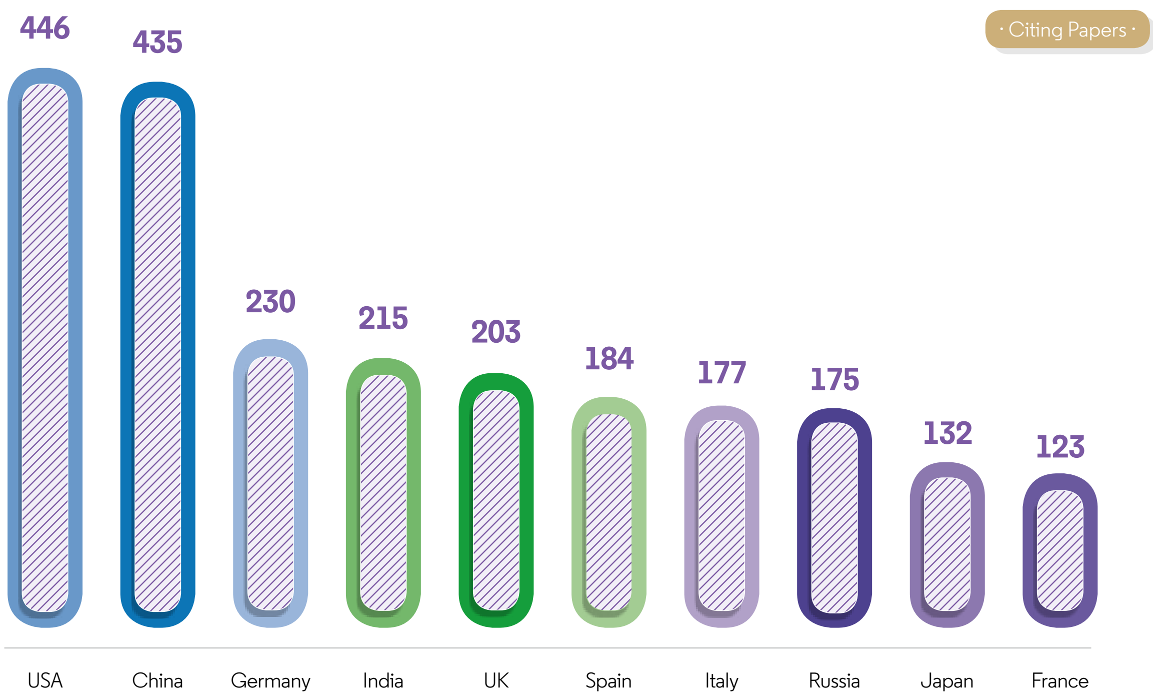
Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	University of the Balearic Islands	Spain	5	16.1%
1	Ruhr University of Bochum	Germany	5	16.1%
3	Polytechnic University of Milan	Italy	3	9.7%
3	University of Oxford	UK	3	9.7%
5	Syngenta	Switzerland	2	6.5%
5	Spanish National Research Council (CSIC)	Spain	2	6.5%
5	University of Lisbon	Portugal	2	6.5%
5	University of Geneva	Switzerland	2	6.5%
5	University of Edinburgh	UK	2	6.5%
5	Utah State University	USA	2	6.5%
5	Baku State University	Azerbaijan	2	6.5%



Analysis of the citing papers (Table 31) indicates that the USA and China are the most active countries, with 446 and 435 citing papers, respectively. The citing papers from the two countries far exceed those from the other listed nations, with Germany, India and the UK following. Among the top institutions, three are in Russia. The Russian Academy of Sciences, St. Petersburg State University and South Ural State University rank, respectively 1st, 3rd and 9th. Meanwhile, the French National Centre for Scientific Research (CNRS) is tied for 1st place and the Chinese Academy of Sciences, having published 82 citing papers, ranks 4th.

Table 31: Top countries and institutions producing citing papers in the Research Front "Non-covalent interactions (halogen, chalcogen, etc.)"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	446	17.4%	1	French National Center for Scientific Research (CNRS)	France	97	3.8%
2	China	435	17.0%	1	Russian Academy of Sciences	Russia	97	3.8%
3	Germany	230	9.0%	3	St Petersburg State University	Russia	86	3.4%
4	India	215	8.4%	4	Chinese Academy of Sciences	China	82	3.2%
5	UK	203	7.9%	5	University of the Balearic Islands	Spain	70	2.7%
6	Spain	184	7.2%	6	Polytechnic University of Milan	Italy	50	1.9%
7	Italy	177	6.9%	7	Spanish National Research Council (CSIC)	Spain	48	1.9%
8	Russia	175	6.8%	8	Indian Institute of Technology (IIT)	India	44	1.7%
9	Japan	132	5.1%	9	South Ural State University	Russia	42	1.6%
10	France	123	4.8%	10	Italian National Research Council (CNR)	Italy	41	1.6%



1.3 KEY HOT RESARCH FRONT – “Chemodynamic therapy”

Chemodynamic therapy (CDT) is a new type of tumor-treatment strategy harnessing an iron-based Fenton reaction. It was first proposed by a research team at Shanghai Institute of Ceramics, Chinese Academy of Science, in 2016. Their strategy is dependent on an in situ Fenton reaction (Fenton-like) that generates oxidative •OH in situ from hydrogen peroxide (H_2O_2) under the catalysis of ferrous ion (Fe^{2+}) or other Fenton-like ions. Due to H_2O_2 overexpression, low catalytic activity, and mild acidity of the tumor microenvironment, this approach was observed to result in irreversible destruction of mitochondria from different tumor cells, DNA strand breakage and the oxidation of protein and membrane of tumor cells, with little harm to normal tissues, which significantly enhances the specificity of tumor treatment. In order to further optimize the therapeutic effect of CDT, extensive research has been carried out from different directions. These include nano-catalysts (iron/non-iron, homogeneous/heterogeneous, organic/inorganic, etc.), further concentration on the tumor microenvironment (reducing intratumoral pH, increasing reaction substrate H_2O_2, reducing antioxidant glutathione, etc.), and the assistance of exogenous energy fields (light, heat, ultrasound, electricity and magnetic fields). Not only can this emerging treatment directly kill tumor cells, but it also organically combines with other tumor treatment strategies (such as chemotherapy) to jointly improve antitumor efficacy.

In this Research Front, the original article “Synthesis of iron nanometallic glasses and their application in cancer therapy by alocalized Fenton reaction”, published by the Shanghai Institute of Ceramics, Chinese Academy of Science in 2016, and the review article “Chemodynamic therapy: tumour microenvironment mediated Fenton and Fenton like reactions” published by East China Normal University and the Shanghai Institute of Ceramics, Chinese Academy of Science, received the most citations. Another paper, “Simultaneous Fenton-like ion delivery and glutathione depletion by MnO2-based nanoagent to enhance chemodynamic therapy,” published by Fuzhou University, also received a high number of citations (Figure 16).

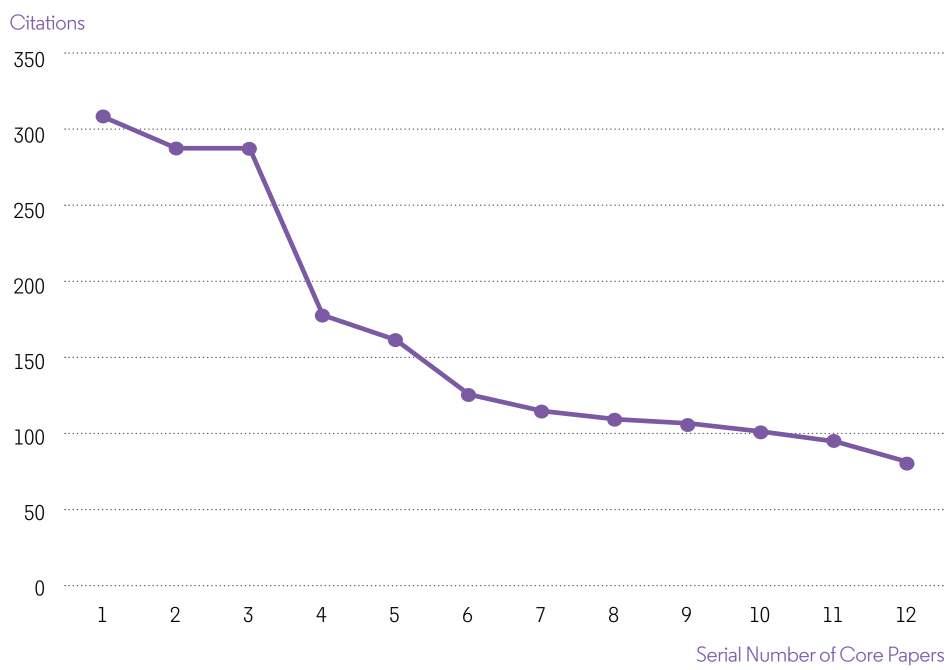


Figure16: Citation frequency distribution curve of core papers in Research Front “Chemodynamic therapy”

In this Research Front, China is the most active and can claim the most outputs. (Table 32). Researchers based in the USA and Australia also contributed to several core papers. Among the top institutions producing core papers, Chinese institutions account for the vast majority, among which the Chinese Academy of Sciences has the largest proportion of core papers. Farther down in the listing, the National Institutes of Health in the USA and the University of Melbourne in Australia also contribute to the foundational literature of this Research Front.

Table 32: Top countries and institutions producing core papers in the Research Front "Chemodynamic therapy"

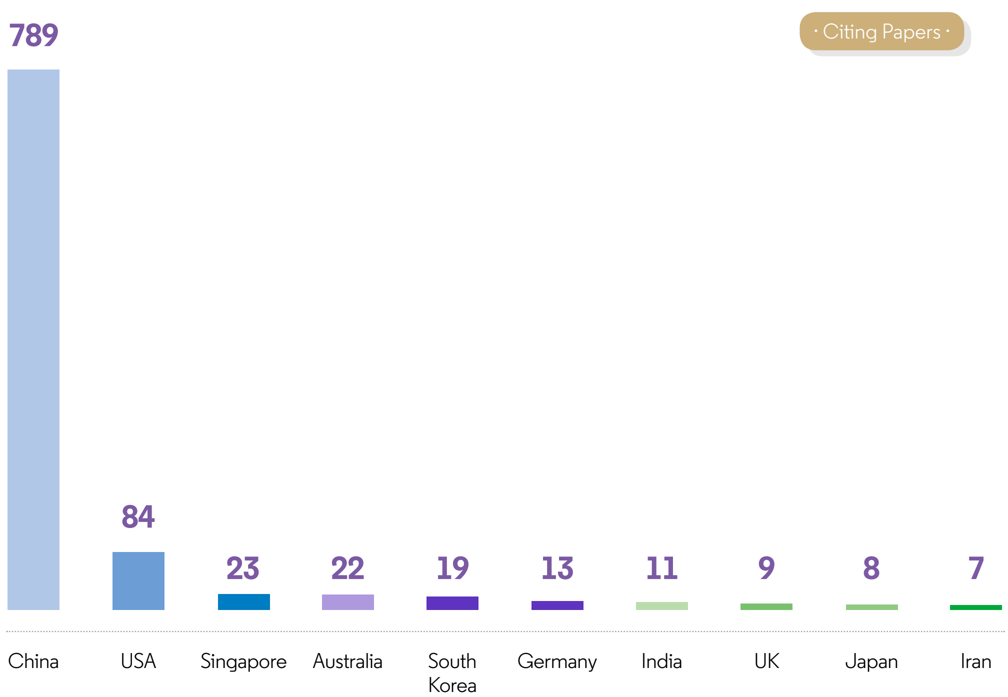
Country Ranking	Country	Citing Papers	Proportion
1	China	11	91.7%
2	USA	2	16.7%
3	Australia	1	8.3%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Chinese Academy of Sciences	China	5	41.7%
2	East China Normal University	China	3	25.0%
3	Fuzhou University	China	2	16.7%
3	Shenzhen University	China	2	16.7%
3	Fudan University	China	2	16.7%
3	National Institutes of Health (NIH)	USA	2	16.7%
3	Jilin University	China	2	16.7%
3	University of Science & Technology - China	China	2	16.7%
9	University of Science & Technology - Beijing	China	1	8.3%
9	Harbin Medical University	China	1	8.3%
9	Shandong University	China	1	8.3%
9	University of Melbourne	Australia	1	8.3%
9	Tongji University	China	1	8.3%
9	University of Jinan	China	1	8.3%
9	Wuhan University	China	1	8.3%

In terms of producing papers that cite the core, this Research Front has attracted a large number of citations from China in the form of 789 citing papers, accounting for 81.8% of the total, followed by the USA, Singapore and Australia. The Top 10 institutions include nine Chinese institutions and one based in the USA: the U.S. National Institutes of Health. The Chinese Academy of Sciences has the largest number of citing papers – 231 – representing about one quarter of the total.

Table 33: Top countries and institutions producing citing papers in the Research Front "Chemodynamic therapy"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	789	81.8%	1	Chinese Academy of Sciences	China	231	23.9%
2	USA	84	8.7%	2	University of Science & Technology - China	China	64	6.6%
3	Singapore	23	2.4%	3	Fudan University	China	40	4.1%
4	Australia	22	2.3%	3	Tongji University	China	40	4.1%
5	South Korea	19	2.0%	5	Shanghai Jiao Tong University	China	38	3.9%
6	Germany	13	1.3%	6	Jilin University	China	34	3.5%
7	India	11	1.1%	7	Shenzhen University	China	33	3.4%
8	UK	9	0.9%	7	Suzhou University	China	33	3.4%
9	Japan	8	0.8%	7	Zhejiang University	China	33	3.4%
10	Iran	7	0.7%	10	U.S. National Institutes of Health (NIH)	USA	32	3.3%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEWOF 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 34). One focuses on the application of chemical principles in virus detection – namely, rapid detection of the COVID-19 causative virus using a chemical sensor. The second emerging front concerns the research and development of a new type of plastics: specifically, block copolymers known as vitrimers. And the third emerging specialty centers on the development of seawater desalination materials "Ultrathin polyamide nanofilms for desalination". All three of these topics are selected here as emerging Research Fronts for the first time.

Table 34: Emerging Research Fronts in chemistry and materials science

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Rapid detection of COVID-19 causative virus using chemical sensor	5	296	2019.8
2	Block copolymer: vitrimers	6	245	2019.7
3	Ultrathin polyamide nanofilms for desalination	14	1881	2018.1

2.2 KEY EMERGING RESEARCH FRONT – "Rapid detection of COVID-19 causative virus using chemical sensor"

The COVID-19 epidemic, caused by the virus SARS-CoV-2, is continuing to spread around the world. The SARS-CoV-2 sensor is a powerful tool to effectively assess clinical progress and to provide awareness of severity or critical trends of infection. The COVID-19 pandemic has demanded the development of frequent, low-cost, effective and rapid means for mass detection. This impetus has resulted in the emergence of new and sensitive sensors. The novel chemical SARS-CoV-2 sensor is simple, inexpensive, sensitive, and accurate, and provides many potential detection schemes for the prevention and control of COVID-19.

In this emerging Research Front, ETH Zurich and Shandong University of Traditional Chinese Medicine jointly prepared a two-dimensional gold nano island (AuNIs) dual-functional plasmonic biosensor, which combined the plasmonic photothermal (PPT) effect and localized surface plasmon resonance (LSPR) sensing transduction, resulting in a precise detection of the specific target in a multigene mixture. The detection limit is as low as 0.22 μm. The Korea Basic Science Institute (KBSI) has produced a sensor by coating graphene sheets of the field-effect transistor (FET) with a specific antibody against SARS-CoV-2 spike protein. The sensor is a highly sensitive immunological diagnostic method for COVID-19 that requires no sample pretreatment or labeling. Based on the colorimetric analysis method of gold nanoparticles (AuNPs), the University of Maryland reported the development of a colorimetric assay based on AuNP), which can diagnose positive COVID-19 cases within 10 minutes from the isolated RNA samples, providing a selective and visual "naked eye" detection method for SARS-CoV-2, without the need for any sophisticated instrumental techniques.

Nowadays, the status of the pandemic remains grim in many parts of the world. The preparation of more sensitive and convenient virus sensors based on chemical technology will remain a long-term task for chemical and biomedical researchers.

2021
RESEARCH FRONTS

PHYSICS

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN PHYSICS

The Top 10 Research Fronts in physics mainly focus on the subfields of condensed matter physics, high-energy physics, theoretical physics and optics. Six Research Fronts pertain to condensed matter physics, and twisted bilayer graphenes, topological states of non-Hermitian systems, high-order topological insulators and superconductors, and two-dimensional van der Waals magnetic materials remain hot topics. Antiferromagnetic spintronics and high-temperature superconductivity in hydrogen-rich compounds under high pressure have become new hot fronts. In high-energy physics, flavor symmetries and lepton masses have newly emerged. In theoretical physics, black hole information paradox and entanglement entropy, and quantum many-body scars and many-body dynamics have attracted much attention. In optics, the hot Research Front focuses on solar-blind ultraviolet photodetector based on Ga_2O_3.

Table 35: Top10 Research Fronts in physics

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Twisted bilayer graphenes	42	6121	2018.8
2	Topological states of non-Hermitian systems	45	4217	2018.7
3	Black hole information paradox and entanglement entropy	28	1792	2018.7
4	Quantum many-body scars and many-body dynamics	36	3093	2018.6
5	Flavor symmetries and lepton masses	27	2376	2018.6
6	High-order topological insulators and superconductors	37	5048	2018.2
7	Antiferromagnetic spintronics	10	2174	2018.1
8	Solar-blind ultraviolet photodetector based on Ga_2O_3	17	1781	2018.1
9	Two-dimensional van der Waals magnets	37	8745	2017.7
10	High-temperature superconductivity in hydrogen-rich compounds under high pressure	27	3676	2017.5

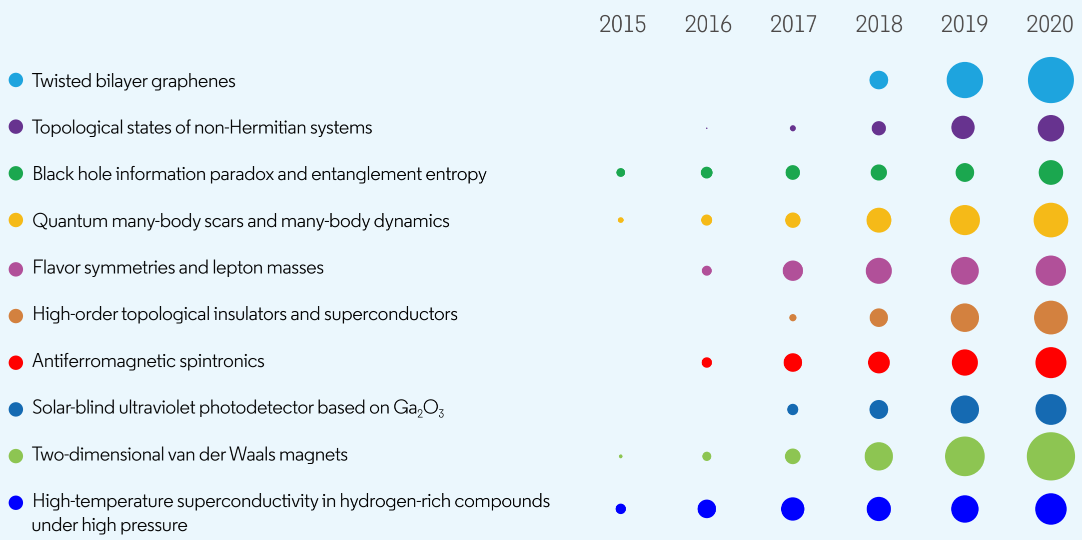


Figure 17: Citing papers for the Top 10 Research Fronts in physics

1.2 KEY HOT RESEARCH FRONT – "High-temperature superconductivity in hydrogen-rich compounds under high pressure"

A superconductor is a substance that conducts electricity with diamagnetism and zero resistance at a certain critical temperature. It can dramatically improve the efficiency of power generation and transmission and has great potential in many fields such as medical treatment, energy, information, transportation, and basic scientific research. Room-temperature superconductivity is the ultimate goal of scientists all over the world. Researchers have made great efforts to find superconductors with higher superconducting critical temperatures. Before the discovery of superconductivity in hydrogen-rich compounds, the highest superconducting critical temperature achieved was in a copper-oxide system: 133 K (kelvin) at ambient pressure and 164 K at high pressures.

Hydrogen-rich compounds were considered promising candidates for room-temperature superconductors, and the breakthrough occurred in 2015, when a high superconducting critical temperature of 203 K at 150 GPa in samples formed by compression of H_2S was reported by a team led by researchers at the Max Planck Institute of Chemistry in Germany. The discovery attracted great attention from scientists. In 2019, a team from George Washington University reported a high superconducting critical temperature of 260K at 180–200 GPa in lanthanum superhydride. Subsequently, many other hydrogen-rich compound superconductors have been reported. However, hydrogen-rich compound superconductors can only exist under very high pressure, which hinders their applications. Room-temperature superconductivity still awaits further breakthroughs.

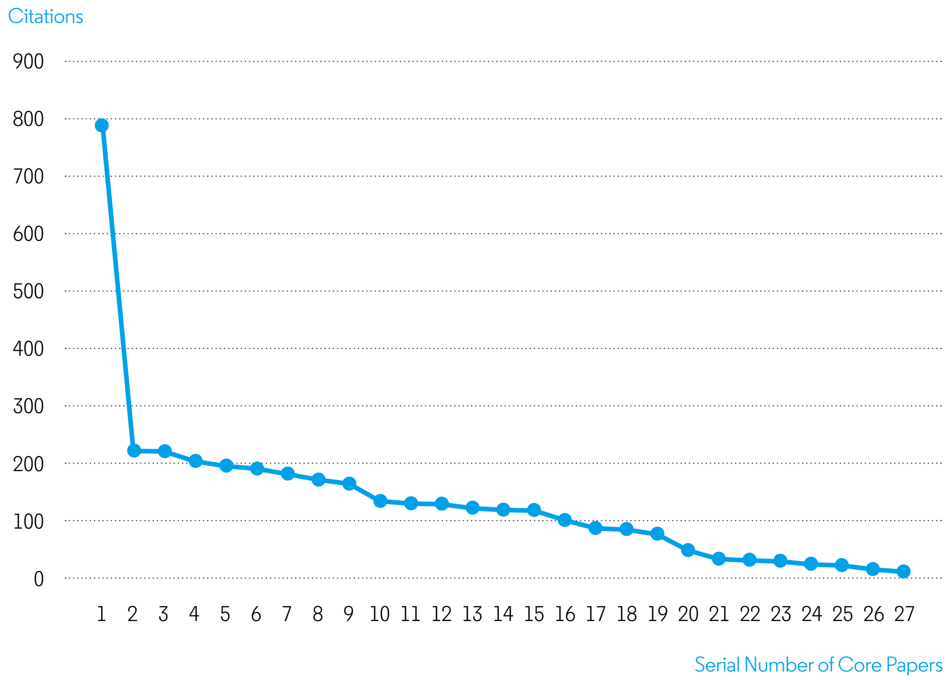


Figure 18: Citation frequency distribution curve of core papers in Research Front "High-temperature superconductivity in hydrogen-rich compounds under high pressure"

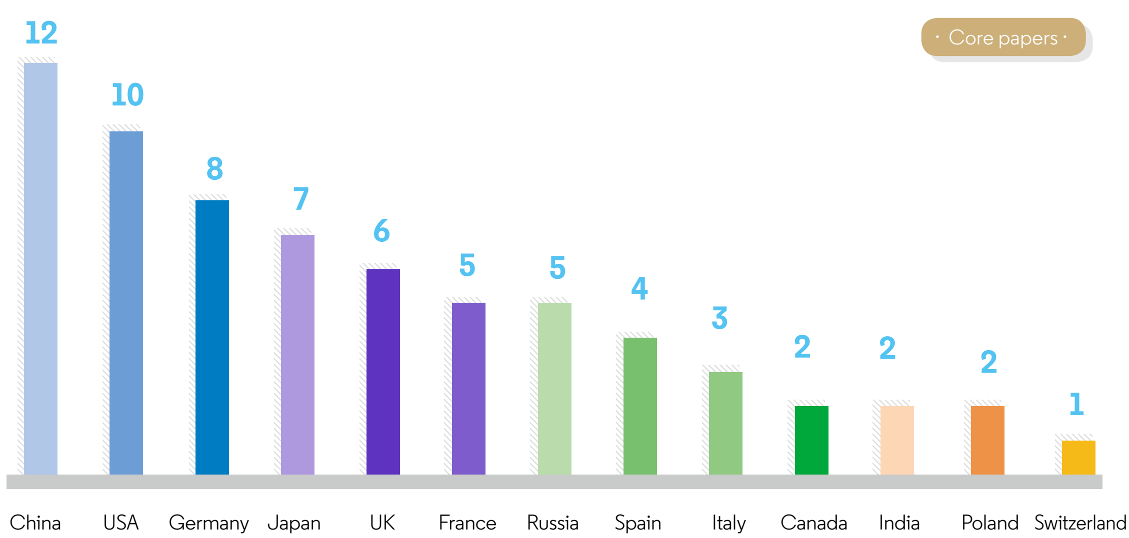
Regarding the citation frequency of individual core papers (Figure 18), the paper published by the Max Planck Institute of Chemistry records the highest citation count at this writing: 785, a total far exceeding others in the core. The theoretical study of hydrogen-rich compounds has also attracted a high rate of citations. Publications on the predicted superconductivity of hydrides published by Donostia International Physics Center (DIPC) in Spain, George Washington University in the USA, and Jilin University in China are all highly cited.

China and the USA are the most active countries in this front. Authors based in the two nations participated in 12 and 10 core papers, respectively (Table 36), accounting for 44.4% and 37.0% of the total. Germany, Japan, and the UK also demonstrate excellent performance. Jilin University, the Max Planck Society and Cambridge University contributed the highest numbers of core papers as individual organizations. On the list of top institutions, China and the USA each are host to three, while Russia and France contain two each, and Germany, the UK, Japan, Spain and Italy each claim one.

Table 36: Top countries and institutions producing core papers in the Research Front "High-temperature superconductivity in hydrogen-rich compounds under high pressure"

Country Ranking	Country	Core Papers	Proportion
1	China	12	44.4%
2	USA	10	37.0%
3	Germany	8	29.6%
4	Japan	7	25.9%
5	UK	6	22.2%
6	France	5	18.5%
6	Russia	5	18.5%
8	Spain	4	14.8%
9	Italy	3	11.1%
10	Canada	2	7.4%
10	India	2	7.4%
10	Poland	2	7.4%
13	Switzerland	1	3.7%

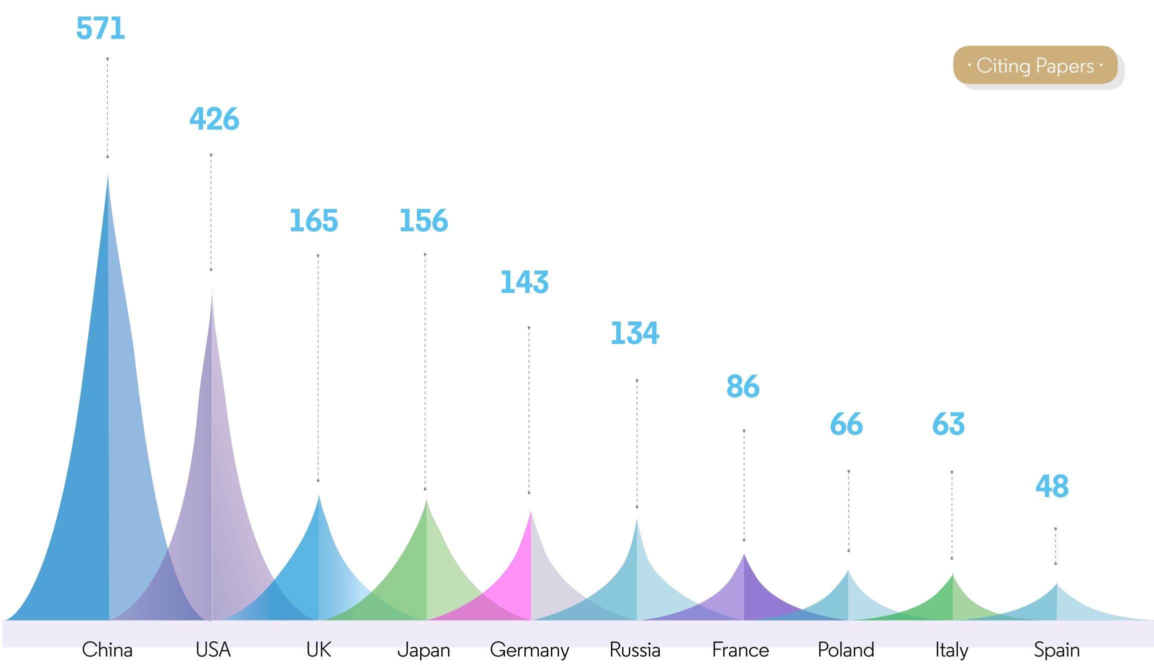
Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Jilin University	China	9	33.3%
2	Max Planck Society	Germany	7	25.9%
3	University of Cambridge	UK	5	18.5%
4	Carnegie Institution for Science	USA	4	14.8%
4	NorthwesternPolytechnical University	China	4	14.8%
4	Tohoku University	Japan	4	14.8%
4	Skolkovo Institute of Science and Technology	Russia	4	14.8%
8	University of theBasqueCountry	Spain	3	11.1%
8	Sapienza University Rome	Italy	3	11.1%
8	Sorbonne University	France	3	11.1%
8	Moscow Institute of Physics and Technology	Russia	3	11.1%
8	George Washington University	USA	3	11.1%
8	United States Department of Energy (DOE)	USA	3	11.1%
8	National Center for Scientific Research of France (CNRS)	France	3	11.1%
8	Jiangsu Normal University	China	3	11.1%



In terms of the citing papers (Table 37), China and the USA are again the most active countries, followed by the UK, Japan and Germany. Among the top institutions, Jilin University and the U.S. Department of Energy published the most citing papers, followed by the Chinese Academy of Sciences, the Russian Academy of Sciences, and Carnegie Institution for Science.

Table 37: Top countries and institutions producing citing papers in the Research Front "High-temperature superconductivity in hydrogen-rich compounds under high pressure"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	571	38.6%	1	Jilin University	China	166	11.2%
2	USA	426	28.8%	2	United States Department of Energy (DOE)	USA	126	8.5%
3	UK	165	11.1%	3	Chinese Academy of Sciences	China	120	8.1%
4	Japan	156	10.5%	4	Russian Academy of Sciences	Russia	74	5.0%
5	Germany	143	9.7%	5	Carnegie Institution for Science	USA	70	4.7%
6	Russia	134	9.0%	6	Center for High Pressure Science & Technology Advanced Research	China	58	3.9%
7	France	86	5.8%	7	Tohoku University	Japan	55	3.7%
8	Poland	66	4.5%	8	National Center for Scientific Research of France (CNRS)	France	54	3.6%
9	Italy	63	4.3%	9	Max Planck Society	Germany	53	3.6%
10	Spain	48	3.2%	10	University of Edinburgh	UK	52	3.5%



1.3 KEY HOT RESARCH FRONT– "Antiferromagnetic spintronics"

Spintronics is an emerging technology that exploits the spin of the electron. This approach offers opportunities for a new generation of devices combining standard microelectronics with new functions such as high-density, low-power information storage and terahertz sources. At present, the major source for spintronic devices lies in ferromagnetic materials. In recent years, the advantages of antiferromagnetic material, such as stability, low energy consumption, and high response frequency, have provided new ideas for the research and development of spintronic devices. Antiferromagnetic spintronics has become a hot topic. A key challenge for this research has been to realize the necessary write and read functions due to the high stability of antiferromagnetic materials. In 2016, researchers at the University of Nottingham in the UK and their collaborators reported a current-induced room-temperature electrical switching of the antiferromagnetic moment in CuMnAs, demonstrating the possibility of electrical detection and manipulation of antiferromagnetic materials. That finding has triggered an upsurge in the study of antiferromagnetic spintronics.

As for the citation frequency of individual core papers (Figure 19), a review of antiferromagnetic spintronics published by researchers at the Czech Academy of Sciences and their collaborators in 2016 has garnered the highest citation total, currently nearing 700. A paper published by researchers at the University of Nottingham and their coauthors has earned a citation tally of 521 at this writing, while the review on antiferromagnetic spintronics by authors at the National Center for Scientific Research of France (CNRS) in 2018 has been cited 485 times. In addition, independent research on the manipulation of antiferromagnetic materials by current induction published by Johannes Gutenberg University of Mainz in Germany and Tsinghua University in China, and a review by the Max Planck Institute for Chemical Physics of Solids, have been also widely cited.

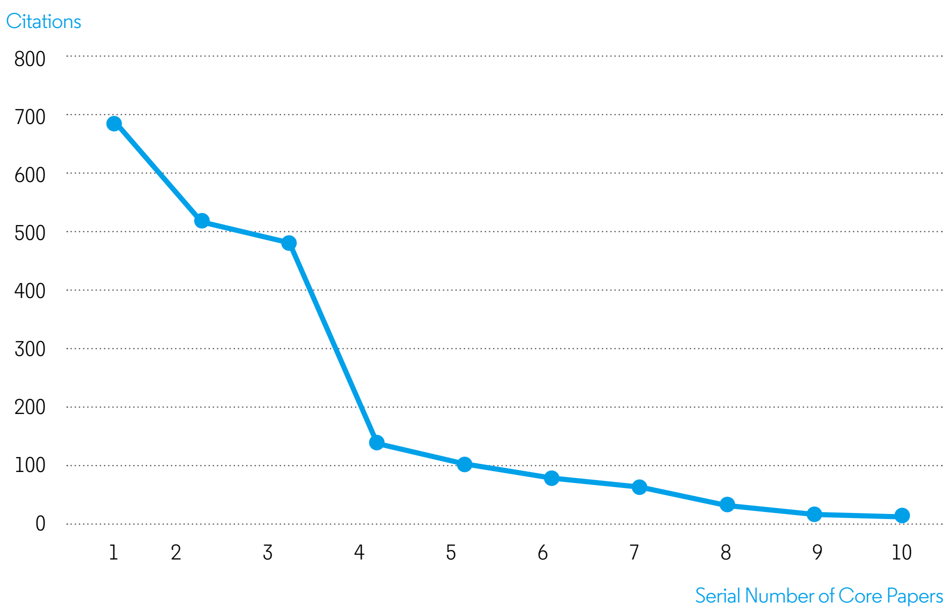
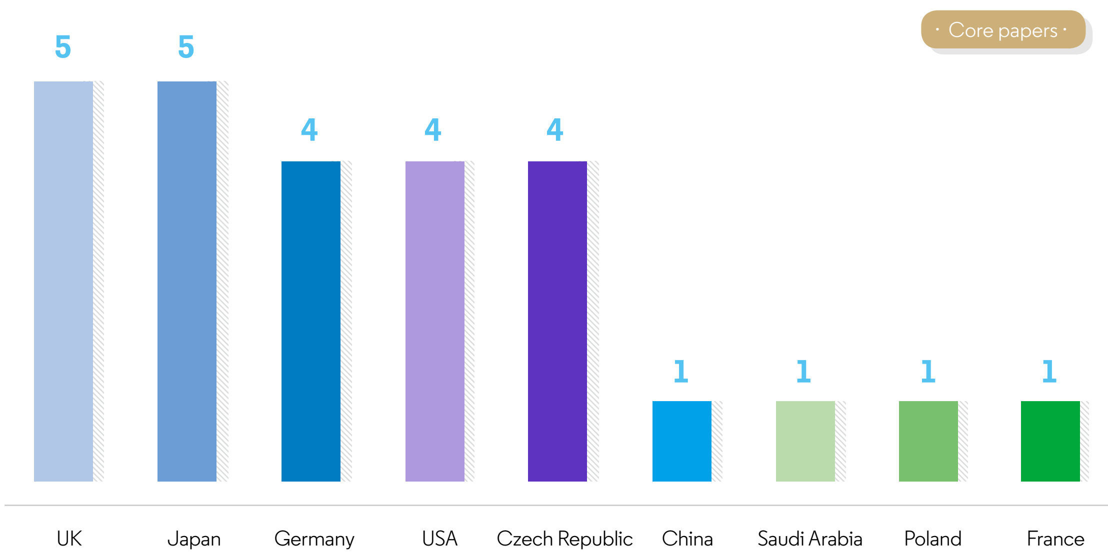


Figure 19: Citation frequency distribution curve of core papers in Research Front "Antiferromagnetic spintronics"

The UK and Japan are the most active countries in this front, followed by Germany, the USA and the Czech Republic (Table 38). The University of Nottingham, the Czech Academy of Sciences, and Tohoku University in Japan contribute the highest numbers of core papers as individual organizations. Among the top institutions, three are in Japan, while the UK, the Czech Republic and the USA are each host to two, and Germany to one.

Table 38: Top countries and institutions producing core papers in the Research Front "Antiferromagnetic spintronics"

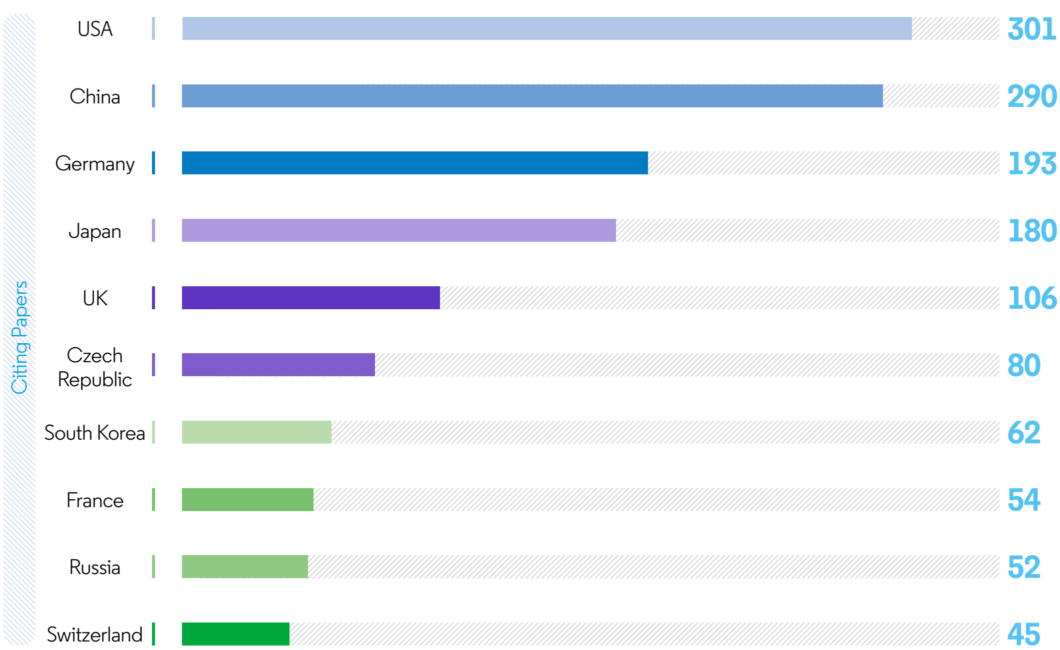
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	UK	5	50.0%	1	University of Nottingham	UK	4	40.0%
1	Japan	5	50.0%	1	Czech Academy of Sciences	Czech Republic	4	40.0%
3	Germany	4	40.0%	3	Tohoku University	Japan	3	30.0%
3	USA	4	40.0%	4	Johannes Gutenberg University of Mainz	Germany	2	20.0%
3	Czech Republic	4	40.0%	4	University of Tokyo	Japan	2	20.0%
6	China	1	10.0%	4	Charles University Prague	Czech Republic	2	20.0%
6	Saudi Arabia	1	10.0%	4	University of California Los Angeles	USA	2	20.0%
6	Poland	1	10.0%	4	Helmholtz Association	Germany	2	20.0%
6	France	1	10.0%	4	Diamond Light Source	UK	2	20.0%
				4	Kyoto University	Japan	2	20.0%



Analysis of the citing papers (Table 39) indicates that the USA and China are the most active countries, followed by Germany and Japan. Among the top institutions, the Chinese Academy of Sciences and the U.S. Department of Energy published the most citing papers, followed by the Czech Academy of Sciences, Johannes Gutenberg University of Mainz, and Tohoku University.

Table 39: Top countries and institutions producing citing papers in the Research Front "Antiferromagnetic spintronics"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	301	26.3%	1	Chinese Academy of Sciences	China	79	6.9%
2	China	290	25.3%	2	United States Department of Energy (DOE)	USA	75	6.6%
3	Germany	193	16.9%	3	Czech Academy of Sciences	Czech Republic	70	6.1%
4	Japan	180	15.7%	4	Johannes Gutenberg University of Mainz	Germany	66	5.8%
5	UK	106	9.3%	5	Tohoku University	Japan	64	5.6%
6	Czech Republic	80	7.0%	6	Helmholtz Association	Germany	55	4.8%
7	South Korea	62	5.4%	7	University of Tokyo	Japan	51	4.5%
8	France	54	4.7%	8	Max Planck Society	Germany	48	4.2%
9	Russia	52	4.5%	9	University of Nottingham	UK	45	3.9%
10	Switzerland	45	3.9%	10	National Center for Scientific Research of France (CNRS)	France	44	3.8%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN PHYSICS

One topic in physics is highlighted as an emerging Research Front: "Superconductivity of infinite layer nickelates".

Table 40: Emerging Research Front in physics

Rank	Emerging Research Front	Core papers	Citation	Mean Year of Core Papers
1	Superconductivity of infinite layer nickelates	19	603	2019.8

2.2 KEY EMERGING RESEARCH FRONT – "Superconductivity of infinite layer nickelates"

Exploring room temperature superconductors remains one of the most important pursuits in condensed matter physics. The first experimental proof that copper-oxide compounds could superconduct at a high temperature was published in 1986 and was later awarded the Nobel Prize in physics. Since then, investigating the mechanism of superconducting and exploring new superconducting materials has been a hot area. Researchers have reported significant progress at frequent intervals, including the high superconducting critical temperature record at ambient pressure made by the copper oxide compounds, and the discovery of the iron-based superconducting system. Copper ranks 29th in the periodic table of elements while nickel ranks 28th. The electronic structure of nickel oxides is similar to that of copper oxides. Therefore, the study of nickel oxides has been attracting wide attention.

In recent years, progress in the investigation of perovskite structure and layered nickel oxides has laid a solid foundation for research on superconductivity in nickel oxides. In 2019, researchers at Stanford University and their collaborators reported the first example of superconductivity in the $Nd_{0.8}Sr_{0.2}NiO_2$ system by converting the perovskite structured nickel oxide into an infinite-layer nickelate. The results suggested the possibility of nickel oxide superconductors and stimulated wider interest. In this front, a paper published by the Stanford researchers and their and collaborators achieved the highest citation total, currently at 150. Other papers focus on the superconducting phase diagram, electronic structure, superconductivity theory prediction, and the superconductivity model of infinite layer nickel oxides. Ongoing research on nickel oxide systems will bring new ideas for high temperature superconductors.

2021

RESEARCH FRONTS

ASTRONOMY AND ASTROPHYSICS

1. HOT RESEARCH FRONT

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

The Top 10 Research Fronts in 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, the search for exoplanets, and the formation of stars and planetary systems. In general, the detection of gravitational waves and related research has had a far-reaching impact in astronomy and astrophysics. Many Research Fronts pertain to this work, such as the study of the properties of black holes and neutron stars, as well as gravitational theory. In addition, the observation and theoretical research of mysterious fast radio bursts have been selected as hot Research Fronts again. The large-scale scientific platforms continue to exert a very high influence, such as the phased and centralized outputs of the Gaia and Kepler missions. Research topics involving black holes, dark matter, and the formation of stars and planetary systems are still notably active and prominent.

Table 41: Top 10 Research Fronts in astronomy and astrophysics

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Observational and theoretical research on fast radio bursts	49	5084	2018.4
2	Possible link between primordial black holes and dark matter	35	3608	2018.1
3	Measurements of neutron stars with GW170817	19	3553	2018
4	Properties of binary black hole mergers	42	4704	2017.7
5	Gaia building the most precise 3D map of the Milky Way	5	6702	2017.6
6	Multi-messenger observations of a binary neutron star merger GW170817	38	11719	2017.3
7	Scalar-tensor theories and implications from gravitational-wave detections	20	3737	2017.1
8	Exoplanets detection and characterization with Kepler	38	6212	2017
9	Protoplanetary disks and their evolution	32	4900	2016.9
10	Stars formation in the epoch of cosmic reionization	50	8354	2016.7

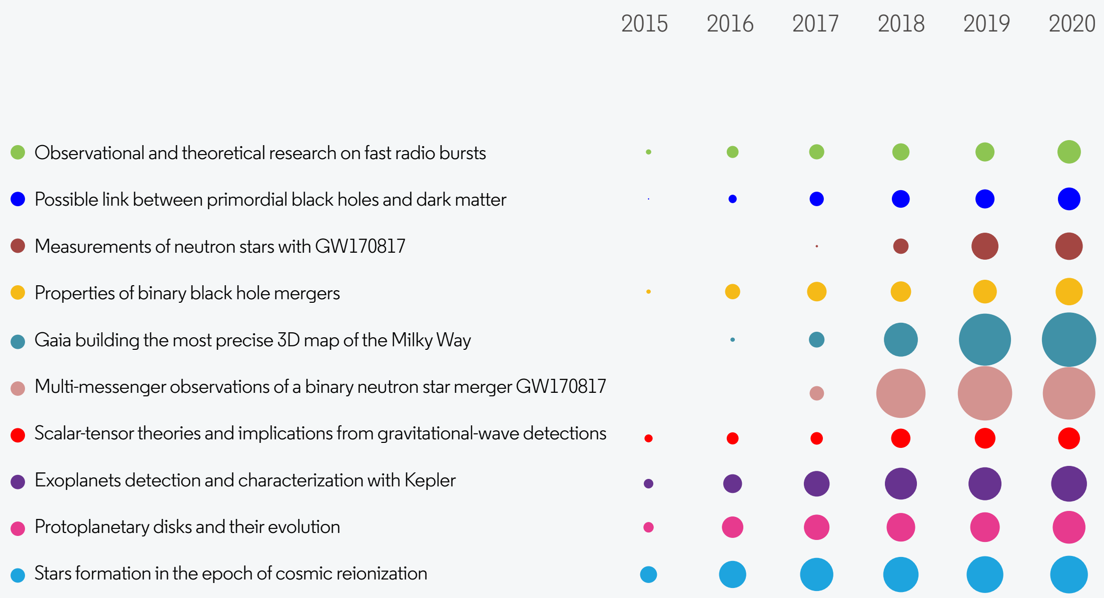


Figure 20: Citing papers for the Top 10 Research Fronts in astronomy and astrophysics

1.2 KEY HOT RESEARCH FRONT – "Possible link between primordial black holes and dark matter"

In the early, radiation-dominated universe, a highly overdense region would gravitationally collapse into a black hole, directly. Such a black hole, formed in the early universe, is called primordial black hole (PBH). Depending on the model, the range of possible PBH masses is enormous – ranging from 10^{-5} g (Planck mass) to more than millions of solar masses.

The dynamical properties of PBHs are close to those of cold dark matter and are consequently recognized as valid candidates to be the actual constituent of dark matter, which occupies about a quarter of the universe's total components.

Because PBHs were formed before the formation of atoms, there is no visible matter around them. Therefore, PBHs are completely dark and must be observed by the bending of light by the gravitational field of black holes – i.e., the gravitational lensing effect. Previous research on the gravitational lensing effect of black holes has provided initial limits on the mass range of PBHs and further constrained the black hole model of dark matter.

The Hot Research Front "Possible link between primordial black holes and dark matter" includes 35 core papers, discussing in depth the observation and property study of PBHs based on the gravitational lensing effect, the possibility of primordial black holes as a source of gravitational waves captured by detectors at the Laser Interferometer Gravitational-Wave Observatory (LIGO), and the possibility of PBHs constituting all dark matter. These findings are based on the analysis of observation data from LIGO and several other ground-based/ space-based astronomical telescopes, including the European Gravitational-Wave Explorer (Virgo). The most-cited core paper, contributed by a research team led by Nobel laureate Prof. Adam Riess at Johns Hopkins University, discusses the possibility that several gravitational wave signals captured by the LIGO/Virgo collaboration since 2015 might result from the merger of stellar-mass PBHs – a possibility that stimulated scientists' interest in exploring black holes as dark matter candidates. The second-most-cited paper restricts the mass range of PGHs based on a variety of astronomical observations, virtually ruling out the possibility of low-mass PBHs being dark matter. The third-most-cited core paper points out that the gravitational-wave event GW150914, observed by the LIGO detectors, can be explained by the coalescence of PBHs; the paper predicts that the proposed PBH scenario may be tested in the near future.

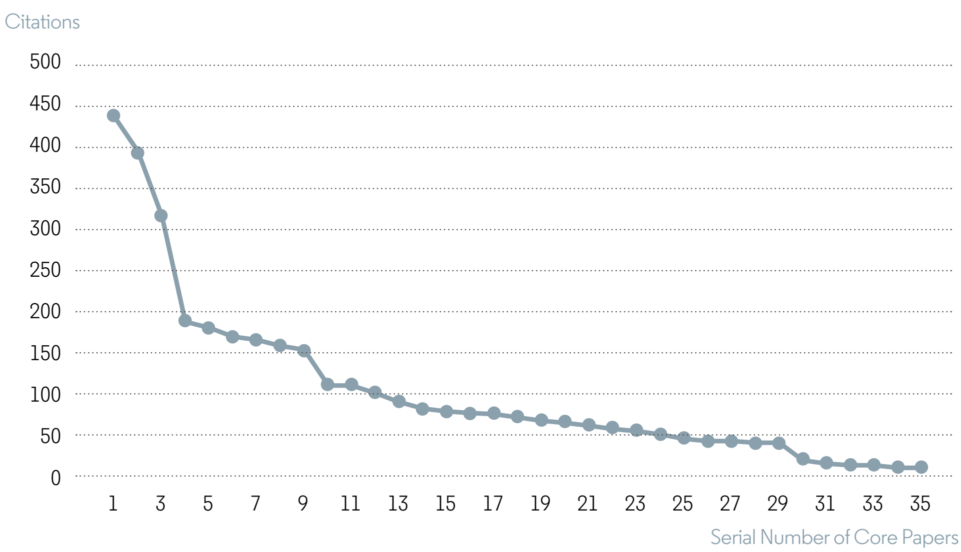


Figure 21: Citation frequency distribution curve of core papers in Research Front "Possible link between primordial black holes and dark matter"

The USA and Japan are the most active contributors to this research front, followed by European countries such as Spain and the UK, with China in 10th place. In terms of institutions, most are based in Japan and Spain, with the University of Tokyo and the Spanish National Research Council contributing eight core papers, respectively. The University of London (UK), CERN and CNRS (both France), the University of Autonoma Madrid (Spain), and Johns Hopkins University (USA) each contribute four core papers.

Table 42: Top countries and institutions producing core papers in the Research Front "Possible link between primordial black holes and dark matter"

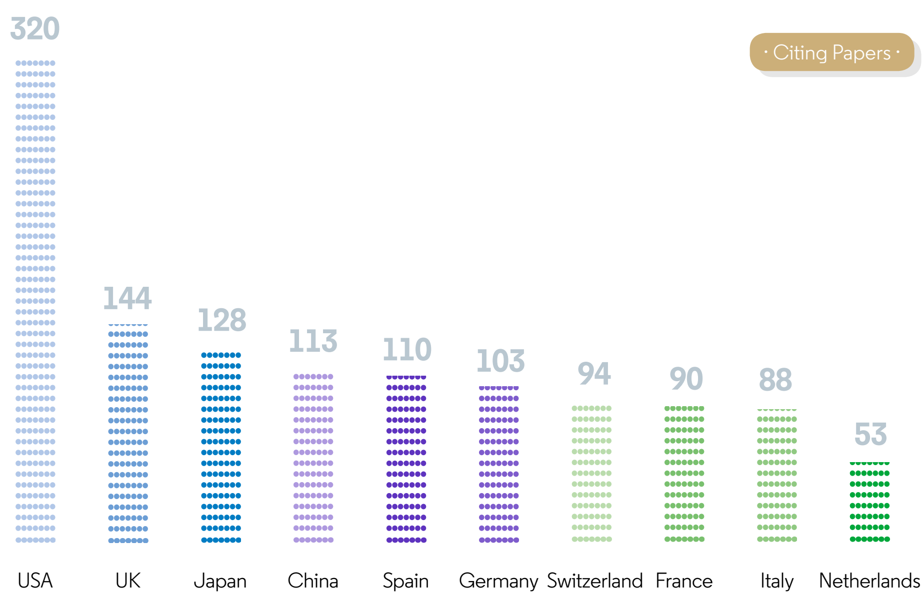
Country Ranking	Country	Core Papers	Proportion
1	USA	13	37.1%
2	Japan	10	28.6%
3	Spain	8	22.9%
3	UK	8	22.9%
5	Switzerland	7	20.0%
6	France	5	14.3%
7	Italy	3	8.6%
7	Germany	3	8.6%
7	Estonia	3	8.6%
10	China	2	5.7%
10	Sweden	2	5.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	University of Tokyo	Japan	8	22.9%
2	Spanish National Research Council (CSIC)	Spain	6	17.1%
3	University of London	UK	4	11.4%
3	European Organization for Nuclear Research (CERN)	Switzerland	4	11.4%
3	National Center for Scientific Research of France (CNRS)	France	4	11.4%
3	University of Autonoma Madrid	Spain	4	11.4%
3	Johns Hopkins University	USA	4	11.4%
8	Kyoto University	Japan	3	8.6%
8	NationalInstituteofChemicalPhysics and Biophysics	Estonia	3	8.6%

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 ranks 1st with 320 reports, while China ranks 4th. The top 10 institutions are situated in eight different countries, highlighting the distinctive feature of this Research Front in relying on internationally collaborative, large-scale scientific facilities.

Table 43: Top countries and institutions producing citing papers in the Research Front "Possible link between primordial black holes and dark matter"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	320	37.8%	1	University of Tokyo	Japan	93	11.0%
2	UK	144	17.0%	2	National Center for Scientific Research of France (CNRS)	France	85	10.0%
3	Japan	128	15.1%	3	National Institute of Nuclear Physics (INFN)	Italy	75	8.9%
4	China	113	13.3%	4	Spanish National Research Council (CSIC)	Spain	64	7.6%
5	Spain	110	13.0%	5	Chinese Academy of Sciences	China	53	6.3%
6	Germany	103	12.2%	6	European Organization for Nuclear Research (CERN)	Switzerland	47	5.5%
7	Switzerland	94	11.1%	7	Johns Hopkins University	USA	46	5.4%
8	France	90	10.6%	8	University of London	UK	42	5.0%
9	Italy	88	10.4%	9	National Institute for Astrophysics (INAF)	Italy	41	4.8%
10	Netherlands	53	6.3%	9	Sorbonne University	France	41	4.8%



1.3 KEY HOT RESEARCH FRONT – "Scalar-tensor theories and implications from gravitational-wave detections"

The current mainstream view holds that gravity is an observed effect of the curvature of space-time, and general relativity is the theory describing gravity. Since it was proposed by Einstein in 1915, general relativity has been tested by a large number of experiments, and no deviation from the prediction of general relativity has been observed within the error range. In 1916, Einstein put forward the possibility of the existence of gravitational waves, but the understanding of the theory's essence has gone through a long process. For various theoretical and experimental reasons, many different modified gravity theories have been proposed to explain some problems faced by general relativity, and scalar-tensor theory is one of them. In these modified gravity theories, there will also be gravitational waves, and their waveforms will be different from those predicted by general relativity. Therefore, by detecting gravitational wave signals, we can test general relativity and study the essence of gravity.

On August 17, 2017, LIGO and the Europe-based Virgo detector made the first detection of gravitational waves produced by colliding neutron stars. The aftermath of this merger was also seen by about 70 ground- and space-based observatories across the electromagnetic spectrum, marking a significant breakthrough for multi-messenger astronomy. The milestone was selected among *Science* magazine's "Top 10 Science Stories of 2017".

The detection of an electromagnetic counterpart (GRB 170817A) to the gravitational-wave signal (GW170817) from the merger of two neutron stars opens a completely new arena for testing theories of gravity. The close arrival time of the gravitational and electromagnetic waves limits the difference in speed of photons and gravitons to be less than about 1 part in 10^{15}. This result has important implications for gravity theory – in pointing to promising new theoretical approaches to the fundamental force as well in imposing stringent constraints on theoretical parameters of a number of existing theories. With the ongoing accumulation of observation-based astrophysical data, many gravitational hypotheses will ultimately be confirmed or refuted in the process of determining the true gravitational theory.

The hot Research Front "Scalar-tensor theories and implications from gravitational-wave detections" includes 20 core papers focusing on observational results and implications from the detection of gravitational waves (e.g., GW170817). According to the citation frequency distribution curve of these core papers, the five papers with the highest citation frequency constitute a distinct first echelon.

The core papers whose citation frequency ranks them at No. 1st, 3rd, 4th and 5th all focus on the implications of the neutron-star merger GW170817 for cosmological scalar-tensor theories. The nearly coincident observation of gravitational and electromagnetic waves signals places an exquisite boundary on the gravitational wave speed. The core paper with the most citations used this result to probe the nature of dark energy, showing that a large class of scalar-tensor theories and dark energy models are highly disfavored. Three alternatives and their combinations emerge as the only possible scalar-tensor dark energy models. The third-most-cited core paper showed that this measurement allows us to place stringent constraints on general scalar-tensor and vector-tensor theories. These constraints severely reduce the viable range of cosmological models that have been proposed as alternatives to general relativistic cosmology. The fourth-most-cited core paper discusses the consequences of this experimental result for models of dark energy and modified gravity characterized by a single scalar degree of freedom. The fifth highly cited core paper discusses the important implications for cosmological scalar-tensor gravity theories and presents the results of combining the new gravity wave results with galaxy cluster observations. In addition, the second-ranked core paper introduces a new class of scalar-tensor theories of gravity that extend Horndeski models.

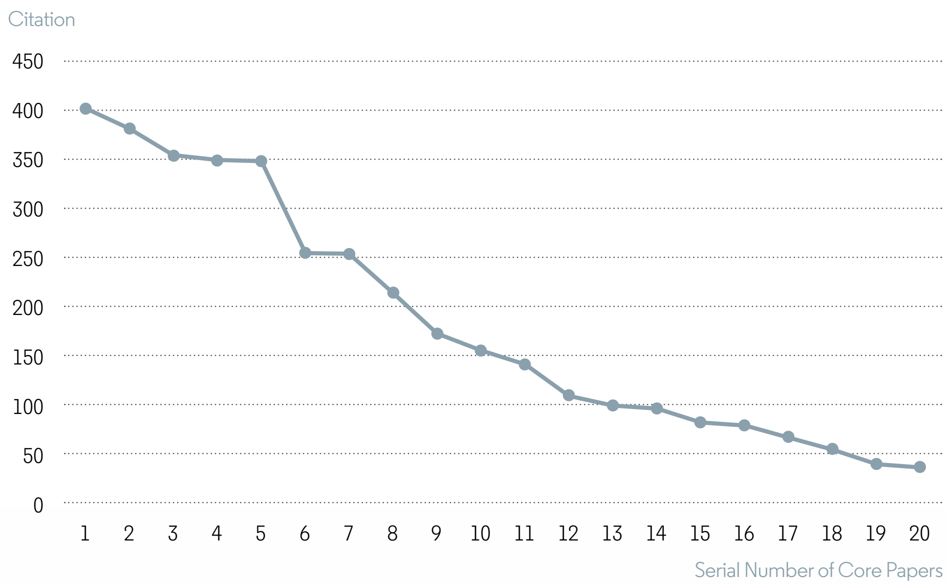
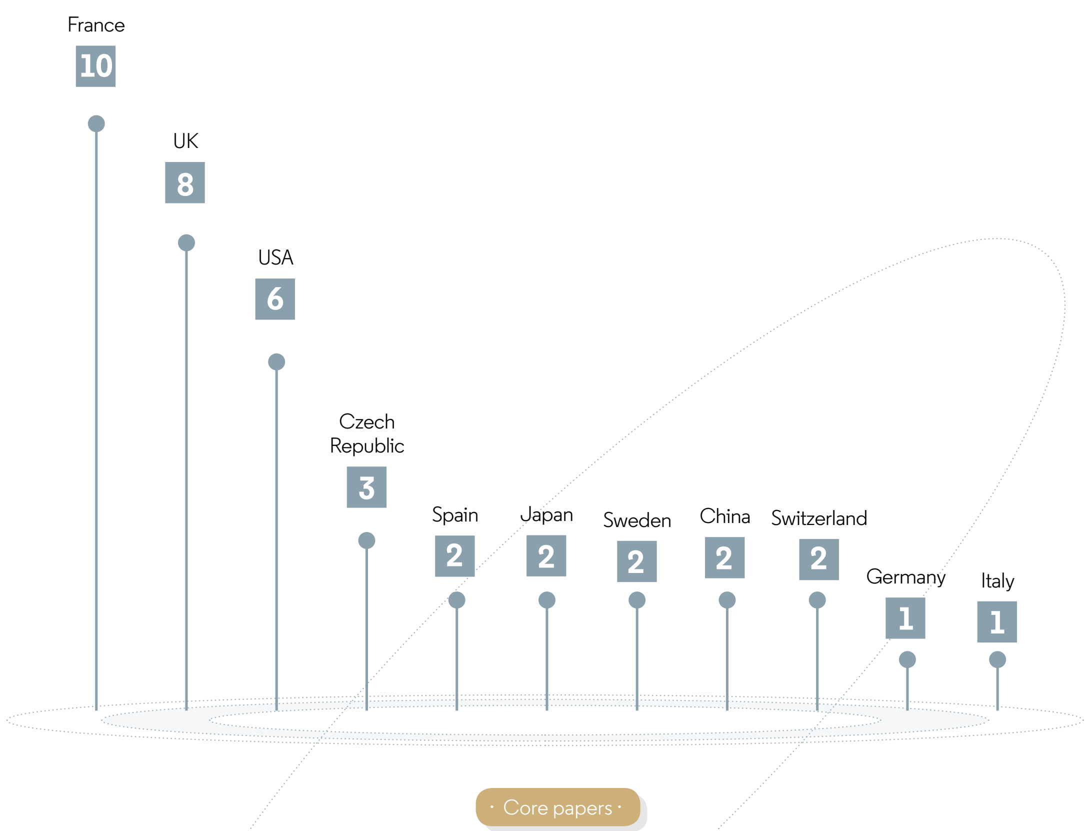


Figure 22: Citation frequency distribution curve of core papers in Research Front "Scalar-tensor theories and implications from gravitational-wave detections"

Analysis of top countries and institutions producing core papers indicates that France takes the lead, producing half of the core papers and occupying the top eight positions on the institution list. The French National Centre for Scientific Research (CNRS), the French Alternative Energies and Atomic Energy Commission (CEA), the Paris Observatory, and the University of Paris (tied for 3rd) constitute the top three. The UK and the USA also performed well in this Research Front, producing eight and six core papers, respectively. The UK-based University of Portsmouth ranks 9th on the top institution list.

Table 44: Top countries and institutions producing core papers in the Research Front "Scalar-tensor theories and implications from gravitational-wave detections"

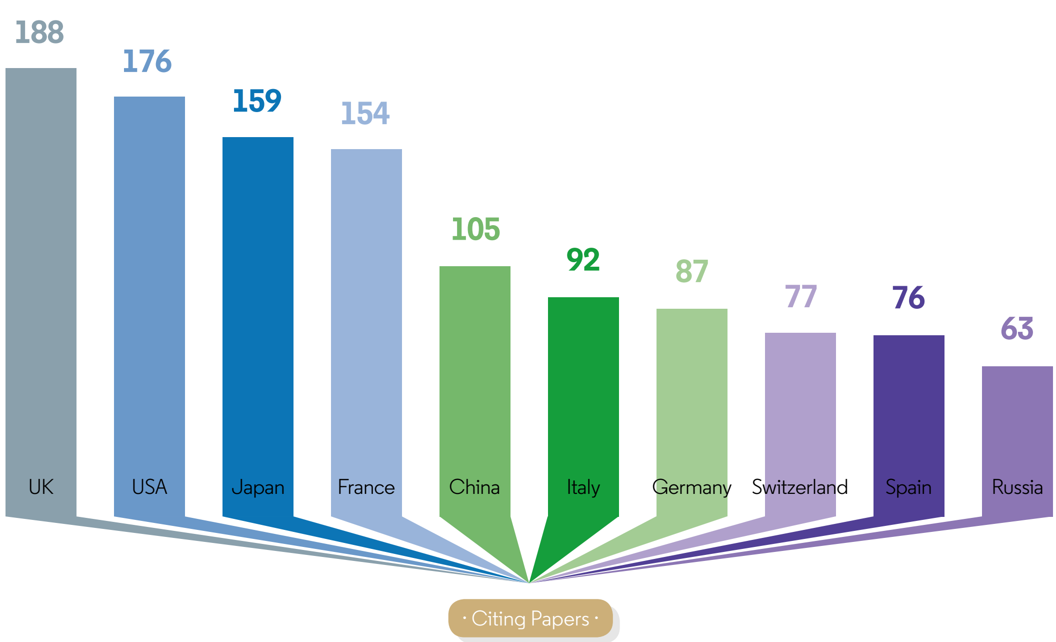
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	France	10	50.0%	1	French National Centre for Scientific Research (CNRS)	France	10	50.0%
2	UK	8	40.0%	1	French Alternative Energies and Atomic Energy Commission (CEA)	France	10	50.0%
3	USA	6	30.0%	3	Paris Observatory	France	7	35.0%
4	Czech Republic	3	15.0%	3	University of Paris	France	7	35.0%
5	Spain	2	10.0%	5	University of Paris Saclay	France	5	25.0%
5	Japan	2	10.0%	6	Centre-Val de Loire University ComUE	France	4	20.0%
5	Sweden	2	10.0%	6	University of Tours	France	4	20.0%
5	China	2	10.0%	6	University of Confederale Leonard de Vinci	France	4	20.0%
5	Switzerland	2	10.0%	9	University of Portsmouth	UK	3	15.0%
10	Germany	1	5.0%					
10	Italy	1	5.0%					



Analysis of the citing papers indicates that the UK takes the lead, producing 188 papers that cite the core literature. Moreover, the USA, Japan, France, and China also perform strongly, each producing more than100 citing papers. French institutions occupy four places among the Top 10 citing papers institutions list, and CNRS, CEA, and the University of Paris Saclay rank among the Top three. In addition, two institutions in Japan, and one each in Italy, Spain, Portugal, and Switzerland also place in the Top 10.

Table 45: Top countries and institutions producing citing papers in the Research Front "Scalar-tensor theories and implications from gravitational-wave detections"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	UK	188	19.9%	1	French National Centre for Scientific Research (CNRS)	France	145	15.3%
2	USA	176	18.6%	2	French Alternative Energies and Atomic Energy Commission (CEA)	France	89	9.4%
3	Japan	159	16.8%	3	University of Paris Saclay	France	81	8.6%
4	France	154	16.3%	4	National Institute for Nuclear Physics (INFN)	Italy	74	7.8%
5	China	105	11.1%	5	Kyoto University	Japan	56	5.9%
6	Italy	92	9.7%	6	Spanish National Research Council (CSIC)	Spain	54	5.7%
7	Germany	87	9.2%	7	University of Lisbon	Portugal	53	5.6%
8	Switzerland	77	8.1%	8	University of Tokyo	Japan	52	5.5%
9	Spain	76	8.0%	9	Paris Observatory	France	47	5.0%
10	Russia	63	6.7%	10	University of Geneva	Switzerland	45	4.8%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

There are two emerging Research Front in astronomy and astrophysics: "Gravitational-wave detections of compact binary mergers" and "Early dark energy and Hubble tension".

Table 46: Emerging Research Fronts in astronomy and astrophysics

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Gravitational-wave detections of compact binary mergers	8	1143	2019.8
2	Early dark energy and Hubble tension	14	592	2019.6

2.2 KEY EMERGING RESARCH FRONT – "Gravitational-wave detections from colliding black holes"

On February 11, 2016, the LIGO team announced the first confirmed observation of gravitational waves from colliding black holes: GW150914. This confirmed a major prediction of Albert Einstein's general theory of relativity (1915) and opened an unprecedented new window onto the cosmos. This detection was the beginning of a new era, and the field of gravitational wave astronomy became a reality. The Nobel Prize in Physics 2017 was shared by three scientists "for decisive contributions to the LIGO detector and the observation of gravitational waves".

Since GW150914, a large number of compact binary mergers have been detected by the LIGO and other ground-based detectors in the frequency band of 10 Hz ~ 1 kHz. This Research Front brings together eight core papers focusing on these gravitational-wave detections. The research topics include: observation of a binary-black-hole coalescence with asymmetric masses GW190412; observation of a compact binary coalescence GW190425 with total mass similar to 3.4 solar mass; observation, candidate electromagnetic counterpart, and astrophysical implications of the 150 solar masses binary black hole merger GW190521; discovery of a gravitational wave binary GW190814 (one component is a 23 solar-mass black hole, while the other 2.6 solar mass component could either be a low-mass black hole or a heavy neutron star); a gravitational-wave transient catalog of compact binary mergers observed by LIGO and Virgo during the first and second observing runs; and binary black hole population properties inferred from the first and second observing runs of LIGO and Virgo.

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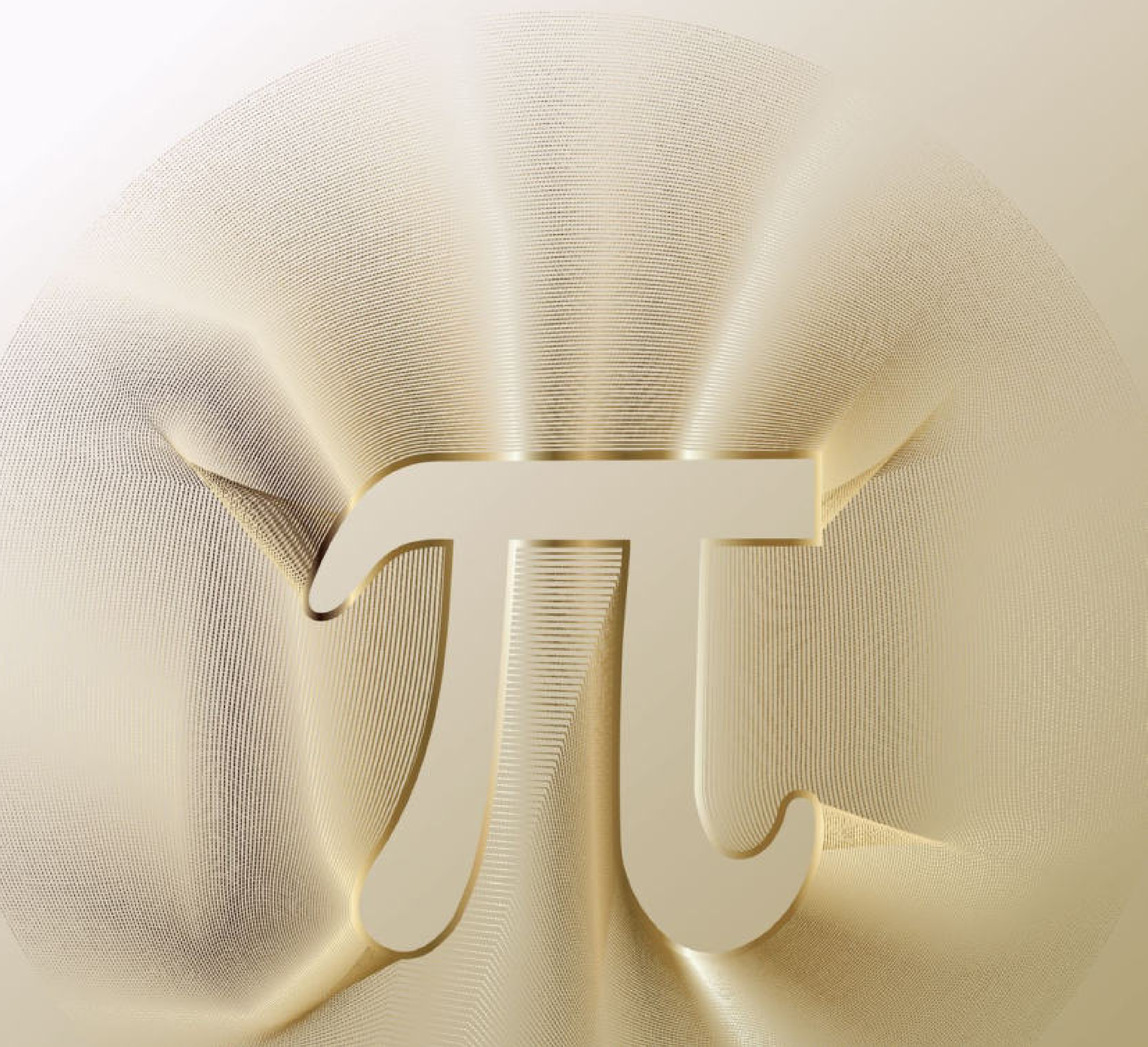
MATHEMATICS



1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN MATHEMATICS

The Top 10 Research Fronts in mathematics mainly focus on: Double phase anisotropic variational problems; analytical study of the transmission properties of optical solitons; medical-image analysis based on deep convolutional neural network; iterative algorithms for splitting common fixed-point problems; dynamic neural network algorithm for optimal robot operation; high-dimensional nonlinear partial differential equations; complex network analysis of nonlinear time series; Bayesian multilevel modeling and its application; numerical solution of fractional reaction diffusion equation; and energy stability of finite difference schemes. The Top 10 Research Fronts in 2021 show both continuity and new development when compared with the fronts selected between 2013 and 2020. Researches 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 for years. In 2021, complex network analysis of nonlinear time series in statistics has been selected as a hot Research Front for the first time.

Table 47: Top10 Research Fronts in mathematics

Rank	Hot Research Fronts	Core papers	Times Cited	Mean Year of Core Papers
1	Double phase anisotropic variational problems	32	1314	2018.3
2	Analytical study of the transmission properties of optical solitons	15	1149	2018.3
3	Algorithms in medical image analysis based on deep convolutional neural network	25	2978	2018.1
4	Iterative algorithms for splitting common fixed point problems	39	2080	2018
5	Dynamic neural network algorithm for optimal robot operation	33	1439	2017.9
6	Methods of solving high-dimensional nonlinear partial differential equations	27	2233	2017.8
7	Complex network analysis of nonlinear time series	12	940	2017.7
8	Bayesian multilevel modeling and its application in mathematical psychology	19	4847	2017.4
9	Numerical solution of fractional reaction diffusion equation	32	2158	2017.3
10	Energy stability of finite difference schemes	18	942	2017.1

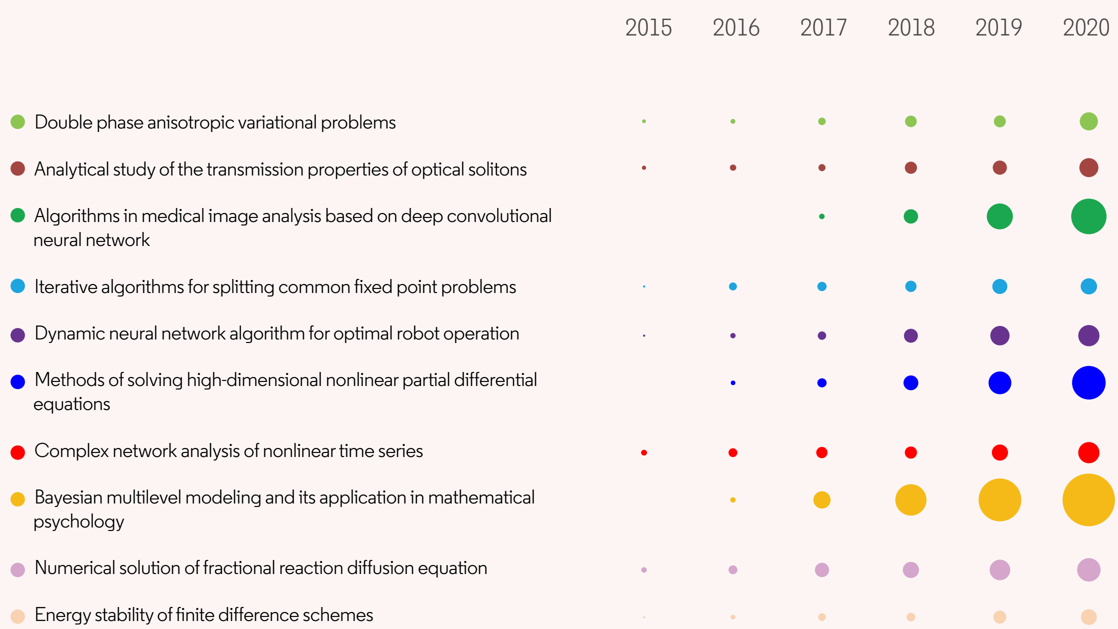


Figure 23: Citing papers for the top 10 Research Fronts in mathematics

1.2 KEY HOT RESEARCH FRONT – "Methods of Solving High-dimensional Nonlinear Partial Differential Equations"

As one of the three scientific revolutions that emerged in the 20th century, nonlinear science can be used to study and reveal many nonlinear phenomena in the fields of natural sciences, engineering technology, and social sciences. Research on these nonlinear phenomena can be carried out based on the corresponding nonlinear system, but there may be unpredictable or unintuitive results. In fact, many important natural science, engineering and technology issues can be attributed to the study of nonlinear partial differential equations, and therefore the solution of these equations has value both in terms of theory and practical application.

Research on nonlinear partial differential equations has been continuously selected among the hot Research Fronts in recent years, such as "Solutions for typical nonlinear evolution equations and their applications" in 2018, "Soliton solutions for higher order nonlinear Schrödinger equation and its applications in optical communication" in 2019, and "Investigation on the solution of integrable nonlocal nonlinear Schrödinger equation" in 2020. Revealing a new aspect compared to previous years, the 2021 Research Front "Methods of solving high-dimensional nonlinear partial differential equations" focuses on data-driven discovery modeling of high-dimensional nonlinear partial differential equations and solving methods based on machine learning and deep learning.

This hot Research Front contains 27 core papers. The frontiers are mainly reflected in the deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations, the extended dynamic mode decomposition driven by the Koopman operator, machine learning of nonlinear partial differential equations based on hidden physics models, deep learning algorithm DGM (Deep Galerkin Method) for solving high-dimensional partial differential equations, VAMPnets (variational approach for Markov processes nets) for deep learning of molecular kinetics, and deep learning-based numerical methods for high-dimensional parabolic partial differential equations.

Among the core papers, the article published in *PNAS* by Steve Brunton and colleagues at of the University of Washington has the highest number of citations. This article has been cited 373 times at this writing, and mainly focuses on discovering governing equations from noisy measurement data by combining sparse promotion technology, machine learning, and nonlinear dynamic systems. Other institutions whose authors have produced core papers cited more than 100 times are also based in the USA, namely the University of Pennsylvania, Princeton University, the University of Washington, Brown University, and the Institute for Disease Modeling. It is worth noting that, as an important study pertaining to the core papers in this Research Front, Frank Noé and colleagues at the Free University of Berlin, Germany, published an article in *Science* in 2019. This article proposed Boltzmann generators using deep learning to sample the equilibrium states of many-body systems, which can, to a certain extent, solve the long-standing challenge of "computing equilibrium states in condensed-matter many-body systems".

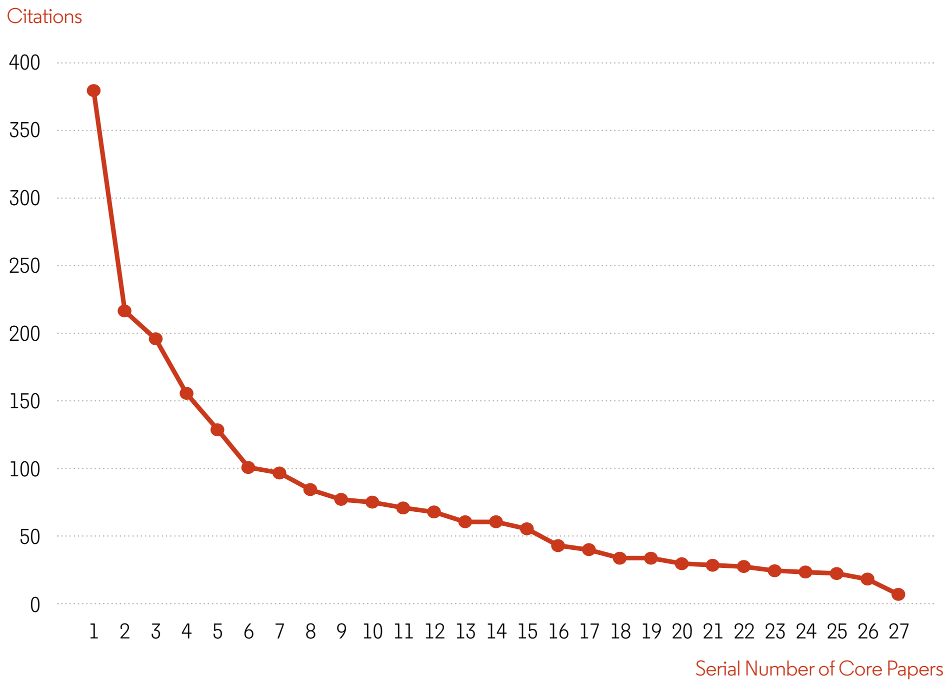


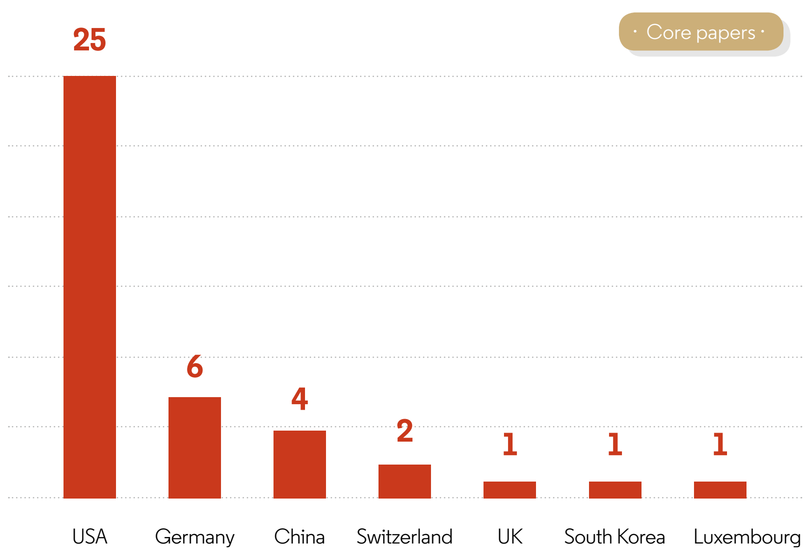
Figure 24: Citation frequency distribution curve of core papers in Research Front "Methods of Solving High-dimensional Nonlinear Partial Differential Equations"

In terms of representation among the core papers in the front (Table 48), the U.S.-based institutions display the most prominent performance, contributing 25 core papers, representing 92.6% of the total, and occupying a dominant position. Germany and China rank 2nd and 3rd, contributing six and four core papers, respectively. Among the top institutions producing core papers, the U.S.-based entities hold nine places, which is far ahead of other countries. The other top-producing institutions are in Germany, China and Switzerland.

Table 48: Top countries and institutions producing core papers in the Research Front "Methods of Solving High-dimensional Nonlinear Partial Differential Equations"

Country Ranking	Country	Core Papers	Proportion
1	USA	25	92.6%
2	Germany	6	22.2%
3	China	4	14.8%
4	Switzerland	2	7.4%
5	UK	1	3.7%
5	South Korea	1	3.7%
5	Luxembourg	1	3.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	University of Washington Seattle	USA	6	22.2%
2	Princeton University	USA	5	18.5%
2	Free University of Berlin	Germany	5	18.5%
4	Brown University	USA	4	14.8%
4	Institute for Disease Modeling	USA	4	14.8%
6	Beijing Institute of Big Data Research	China	3	11.1%
6	University of California Santa Barbara	USA	3	11.1%
8	University of Pennsylvania	USA	2	7.4%
8	Peking University	China	2	7.4%
8	Rice University	USA	2	7.4%
8	University of Notre Dame	USA	2	7.4%
8	Swiss Federal Institute of Technology Zurich	Switzerland	2	7.4%
8	Massachusetts Institute of Technology (MIT)	USA	2	7.4%

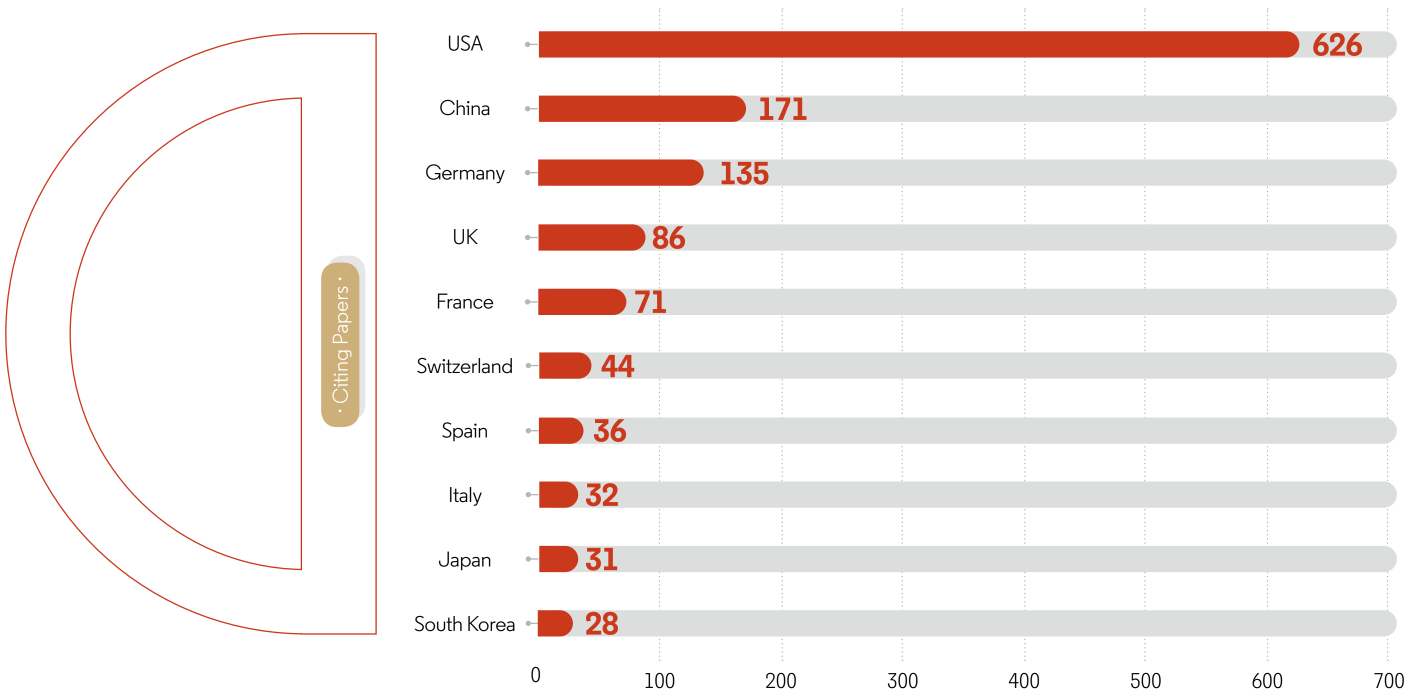


In terms of the citing papers (Table 49), the USA maintains its leading position, producing 626 citing papers, with a contribution rate of more than 50%. At the same time, China, Germany, and other countries are also actively following up on this front, gradually narrowing the gap with the USA. Among the top-producing institutions, the USA accounts for seven places, and the University of Washington in Seattle ranks 1st by number of core papers and as well as by citing papers produced. Prolific citing institutions in other countries that also contributed notably to the core papers include the Free University of Berlin and the Swiss Federal Institutes of Technology Zurich.

Table 49: Top countries and institutions producing citing papers in the Research Front "Methods of Solving High-dimensional Nonlinear Partial Differential Equations"

Country Ranking	Country	Citing Papers	Proportion
1	USA	626	51.1%
2	China	171	14.0%
3	Germany	135	11.0%
4	UK	86	7.0%
5	France	71	5.8%
6	Switzerland	44	3.6%
7	Spain	36	2.9%
8	Italy	32	2.6%
9	Japan	31	2.5%
10	South Korea	28	2.3%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	University of Washington Seattle	USA	63	5.1%
2	Massachusetts Institute of Technology (MIT)	USA	59	4.8%
3	United States Department of Energy (DOE)	USA	50	4.1%
4	Stanford University	USA	35	2.9%
5	Free University of Berlin	GERMANY	34	2.8%
6	National Center for Scientific Research of France (CNRS)	France	33	2.7%
7	Princeton University	USA	32	2.6%
8	Brown University	USA	31	2.5%
9	Swiss Federal Institute of Technology Zurich	Switzerland	27	2.2%
9	New York University	USA	27	2.2%



1.3 KEY HOT RESEARCH FRONT – "Complex network analysis of nonlinear time series"

Complex networks highly summarize the important feature of complex systems, which consist of multiple elementary units (or nodes) and the interactions between them. With the help of graph theory and related methods in statistics, complex network theory can describe and characterize the evolutionary mechanisms and overall functional behavior of complex systems. The small-world networks proposed in 1998 by Duncan J. Watts and Steven Strogatz illustrate that a small number of random connections can have a significant impact on the network topology, while the scale-free networks proposed by Albert-Laszlo Barabasi and Reka Albert reveal the universality of growth and optimization mechanisms in the self-organization evolution of complex systems. Following these pioneering works, complex network theory has gradually diffused from mathematical sciences to different disciplines such as life sciences, engineering sciences, and even social sciences, and now underlies hot research topics in related fields.

A time series is a set of numerical values of any variable that changes with time, and the time points are usually equally spaced and discrete. The study of complex network dynamics based on time series measurement signals has recently received increasing attention from researchers in different fields, and different construction and analysis algorithms for different complex networks of time series have been proposed and successfully applied to the investigation of different complex dynamical systems. Consequently, complex network methods have become a promising tool for the study of time series.

This hot Research Front includes 12 core papers, focusing on the topics of using multiple complex network theories and methods for nonlinear time series analysis to characterize the nonlinear dynamics of fluids, and analyzing electroencephalogram (EEG) time series to construct EEG functional brain networks for the analysis of human-emotion recognition and other processes.

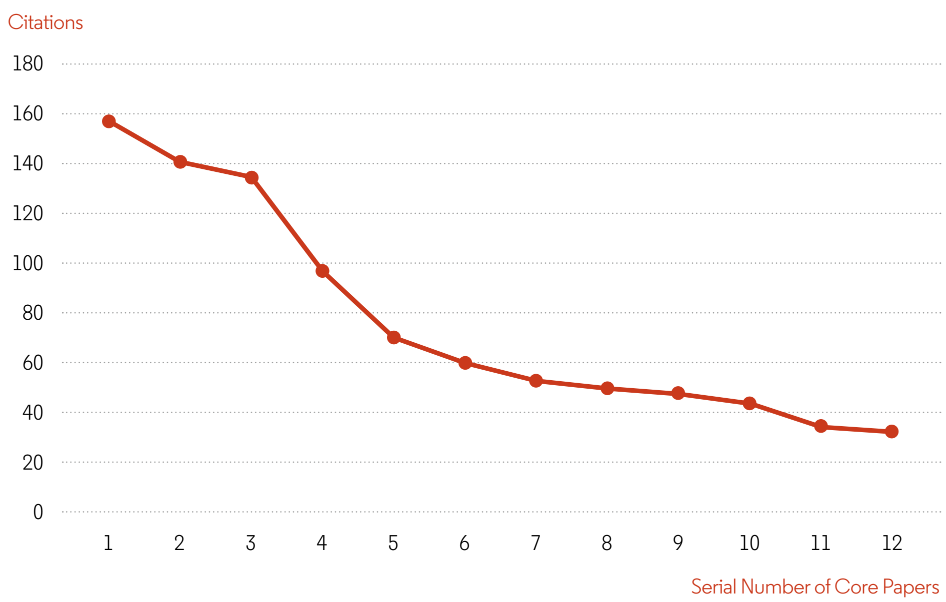


Fig 25: Citation frequency distribution curve of core papers in Research Front "Complex network analysis of nonlinear time series"

Among the top countries and institutions producing these core papers, China ranks 1st, contributing 83.3% of the core papers. The number of core papers contributed by Germany, the UK, and Russia ranks 2nd, 3rd, and 4th, respectively, with each contributing to more than 10% of the core papers. In terms of institutions, Chinese institutions play important roles in this front, with Tianjin University publishing nearly half of all core papers, and Shanghai Jiao Tong University, East China Normal University, Southeast University, Nanjing University of Technology, and Yantai University also actively participating in the research. The most-cited core paper, by researchers at Shanghai Jiao Tong University, investigates the nonlinear characteristics of EEG time series and proposes a novel emotion analysis and recognition model with better emotion-recognition performance. The research team from Tianjin University also has made a series of important breakthroughs in nonlinear time series analysis methods based on complex networks. These include phase-space-based recursive networks and visibility graph; Markov chain-based transformation networks; complex networks for two-phase flow; fluid dynamics; fluid structure and their applications in vertical gas-liquid two-phase flow; and inclined oil-water two-phase flow. Representing other nations, research institutions such as the Potsdam Institute for Climate Impact Research and the Humboldt University of Berlin, the University of Aberdeen in the UK, and Saratov State University in Russia are also ranked among the top contributing institutions.

Table 50: Top countries and institutions producing core papers in the Research Front "Complex network analysis of nonlinear time series"

Country Ranking	Country	Core Papers	Proportion
1	China	10	83.3%
2	Germany	3	25.0%
2	UK	3	25.0%
4	Russia	2	16.7%
5	South Korea	1	8.3%
5	Australia	1	8.3%
5	Sweden	1	8.3%
5	Portugal	1	8.3%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Tianjin University	China	6	50.0%
2	Potsdam Institute for Climate Impact Research	Germany	3	25.0%
2	Humboldt University of Berlin	Germany	3	25.0%
4	Shanghai Jiao Tong University	China	2	16.7%
4	University of Aberdeen	UK	2	16.7%
4	Saratov State University	Russia	2	16.7%
7	Stockholm University	Sweden	1	8.3%
7	University of Reading	UK	1	8.3%
7	East China Normal University	China	1	8.3%
7	Southeast University - China	China	1	8.3%
7	University of Potsdam	Germany	1	8.3%
7	University of Western Australia	Australia	1	8.3%
7	Nanjing University of Science & Technology	China	1	8.3%
7	Yantai University	China	1	8.3%
7	Magdeburg-Stendal University of Applied Sciences	Germany	1	8.3%
7	University of Lisbon	Portugal	1	8.3%
7	Kyungpook National University	South Korea	1	8.3%
7	Imperial College London	UK	1	8.3%

By the measure of citing papers, China is the most active country and contributes more than half of all citing papers. The USA ranks 2nd with 81 citing papers. Among the Top citing institutions, eight of the 13 institutions are based in China, including Tianjin University, China University of Geosciences, the Chinese Academy of Sciences, the University of Electronic Science and Technology of China, and the University of Shanghai for Science and Technology.

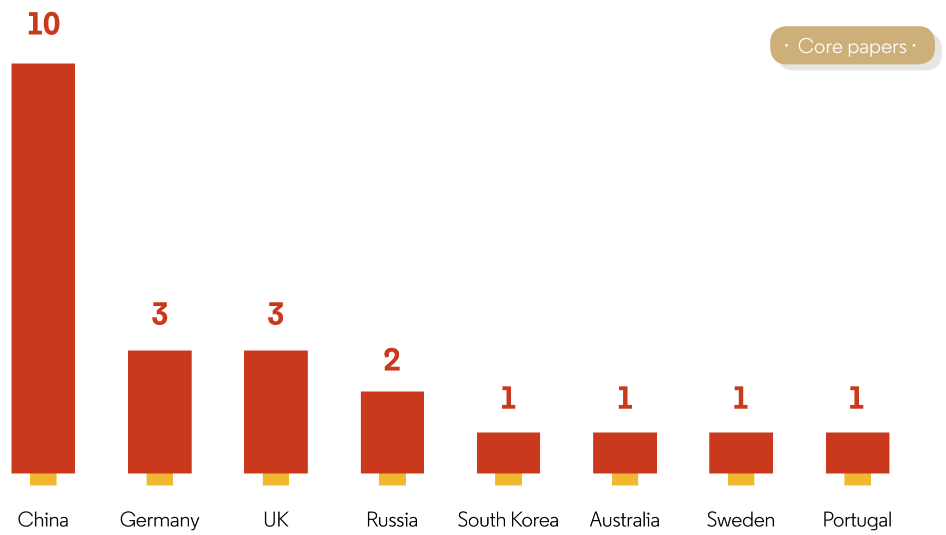
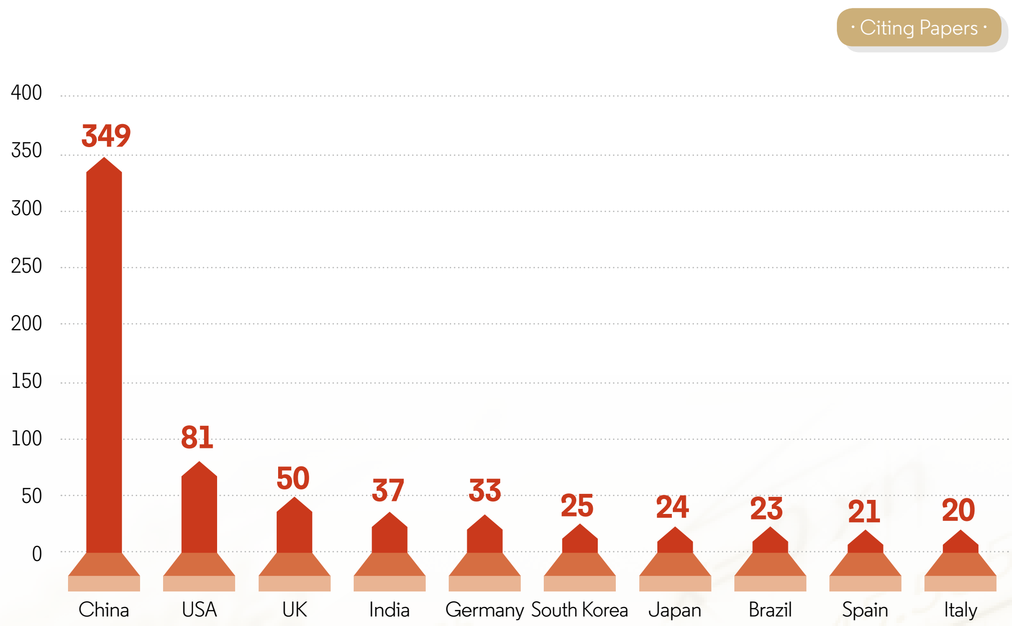


Table 51: Top countries and institutions producing citing papers in the Research Front "Complex network analysis of nonlinear time series"

Country Ranking	Country	Citing Papers	Proportion
1	China	349	51.0%
2	USA	81	11.8%
3	UK	50	7.3%
4	India	37	5.4%
5	Germany	33	4.8%
6	South Korea	25	3.7%
7	Japan	24	3.5%
8	Brazil	23	3.4%
9	Spain	21	3.1%
10	Italy	20	2.9%

Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	Tianjin University	China	59	8.6%
2	China University of Geosciences	China	22	3.2%
3	Potsdam Institute for Climate Impact Research	Germany	21	3.1%
4	Chinese Academy of Sciences	China	19	2.8%
5	University of Electronic Science & Technology of China	China	17	2.5%
6	University of Shanghai for Science and Technology	China	16	2.3%
7	Humboldt University of Berlin	Germany	14	2.0%
8	Ministry of Land and Resources	China	13	1.9%
9	Zhejiang University	China	12	1.8%
10	Harbin Institute of Technology	China	11	1.6%
10	Indian Institute of Technology (IIT)	India	11	1.6%
10	King Abdulaziz University	Saudi Arabia	11	1.6%
10	University of Aberdeen	UK	11	1.6%


· Citing Papers ·
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Italy

2021
RESEARCH FRONTS

INFORMATION SCIENCE

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN INFORMATION SCIENCE

The Top 10 Research Fronts in information science mainly focus on deep learning and its applications, such as in 6G communication, plant classification and disease detection, ECG classification and automatic diagnosis of arrhythmia, human activity recognition, video action recognition, multi-modal sentiment analysis, and data mining of electronic health records. Blockchain technology, pathway databases, and UAV-aided communication technology are also highlighted as hot fronts (Table 52). In this latest roundup, "UAV-based wireless communication technology" is the continuation and expansion of the hot Research Front "Research on UAV wireless communication network, transmission security and trajectory optimization" in 2020, while other specialty areas have been identified among the Hot Research Fronts for the first time.

Table 52: Top10 Research Fronts in information science

Rank	Hot Research Fronts	Core papers	Times Cited	Mean Year of Core Papers
1	The application of deep learning in 6G communication technology	45	3657	2018.8
2	Blockchain technology for peer-to-peer energy trading	27	2576	2018.3
3	Data integration, analysis, memory optimization, and visualization research for pathway databases	8	5692	2018.1
4	Deep neural network for plant classification and disease detection	25	2437	2017.8
5	Convolutional neural network for ECG classification and automatic diagnosis of arrhythmia	20	2361	2017.6
6	Research on human activity recognition system using sensors and deep learning	20	2554	2017.3
7	Deep neural networks for video action recognition	13	1436	2017.3
8	Research on multi-modal sentiment analysis based on deep learning methods such as convolutional neural networks	15	1433	2017.3
9	Deep learning for data mining of electronic health records	9	1635	2017.1
10	UVA-based wireless communication technology	11	3150	2017

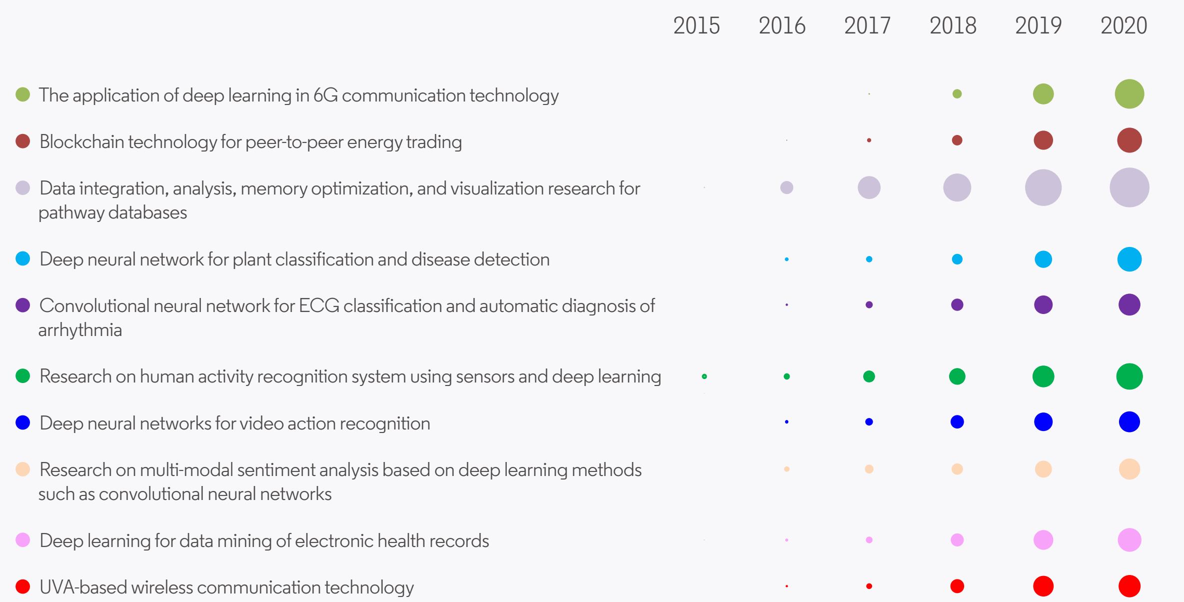


Figure 26: Citing papers for the Top 10 Research Fronts in information science

1.2 KEY HOT RESEARCH FRONT – "Deep neural networks for video action recognition"

With the rapid development of video devices and networks, video understanding and action recognition have attracted the attention of more and more researchers. Compared with images, video content and backgrounds are more complex and changeable. Different action categories have similarities, and the same category has different characteristics in different scenarios. At present, the common technologies of video action recognition include artificial features-based video action recognition, double stream based neural network, three-dimensional convolution based neural network, and so on. In practical application, accurate action recognition is helpful for monitoring public opinion, advertising, video retrieval, intelligent medical monitoring, automatic driving, traffic security, and other related tasks.

"Deep neural networks for video action recognition" includes 13 core papers, covering visual genome data sets, spatio-temporal representation learning of action recognition, deep visual-semantic alignment, visual recognition and description based on long-term recurrent convolutional network, long-term temporal convolutions, asymmetric 3D convolutional neural networks, and spatio-temporal deformable 3D ConvNets with attention for action recognition. Among the seven core papers cited more than 100 times each (Figure 27), three papers were published by USA-based institutions, with one from the University of California, Berkeley, and two from Stanford University. Two papers were led by China-based researchers, from Shenzhen Institute of Advanced Technology, the Chinese Academy of Sciences and Tianjin University. Two papers were authored by researchers in France, respectively from the National Institute of Information and Automation and the French National Centre for Scientific Research.

Among the 13 core papers, the most cited is "Long-term recurrent convolutional networks for visual recognition and description" by Jeff Donahue at the University of California, Berkeley, and colleagues, published in 2017. The report – one of a continuing series presented in conference proceedings – proposes a long-term time recursive convolutional network (LRCN) model, which is a new end-to-end trainable recursive convolutional architecture for large-scale visual learning. The report also demonstrates the value of these models for video-recognition tasks, image captioning, retrieval problems, and video description challenges. The other highly cited papers in the core include "Visual Genome: Connecting language and vision using crowdsourced dense image annotations," published in 2017 by a team led by Fei-Fei Li at Stanford University. This paper reports the use of crowdsourcing methods to construct the Visual Genome dataset, which is the first large-scale visual relationship dataset to provide detailed labels of object interaction and attributes, as well as to combine semantics and images to promote the further development of artificial intelligence. In terms of a training and testing data set for instructing computers to understand images, the Visual Genome is another important achievement from Li's team after ImageNet.

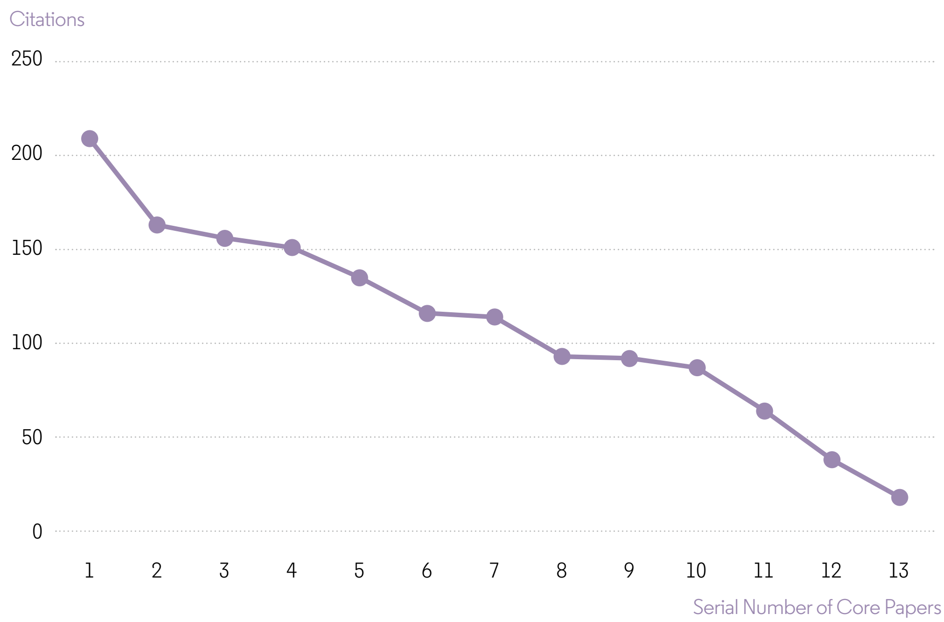


Figure 27: Citation frequency distribution curve of core papers in Research Front "Deep neural networks for video action recognition"

Both the USA and China contribute five core papers (Table 53), while France-based authors participate in three, and the Netherlands and the UK each contribute two. In terms of the organizational distribution of core papers, the University of Bretagne Loire, INRIA, and the Chinese Academy of Sciences tie for 1st place with three core papers each, and Stanford University ranks 2nd with two papers.

Table 53: Top countries and institutions producing core papers in the Research Front "Deep neural networks for video action recognition"

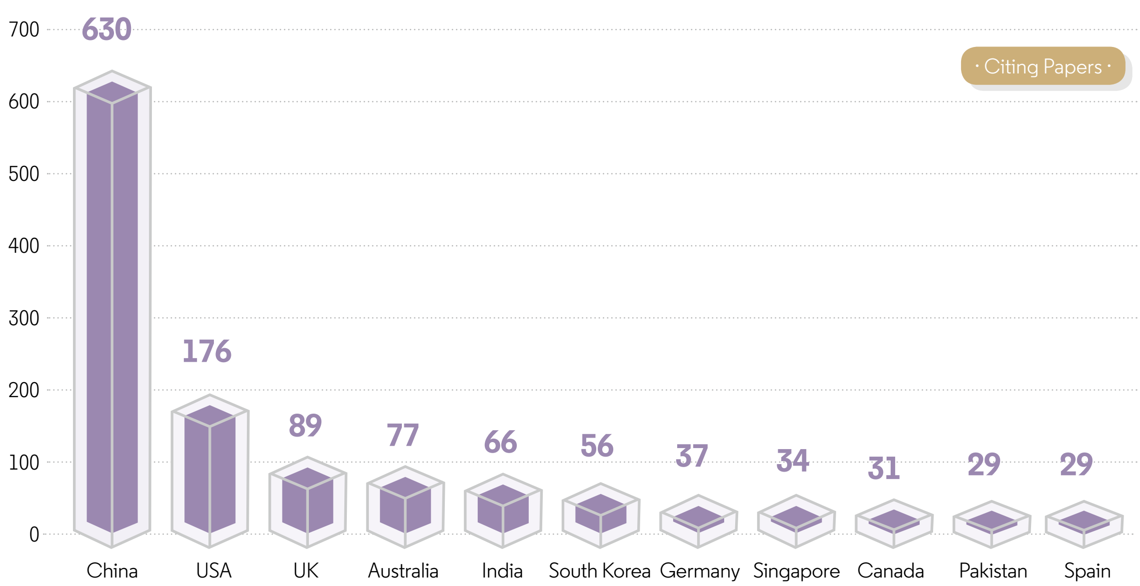
Country Ranking	Country	Core Papers	Proportion
1	USA	5	38.5%
1	China	5	38.5%
3	France	3	23.1%
4	Netherlands	2	15.4%
4	UK	2	15.4%
6	Switzerland	1	7.7%
6	Germany	1	7.7%
6	Singapore	1	7.7%
6	Australia	1	7.7%

Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	University of Bretagne Loire	France	3	23.1%
1	Chinese Academy of Sciences	China	3	23.1%
1	INRIA	France	3	23.1%
4	Stanford University	USA	2	15.4%

From the perspective of citing papers (Table 54), China is the most prolific contributor, with 630 citing papers, far ahead of the USA and its second-ranking 176 reports. The UK, Australia, India and South Korea are among the other notable performers. The top prolific institutions, based on citing papers, are all located in China. The Chinese Academy of Sciences, Tianjin University, and Zhejiang University are the top three, with their output indicating that a number of Chinese universities and research institutions have rapidly carried out follow-up research in this specialty area.

Table 54: Top countries and institutions producing citing papers in the Research Front "Deep neural networks for video action recognition"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	630	53.1%	1	Chinese Academy of Sciences	China	104	8.8%
2	USA	176	14.8%	2	Tianjin University	China	30	2.5%
3	UK	89	7.5%	3	Zhejiang University	China	25	2.1%
4	Australia	77	6.5%	4	Beijing University Posts & Telecommunications	China	24	2.0%
5	India	66	5.6%	4	Tsinghua University	China	24	2.0%
6	South Korea	56	4.7%	4	Xidian University	China	24	2.0%
7	Germany	37	3.1%	7	Beihang University	China	22	1.9%
8	Singapore	34	2.9%	7	Peking University	China	22	1.9%
9	Canada	31	2.6%	9	Northwestern Polytechnical University	China	21	1.8%
10	Pakistan	29	2.4%	10	University of Electronic Science & Technology of China	China	20	1.7%
10	Spain	29	2.4%					



UUS1.3 KEY HOT RESEARCH FRONT – "UVA-based wireless communication technology"

With the popularization of Internet of Things applications, wireless networks will support a huge number of access devices, and the current cellular infrastructure will face huge challenges. However, it is difficult to realize the interconnection of everything by deploying traditional ground-based communication stations. For example, the deployment of ground-based stations in remote or rough terrain faces the issues of high cost and logistical difficulty. In special scenarios, such as disasters or other emergencies, or in temporary situations involving, for example, sports venues, ground-based stations might be overloaded and might even fail. In such cases, the temporary deployment of ground communication facilities is time-consuming and costly. With the widespread application of low-cost, miniaturized and integrated UAVs in civil and industrial fields, using UAVs as aerial based stations to assist ground communications has become an effective solution to temporary communication problems in special situations. These advances have also prompted high-speed data transmission equipped with advanced transceivers and smart sensor devices to become another new research hotspot in the field of wireless communication.

And the concept has proved itself: In one example, during the heavy rainfall in Henan Province in July 2021, the mobile public network base station carried by the "Pterosaur-2H" UAV emergency communication platform achieved stable continuous mobile signal coverage of about 50 square kilometers for five hours, opening the emergency communication guarantee lifeline.

"UAV-based wireless communication technology" includes 11 core papers, focusing on areas that include: improving energy efficiency through trajectory optimization; the solution for maximizing the minimum throughput of multiusers in downlink communication, realized by optimizing multiuser communication scheduling jointly with the UAV's trajectory and power control, or by jointly optimizing UAV's trajectory and orthogonal frequency division multiple access resource allocation; UAV vehicle-mounted base station deployment algorithm that maximizes the number of users covered. Five of the core papers in this front have been cited more than 300 times each (Figure 28). Of those five, four include authors from the National University of Singapore, while Virginia Tech contributes one. The most-cited paper is "Wireless communications with unmanned aerial vehicles: Opportunities and Challenges" published by Yong Zeng and colleagues at the National University of Singapore in 2016. It introduces the basic networking architecture and main channel characteristics, highlighting the key design considerations as well as the new opportunities to be exploited.

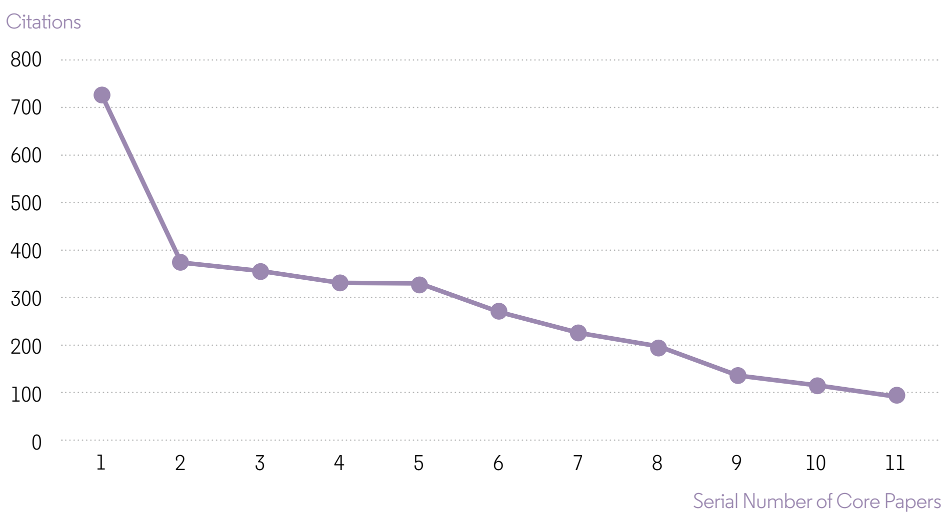


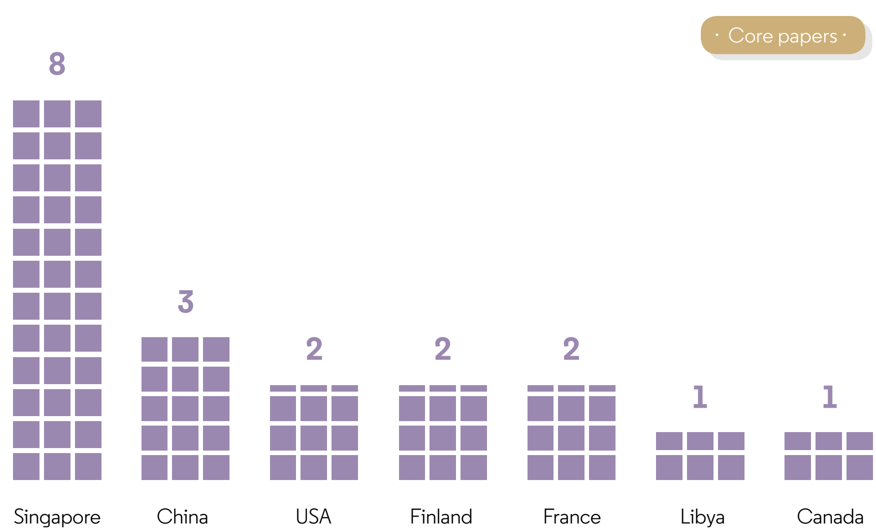
Figure 28: Citation frequency distribution curve of core papers in Research Front "UVA-based wireless communication technology"

Singapore contributes most of the research work in this front (Table 55). In terms of institutions producing core papers, the National University of Singapore has published the most, and Huawei's French R&D Center has published two papers in collaboration with the University of Sacre in Paris, Virginia Tech, and the University of Oulu in Finland.

Table 55: Top countries and institutions producing core papers in the Research Front "UVA-based wireless communication technology"

Country Ranking	Country	Core Papers	Proportion
1	Singapore	8	72.7%
2	China	3	27.3%
3	USA	2	18.2%
3	Finland	2	18.2%
3	France	2	18.2%
6	Libya	1	9.1%
6	Canada	1	9.1%

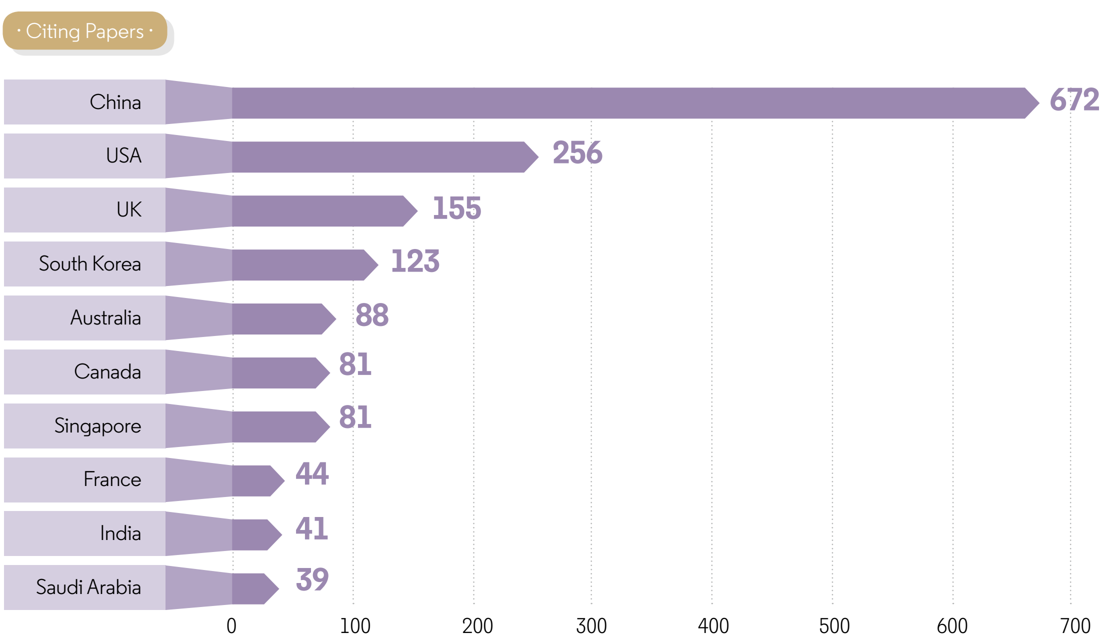
Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	National University of Singapore	Singapore	8	72.7%
2	Huawei France R&D	China/ France	2	18.2%
2	University of Paris Saclay	France	2	18.2%
2	Virginia Polytechnic Institute	USA	2	18.2%
2	Agency for Science, Technology and Research (A*STAR)	Singapore	2	18.2%
7	Carleton University	Canada	1	9.1%
7	Southwest University	China	1	9.1%
7	University of Oulu	Finland	1	9.1%
7	Sirte University	Libya	1	9.1%
7	University of Benghazi	Libya	1	9.1%
7	Nanyang Technological University	Singapore	1	9.1%



Analysis of the citing papers (Table 56) indicates that China is the country with the most active follow-up work on this Research Front, followed by the USA, the UK, and South Korea. Among the Top 10 institutions for citing papers, China-based entities occupy seven seats, among which Beijing University of Posts and Telecommunications and Southeast University are the two most active research institutions. In addition, Singapore, the USA, Australia, and the UK each have institutions on the list.

Table 56: Top countries and institutions producing citing papers in the Research Front "UVA-based wireless communication technology"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	672	51.0%	1	Beijing University Posts & Telecommunications	China	83	6.3%
2	USA	256	19.4%	2	Southeast University	China	82	6.2%
3	UK	155	11.8%	3	Army Engineering University of PLA	China	62	4.7%
4	South Korea	123	9.3%	4	National University of Singapore	Singapore	51	3.9%
5	Australia	88	6.7%	5	Virginia Polytechnic Institute	USA	49	3.7%
6	Canada	81	6.2%	6	Nanjing University of Aeronautics & Astronautics	China	47	3.6%
6	Singapore	81	6.2%	7	Chinese Academy of Sciences	China	37	2.8%
8	France	44	3.3%	8	University of New South Wales	Australia	36	2.7%
9	India	41	3.1%	8	Xidian University	China	36	2.7%
10	Saudi Arabia	39	3.0%	10	Nanjing University of Posts and Telecommunications	China	35	2.7%
				10	Queen Mary University London	UK	35	2.7%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN INFORMATION SCIENCE

"Research on deep neural networks for detection and diagnosis of COVID-19 from medical images" was selected as the emerging Research Front in information science for 2021.

Table 57: Emerging Research Front in information science

Rank	Emerging Research Front	Core papers	Citations	Mean Year of Core Papers
1	Research on deep neural networks for detection and diagnosis of COVID-19 based on medical images	12	338	2020

2.2 KEY EMERGING RESARCH FRONT – "Research on deep neural networks for detection and diagnosis of COVID-19 based on medical images"

A key step in the fight against COVID-19 is effective screening of infected patients so that the afflicted can receive immediate treatment and care and are isolated to mitigate the spread of the virus. The matter of how to use advanced AI deep learning technology to identify COVID-19 quickly and accurately has become an emerging key research direction in the field of information science.

This Research Front focuses on how to use deep-learning technology to promptly recognize COVID-19 based on medical image data. From the perspective of data sources, most of the studies use X-ray images for automatic identification, while two papers report the use of CT image data for identification. In the early stage of the epidemic, as the available data set was small, some studies used data-enhanced methods for deep-learning training to improve performance in identifying COVID-19. These recognition methods include the auxiliary classifier Generative Adversarial Networks (GAN), deep transfer learning method, multi-objective differential evolution convolutional neural network, and Deep Bayes-squeezeNet – a structure based on artificial intelligence.

2021

RESEARCH FRONTS

ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

1. HOT RESEARCH FRONT

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

The top 10 Research Fronts of 2021 related to economics, psychology and other social sciences display a strong interdisciplinarity, mainly focusing on psychology, sociology, and economic management. Among these specialty areas, three Research Fronts in economic management pertain to blockchain technology and supply-chain management, social media and marketing, corporate knowledge management and innovation performance; three Research Fronts in the field of sociology are related to land resource use efficiency and land system reform, the spread and influence of fake news, and studies on the problem of shared bicycles; two Research Fronts in the field of psychology concern the public mental-health aspects of the COVID-19 pandemic. The interdisciplinary research is related to the intersection of information technology with economics, psychology, and management.

Compared with the Research Fronts featured in this category in years past, the sharing economy has now been highlighted in three consecutive surveys. The application of blockchain technology in the supply chain, which was an emerging Research Front in 2020, has become a hot Research Front in 2021. Moreover, the studies of social, economic, and psychological issues related to COVID-19 appear in both hot and emerging Research Fronts in 2021.

In addition, the top 10 Research Fronts highlight the application of new technologies in economics, psychology and social sciences, such as "blockchain technology and supply chain management", "Application of robots in tourism, marketing, and services industries, accelerated by the COVID-19 pandemic", "Application of Virtual Reality Technology in Mental Illness Treatment, Education and Training", and "Social media and marketing".

Table 58: Top10 Research Fronts in economics, psychology and other social sciences

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	The impact of the COVID-19 pandemic on mental health	31	6035	2020
2	Blockchain technology and supply chain management	31	1270	2019.5
3	Application of robots in tourism, marketing, and services industries, accelerated by the COVID-19 pandemic	47	2347	2019.1
4	Land use efficiency and land system reform	24	1075	2018.7
5	The spread and influence of fake news	12	1660	2018.5
6	Application of Virtual Reality Technology in Mental Illness Treatment, Education and Training	17	1149	2018
7	Social media and marketing	13	896	2018
8	Enterprise Knowledge Management and Innovation Performance	14	860	2018
9	Research on bike sharing	35	2100	2017.9
10	Growth mentality and achievement(performance) improvement	13	1107	2017.8

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

1.2 KEY HOT RESEARCH FRONT: "The impact of the COVID-19 pandemic on mental health"

Needless to say, the outbreaks and rapid spread of COVID-19 has had a huge impact on all aspects of society, including people's physical and mental health, with especially heavy pressure falling on front-line medical staff. Extreme stress caused moderate to severe psychological distress, accompanied by corresponding physical symptoms, including headache and fatigue.

This Research Front mainly focuses on the mental health burden on medical staff and the public in areas hit hard by COVID-19. The studies investigate the prevalence of insomnia and other physical symptoms reported by medical staff in different countries or regions during acute episodes of the pandemic. The research also examines the relationship between physical symptoms and depression, anxiety, stress, and post-traumatic stress disorder (PTSD). Some studies, with the help of demographic data, evaluate the prevalence of psychiatric symptoms and the people most susceptible (such as women, individuals with chronic diseases and past psychiatric history, etc.), and the main symptoms in the general population. The studies also aim to identify the risk factors for psychological distress and to find ways to take targeted psychological intervention measures for stress trauma. The significance of this Research Front lies in helping medical staff and communities assist the public to be better prepared in responding to disasters by understanding the mental-health problems and response measures in the face of public health emergencies.

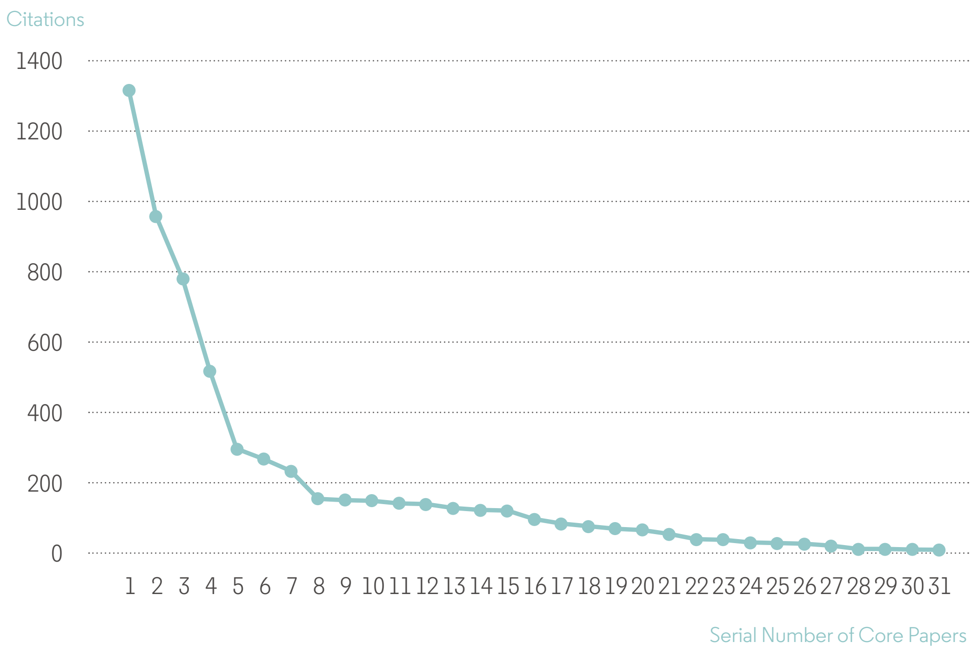


Figure 30: Citation frequency distribution curve of core papers in Research Front "The impact of the COVID-19 pandemic on mental health"

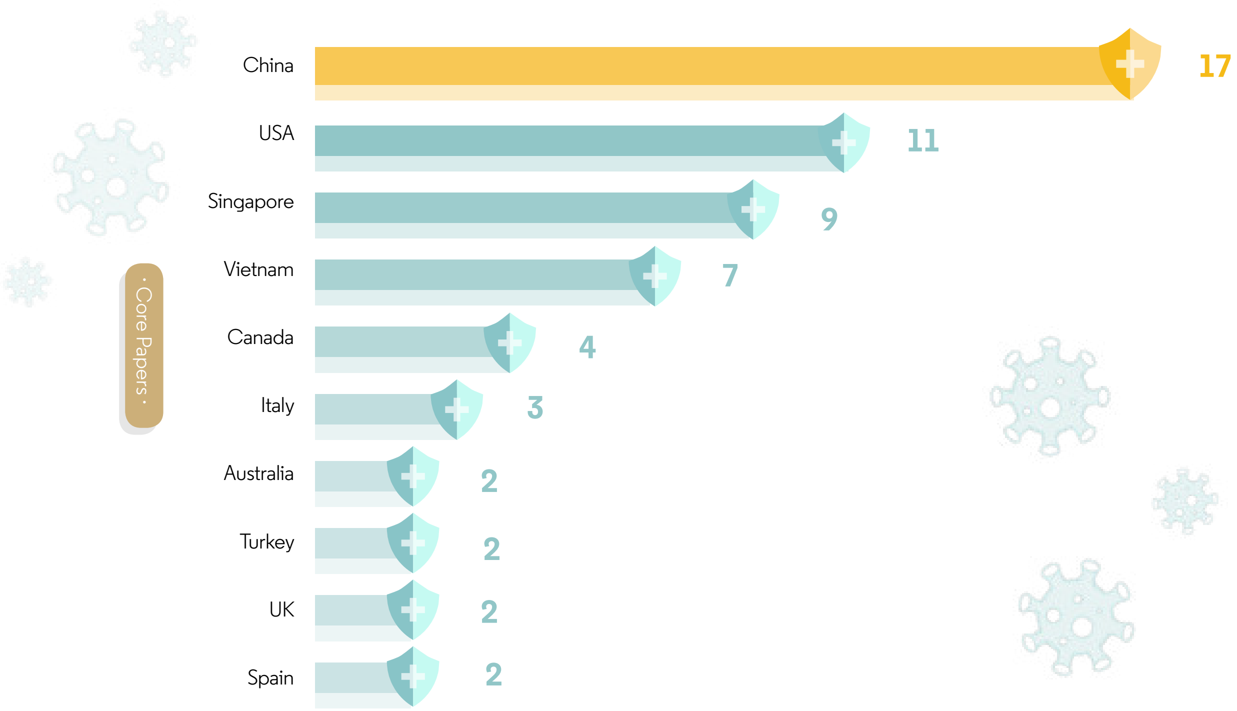
Thirty-one core papers anchor this Research Front. Among them, the most-cited paper (cited 1,282 times at this writing) was published in *Lancet* by Samantha Brooks from King's College, the University of London on February 26th, 2020. The paper reviews 24 articles on the psychological impact of isolation, including post-traumatic stress symptoms, confusion, and anger. The influencing factors include the length of isolation, fear of infection, depression, boredom, insufficient supplies, inadequate information, economic loss, and stigmatization.

The core papers ranking second to fourth by citation count were published in *International Journal of Environmental Research and Public Health, JAMA Network Open, and Lancet Psychiatry*. Through online surveys, demographic data collection, and other methods, these papers investigate anxiety, depression, stress levels, and the influencing factors during the pandemic in China and the UKUK These reports also provide evidence-based strategies for reducing the adverse psychological effects and psychiatric symptoms.

China has contributed most prolifically to this front, with 17 core papers. Among the 10 Top institutions, three are in China. However, from an institutional perspective, the National University of Singapore has contributed the most with nine core papers, accounting for 29% of this front's foundational literature (Table 59).

Table 59: Top countries and institutions producing core papers in the Research Front "The impact of the COVID-19 pandemic on mental health"

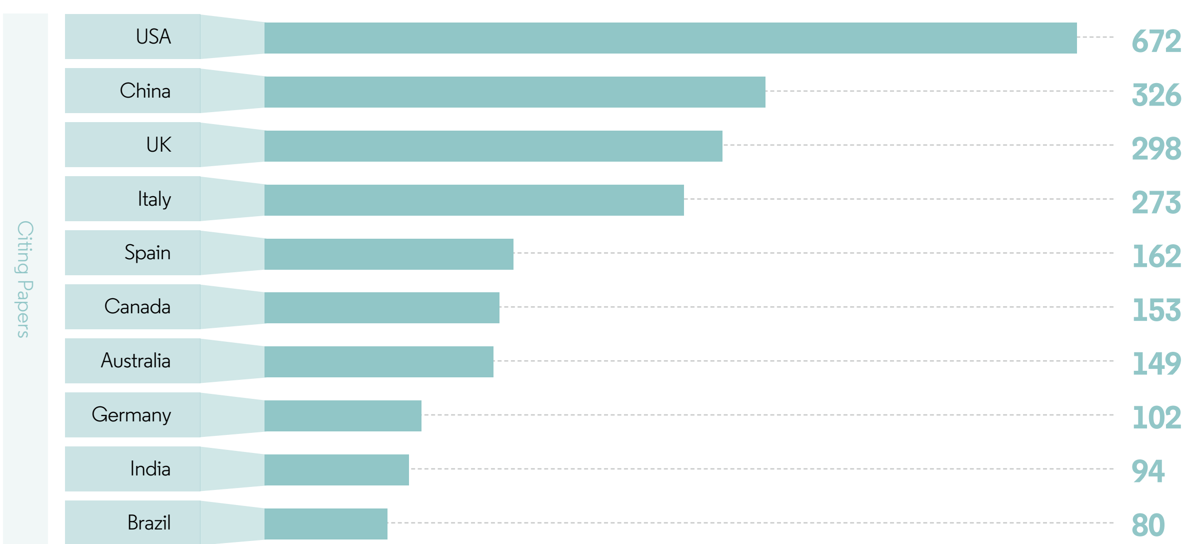
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	17	54.8%	1	National University of Singapore	Singapore	9	29.0%
2	USA	11	35.5%	2	Johns Hopkins University	USA	7	22.6%
3	Singapore	9	29.0%	2	Hanoi medical University	Vietnam	7	22.6%
4	Vietnam	7	22.6%	4	Huazhong University of Science & Technology	China	5	16.1%
5	Canada	4	12.9%	5	Nguyen tat thanh University	Vietnam	4	12.9%
6	Italy	3	9.7%	5	Huaibei Normal University	China	4	12.9%
7	Australia	2	6.5%	5	University of Toronto	Canada	4	12.9%
7	Turkey	2	6.5%	5	Duy Tan University	Vietnam	4	12.9%
7	UK	2	6.5%	5	Wuhan University	China	4	12.9%
7	Spain	2	6.5%	10	University Health Network Toronto	Canada	3	9.7%



In terms of citing papers, the USA ranks 1st with 529 citing papers, followed by China, the UK, and Italy. This rank order may correspond to the epidemic's global development and progression. Table 60 also shows that a range of major countries have begun to pay attention to the social impact of the epidemic. At the institutional level, the table presents a completely different distribution compared to the analysis of core papers. Harvard University, King's College London, and the University of Toronto emerge as the top three institutions, while Chinese institutions fails to enter the Top 10 citing institutions.

Table 60: Top countries and institutions producing citing papers in the Research Front "The impact of the COVID-19 pandemic on mental health"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	529	16.3%	1	Harvard University	USA	66	2.0%
2	China	326	10.0%	2	Kings College London	UK	62	1.9%
3	UK	298	9.2%	3	University of Toronto	Canada	53	1.6%
4	Italy	273	8.4%	4	University College London	UK	45	1.4%
5	Spain	162	5.0%	5	Sapienza University Rome	Italy	42	1.3%
6	Canada	153	4.7%	6	Johns Hopkins University	USA	36	1.1%
7	Australia	149	4.6%	7	National University of Singapore	Singapore	35	1.1%
8	Germany	102	3.1%	8	CIBER	Spain	31	1.0%
9	India	94	2.9%	8	University of Melbourne	Australia	31	1.0%
10	Brazil	80	2.5%	8	University of Padua	Italy	31	1.0%



1.3 KEY HOT RESEARCH FRONT – "Application of robots in tourism, marketing, and services industries, accelerated by the COVID-19 pandemic"

Driven by emerging technologies such as artificial intelligence (AI), the use of service robots and AI to provide human services has attracted increasing attention from tourism, marketing, hotels, and various service industries. The application of intelligent automation in these areas is expected to improve continuously. Meanwhile, AI may drastically change marketing strategies and customer behaviors by enhancing the customer experience.

The global outbreak of COVID-19 hit particularly hard at tourism and other service industries. However, intelligent technology and the internet are rapidly changing the characteristics of organizational boundaries, accelerating the application of digital tourism and robots in the service industry. For example, humanoid robots play an increasingly important role in hotels and travel services; service robots enhance consumers' experience with technology, rapidly changing the nature of services, the customer experience, and the relationship between customers and service providers; and social-assistance robots have the potential to play a large role in the elderly care value network. These advances will speed the transformation and development of tourism and service industries.

There are 47 core papers in this front, of which the most-cited paper has now been cited approximately 500 times. The article was published in the *Journal of Marketing* in 2016 by Katherine N. Lemon of Boston College in the USA.

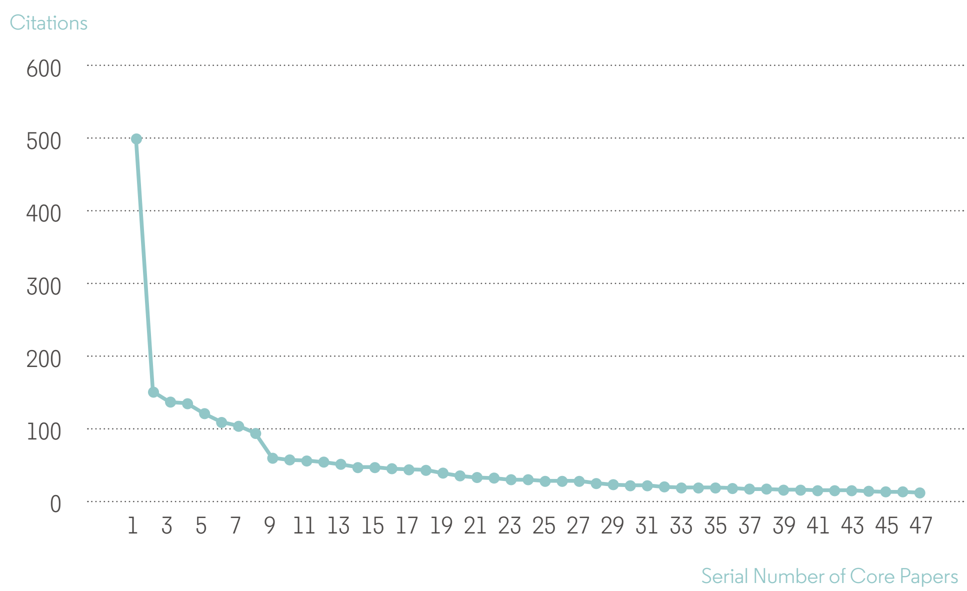
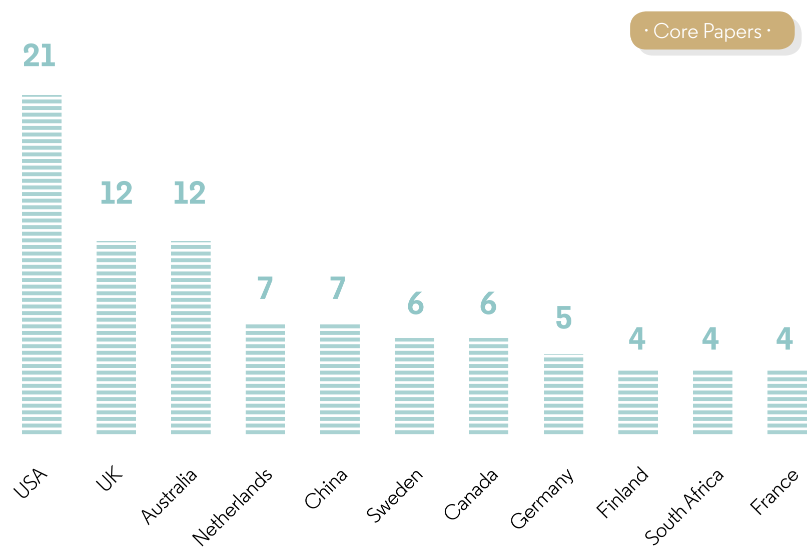


Figure 31: Citation frequency distribution curve of core papers in Research Front "Application of robots on tourism, marketing, and services & the positive effects of COVID-19 on it"

The top three countries contributing to this hot Research Front are the USA, the UKUK, and Australia. The US contributed 21 papers, accounting for 44.7% of the core. China-based institutions can claim seven core papers in this hot front, ranking fourth. The distribution at the institutional level is relatively balanced. Among the 13 Top institutions, five are in the USA. The institution with the most core papers is the University of Queensland in Australia, accounting for 10.6% of all papers, followed by the University of Johannesburg in South Africa.

Table 61: Top countries and institutions producing the core papers in the Research Front "Application of robots in tourism, marketing, and services industries, accelerated by the COVID-19 pandemic"

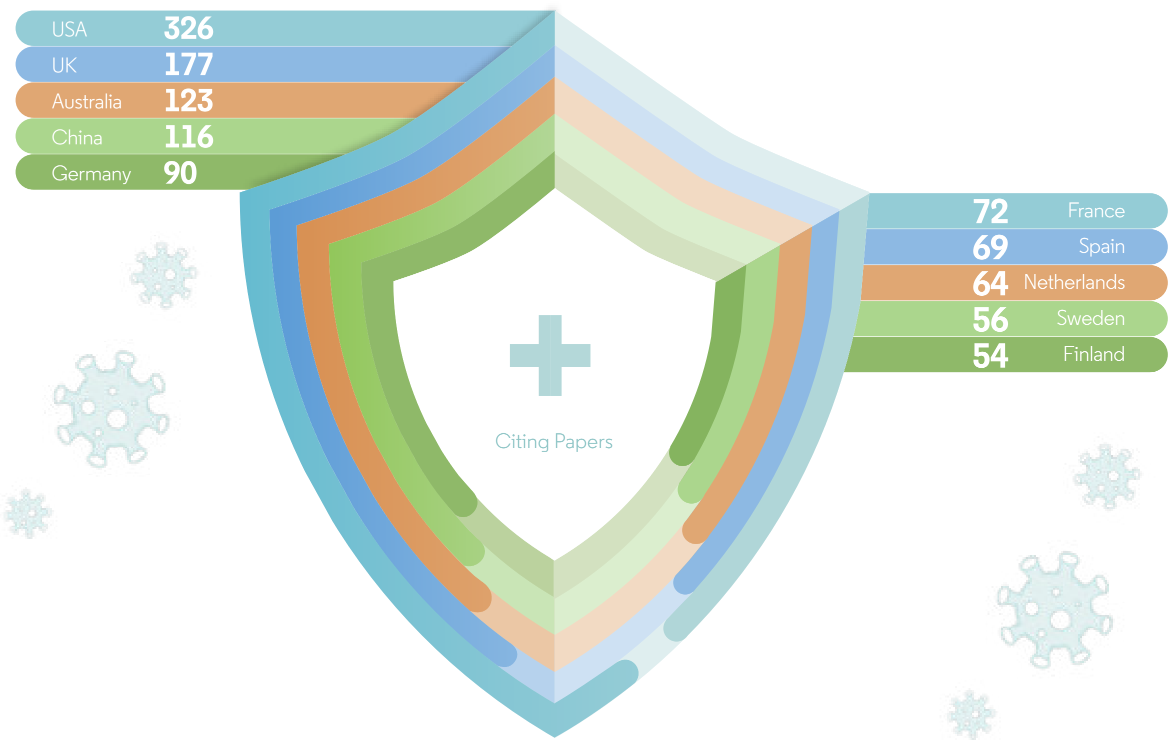
Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	21	44.7%	1	University of Queensland	Australia	5	10.6%
2	UK	12	25.5%	2	University of Johannesburg	South Africa	4	8.5%
2	Australia	12	25.5%	3	University of Southern California	USA	3	6.4%
4	Netherlands	7	14.9%	3	Arizona State University	USA	3	6.4%
4	China	7	14.9%	3	Boston College	USA	3	6.4%
6	Sweden	6	12.8%	3	EDHEC Business School	France	3	6.4%
6	Canada	6	12.8%	3	University of Groningen	Netherlands	3	6.4%
8	Germany	5	10.6%	3	HongKongPolytechnic University	China	3	6.4%
9	Finland	4	8.5%	3	Florida State University	USA	3	6.4%
9	South Africa	4	8.5%	3	University of Surrey	UK	3	6.4%
9	France	4	8.5%	3	Babson College	USA	3	6.4%
				3	University of South Australia	Australia	3	6.4%



In terms of citing papers (Table 62), the USA ranks 1st with 326 citing papers, and the UKUK, Australia, and China each contribute more than 100. The table shows that China's attention to this specialty area is gradually increasing. At the institutional level, entities from the USA and Europe are the mainstays. Karlstad University in Sweden and Maastricht University in the Netherlands have the most citing papers, while the Hong Kong Polytechnic University ranks 3rd.

Table 62: Top countries and institutions producing citing papers in the Research Front "Application of robots on tourism, marketing, and services & the positive effects of COVID-19 on it"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	326	26.0%	1	Karlstad University	Sweden	27	2.1%
2	UK	177	14.1%	1	Maastricht University	Netherlands	27	2.1%
3	Australia	123	9.8%	3	HongKongPolytechnic University	China	25	2.0%
4	China	116	9.2%	4	University of Queensland	Australia	24	1.9%
5	Germany	90	7.2%	5	University of Surrey	UK	23	1.8%
6	France	72	5.7%	6	University of Zaragoza	Spain	20	1.6%
7	Spain	69	5.5%	7	Fordham University	USA	17	1.4%
8	Netherlands	64	5.1%	7	Queensland University of Technology	Australia	17	1.4%
9	Sweden	56	4.5%	7	University of Johannesburg	South Africa	17	1.4%
10	Finland	54	4.3%	10	Florida State University	USA	16	1.3%



2. EMERGING RESEARCH FRONT

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

Seven specialty areas within economics, psychology, and other social sciences have been selected as emerging Research Fronts. Among them, four fronts are related to the COVID-19 epidemic. Specifically, these four focus on: the measurement and evaluation of the COVID-19 fear scale; the investigation of the mental health problems of medical staff; surveys of knowledge, attitudes, and practices surrounding COVID-19 in various countries; and the impact of COVID-19 on financial markets. Among these fronts, "Psychometric assessment of COVID-19 anxiety" was chosen as the key Emerging Research Front of 2020 in economics, psychology and other social sciences.

Table 63: Emerging Research Fronts in economics, psychology and other social sciences

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Psychometric assessment of COVID-19 anxiety	16	762	2020
2	Surveys of knowledge, attitudes and practices of COVID-19 in various countries	12	636	2020
3	COVID-19 and financial market volatility	10	202	2020
4	Application of Comprehensive Fuzzy Multi-criteria Decision Method	10	194	2020
5	COVID-19 and the mental health of medical staff	6	192	2020
6	Immigrant Family Research	9	129	2019.8
7	New method of stock return forecast (economic constraint method)	7	131	2019.7

2.2 KEY EMERGING RESARCH FRONT – "Psychometric assessment of COVID-19 anxiety"

As noted above, the social impact of the COVID-19 pandemic has become a field of study unto itself. Fear of the disease has caused unprecedented mental health problems. A more general phobia toward coronavirus has appeared, which has seriously affected people's everyday life and productivity. "Coronaphobia," a relatively new pandemic-related construct, is strongly tied to functional impairment and psychological distress. The extent of the problem compelled researchers to systematically investigate the psychological distress experienced by the public during the crisis. To address mental-health problems caused or exacerbated by the pandemic, social scientists and psychologists are studying the development of fear, anxiety, stress, and other mental fallout. This activity has now attained sufficient critical mass to constitute an officially emergent Research Front.

Research from this front's 16 core papers shows that the current psychological measurement and evaluation of coronaphobia now involves separate evaluative scales: these include the Fear of COVID-19 Scale (FCV-19S); the Coronavirus Anxiety Scale (CAS; the Pandemic Grief Scale (PGS); the Fear of the Coronavirus Questionnaire (FCQ); and the COVID Stress Scales (CSS). Each scale has a different measurement structure and specifics, and each has carried out a multi-sample reliability and validity test.

Using these tools, researchers have determined that, compared with the general population, people with existing mental health conditions may be more susceptible to stressors related to new coronary pneumonia. For example, people with anxiety or mood disorders are more negatively affected by new coronary pneumonia; people with anxiety disorders are more worried about danger, pollution, and socio-economic consequences, showing symptoms of xenophobia and traumatic stress; the use of new media and more media participation are related to negative psychological results, but some media content is related to positive psychological effects. These studies indicate that health professionals should be fully aware of the existence of coronaphobia and the necessity of timely communication with the public through official channels. Meanwhile, these papers also provide informative insights for government policymaking on how to slow the spread of the virus.

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.

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