2020 RESEARCH FRONTS

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I. METHODOLOGY

1. BACKGROUND

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

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

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

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

In 2013, Clarivate published an inaugural report in which 100 hot Research Fronts were identified. In 2014 and 2015, *Research Fronts 2014* and *Research Fronts 2015* were undertaken as a collaborative project by the Joint Research Center of Emerging Technology Analysis established by Clarivate and the National Science Library, Chinese Academy of Sciences (CAS). In 2016, 2017, 2018, and 2019, 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*, and *Research Fronts 2019*. These reports have gained widespread attention from around the world.

This year, the same methodology was employed. For the newest edition, *Research Fronts 2020*, 110 hot Research Fronts and 38 emerging Research Fronts were identified based on co-citation analysis that generated 11,626 Research Fronts in the Clarivate database Essential Science Indicators (ESI).

2. METHODOLOGY AND PRESENTATION OF DATA

The study was conducted in two parts. Clarivate selected Research Fronts and provided data on the core papers and citing papers of the selected 148 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 within the Institutes of Science and Development, CAS. For the 2020 update, the Research Fronts drew on ESI data from 2014 to 2019, which were obtained in March 2020.

2.1 RESEARCH FRONTS SELECTION

Research Fronts 2020 presents a total of 148 Research Fronts, including 110 hot and 38 emerging ones. In 2020, the Research Fronts are classified into 11* broad research areas in the sciences and social sciences. Starting from 11,626 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 148 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 a Top 10 list in each broad area, 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 and citation behaviors in various disciplines, some fronts are much smaller than others in terms of number of core and citing papers.

2.1.2 SELECTING THE EMERGING RESEARCH FRONTS

A Research Front with core papers of recent vintage indicates a specialty with a young foundation that is rapidly growing. To identify emerging specialties, the immediacy of the core papers is a priority, and that is why it is characterized as “emerging.” 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 2018 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 analysts with domain knowledge made the final selection of emerging Research Fronts and grouped them into 11 broader fields. Thirty-eight fronts were selected as emerging, and the earliest mean year of the emerging fronts was 2018.6. Because the selection was not limited to any research area, the 38 fronts are distributed unevenly in the 11 fields. For example, there is no emerging Research Front in Mathematics and Information Science, while there are six emerging Research Fronts in "Chemistry and Materials Sciences”, but only one in “Ecology and Environmental Sciences", "Geosciences", and “Astronomy and Astrophysics.”

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 38 emerging ones.

* 21 ESI fields were classified into 11* broad research areas. In Research Fronts 2020, the broader area of Mathematics, Computer Science and Engineering in previous reports has been split into two areas: Mathematics, and Information Science. In this report, the field of Engineering is no longer covered.

2.2 FINAL SELECTION AND INTERPRETATION OF KEY RESEARCH FRONTS

Based on 148 Research Fronts provided by Clarivate, analysts at the Institute of Strategic Information, conducted a detailed analysis and interpretation to highlight 31 key Research Fronts (Chapter 2 to Chapter 12) of particular interest, including both hot and emerging fronts.

As discussed above, a Research Front consists of a core of highly cited papers along with the citing papers that have frequently co-cited the core. In other words, core papers are all highly cited papers in ESI – papers that rank in the top 1% in terms of citations in the same ESI field and in the same publication year. Since the authors, institutions and countries/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 2019 and the earliest citing paper was published in 2015, 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 2020, 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.

By taking advantage of the above two indicators as well as our domain experts' judgment, we selected 22 key hot Research Fronts from the 110 hot Research Fronts in the 11 broad research areas. Moreover, based on CPT and experts' judgment, nine key emerging Research Fronts were selected from the 38 emerging Research Fronts. Thus, we interpret in detail the selected 31 key Research Fronts from the 148 Research Fronts.

2.2.2 PRESENTATION AND DISCUSSION OF KEY RESEARCH FRONTS

(1) Examination of key hot Research Fronts

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. The selected key Research Fronts are highlighted with a purple background and are subsequently examined in greater detail. Since the papers analyzed in this report were published between 2014 and 2019, their average publication year will also fall into this period.

A bubble diagram shows the age distribution of the citing articles in the 10 Research Fronts listed for each broad area. Key hot Research Fronts selected based on core papers (P) are marked in blue bubbles, and those selected based on CPT are marked in red bubbles. 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.

The second table for each area analyzes the affiliated countries and institutions of the core papers, thereby revealing the players making fundamental contributions in the key hot Research Fronts. Countries and institutions of the citing papers are analyzed in the third 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 data to better understand the content, research efforts, and ongoing trends in the key emerging Research Fronts.

II. AGRICULTURAL, PLANT AND ANIMAL SCIENCES

1. HOT RESEARCH FRONT

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

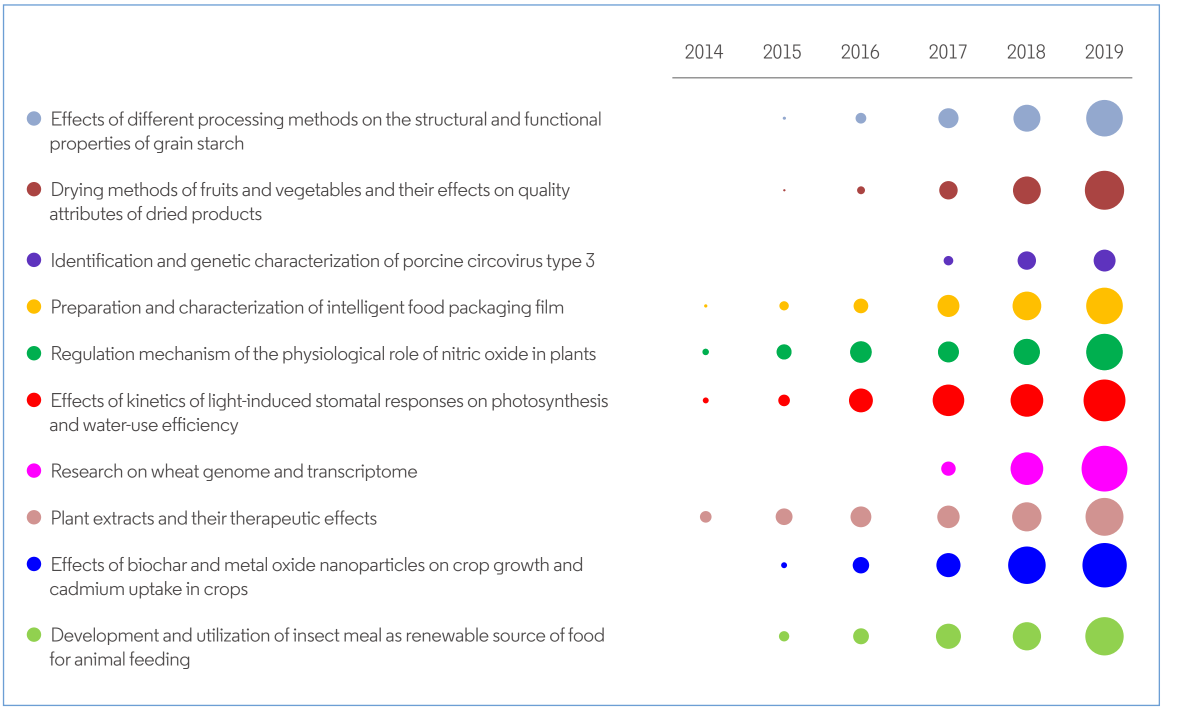
The Top 10 hot Research Fronts in agricultural, plant and animal sciences mainly involve six subfields, consisting of food science and engineering, animal infectious diseases, plant physiology, crop science, medicinal plants, and animal nutrition (Table 1). Among these specialties, the subfield of food science and engineering accounts for the largest share of the Top 10, with three hot Research Fronts, pertaining respectively to food processing methods, the drying and processing of fruits and vegetables, and food-intelligent packaging. One hot Research Front on animal infectious diseases involves the identification and genetic characteristics of porcine circovirus type 3. Two hot Research Fronts occupy the subfield of plant physiology, studying the physiological effects of nitric oxide and light-induced stomatal dynamics. Crop science also accounts for two hot Research Fronts, one devoted to the wheat genome and transcriptome, the other to crop growth and heavy metal pollution control. One hot Research Front is related to medicinal plants, examining the therapeutic effects of plant extracts on diseases. There is also one hot Research Front on animal nutrition, studying how to use insect powder as a new renewable animal feed resource.

Compared with previous years, the subfield of food science and engineering registers a higher number of hot fronts. Among them, smart packaging and animal infectious diseases mark their first appearances on the Top 10 hot Research Front list. In the medicinal plant subfield, the topic of gene regulation of medicinal compounds was previously highlighted in the Top 10 report in 2018, while the therapeutic effect of plant extracts is highlighted in 2020. In the subfield of animal nutrition, a hot front from the 2018 report is on feed additives, while now reflects updated research on alternative resources for animal feed.

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

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Effects of different processing methods on the structural and functional properties of grain starch	20	669	2018
2	Drying methods of fruits and vegetables and their effects on quality attributes of dried products	23	725	2017.8
3	Identification and genetic characterization of porcine circovirus type 3	20	863	2017.7
4	Preparation and characterization of intelligent food packaging film	22	905	2017.6
5	Regulation mechanism of the physiological role of nitric oxide in plants	24	962	2017.4
6	Effects of kinetics of light-induced stomatal responses on photosynthesis and water-use efficiency	18	1344	2017.3
7	Research on wheat genome and transcriptome	9	967	2017.3
8	Plant extracts and their therapeutic effects	15	946	2017.2
9	Effects of biochar and metal oxide nanoparticles on crop growth and cadmium uptake in crops	18	1426	2017.1
10	Development and utilization of insect meal as renewable source of food for animal feeding	35	1888	2017

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



1.2 KEY HOT RESEARCH FRONT – "Effects of kinetics of light-induced stomatal responses on photosynthesis and water-use efficiency"

As the world's population grows, the increase in global demand for staple foods now outpaces the increase in yields, and the gap is widening. The methods of the Green Revolution, which transformed global agriculture during the 1950s and 1960s, have now reached the biological limit of yield growth, and the rate of yield growth is slowing and even threatening to stagnate. The use of photosynthesis to increase crop yield, although it has become a key method for that purpose, is still very limited, and far from its full biological potential. Therefore, it is urgent to accelerate the understanding of the processes and mechanisms of crop photosynthesis. Leaf stomata can affect plant productivity and water-use efficiency by controlling the absorption of carbon dioxide during photosynthesis and transpiration. Thus, the study of light-induced stomatal dynamics in photosynthesis and water use has become an important Research Front.

Eighteen core papers underlie this hot front, focusing on the anatomical, physiological, and biochemical mechanisms of leaf stomata opening and closing, and regulation strategies to improve these processes. Specifically, the front pertains to the effects of anatomical, physiological, and biochemical characteristics on the rapidity of stomata opening and closing, the change rate of stomatal conductance, and the relationship between the rapidity of stomata opening and closing with CO_2 absorption and water use during photosynthesis. For the regulation research, efforts center on the following: the optogenetic manipulation of stomatal dynamics; the effect of some protein genes (such as the H protein of the glycine cleavage system, the photosystem II subunit S, 1,7-bisphosphatase, fructose 1,6-bisphosphate aldolase and photorespiration glycine decarboxylase-H protein) on photosynthesis, water-use efficiency, and crop growth and yield; and the effect of light fluctuations on stomatal conductance and photosynthesis.

Among the top 10 countries and institutions producing this front's core papers (Table 2), the UK can boast the highest contribution, reaching 77.8%. The USA ranks 2nd, accounting for 38.9% of the total. Among the prolific contributing institutions, the University of Essex in the UK ranks 1st, with a contribution rate of 50.0%, followed by the University of Illinois at Urbana-Champaign in the USA.

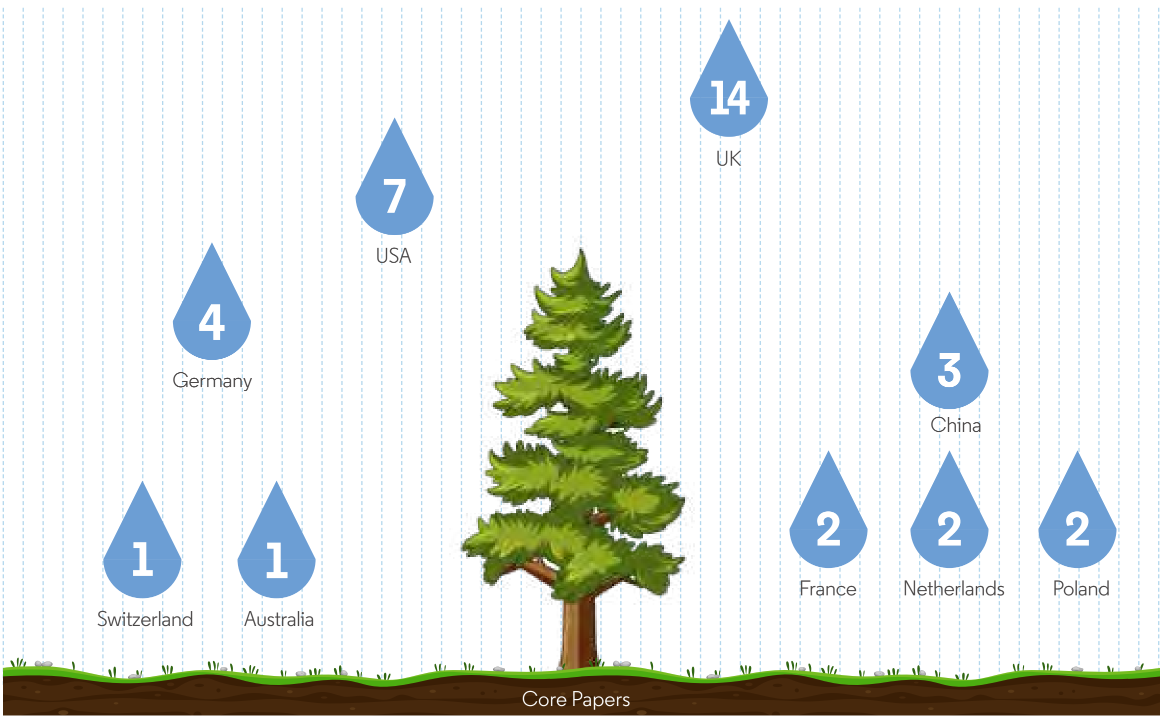


Table 2: Top countries and institutions producing core papers in the Research Front "Effects of kinetics of light-induced stomatal responses on photosynthesis and water-use efficiency"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	UK	14	77.8%	1	University of Essex	UK	9	50.0%
2	USA	7	38.9%	2	University of Illinois Urbana-Champaign	USA	7	38.9%
3	Germany	4	22.2%	3	United States Department of Agriculture (USDA)	USA	5	27.8%
4	China	3	16.7%	4	University of California Berkeley	USA	4	22.2%
5	Poland	2	11.1%	5	Lawrence Berkeley National Laboratory	USA	3	16.7%
5	Netherlands	2	11.1%	5	Howard Hughes Medical Institute	USA	3	16.7%
5	France	2	11.1%	7	University of Glasgow	UK	2	11.1%
8	Switzerland	1	5.6%	7	Polish Academy of Sciences	Poland	2	11.1%
8	Australia	1	5.6%	7	Max Planck Society	Germany	2	11.1%
				7	Lancaster University	UK	2	11.1%
				7	Heinrich Heine University Dusseldorf	Germany	2	11.1%
				7	Chinese Academy of Sciences	China	2	11.1%

In terms of countries that cite the core papers in this hot front (Table 3), the USA is the most prolific contributing country, while the UK ranks 2nd. China ranks 3rd and performs better in terms of citing activity than in its contribution to core papers. In terms of citing institutions, the Max Planck Society in Germany, the University of Illinois at Urbana-Champaign in the USA, and the Australian National University are in the lead, with the Chinese Academy of Sciences ranking 4th.

Table 3: Top countries and institutions producing citing papers in the Research Front "Effects of kinetics of light-induced stomatal responses on photosynthesis and water-use efficiency"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	267	29.6%	1	Max Planck Society	Germany	61	6.8%
2	UK	195	21.6%	2	University of Illinois Urbana-Champaign	USA	56	6.2%
3	China	163	18.1%	3	Australian National University	Australia	42	4.7%
4	Germany	135	15.0%	4	University of Essex	UK	40	4.4%
5	Australia	99	11.0%	4	Chinese Academy of Sciences	China	40	4.4%
6	France	49	5.4%	6	United States Department of Agriculture (USDA)	USA	34	3.8%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
7	Netherlands	49	5.4%	7	National Research Institute for Agriculture, Food and Environment	France	33	3.7%
8	Spain	49	5.4%	8	Lancaster University	UK	30	3.3%
9	Brazil	41	4.5%	9	Wageningen University & Research Center	Netherlands	27	3.0%
10	Japan	39	4.3%	10	French National Center for Scientific Research (CNRS)	France	25	2.8%

1.3 KEY HOT RESEARCH FRONT – "Effects of biochar and metal oxide nanoparticles on crop growth and cadmium uptake in crops"

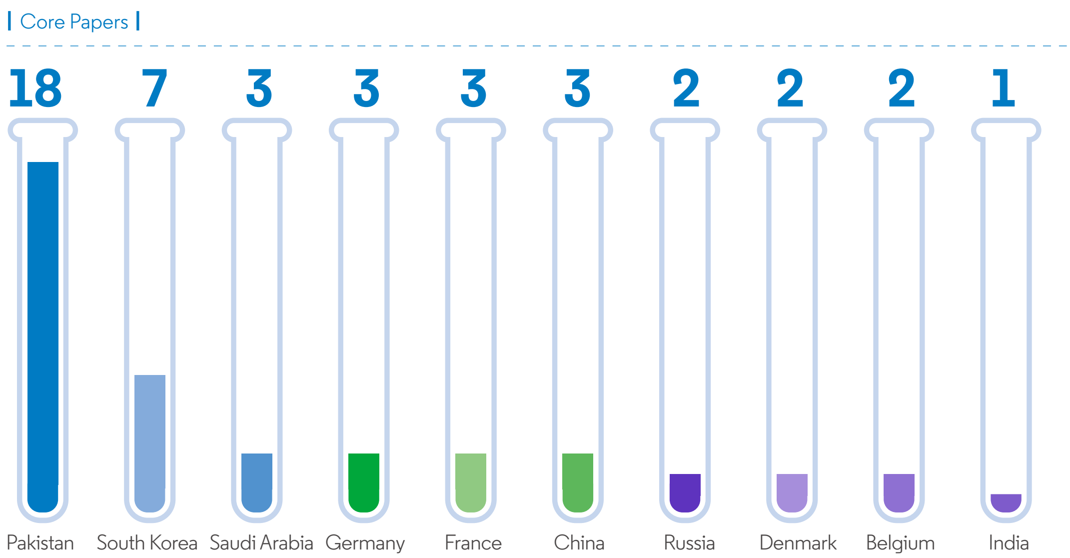
Today, heavy-metal pollution is a growing problem. These pollutants mainly accumulate in the soil and then transfer to the food chain through crops growing in the contaminated soil, threatening human health globally and constituting a major obstacle to sustainable agricultural food production. The problem of cadmium pollution is particularly serious, with occasional incidents of cadmium exceeding safety standards. Therefore, the remediation of cadmium pollution in soil, and the reduction of cadmium absorption and accumulation in crops, have become the hot research topic in the field of agricultural science and technology. As soil amendments, biochar and oxide nanoparticles can not only alleviate the toxicity of cadmium, but also reduce the adverse effects of drought and salt stress on crops, thus promoting crop growth. Therefore, work on the effects of biochar and metal oxide nanoparticles on crop growth and cadmium absorption has become the current hot Research Front.

Eighteen papers constitute the core of this front. They focus on the effects of the application of biochar, various metal oxide nanoparticles and other soil amendments, alone or combination, on crop growth and cadmium uptake and accumulation. The application models of soil amendments include biochar alone, silicon nanoparticles alone, zinc and iron oxide nanoparticles in combination, combined biochar and zinc oxide nanoparticles, and biochar application combined with limestone and lignite. The research results show that these soil amendments not only play a role in reducing the absorption and accumulation of cadmium, but also have a positive impact on crop growth, yield, and stress tolerance.

Among the Top 10 countries and institutions producing core papers (Table 4), Pakistan has the highest contribution rate of 100%, and almost all its papers are published in collaboration with other countries. South Korea ranks 2nd, and China ranks 3rd together with Saudi Arabia, Germany, and France. Among the top contributing institutions, Government College University Faisalabad, University of Agriculture Faisalabad, and Bahaddin Zakaria University from Pakistan perform outstandingly and are listed in the top three.

Table 4: Top countries and institutions producing core papers in the Research Front "Effects of biochar and metal oxide nanoparticles on crop growth and cadmium uptake in crops"

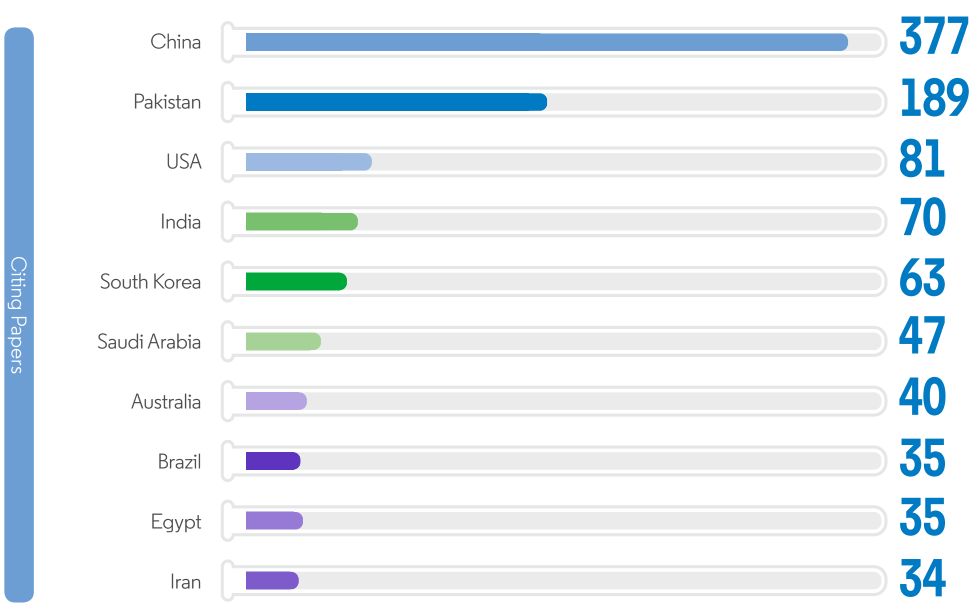
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Countries	Core Papers	Proportion
1	Pakistan	18	100.0%	1	Government College University Faisalabad	Pakistan	18	100.0%
2	South Korea	7	38.9%	2	University of Agriculture Faisalabad	Pakistan	14	77.8%
3	Saudi Arabia	3	16.7%	3	Bahauddin Zakariya University	Pakistan	7	38.9%
3	Germany	3	16.7%	4	Kangwon National University	South Korea	5	27.8%
3	France	3	16.7%	5	University of Wuppertal	Germany	3	16.7%
3	China	3	16.7%	5	University of Aix-Marseille	France	3	16.7%
7	Russia	2	11.1%	5	King Saud University	Saudi Arabia	3	16.7%
7	Denmark	2	11.1%	5	French National Research Institute for Sustainable Development (IRD)	France	3	16.7%
7	Belgium	2	11.1%	5	French National Center for Scientific Research (CNRS)	France	3	16.7%
10	India	1	5.6%					



In terms of countries that cite the core papers of this hot front (Table 5), China is the top contributor, accounting for nearly 45% -- far ahead of other countries, with its contribution rate at twice that of 2nd-ranked Pakistan. The leading citing institution is Government College University Faisalabad of Pakistan, followed by University of Agriculture Faisalabad of Pakistan, and the Chinese Academy of Sciences in turn.

Table 5: Top countries and institutions producing citing papers in the Research Front "Effects of biochar and metal oxide nanoparticles on crop growth and cadmium uptake in crops"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	377	44.8%	1	Government College University Faisalabad	Pakistan	120	14.3%
2	Pakistan	189	22.4%	2	University of Agriculture Faisalabad	Pakistan	86	10.2%
3	USA	81	9.6%	3	Chinese Academy of Sciences	China	65	7.7%
4	India	70	8.3%	4	Bahauddin Zakariya University	Pakistan	50	5.9%
5	South Korea	63	7.5%	5	King Saud University	Saudi Arabia	35	4.2%
6	Saudi Arabia	47	5.6%	5	Chinese Academy of Agricultural Sciences	China	35	4.2%
7	Australia	40	4.8%	7	Kangwon National University	South Korea	27	3.2%
8	Brazil	35	4.2%	8	Huazhong Agricultural University	China	25	3.0%
8	Egypt	35	4.2%	9	COMSATS University Islamabad	Pakistan	24	2.9%
10	Iran	34	4.0%	10	Korea University	South Korea	23	2.7%



2. EMERGING RESEARCH FRONT

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

In the area of agricultural, plant and animal sciences, one emerging Research Front has been identified: "Research on biological regulation technology and mechanism of degradable waste resource utilization" (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	Research on biological regulation technology and mechanism of degradable waste resource utilization	5	81	2019

2.2 KEY EMERGING RESEARCH FRONT – "Research on biological regulation technology and mechanism of degradable waste resource utilization"

Degradable waste refers to organic waste that can be decomposed naturally, including food waste from urban life, urban sludge and organic domestic waste, as well as livestock and poultry manure and farming waste generated during agricultural production. With the rapid development of China's economy and the continuous improvement in its people's living standard, China's biodegradable wastes have shown various types of characteristics: large quantities, low value, high pathogenicity, and low resource utilization, which have brought serious hidden dangers to ecological safety and health, and to the prevention of epidemics. Currently, organic waste disposal methods have gradually changed from discarding and composting to microbial conversion-based composting and anaerobic digestion technology. Pertinent research focuses on the succession of microbial communities during fermentation, but there are few studies on biological regulation and mechanisms. In addition, research on the biotransformation of organic wastes by insects such as fly maggots and water flies is in its infancy. In particular, the regulation mechanism of efficient insect-microbe transformation will become a hot topic in the future.

The core papers in this emerging Research Front focus on: the role of bacterial communities in the transformation of organic nitrogen toward enhanced bioavailability during composting with different wastes; assessment of the evolution of multiorigin humin components and influencing factors during composting; diversity in the mechanisms of humin formation during composting with different materials; enhanced biotic contributions to the dechlorination of pentachlorophenol by humus respiration from different compostable environments; and the improvement of lignocellulose-degrading performance during straw composting from diverse sources with actinomycetes inoculation by regulating the activity of key enzymes.

III. 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 ecological and environmental sciences, as the name implies, are mainly distributed in two sub-areas: environmental-science topics pertaining to the analysis, treatment and risk of pollutants; and ecological-science topics related to examining changes and impacts to ecosystems. Throughout the Top 10 hot Research Fronts, the predominant themes involve water environments, specific pollutants, and multidisciplinary solutions to today's most pressing environmental concerns.

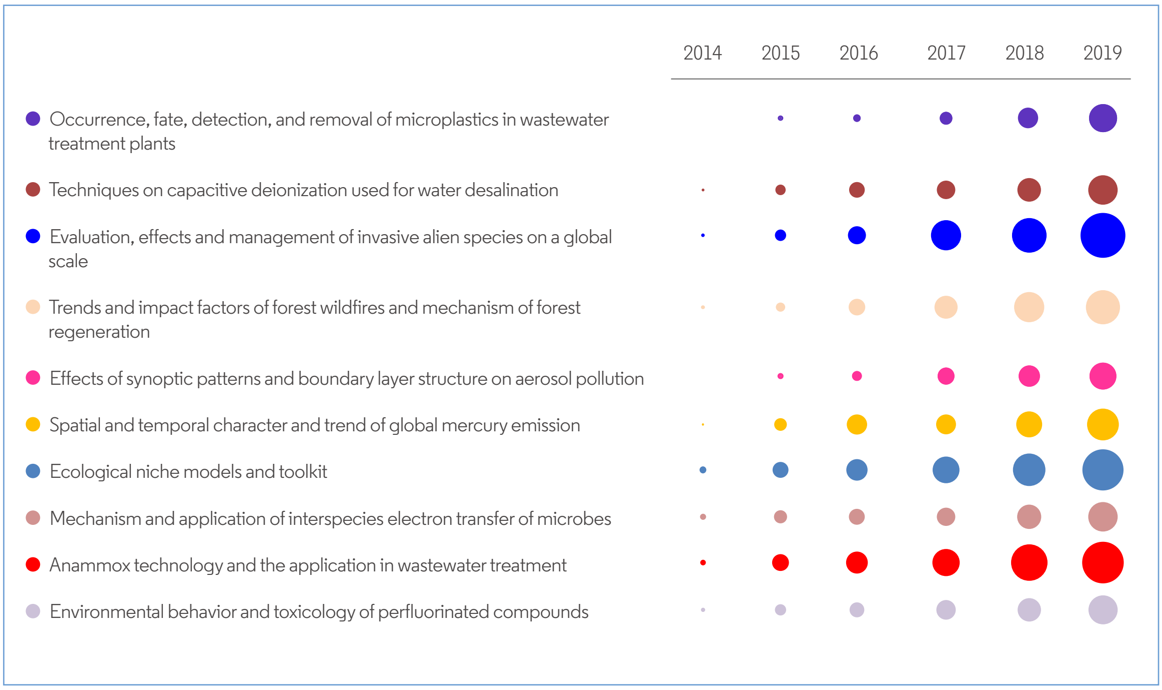
Seven hot Research Fronts (Table 7 and Figure 2) are devoted to the environmental-science subfield and mainly focus on sewage-treatment theory and technology, as well as the character, fate, and risk of environmental pollutants. The hot fronts related to sewage treatment include "Anammox technology and application in wastewater treat-ment", "Mechanism and application of interspecies electron transfer of microbes", and "Occurrence, fate, detection, and removal of microplastics in wastewater treatment plants". The first two of these specialty areas also appeared among the hot Research Fronts of 2019, while the latter front represents the response to the pollution issue of microplastics in ocean and inland waters, an issue that has garnered worldwide attention in recent years. The Research Fronts related to the fate and risk of pollutants focus on pervasive as well as emerging pollutants worldwide, including "Spatial and temporal character and trend of global mercury emission" and "Environmental behavior and toxicology of perfluorinated compounds". "Spatial and temporal character and trend of global mercury emission" has also appeared in the previous reports for 2016 and 2017. New among the environmental-science subfields for 2020 are "Effects of synoptic patterns and boundary layer structure on aerosol pollution" and "Techniques on capacitive deionization used for water desalination".

The other three hot Research Fronts in the ecological-science subfield mainly emphasize bioinvasion, forest wildfires, and ecology models, including "Evaluation, effects and management of invasive species on a global scale", "Trends and impact factors of forest wildfires and mechanism of forest regeneration", and "Ecological niche models and toolkit". "Evaluation, effects and management of invasive species on a global scale" has been selected as a hot Research Front for three consecutive years.

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

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Occurrence, fate, detection, and removal of microplastics in wastewater treatment plants	16	1292	2017.4
2	Techniques on capacitive deionization used for water desalination	23	1991	2017.1
3	Evaluation, effects and management of invasive alien species on a global scale	34	2751	2017
4	Trends and impact factors of forest wildfires and mechanism of forest regeneration	15	1786	2016.9
5	Effects of synoptic patterns and boundary layer structure on aerosol pollution	12	963	2016.8
6	Spatial and temporal character and trend of global mercury emission	19	1557	2016.5
7	Ecological niche models and toolkit	17	2491	2016.4
8	Mechanism and application of interspecies electron transfer of microbes	18	1909	2016.4
9	Anammox technology and the application in wastewater treatment	28	2799	2016.3
10	Environmental behavior and toxicology of perfluorinated compounds	14	1322	2016.3

Figure 2: Citing papers for the Top 10 Research Fronts in ecology and environmental sciences



1.2 KEY HOT RESEARCH FRONT – "Evaluation, effects and management of invasive alien species on a global scale"

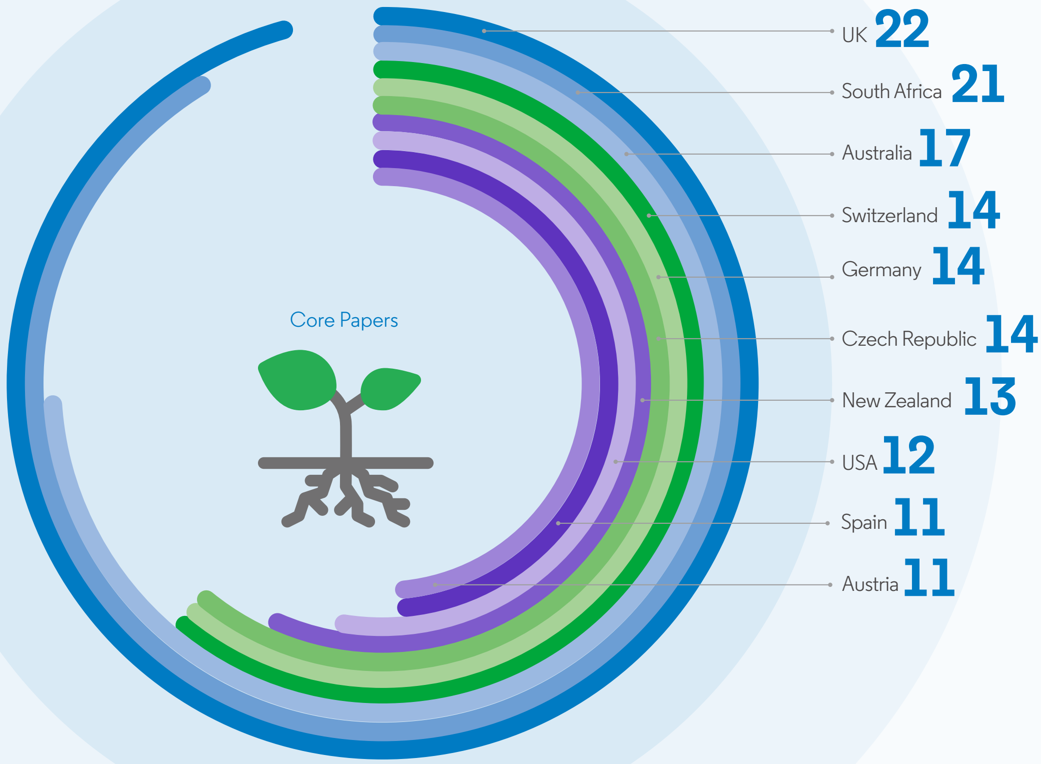
Invasive alien species (IAS) are species that are introduced into new areas and, once there, are able to adapt, become established, reproduce, and spread, colonizing the environment, creating new populations and impacting biodiversity, health and the economy. IAS are often introduced as a result of the globalization of economies through the movement of people and goods, for instance, via shipping, consignments of wood products carrying insects, or the transport of ornamental plants to new areas. Increasing globalization and international and trans-regional trade and communication facilitate IAS arrival, establishment, and subsequent environmental impacts. In recent years, the numbers of invasive species has been increasing rapidly, and IAS are expanding globally at an unprecedented speed. Research on the evaluation, effects, and management of IAS on a global scale has become a hot theme in ecology and has now registered among the Research Fronts for the third consecutive year.

Thirty-four core papers identify this Research Front, covering multiple themes pertaining to IAS, including the global extent, risk assessment, geographical distribution, and hot spots of IAS concentration; the variety and severity of IAS and the associated ecological and socio-economic impacts worldwide, including the effects on such factors as biodiversity, species extinction, agriculture, community livelihood and human well-being; the impacts of IAS on cities and islands; and research on public perception, decision-making, and academic research of IAS.

As for the top countries and institutions in this front (Table 8), core papers from the UK, South Africa and Australia each contribute to more than 50% of the total of 34, ranking from 1st to 3rd – a phenomenon reflecting this topic's heightened degree of international co-authorship. Core papers from Switzerland, Germany and the Czech Republic each total more than 40% of the core, giving these nations an equal share of 4th place. The main contributing institutions in terms of core papers are Stellenbosch University of South Africa, the Czech Academy of Sciences, and Charles University Prague.

Table 8: Top countries and institutions producing core papers in the Research Front "Effects and management of invasive alien species on a global scale"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	UK	22	64.7%	1	Stellenbosch University	South Africa	19	55.9%
2	South Africa	21	61.8%	2	Czech Academy of Sciences	Czech Republic	14	41.2%
3	Australia	17	50.0%	3	Charles University Prague	Czech Republic	11	32.4%
4	Switzerland	14	41.2%	4	University of Vienna	Austria	10	29.4%
4	Germany	14	41.2%	4	Spanish National Research Council (CSIC)	Spain	10	29.4%
4	Czech Republic	14	41.2%	6	Italian National Institute for Environmental Protection and Research (ISPRA)	Italy	9	26.5%
7	New Zealand	13	38.2%	7	University of Fribourg	Switzerland	8	23.5%
8	USA	12	35.3%	7	University College London	UK	8	23.5%
9	Spain	11	32.4%	7	University of Adelaide	Australia	8	23.5%
9	Austria	11	32.4%	7	Institute of Zoology - Zoological Society of London	UK	8	23.5%



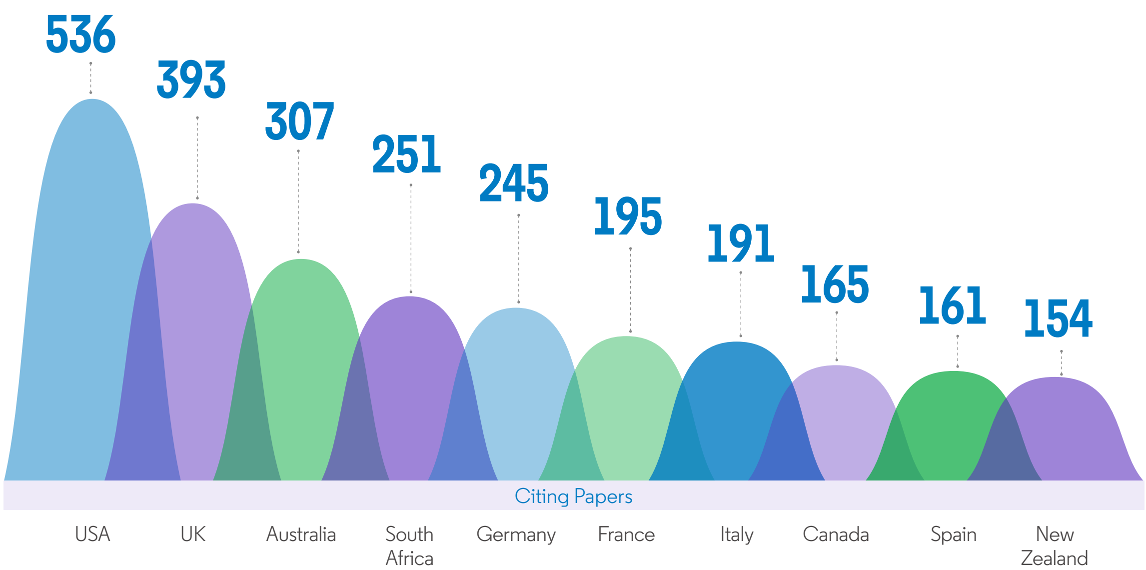
In terms of the countries and institutions that cite the core papers (Table 9), the USA, the UK, and Australia are the three most prolific in this regard. Meanwhile, the top citing institutions are located in South Africa, France, the Czech Republic and the UK.

Based on the production of both core papers and citing papers, the UK, Australia, South Africa and the USA are outstanding countries. As noted above, because this Research Front focuses on ecology issues on a global scale, the degree of international cooperation on core papers is relatively high. Among all the institutions, the Stellenbosch University of South Africa, the Czech Academy of Sciences, Charles University Prague of Czech Republic, the University of Vienna in Austria, and the Spanish National Research Council (CSIC) have contributed a large proportion of core papers and citation papers, demonstrating their important roles in this Research Front.

Table 9: Top countries and institutions producing citing papers in the Research Front "Effects and management of invasive alien species on a global scale"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	536	29.0%	1	Stellenbosch University	South Africa	170	9.2%
2	UK	393	21.3%	2	French National Center for Scientific Research (CNRS)	France	134	7.3%
3	Australia	307	16.6%	3	Czech Academy of Sciences	Czech Republic	117	6.3%
4	South Africa	251	13.6%	4	Spanish National Research Council (CSIC)	Spain	104	5.6%
5	Germany	245	13.3%	5	Charles University Prague	Czech Republic	96	5.2%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
6	France	195	10.6%	6	University of Vienna	Austria	75	4.1%
7	Italy	191	10.3%	7	United States Department of Agriculture (USDA)	USA	73	4.0%
8	Canada	165	8.9%	8	South African National Biodiversity Institute	South Africa	70	3.8%
9	Spain	161	8.7%	9	Queens University of Belfast	UK	61	3.3%
10	New Zealand	154	8.3%	10	National Research Institute for Agriculture, Food and Environment	France	56	3.0%



1.3 KEY HOT RESEARCH FRONT – "Anammox technology and the application in wastewater treatment"

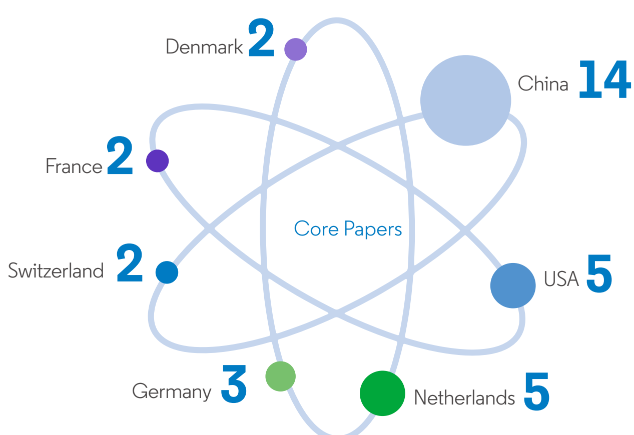
Anaerobic ammonium oxidation (anammox) technology is a new type of biological nitrogen-removal technology developed in 1990s, which has a wide potential for application in wastewater treatment. Anammox is a biological process in which the anammox bacteria oxidizes ammonium into nitrogen gas and generates nitrate with nitrite as the electron acceptor under anaerobic or anoxic conditions. The anammox process is an autotrophic biological nitrogen-removal reaction. In comparison with traditional nitrification–denitrification processes, the anammox process has various advantages, including energy saving and low sludge yield. Moreover, the anammox process does not require organic carbon sources and oxygen to proceed, nor does it produce nitrous oxide, which means lower emission of greenhouse gas. Given these advantages, anammox technology is recognized as the most promising biological nitrogen-removal technology at present. Anammox has been intensely studied around the world, and related research topics have now been selected among the hot Research Fronts for the second year.

Twenty-eight core papers anchor this Research Front, largely focusing on four aspects: (1) The exploration of different anammox processes; (2) Effects of factors such as influent C/N ratios and temperature on the wastewater treatment with anammox technology; (3) Research on physiology, microbiome, microbial community interaction and microbial ecology of anammox bacteria; and (4) The composition, structure, and function of extracellular polymeric substances (EPS) in granular sludge, and strategies for controlling them. Based on the mechanism of anammox, scientists have developed several processes, such as the combined technology of partial nitrification-anammox (PN-anammox) process. In 2014, Karlsruhe Institute of Technology in Germany and a multinational European team published a paper in *Water Research* that investigated and summarized the development, implementation and optimization of the combined process of partial nitritation/anammox. At this writing the paper has been cited 610 times, making it the most-cited core paper in this front.

According to the statistics on top countries and institutions in this front (Table 10), most of the core papers (14) list contributing authors in China, accounting for 50% of the total 28 core papers. The USA and the Netherlands both account for five papers, tying them for 2nd place. The main contributing institutions of the core papers are also based in China. Beijing University of Technology, Harbin Institute of Technology, and Hunan University rank 1st, 3rd, and 4th, respectively.

Table 10: Top countries and institutions producing core papers in the Research Front "Anammox technology and the application in wastewater treatment"

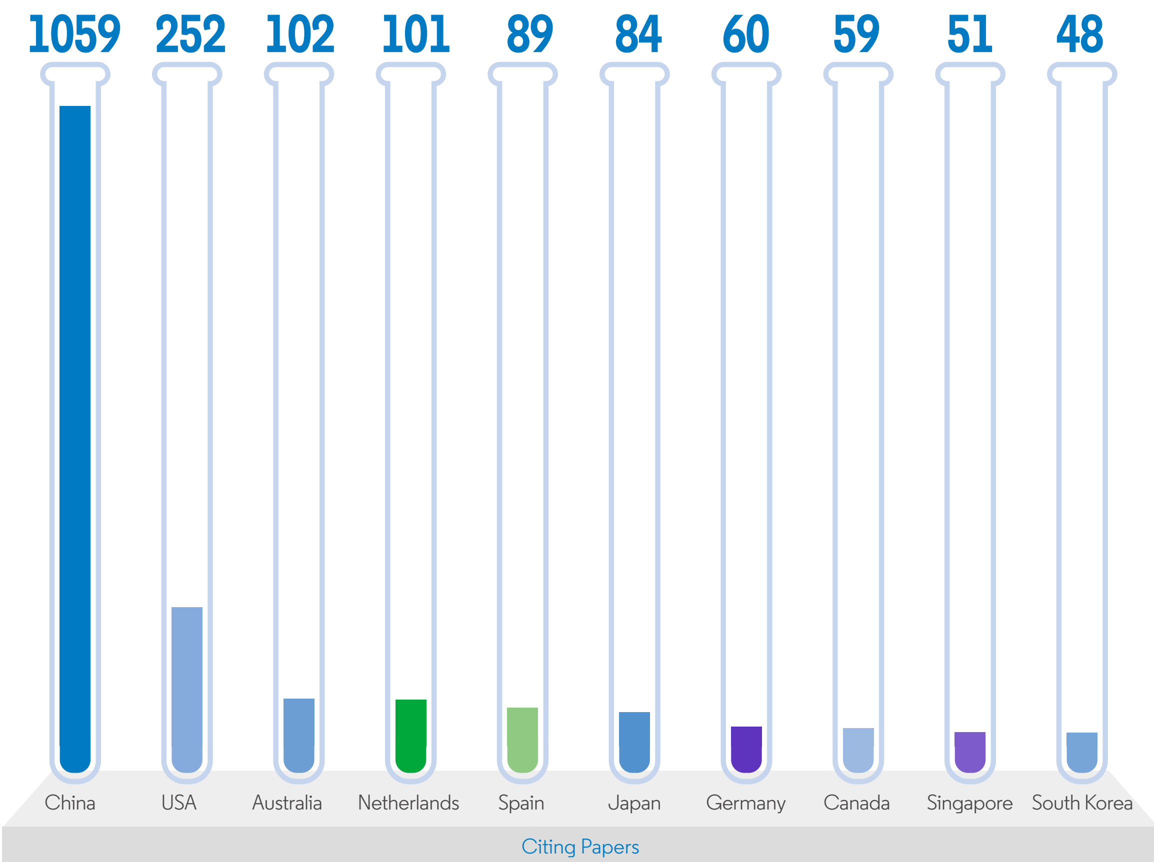
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	14	50.0%	1	Delft University of Technology	Netherlands	5	17.9%
2	USA	5	17.9%	1	Beijing University of Technology	China	5	17.9%
2	Netherlands	5	17.9%	3	Harbin Institute of Technology	China	4	14.3%
4	Germany	3	10.7%	4	Hunan University	China	3	10.7%
5	Switzerland	2	7.1%	5	Swiss Federal Institutes of Technology Domain	Switzerland	2	7.1%
5	France	2	7.1%	5	Karlsruhe Institute of Technology	Germany	2	7.1%
5	Denmark	2	7.1%	5	Helmholtz Association	Germany	2	7.1%
				5	Aalborg University	Denmark	2	7.1%



By the measure of citing papers (Table 11), China is still the most important source of reports that cite the core papers of this front. In terms of institutions, six of the top 10 institutions are situated in China. Data analysis shows that China is leading the activity in this Research Front, in terms of both core and citing papers, and Chinese institutions also play important roles in this front.

Table 11: Top countries and institutions producing citing papers in the Research Front "Anammox technology and the application in wastewater treatment"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	1059	57.5%	1	Harbin Institute of Technology	China	133	7.2%
2	USA	252	13.7%	2	Beijing University of Technology	China	123	6.7%
3	Australia	102	5.5%	3	Chinese Academy of Sciences	China	116	6.3%
4	Netherlands	101	5.5%	4	Delft University of Technology	Netherlands	70	3.8%
5	Spain	89	4.8%	5	Tongji University	China	58	3.2%
6	Japan	84	4.6%	6	University of Queensland	Australia	51	2.8%
7	Germany	60	3.3%	7	Nanyang Technological University	Singapore	46	2.5%
8	Canada	59	3.2%	8	Tsinghua University	China	41	2.2%
9	Singapore	51	2.8%	9	Zhejiang University	China	38	2.1%
10	South Korea	48	2.6%	10	Ghent University	Belgium	35	1.9%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ECOLOGY AND ENVIRONMENTAL SCIENCES

The area of ecology and environmental sciences features one emerging Research Front: "Impact of blended biodiesel and additive on performance and emission of biodiesel fueled diesel engine".

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 blended biodiesel and additive on performance and emission of biodiesel fueled diesel engine	14	208	2018.9

2.2 KEY EMERGING RESARCH FRONT – "Impact of blended biodiesel and additive on performance and emission of biodiesel fueled diesel engine"

Biodiesel is an engine fuel created by chemically reacting fatty acids and alcohol. Practically speaking, this usually means combining vegetable oil or animal fat with methanol or ethanol in the presence of a catalyst. Biodiesel is a new type of liquid fuel which can partly replace petroleum diesel. It is non-toxic, biodegradable, renewable, environmentally friendly, and available from a wide range of raw-material sources, while also demonstrating good performance in engine starting and combustion with low exhaust emission. Biodiesel is of great strategic significance in reducing diesel engine emission and pollution, reducing environmental pressure, and promoting energy structure adjustment. It has been considered one of the most promising alternatives to petrol fuels. Many countries are vigorously promoting the development and application of biodiesel, making the key technologies of biodiesel production and the combustion performance of biodiesel major points of study.

The main content of this emerging Research Front concerns studying the actions of biodiesel blended with alcohol, water or acetone, and additives such as nano-additive and oxygenated additive on engine performance, combustion and emission characteristics.

IV. GEOSCIENCES

1. HOT RESEARCH FRONT

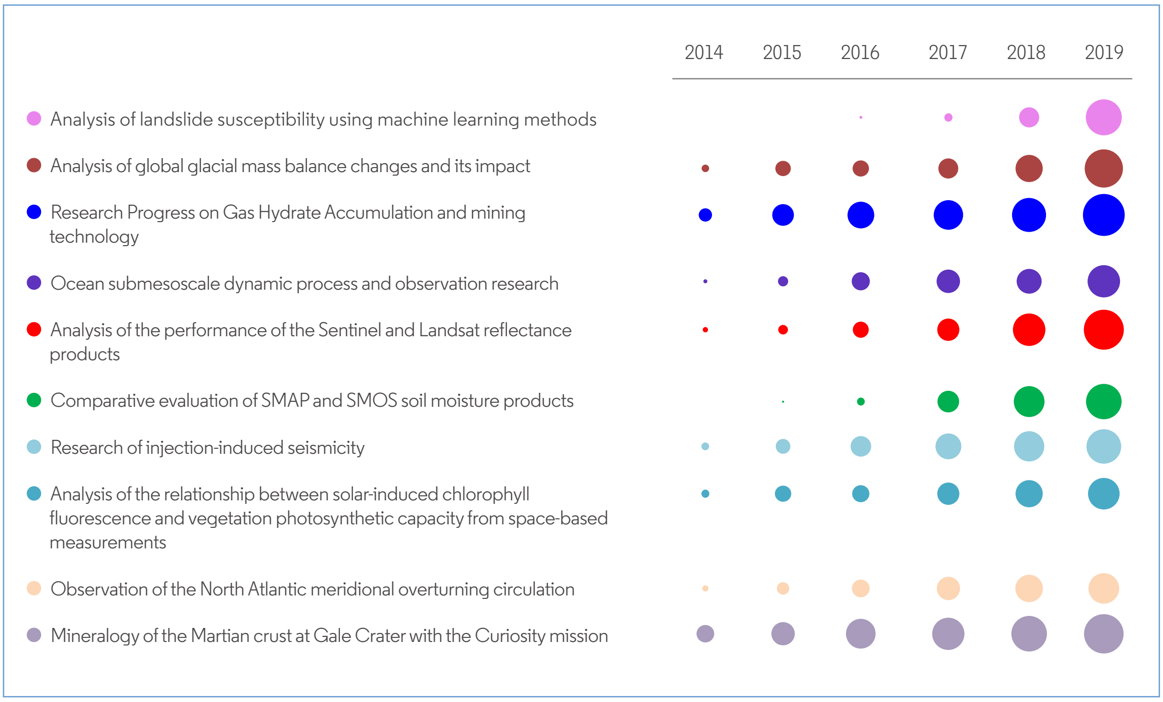
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN GEOSCIENCES

Seven of the Top 10 Research Fronts in geosciences focus on geology. "Research of injection-induced seismicity" has been selected as hot Research Front for three consecutive years, while "Mineralogy of the Martian crust at Gale Crater with the Curiosity mission" has been in the Top 10 for four consecutive years, demonstrating that research on certain subjects remains consistently at the forefront from year to year. In terms of research methods in geosciences, hot Research Fronts have increasingly used space-based detection platforms and methods reliant on artificial intelligence (AI) to conduct geological research since 2017, reflecting the great contribution of the latest remote-sensing and information technology to the development of the field. Examples of this trend include "Analysis of landslide susceptibility using machine learning methods", "Analysis of the performance of the Sentinel and Landsat reflectance products", "Comparative evaluation of SMAP and SMOS soil moisture products", and "Analysis of the relationship between solar-induced chlorophyll fluorescence and vegetation photosynthetic capacity from space-based measurements". Among the Top 10, there are two Research Fronts pertaining to marine sciences, and one front in climate change.

Table 13: Top 10 Research Fronts in geosciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Analysis of landslide susceptibility using machine learning methods	47	1580	2018.3
2	Analysis of global glacial mass balance changes and its impact	18	1188	2017.4
3	Research progress on gas hydrate accumulation and mining technology	36	2179	2017.3
4	Ocean submesoscale dynamic process and observation research	17	1057	2017.2
5	Analysis of the performance of the Sentinel and Landsat reflectance products	13	1198	2017.1
6	Comparative evaluation of SMAP and SMOS soil moisture products	16	1134	2017.1
7	Research of injection-induced seismicity	24	1909	2016.8
8	Analysis of the relationship between solar-induced chlorophyll fluorescence and vegetation photosynthetic capacity from space-based measurements	26	2141	2016.6
9	Observation of the North Atlantic meridional overturning circulation	11	1068	2016.5
10	Mineralogy of the Martian crust at Gale Crater with the Curiosity mission	24	2580	2016

Figure 3: Citing papers for the Top 10 Research Fronts in geosciences



1.2 KEY HOT RESEARCH FRONT – "Research progress on gas hydrate accumulation and mining technology"

Natural gas hydrates, commonly known as "combustible ice", consist of an ice-like crystalline substance formed by natural gas and water under high pressure and low temperature. They are widely distributed in deep-sea sediments or terrestrial permafrost. With the advantages of broad distribution, large reserves, shallow burial, high energy efficiency and low pollution, these gas hydrates hold promise as one of the best alternative energy sources in the post-oil era.

The basic principle of extracting natural gas hydrates is to change the stable occurrence conditions of the solid by hydrate-based gas separation processing, and then collect free gas to achieve continuous exploitation. The main methods include depressurization, thermal stimulation, hydrate inhibitors, CO_2-methane replacement, and hydraulic lifting. So far, the exploitation method of natural gas hydrates is still in the conceptual and experimental stage, and there is no complete theory of exploitation. "Production Safety", "Equipment Safety", and "Environmental Safety" – the three technical challenges that restrict the safe and efficient development of natural gas hydrate -- have not achieved a fundamental breakthrough yet. There is still a long way to go for commercialization.

Many countries, especially energy-deficit countries, put a high priority on research into natural gas hydrates. The USA, India, Japan, South Korea, Germany, and Canada are particularly active, treating natural gas hydrates as national development priorities, making R&D plans, and setting up specialized research institutions to advance drilling and trial production.

The quantitative analysis of this Research Front conforms to the descriptions above. Among nations, the USA, India, Japan and China are the notable participants in this hot Research Front, with the USA registering as most prolific. In terms of the core papers, one third of top-producing institutions are based in the USA. Among them, the U.S. Geological Survey published 13 core papers. Notably, the top three most-cited papers in this Research Front are from a team led by Professor Praveen Linga at the National University of Singapore. The team reviewed various studies on the resource potential of natural gas hydrates, current research progress in laboratory settings, and several recent field trials. The reviews also offer detailed discussion of possible limitations in each production method and the challenges to be addressed for large-scale production.

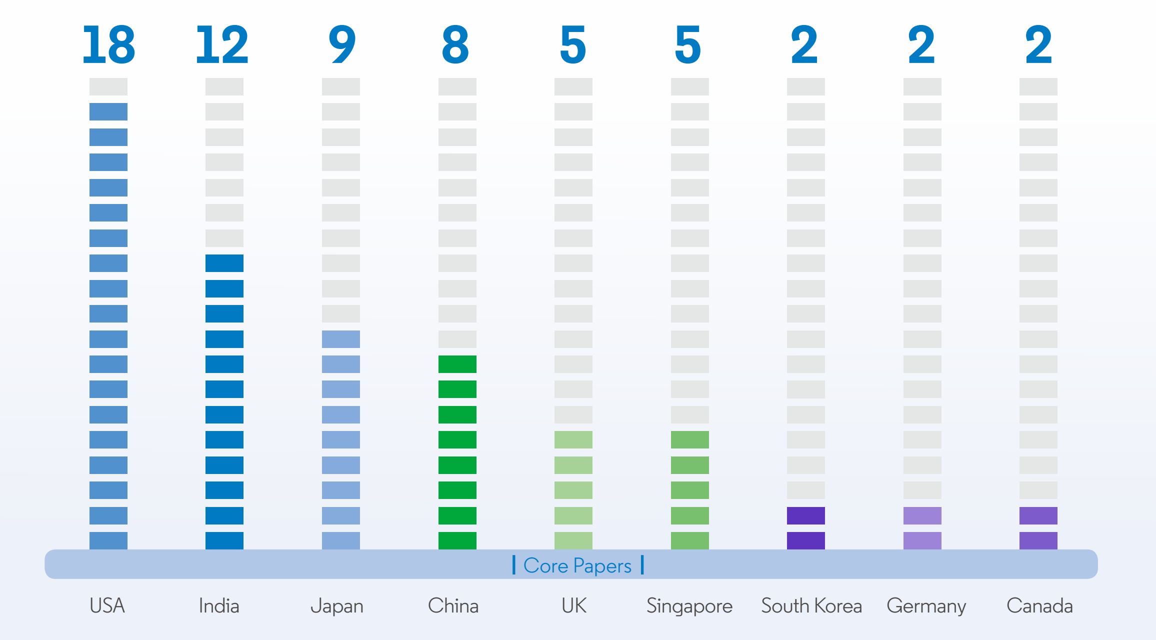


Table 14: Top countries and institutions producing core papers in the Research Front "Research progress on gas hydrate accumulation and mining technology"

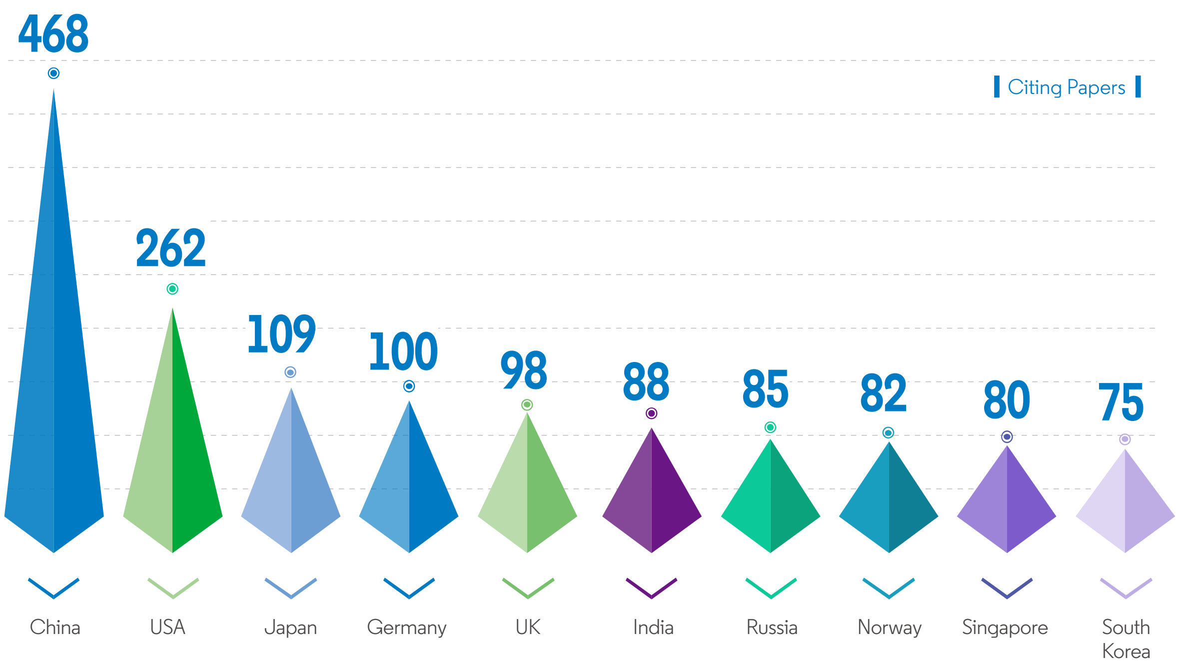
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	18	50.0%	1	U.S. Geological Survey	USA	13	36.1%
2	India	12	33.3%	4	Oil and Natural Gas Corporation Ltd	India	5	13.9%
3	Japan	9	25.0%	2	National Institute of Advanced Industrial Science and Technology (AIST)	Japan	8	22.2%
4	China	8	22.2%	3	National Energy Technology Laboratory	USA	7	19.4%
5	UK	5	13.9%	4	National University of Singapore	Singapore	5	13.9%
5	Singapore	5	13.9%	6	University of Tokyo	Japan	4	11.1%
7	South Korea	2	5.6%	6	Dalian University of Technology	China	4	11.1%
7	Germany	2	5.6%	8	University of California Berkeley	USA	3	8.3%
7	Canada	2	5.6%	8	National Chemical Laboratory	India	3	8.3%
				8	Japan Oil, Gas and Metals National Corporation (JOGMEC)	Japan	3	8.3%
				8	Georgia Institute of Technology	USA	3	8.3%
				8	Chinese Academy of Sciences	China	3	8.3%

In China, the study of gas hydrates started late but has progressed rapidly. At present, it is in the stage of development from fundamental hydrate research to exploitation technology. As for countries and institutions producing citing papers, China ranks 1st with 468. The Chinese Academy of Sciences (CAS), Dalian University of Technology, and China University of Petroleum takes the top three places of the Top 10 institutions. In the top spot, the Guangzhou Institute of Energy Conversion (part of the CAS) registers as most prolific, having contributed 82 of the 108 citing papers credited to the CAS.

Table 15: Top countries and institutions producing citing papers in the Research Front "Research progress on gas hydrate accumulation and mining technology"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	468	36.8%	1	Chinese Academy of Sciences	China	108	8.5%
2	USA	262	20.6%	2	Dalian University of Technology	China	95	7.5%
3	Japan	109	8.6%	3	China University of Petroleum	China	92	7.2%
4	Germany	100	7.9%	4	National University of Singapore	Singapore	78	6.1%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
5	UK	98	7.7%	5	Helmholtz Association	Germany	66	5.2%
6	India	88	6.9%	6	Russian Academy of Sciences	Russia	61	4.8%
7	Russia	85	6.7%	7	The Arctic University of Norway	Norway	50	3.9%
8	Norway	82	6.4%	8	National Institute of Advanced Industrial Science and Technology (AIST)	Japan	45	3.5%
9	Singapore	80	6.3%	9	Geomar	Germany	44	3.5%
10	South Korea	75	5.9%	10	CSIR India	India	42	3.3%



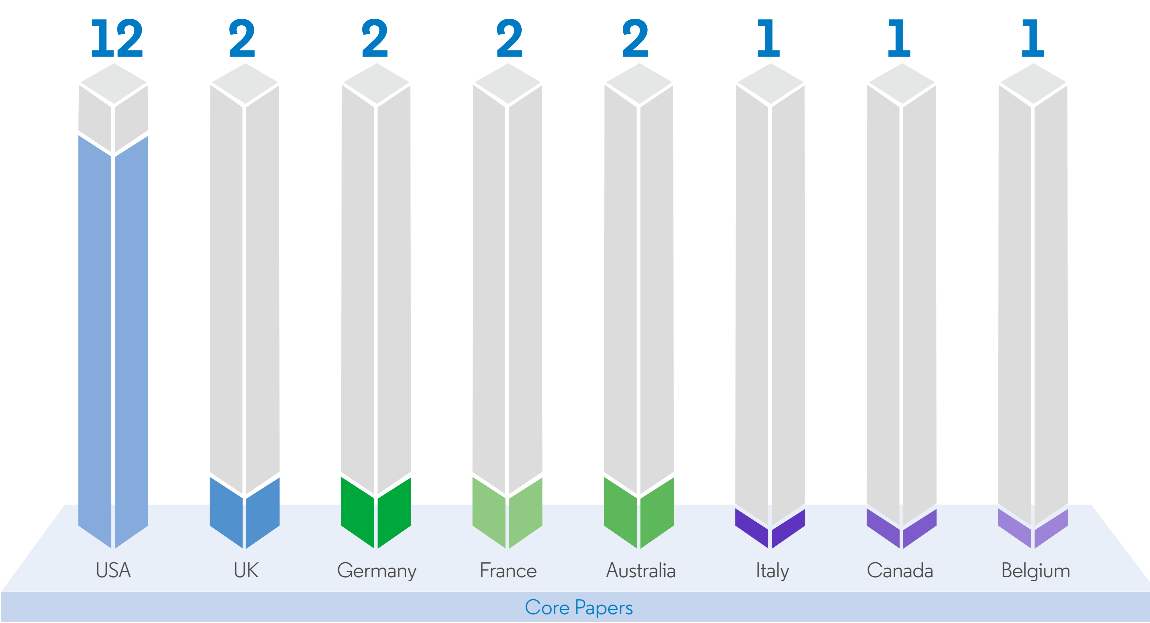
1.3 KEY HOT RESARCH FRONT – "Analysis of the performance of the Sentinel and Landsat reflectance products"

The Sentinel family is one of two types of satellite missions of the Copernicus Space Component. There are currently seven satellites in orbit. The Sentinels carry a range of technologies, such as radar and multi-spectral imaging instruments, for land, ocean, and atmospheric monitoring. The Landsat series of earth-observation satellites is a joint mission of NASA and the U.S. Geological Survey. Eight satellites have been launched so far, and two are still in orbit. The Landsat program's critical role is to investigate underground mineral deposits, marine resources and groundwater resources. The remote-sensing data of these two series of satellites are free and open to the public, which has greatly promoted technological and industrial innovation, helping the development of the industry and producing high economic value.

The 13 core papers in the hot Research Front focus on analyzing the change detection capabilities of Sentinel-2A, Sentinel-2B, Landsat-7 and Landsat-8, comparing the performance of atmospheric and land surface reflectance products of these two series. In terms of top countries and institutions producing core papers, the USA has the highest contribution rate (92.3%). Among USA-based institutions, South Dakota State University and NASA are each represented on six core papers. The most-cited paper in this Research Front ("Continuous change detection and classification of land cover using all available Landsat data", with 305 citations at this writing) is from Boston University. This paper used 519 Landsat images and developed a new algorithm for continuous change detection and classification of land cover. The algorithm can provide land cover maps for any given time.

Table 16: Top countries and institutions producing the 34 core papers in the Research Front "Analysis of the performance of the Sentinel and Landsat reflectance products"

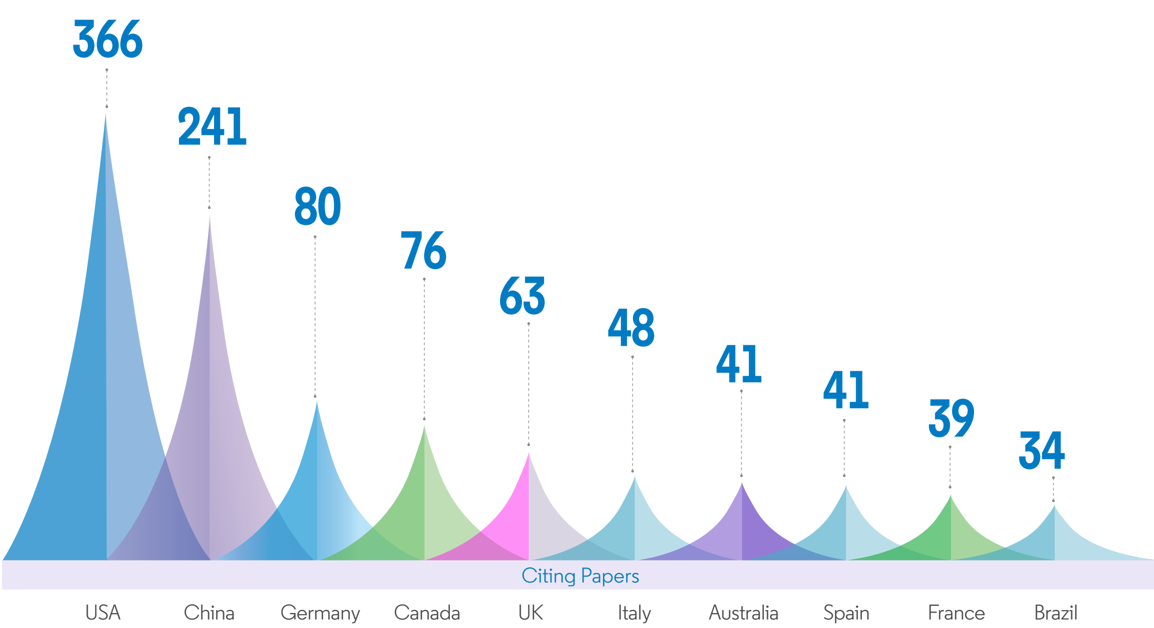
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	12	92.3%	1	South Dakota State University	USA	6	46.2%
2	UK	2	15.4%	1	National Aeronautics & Space Administration (NASA)	USA	6	46.2%
2	Germany	2	15.4%	3	University of Maryland College Park	USA	4	30.8%
2	France	2	15.4%	4	Thales Group	France	2	15.4%
2	Australia	2	15.4%	4	Geoscience Australia	Australia	2	15.4%
6	Italy	1	7.7%					
6	Canada	1	7.7%					
6	Belgium	1	7.7%					



In terms of the countries producing the citing papers, the USA ranks 1st with 366. China also performs actively in this Research Front and ranks 2nd. Among the Top 10 institutions, six are based in the USA. The CAS ties for first place with 104, represented by the Institute of Remote Sensing and Digital Earth and the Institute of Geographic Sciences and Natural Resources Research of the CAS.

Table 17: Top countries and institutions producing citing papers in the Research Front "Analysis of the performance of the Sentinel and Landsat reflectance products"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	366	42.0%	1	Chinese Academy of Sciences	China	104	11.9%
2	China	241	27.6%	2	National Aeronautics & Space Administration (NASA)	USA	66	7.6%
3	Germany	80	9.2%	3	University of Maryland College Park	USA	56	6.4%
4	Canada	76	8.7%	4	U.S. Geological Survey	USA	55	6.3%
5	UK	63	7.2%	5	S Dakota State University	USA	53	6.1%
6	Italy	48	5.5%	6	United States Department of Agriculture (USDA)	USA	39	4.5%
7	Australia	41	4.7%	7	National Resources Canada	Canada	35	4.0%
7	Spain	41	4.7%	8	Boston University	USA	29	3.3%
9	France	39	4.5%	9	Humboldt University of Berlin	Germany	27	3.1%
10	Brazil	34	3.9%	10	Canadian Forest Service	Canada	24	2.8%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN GEOSCIENCES

"Study on Indonesian volcanic eruption prediction model" was selected as the emerging Research Front in geosciences for 2020.

Table 18: Emerging Research Front in geosciences

Rank	Emerging Research Front	Core papers	Citations	Mean Year of Core Papers
1	Study on Indonesian volcanic eruption prediction model	7	134	2018.6

2.2 KEY EMERGING RESARCH FRONT – "Study on Indonesian volcanic eruption prediction model"

Volcanic eruptions are one of the major natural disasters facing humankind. According to available statistics, nearly 20% of the world's population lives within the volcanic hazard and impact zones. Over the past 400 years, volcanic eruptions have killed more than 270,000 people. Indonesia is adjacent to a tectonically active region with frequent earthquakes and volcanic activity. At least 95 volcanoes have erupted in Indonesia since 1500 A.D. The eruption of Tambora in 1815 caused a "summer-less year" in the northern hemisphere, and the Toba volcanic super-eruption of 74,000 years ago was the largest volcanic eruption on Earth in the past 2 million years.

Prediction and early warning of volcanic eruption are the basis for volcanic hazard mitigation and preparedness. Volcano monitoring captures the precursors of volcanic eruptions by monitoring and detecting changes in the dynamics of underground magma, and thus provide a scientific basis for volcanic eruption forecasting and research. The development of an eruption-prediction model based on geologic activity data obtained from monitoring enables early prediction of these destructive events.

The core paper of the emerging research front "Study on Indonesian volcanic eruption prediction model " in geosciences focuses on the systematic study of the recent series of volcanic eruptions of Sinabung and Kelud volcanoes in Indonesia from the perspectives of volcanology, petrology, geochemistry, remote sensing, and geology. The comparative analysis of the two volcanoes based on eruption-prediction models and the social response to eruptions is of great value for the future study of volcanic events and geological evolution. The USA occupies a dominant position in the emerging research front, and Indonesia, as the host country, cooperates closely with US institutions.

V. CLINICAL MEDICINE

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN CLINICAL MEDICINE

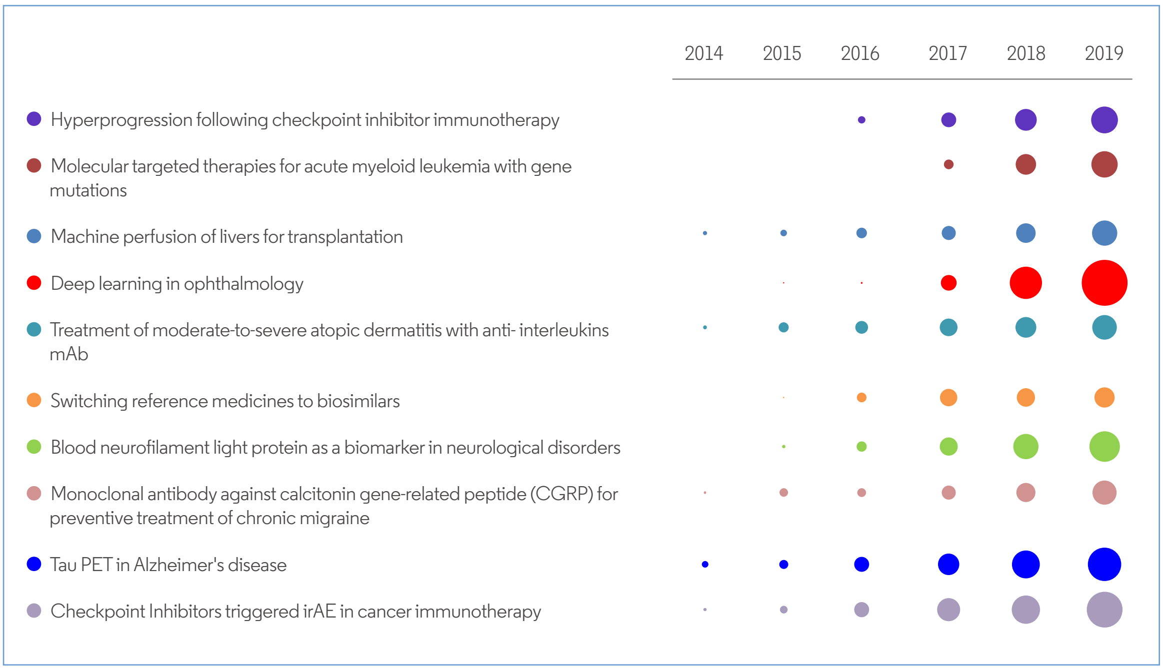
The Top 10 Research Fronts in clinical medicine focus on targeted therapy and immunotherapy for tumors, new targeted-therapy drugs for common chronic diseases, early diagnosis of neurodegenerative diseases, medical artificial intelligence (AI), the standardized use of biosimilars, and organ transplantation. Among these specialty areas, targeted therapy and immunotherapy predominate in 2020.

Compared with previous years, new fronts have emerged in the Top 10, such as hyperprogression following checkpoint inhibitor immunotherapy, and deep learning in ophthalmology. Meanwhile, many fronts have shown obvious sustainability and development. In 2019, for example, biosimilars research focused mainly on efficacy and safety, while in 2020 more attention has fallen on the long-term efficacy of switching from reference medicines to biosimilars. The story is similar in tau PET imaging, as studies in 2019 focused mainly on binding characteristics of tau PET in neurodegenerative diseases, while in 2020 the application of tau PET in Alzheimer's disease has become the focus.

Table 19: Top 10 Research Fronts in clinical medicine

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Hyperprogression following checkpoint inhibitor immunotherapy	13	1466	2017.8
2	Molecular targeted therapies for acute myeloid leukemia with gene mutations	12	1432	2017.7
3	Machine perfusion of livers for transplantation	27	1574	2017.6
4	Deep learning in ophthalmology	21	3353	2017.5
5	Treatment of moderate-to-severe atopic dermatitis with anti-interleukins mAb	18	2100	2017.4
6	Switching reference medicines to biosimilars	33	2053	2017.4
7	Blood neurofilament light protein as a biomarker in neurological disorders	26	2404	2017.2
8	Monoclonal antibody against calcitonin gene-related peptide (CGRP) for preventive treatment of chronic migraine	27	2187	2017.2
9	Tau PET in Alzheimer's disease	42	4114	2017
10	Checkpoint Inhibitors triggered irAE in cancer immunotherapy	39	3793	2017

Figure 4: Citing papers for the Top 10 Research Fronts in clinical medicine



1.2 KEY HOT RESEARCH FRONT – "Deep learning in ophthalmology"

Medical-image recognition is an important research and application field in deep-learning-based AI, centering mainly on image classification, detection, segmentation, retrieval, auxiliary diagnosis, and treatment. Because of the special anatomical structure of the eye, high dependence on diagnosis imaging, the relatively low cost of ophthalmology medical imaging, convenient operations and easy data acquisition, ophthalmology diagnosis and treatment has become a frontier field in deep-learning medicine, demonstrating effective performance in various eye diseases such as diabetic retinopathy, glaucoma, and cataracts. Diabetic retinopathy is a significant cause of blindness, with clear diagnostic criteria and mature classification systems. Therefore, compared with other eye diseases, the application of deep-learning-based AI in diabetic retinopathy has achieved greater prominence.

This hot Research Front, "Deep learning in ophthalmology", includes 21 core papers, which mainly focus on the application of deep-learning-based AI in automatic diagnosis and screening of retinal diseases such as diabetic retinopathy and macular degeneration. Among these core reports, a paper published in *JAMA* in November 2016 by Varun Gulshan, Google Inc., and colleagues, with 1,104 citations to date, applied a deep-learning algorithm to diabetic retinopathy diagnosis, with sensitivity on EyePACS and MESSIDOR datasets at 97.5% and 96.1%, respectively. The accuracy rate is comparable to that of experienced ophthalmologists. Prior to this, a paper published in *Investigative Ophthalmology & Visual Science* in October 2016 by Michael Abràmoff, University of Iowa, and colleagues, pointed out that deep-learning algorithms enhanced IDx-DR X2.1 system can improve the efficiency of diabetic retinopathy screening, implying deep learning as a promising new tool in diabetic retinopathy recognition. After more than 20 years of R&D and a long approval process, the IDx-DR system developed by Abràmoff was finally approved by the FDA in April 2018, making it the world's first autonomous AI screening system for diabetic retinopathy to be approved for use in primary care. This is also a milestone in the clinical application of AI equipment.

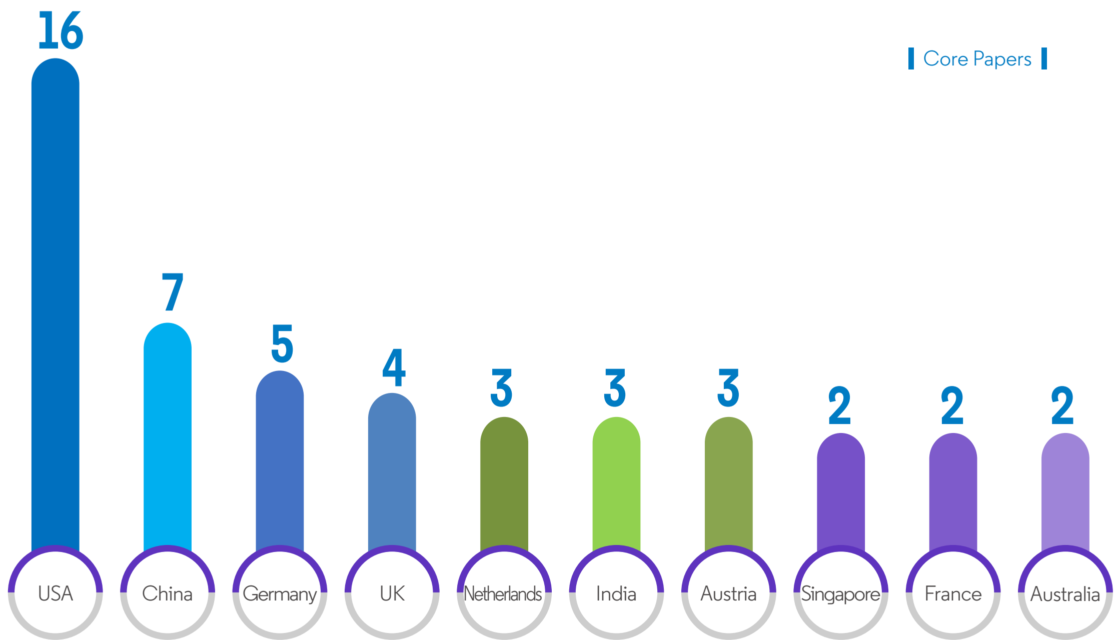
Although deep learning have shown promise for applications in ophthalmology, problems and challenges remain, including the interpretability of deep-learning results, the acquisition of high-quality annotation data, the integration of multi-dimensional ophthalmic datasets, approval and regulatory standards, and the cost-effectiveness of clinical applications. Explainable and credible post-deep learning and next-generation AI may bring new opportunities.

In terms of producing core papers for this front, the USA ranks 1st, contributing nearly 80% of the core, occupying a leading position in AI applied ophthalmology. China ranks 2nd, contributing nearly 33.3% of the core. As for top institutions, world-renowned universities such as Stanford University, Harvard University, and University College London, and Google Inc. and its sister company Verily Life Science perform well. The Chinese University of Hong Kong also registers outstanding performance in promoting the application of AI in ophthalmology.

Table 20: Top countries and institutions producing core papers in the Research Front "Deep learning in ophthalmology"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	16	76.2%	1	Stanford University	USA	4	19.0%
2	China	7	33.3%	1	Harvard University	USA	4	19.0%
3	Germany	5	23.8%	1	Google Inc	USA	4	19.0%
4	UK	4	19.0%	1	Chinese University of Hong Kong	China	4	19.0%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
5	Netherlands	3	14.3%	5	Verily Life Science	USA	3	14.3%
5	India	3	14.3%	5	University College London	UK	3	14.3%
5	Austria	3	14.3%	5	Moorfields Eye Hospital NHS Foundation Trust	UK	3	14.3%
8	Singapore	2	9.5%	5	Johns Hopkins University	USA	3	14.3%
8	France	2	9.5%	5	Eindhoven University of Technology	Netherlands	3	14.3%
8	Australia	2	9.5%					

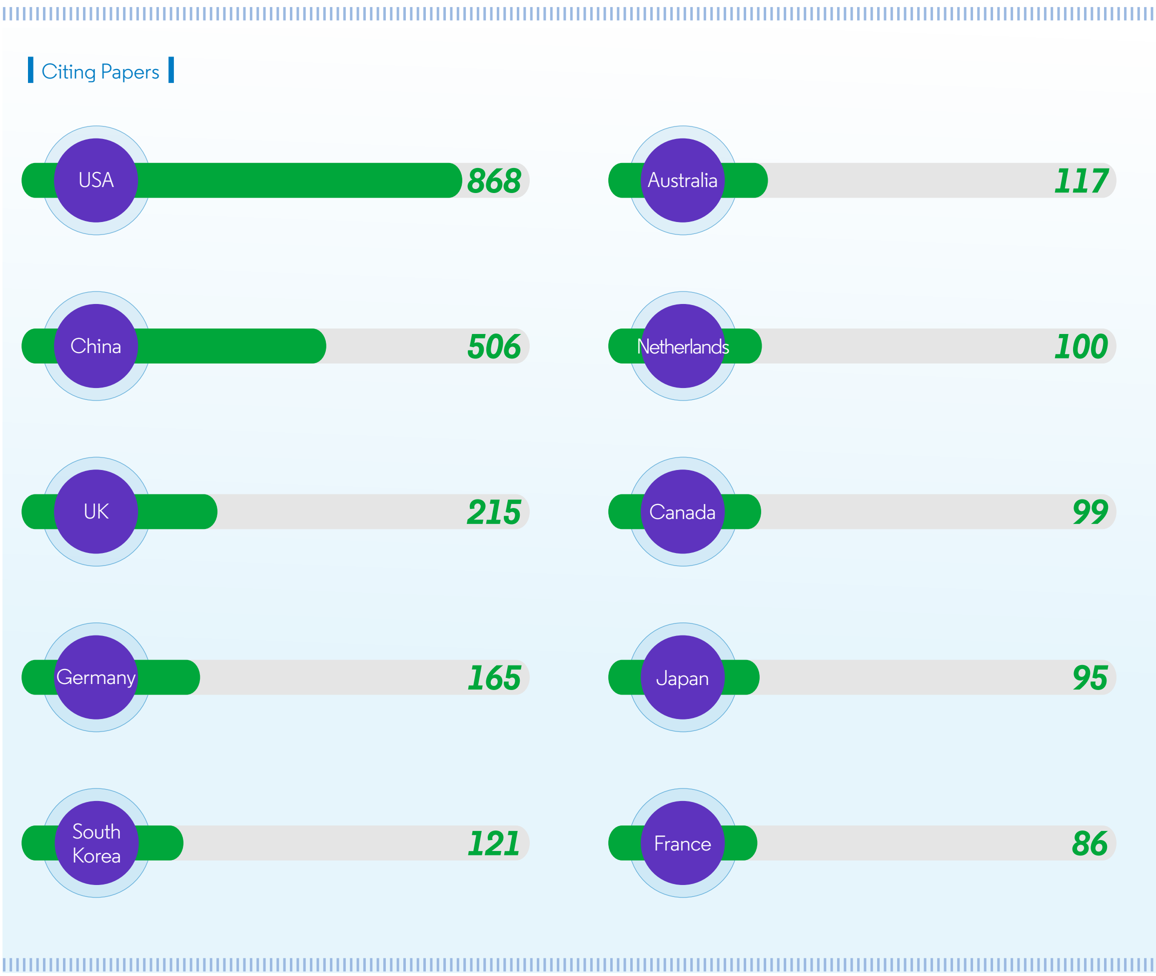


As for citing papers, the USA dominates again, reflecting a boom in AI-based ophthalmology research. Ranked 2nd, China's output has also trended strongly in this area, with citing papers exceeding 500 – more than twice the rate of the next-ranked nation. Top institutions on the basis of citing papers are Harvard University, Stanford University, and the Chinese Academy of Sciences.

Table 21: Top countries and institutions producing citing papers in the Research Front "Deep learning in ophthalmology"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	868	40.8%	1	Harvard University	USA	134	4.40%
2	China	506	23.8%	2	Stanford University	USA	83	3.90%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
3	UK	215	10.1%	3	Chinese Academy of Sciences	China	63	3.80%
4	Germany	165	7.8%	4	University College London	UK	50	3.60%
5	South Korea	121	5.7%	5	Sun Yat Sen University	China	42	3.60%
6	Australia	117	5.5%	6	Johns Hopkins University	USA	41	3.50%
7	Netherlands	100	4.7%	7	Brigham & Women's Hospital	USA	41	3.00%
8	Canada	99	4.7%	8	National University of Singapore	Singapore	38	3.00%
9	Japan	95	4.5%	9	Shanghai Jiao Tong University	China	37	3.00%
10	France	86	4.0%	10	University of California San Francisco	USA	35	1.6%
				10	Radboud University Nijmegen	Netherlands	35	1.6%



1.3 KEY HOT RESARCH FRONT – "Tau PET in Alzheimer's disease"

Alzheimer's disease (AD) is a progressive and fatal neurodegenerative disease with insidious onset. Early detection and intervention are of great significance in alleviating AD and delaying disease progression. With the development of molecular imaging, amyloid positron emission tomography (PET) and tau PET emerged, allowing non-invasive visualization and quantitative detection of amyloid plaques (amyloid-beta deposition) and neurofibrillary tangles (hyperphosphorylated tau protein aggregation) in vivo, which are helpful for early diagnosis, course monitoring, and evaluation of curative effect in AD. Compared with amyloid plaques, neurofibrillary tangles have a higher correlation with cognitive impairment and neurodegeneration. Therefore, applications of tau PET have shown more value in AD diagnosis and monitoring.

The hot Research Front "Tau PET in Alzheimer's disease" includes 42 core papers, which mainly cover tau PET usage in determining the relationship between location and concentration of tau protein and degree of cognitive impairment, neuropathological changes, disease progression, and the relationship between tau pathology and amyloid pathology. This research further verified that tau protein abnormality is closely related to the occurrence and development of AD, and that results obtained by tau PET are suitable for evaluating tau protein abnormality in the disease. There are also a number of studies on the pharmacokinetics, quantitative methods and imaging characteristics of novel radioligands for tau PET (such as F-18-MK-6240, F-18-flotaucipir, F-18-THK5351, AV-1451, etc.), to evaluate the affinity and specificity of radioligands for tau protein, as well as their clinical utility and limitations. Some studies have shown that AV-1451 binds with similar affinities to tau fibrils and monoamine oxidases, which may limit its clinical utility, and have also found that off-target F-18-AV-1451 binding in the basal ganglia is associated with age-related increases in iron accumulation.

Among the top countries and institutions producing these core papers, the USA has the highest contribution rate. The University of California, San Francisco, ranks 1st among the top institutions. It is worth mentioning that Yonsei University in South Korea has performed well and is the only listed top institution in Asia.

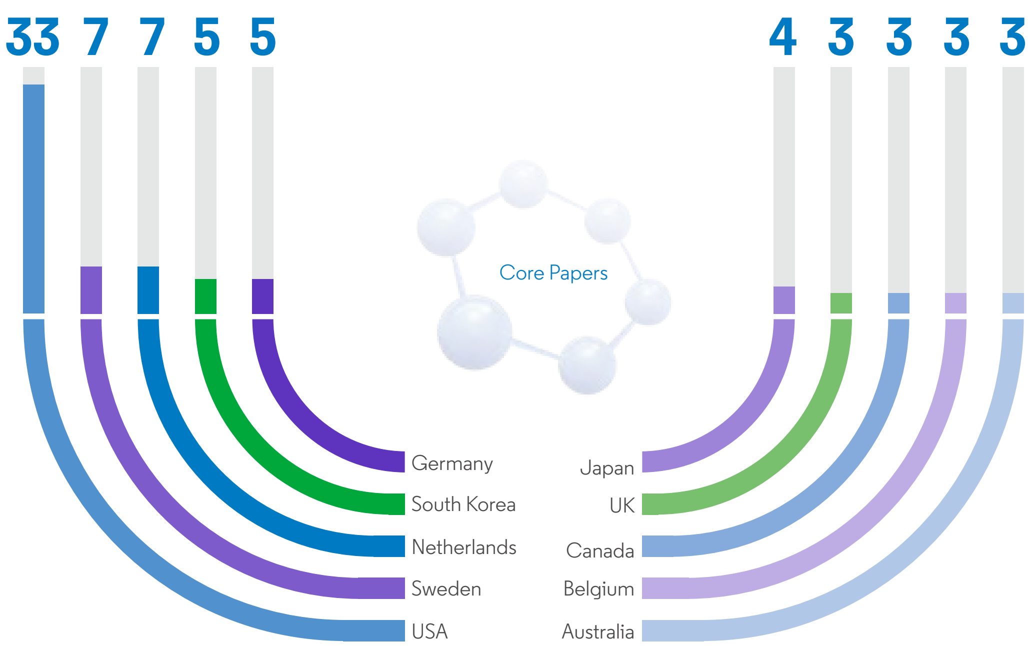


Table 22: Top countries and institutions producing core papers in the Research Front "Tau PET in Alzheimer's disease"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	33	78.6%	1	University of California San Francisco	USA	9	21.4%
2	Sweden	7	16.7%	2	Harvard University	USA	8	19.0%
2	Netherlands	7	16.7%	3	Mayo Clinic	USA	7	16.7%
4	South Korea	5	11.9%	4	University of California Berkeley	USA	6	14.3%
4	Germany	5	11.9%	5	Yonsei University	South Korea	5	11.9%
6	Japan	4	9.5%	5	Lawrence Berkeley National Laboratory	USA	5	11.9%
7	UK	3	7.1%	5	Helmholtz Association	Germany	5	11.9%
7	Canada	3	7.1%	5	Brigham & Women's Hospital	USA	5	11.9%
7	Belgium	3	7.1%	9	University of Gothenburg	Sweden	4	9.5%
7	Australia	3	7.1%	9	Tohoku University	Japan	4	9.5%

In terms of citing papers, the USA produced 49.1% of citing papers, being the most active country in research on tau PET in AD. All the other entries in Table 23 are countries situated in Europe and North America, except for Japan, which is the sole representative of Asia. The top 10 institutions producing citing papers are all based in Europe and the USA, with six of them in the latter country. The Mayo Clinic and Harvard University are the top two citing institutions in the field.

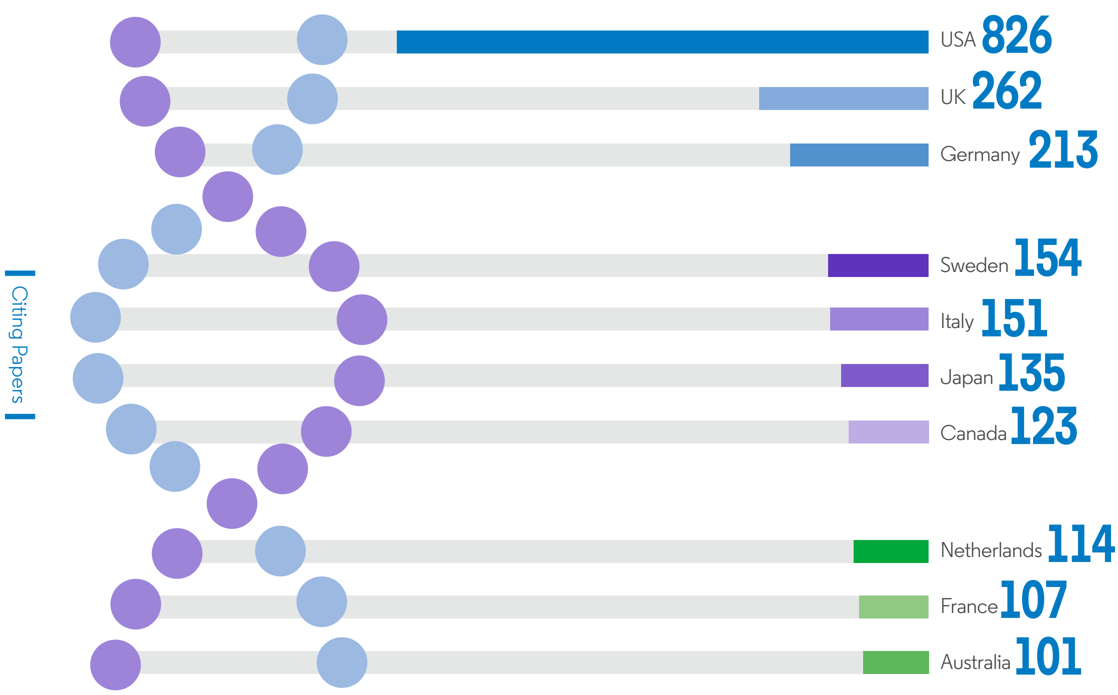


Table 23: Top countries and institutions producing citing papers in the Research Front "Tau PET in Alzheimer's disease"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	826	49.1%	1	Mayo Clinic	USA	162	9.6%
2	UK	262	15.6%	2	Harvard University	USA	159	9.4%
3	Germany	213	12.7%	3	University College London	UK	121	7.2%
4	Sweden	154	9.2%	4	University of California San Francisco	USA	119	7.1%
5	Italy	151	9.0%	5	Helmholtz Association	Germany	108	6.4%
6	Japan	135	8.0%	6	University of California Berkeley	USA	79	4.7%
7	Canada	123	7.3%	7	University of Pennsylvania	USA	77	4.6%
8	Netherlands	114	6.8%	8	University of Gothenburg	Sweden	76	4.5%
9	France	107	6.4%	9	Institut National de la Sante et de la Recherche Medicale (INSERM)	France	75	4.5%
10	Australia	101	6.0%	10	Washington University in St. Louis	USA	74	4.4%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CLINICAL MEDICINE

The 14 emerging Research Fronts in clinical medicine mainly focus on cancer prevention and treatment, the relationship of gut pathobionts with human diseases, oral GLP-1 receptors for diabetes, and organ transplantation from HCV-infected donors. In all, 10 Research Fronts examine cancer prevention and treatment, such as the optimization of targeted therapies, new methods of tumor immunotherapy, AI in tumor imaging, new anti-cancer drugs, and BCMA CAR-T therapy. The key emerging Research Front in 2020 is the continuation of "Combination treatment with immune checkpoint inhibitors in renal cell carcinoma in randomized phase 1/2", a front identified in 2019.

Table 24: Emerging Research Fronts in clinical medicine

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Oral Semaglutide in patients with type 2 diabetes	8	211	2019
2	Combined therapy for AML patients unsuitable for intensive chemotherapy	3	203	2019
3	Mechanisms of circulating tumor cells to enable metastasis	4	142	2019
4	Neoantigen vaccine trial for newly diagnosed glioblastoma	2	131	2019

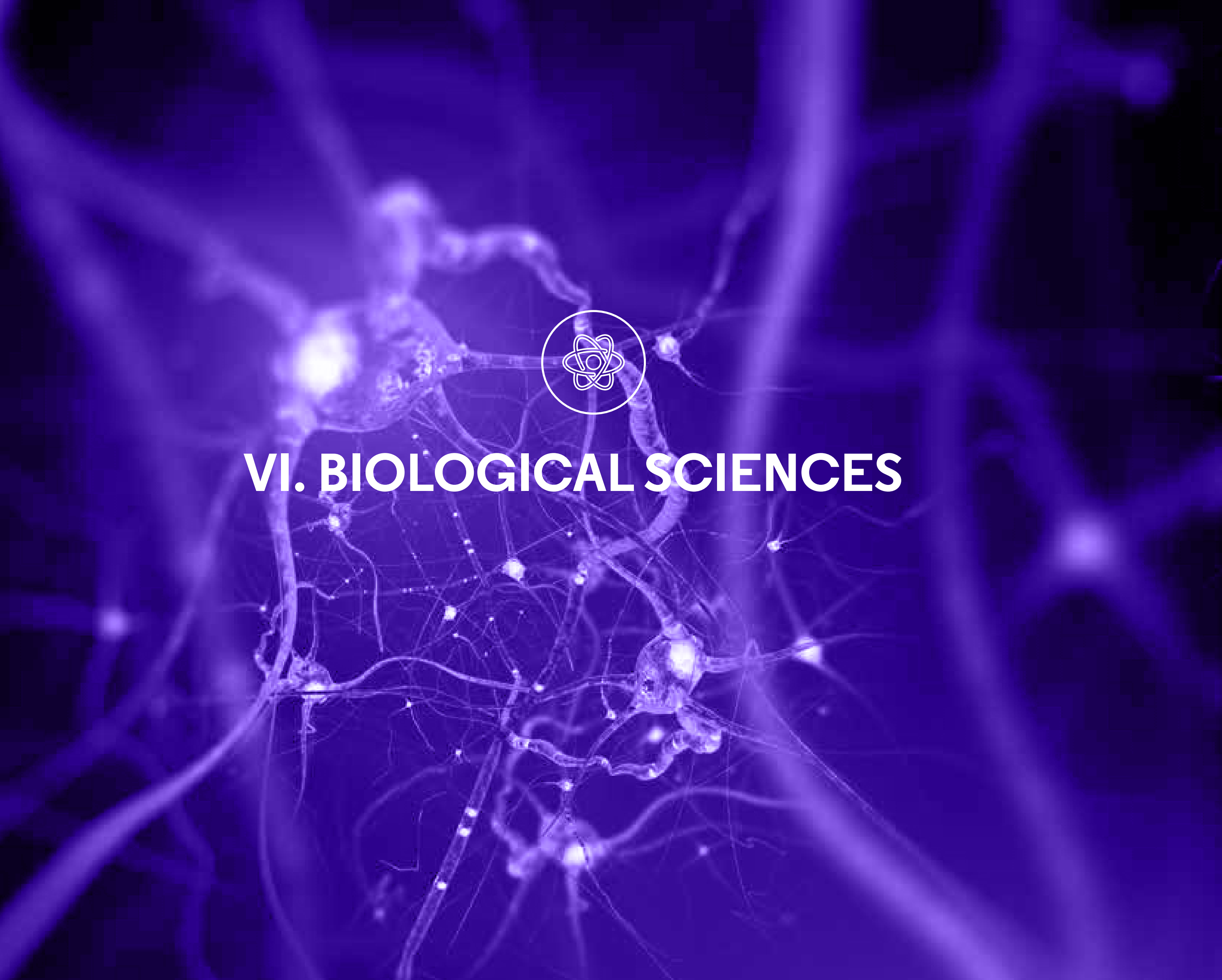
Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
5	PARPi and in combination with immunotherapy in cancer	7	125	2019
6	Anti-PD-1/PD-L1 combined therapy for advanced renal-cell carcinoma first-line therapy	4	787	2018.8
7	Combined ibrutinib for treatment of chronic lymphocytic leukaemia	6	234	2018.8
8	Gut pathobiont derived autoimmunity	4	132	2018.8
9	BCMA CAR-T therapy for multiple myeloma	6	204	2018.7
10	Radiotherapy for metastatic prostate cancer	3	158	2018.7
11	Roles of bacteriophage in inflammatory bowel diseases	6	135	2018.7
12	Application of deep-learning technology to skin cancer	9	297	2018.6
13	Transplanting organs from HCV-infected donors to Uninfected Recipients	9	276	2018.6
14	Application of real-time convolutional neural network for detecting gastric cancer in endoscopic images	9	241	2018.6

2.2 KEY EMERGING RESARCH FRONT – "Anti-PD-1/PD-L1 combined therapy for advanced renal-cell carcinoma first-line therapy"

Renal cell carcinoma is the most common and a highly malignant type of adult renal cancer, accounting for nearly 90% of renal cancer cases, with high incidence in North America and Europe. The treatment of renal cell carcinoma has undergone three major stages in the past 10 years, progressing through non-specific immunotherapy, molecular targeted therapy, and new immunotherapy. Recently, new immunotherapies represented by immune checkpoint inhibitors (such as PD-1/PD-L1, CTLA-4) have made unprecedented progress in cancer treatment. As for renal cell carcinoma, several immunotherapy drugs, such as Opdivo, Keytruda and Tecentriq, have been approved for the treatment of different renal cell carcinomas. However, problems persist, such as immunotherapies being effective only for some patients, high-dose adverse reactions, drug resistance, and high treatment costs. To this end, combined immune strategies have been proposed. Currently, research into combined immune strategy mainly focuses on two kinds of combined strategies: dual immune checkpoint inhibitors, and immune checkpoint inhibitors with targeted drugs.

The four core papers of the emerging Research Front "Anti-PD-1/PD-L1 combined therapy for advanced renal-cell carcinoma first-line therapy" all concern phase III clinical trials of PD-1/PD-L1 inhibitor combination therapies versus sunitinib first-line standard therapy. Four studies have all confirmed that immune combination therapies are better than sunitinib therapy. Combined immunotherapy is emerging as the first-line treatment for renal cell carcinoma.

Although immune combination therapy has achieved gratifying results, many problems still require urgent attention, such as the increasingly complex biological effects of combined immunotherapy, the management of immune-related adverse events, and the need to identify effective efficacy-prediction biomarkers.



VI. 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 nervous system diseases, intestinal microbiota and human diseases, multidrug-resistant bacteria, depression, cancer-related basic research, protein targeted degradation, and carbonic anhydrase inhibitors.

Specifically, research on nervous system diseases accounts for the most Research Fronts, covering three: "Relationship between astrocytes and neurodegenerative diseases and brain aging", "Nanoparticle-mediated intracerebral drug delivery system", and "Lymphatic pathways in nervous system diseases".

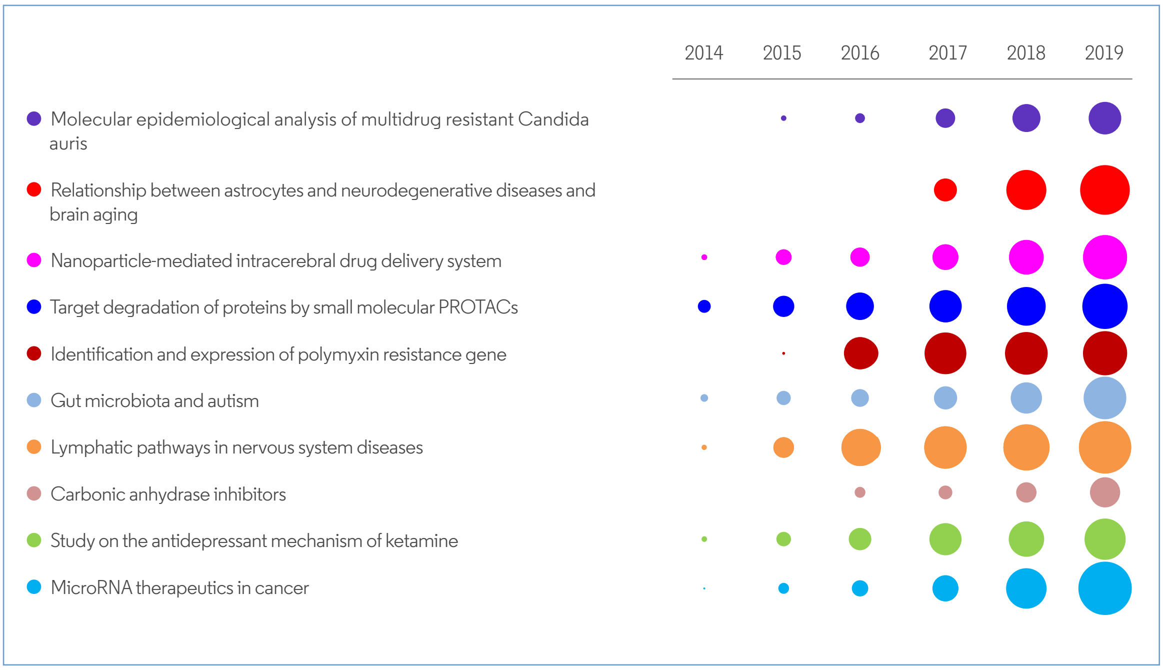
Two Research Fronts related to multidrug resistant bacteria are "Molecular epidemiological analysis of multidrug resistant Candida auris" and "Identification and expression of polymyxin resistance gene". Polymyxin resistance gene-related research has been identified among the Top 10 hot Research Fronts for the second time. The Research Front designated "Target degradation of proteins by small molecule PROTACs" marks the continuation of "Small molecule PROTACs induced protein degradation", a Research Front identified in 2019.

Cancer-related basic research has always been an active subject among the hot Research Fronts over the years, and new points of growth emerge every year. For this report, the hot Research Front on cancer-related research is " MicroRNA therapeutics in cancer ".

Table 25: Top 10 Research Fronts in biological sciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Molecular epidemiological analysis of multidrug resistant Candida auris	41	2460	2017.6
2	Relationship between astrocytes and neurodegenerative diseases and brain aging	6	1501	2017.5
3	Nanoparticle-mediated intracerebral drug delivery system	19	1431	2017.3
4	Target degradation of proteins by small molecular PROTACs	45	4766	2017.2
5	Identification and expression of polymyxin resistance gene	9	2569	2017.2
6	Gut microbiota and autism	20	1542	2017.2
7	Lymphatic pathways in nervous system diseases	27	3868	2017.1
8	Carbonic anhydrase inhibitors	48	1645	2018.1
9	Study on the antidepressant mechanism of ketamine	30	2380	2017.2
10	MicroRNA therapeutics in cancer	8	1587	2017

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



1.2 KEY HOT RESEARCH FRONT – "Relationship between astrocytes and neurodegenerative diseases and brain aging"

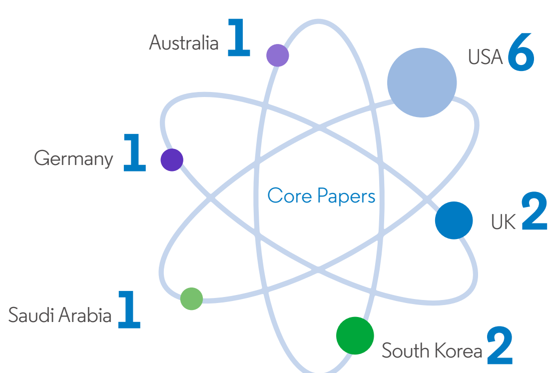
For a long time, researchers focused on neurons in studying the mechanisms and treatment of nervous system diseases. In recent years, however, scientists have increasingly recognized that glial cells (such as microglia and astrocytes) are involved in driving nervous system afflictions, including neurodegenerative conditions such as Alzheimer's disease and Parkinson's disease, as well as injury to the brain and spinal cord, along with processes by which the brain ages.

This hot Research Front provides new insights into the function of microglia and astrocytes, and deepens understanding of the mechanism of neuronal glial interaction in aging and senile diseases. Astrocytes play a role in a series of human neurodegenerative diseases or brain damage. For example, the activated microglia will release three key factors, thus promoting the formation of astrocytes with neurotoxic reaction (i.e., killing neurons). Microglia promote the activation of astrocytes during aging. Reactive astrocytes lose the ability to function normally; they produce complement components, and release a toxic factor that kills neurons and oligodendrocytes. The up-regulation of aging-response genes by astrocytes can lead to the decline of cognitive function in susceptible brain regions during normal aging, and make the aged brain more vulnerable to damage. These new insights are of great significance and provide opportunities for the development of new therapies for neurodegenerative diseases.

In terms of the distribution of core papers, the USA is the largest contributor. Stanford University records the most prominent contribution, with the largest number of core papers, with those papers also recording the highest citation impact. One of the core reports from Stanford has been cited more than 900 times.

Table 26: Top countries and institutions producing core papers in the Research Front "Relationship between astrocytes and neurodegenerative diseases and brain aging"

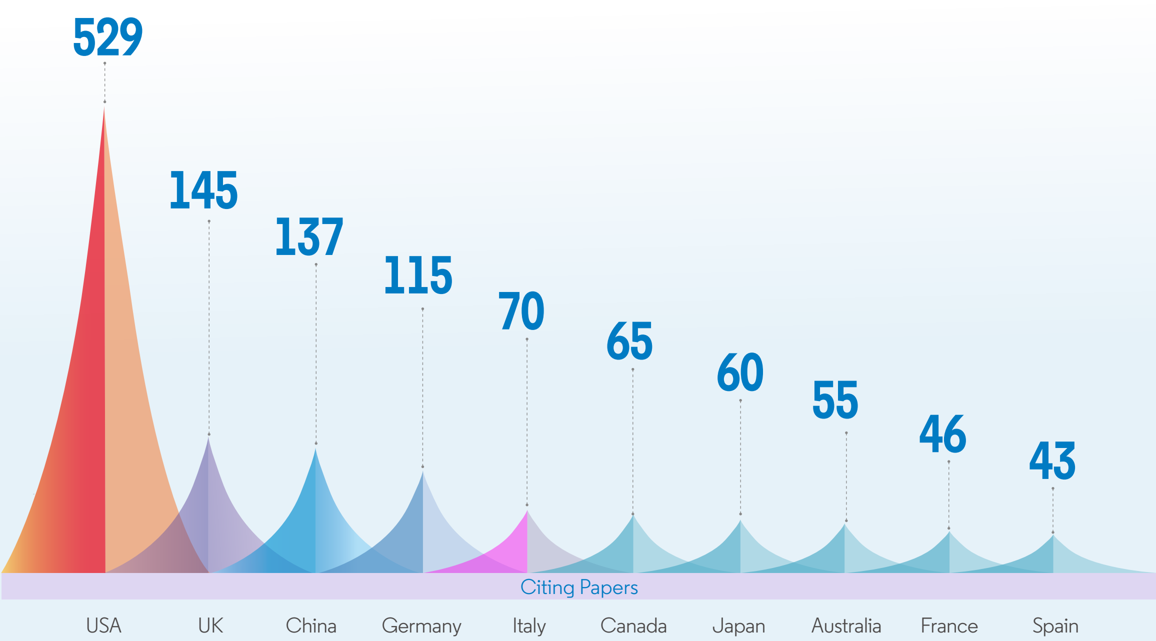
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	6	100.0%	1	Stanford University	USA	4	66.7%
2	UK	2	33.3%	2	University of Cambridge	UK	2	33.3%
2	South Korea	2	33.3%	2	Johns Hopkins University	USA	2	33.3%
4	Saudi Arabia	1	16.7%	2	Harvard University	USA	2	33.3%
4	Germany	1	16.7%	2	Adrienne Helis Malvin Medical Research Foundation	USA	2	33.3%
4	Australia	1	16.7%					



In terms of countries that cite the front's core papers (Table 27), the USA displays a distinct advantage. Not only does its total number of citing papers far exceed that of other countries, but six of the top 10 institutions producing citing papers are based in the USA. Among them, Harvard University contributes twice as many citing papers as the 2nd-ranked Helmholtz Association in Germany, indicating that Harvard has been particularly active in follow-up research in this front.

Table 27: Top countries and institutions producing citing papers in the Research Front "Relationship between astrocytes and neurodegenerative diseases and brain aging"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	529	45.2%	1	Harvard University	USA	70	6.0%
2	UK	145	12.4%	2	Helmholtz Association	Germany	35	3.0%
3	China	137	11.7%	3	Stanford University	USA	33	2.8%
4	Germany	115	9.8%	3	Institut National de la Sante et de la Recherche Medicale (INSERM)	France	33	2.8%
5	Italy	70	6.0%	5	US Department Health and Human Services	USA	31	2.6%
6	Canada	65	5.6%	5	National Institutes of Health (NIH)	USA	31	2.6%
7	Japan	60	5.1%	7	University College London	UK	29	2.5%
8	Australia	55	4.7%	8	Washington University in St. Louis	USA	28	2.4%
9	France	46	3.9%	8	Johns Hopkins University	USA	28	2.4%
10	Spain	43	3.7%	10	French National Center for Scientific Research (CNRS)	France	27	2.3%



1.3 KEY HOT RESARCH FRONT – "Target degradation of protein by small molecular PROTACs"

Targeted protein degradation (TPD) is a new direction in drug R&D in the wake of protein kinase inhibitors and monoclonal antibodies. Traditional drug R&D strategies focus on how to treat diseases by directly regulating the activity of proteins or enzymes. However, traditional small-molecule and antibody drugs can only inhibit the activity of target protease and induce apoptosis of cancer cells by targeted binding. The target protein in cancer cells often restores its activity and achieves drug resistance through overexpression of target protein or new mutation of target protein. The defects of traditional small-molecule inhibitors make small-molecule drugs decline gradually. This increases the urgency of introducing revolutionary new technologies into the research and development of small-molecule drugs.

Proteolysis targeting chimera (PROTAC) technology emerged to answer this need. PROTAC uses small molecules to knock out the functional target protein, instead of simply inhibiting its activity. The agent marks the target protein as a degradation protein, then promotes the degradation signal through proteasome, and finally inhibits the proliferation of cancer cells. PROTAC technology has become a new way to transform the degradation mode of target proteins, opening up additional avenues for the development of small-molecule drugs.

Forty-five core papers constitute the foundation of this hot Research Front. On 13 of these core reports, Craig Crews of Yale University, a pioneer in the field of PROTAC, is the corresponding author. PROTAC technology can degrade a variety of target proteins, including transcription factors, skeleton proteins, enzymes and regulatory proteins. Due to the high efficiency with which PROTACs induce target protein degradation, this technology has attracted the attention of many researchers in different fields, from cancer to neuron diseases.

In order to bring protein-degradation agents based on PROTACs technology into clinical practice, Crews established the company Arvinas in 2013. Other companies, including Novartis, have similar molecules that are close to clinical trials.

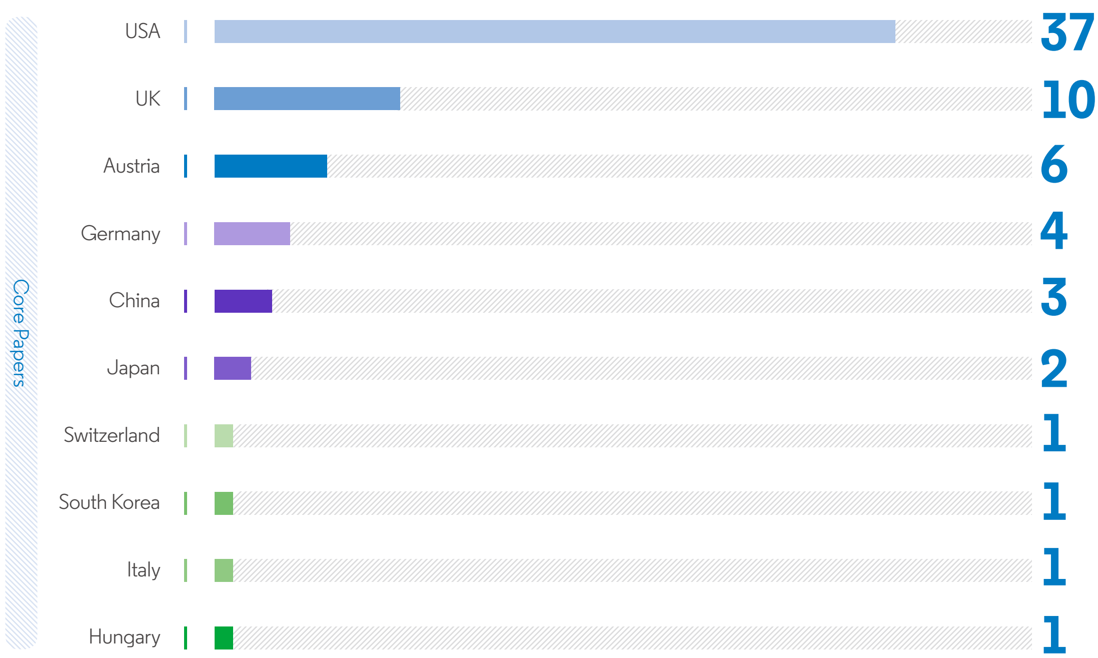
As the technology of protein targeted degradation continues to fulfill its potential, one exciting development is the opportunity to exploit proteomic varieties that previously could not be targeted by drugs for treatment. The prospect for further application of protein targeted degradation therapy is considered boundless.

The USA is the main contributor to the core papers in this hot Research Front, fielding eight of the top 10 institutions. Three companies -- Arvinas, Novartis, and Celgene -- enter the top 10 organizations in terms of core papers, further confirming the successful commercialization of PROTACs.

Table 28: Top countries and institutions producing core papers in the Research Front "Target degradation of protein by small molecular PROTACs"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	37	82.2%	1	Yale University	USA	17	37.8%
2	UK	10	22.2%	2	Harvard University	USA	12	26.7%
4	Germany	4	8.9%	3	Arvinas LLC	USA	10	22.2%
3	Austria	6	13.3%	4	Dana-Farber Cancer Institute	USA	9	20.0%
5	China	3	6.7%	5	University of Dundee	UK	6	13.3%
6	Japan	2	4.4%	6	Novartis	USA	4	8.9%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
7	Switzerland	1	2.2%	6	Massachusetts Institute of Technology (MIT)	USA	4	8.9%
7	South Korea	1	2.2%	8	University of Michigan	USA	3	6.7%
7	Italy	1	2.2%	8	Celgene Corporation	USA	3	6.7%
7	Hungary	1	2.2%	8	Austrian Academy of Sciences	Austria	3	6.7%



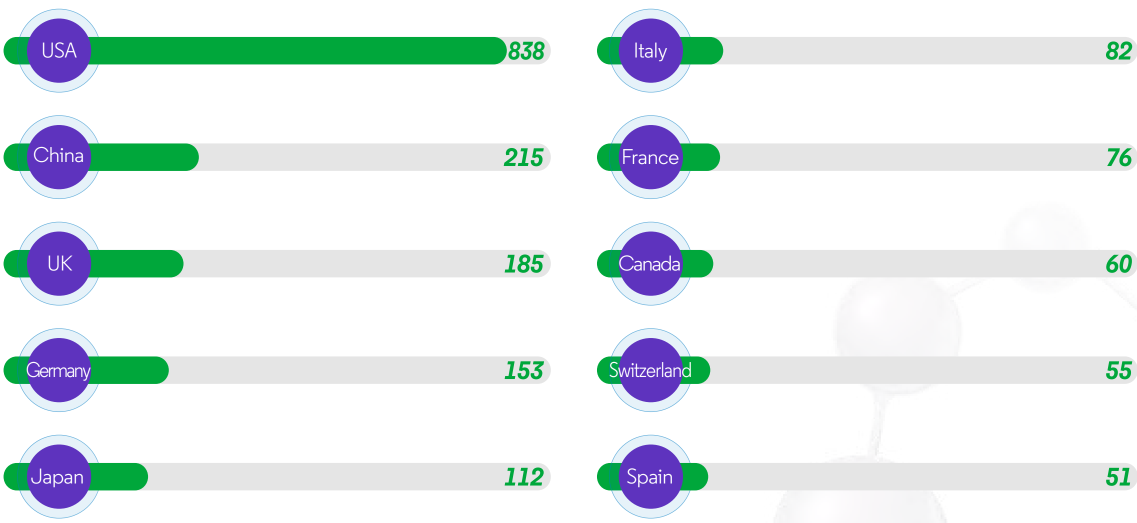
According to the distribution of citing papers, the USA participated in 838 citing papers and ranks 1st. China ranks 2nd with 215 citing papers, indicating that China has increasingly carried out follow-up studies in this specialty. In terms of institutions, the USA accounts for 10 institutions, demonstrating an absolute advantage.

Table 29: Top countries and institutions producing citing papers in the Research Front "Target degradation of protein by small molecular PROTACs"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	838	55.1%	1	Harvard University	USA	178	11.7%
2	China	215	14.1%	2	Dana-Farber Cancer Institute	USA	127	8.3%
3	UK	185	12.2%	3	Yale University	USA	57	3.7%
4	Germany	153	10.1%	4	Massachusetts Institute of Technology (MIT)	USA	48	3.2%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
5	Japan	112	7.4%	5	Celgene Corporation	USA	46	3.0%
6	Italy	82	5.4%	6	Memorial Sloan-Kettering Cancer Center	USA	43	2.8%
7	France	76	5.0%	6	Institut National de la Sante et de la Recherche Medicale (INSERM)	France	43	2.8%
8	Canada	60	3.9%	6	Howard Hughes Medical Institute	USA	43	2.8%
9	Switzerland	55	3.6%	9	Mayo Clinic	USA	41	2.7%
10	Spain	51	3.4%	10	UTMD Anderson Cancer Center	USA	40	2.6%
				10	National Institutes of Health (NIH)	USA	40	2.6%

Citing Papers



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN BIOLOGICAL SCIENCES

Nine fronts in the field of biological sciences have been selected as emerging Research Fronts. The main research topics include basic research related to nervous system diseases, cancer, intestinal microbiology, depression and gene editing technology.

Three Research Fronts pertaining to nervous system diseases are “Single cell RNA sequencing technology”, “Blood-brain barrier disruption: an early biomarker of human cognitive impairment”, and “Genetic meta-analysis of Alzheimer’s disease”.

Three Research Fronts focus on basic studies of cancer, namely, “Mechanism of immune checkpoint inhibitors activating T cells", "Implantation of virus-specific memory T cells into tumors", and "Study on regulation of tumor formation by long-chain non coding RNA".

The other three emerging Research Fronts pertain to gut microbiota, depression and gene editing technology. Respectively, these fronts are "A new genome of human intestinal microbiota", "Meta-analysis of genome-wide association of depression", and "Off target effect of single base gene editing technology based on CRISPR system".

Table 30: Emerging Research Fronts in biological sciences

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Single cell RNA sequencing technology	6	254	2019
2	Off target effect of single base gene editing technology based on CRISPR system	7	188	2019
3	A new genome of human intestinal microflora	5	181	2019
4	Meta-analysis of genome-wide association of depression	5	503	2018.8
5	Mechanism of immune checkpoint inhibitors activating T cells	4	196	2018.8
6	Blood-brain barrier disruption: an early biomarker of human cognitive impairment	4	187	2018.8
7	Implantation of virus-specific memory T cells into tumors	6	222	2018.7
8	Study on the regulation of tumor formation by long-chain non coding RNA	7	155	2018.7
9	Genetic meta-analysis of Alzheimer's disease	3	143	2018.7

2.2 KEY EMERGING RESARCH FRONT – "Meta-analysis of genome-wide association of depression"

Depression is one of the most serious and perplexing public health problems in the world. The World Health Organization has estimated that depression affects nearly 15 percent of adults worldwide, but only about half respond well to existing treatments such as drugs and psychotherapy. Despite decades of effort, the precise biological mechanism of depression continues to elude researchers.

Understanding the genetic basis of depression has presented particular difficulty. The selected emerging Research Front, "Meta-analysis of genome-wide association of depression," describes meta-analyses of genome-wide association studies on depression. This research supports the conclusion that depression is, to some extent, determined by genes. One of the core papers, published in the journal *Nature Neuroscience*, identified 44 gene variants, each of which affects a person's risk of depression. Among them, 30 gene variants were identified for the first time. This landmark research is a big step towards elucidating the underlying biological mechanisms of depression. The discovery of new genetic variants holds the promise of new therapies for this pervasive and potentially debilitating mood disorder.

VII. CHEMISTRY AND MATERIALS SCIENCE

1. HOT RESEARCH FRONT

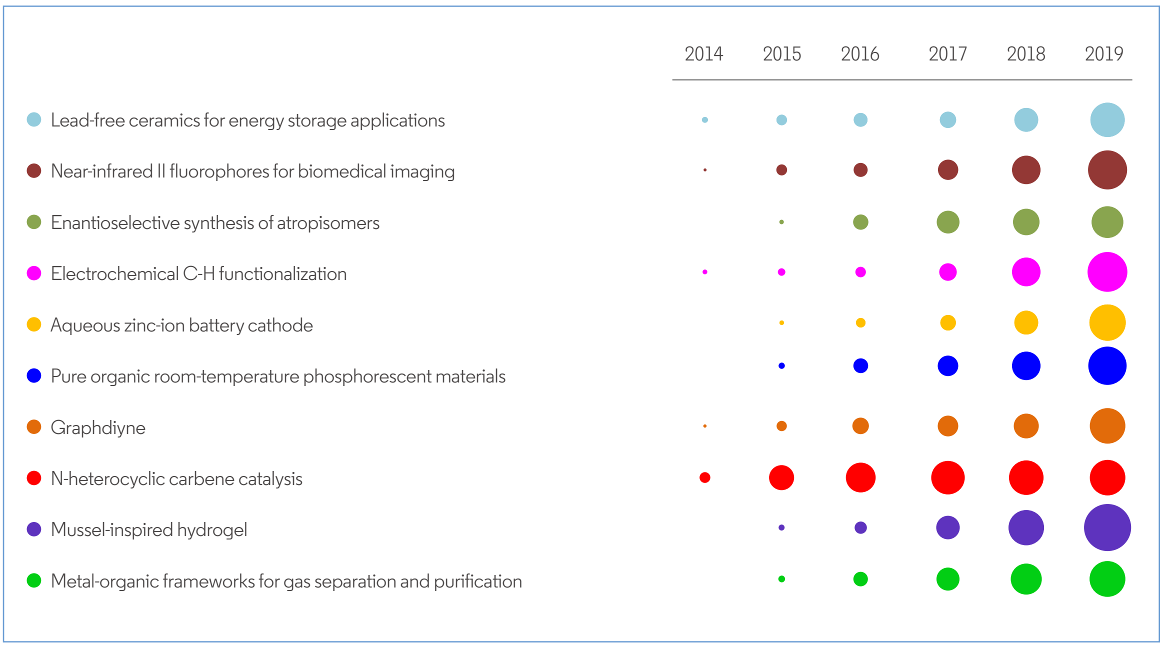
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

The hot Research Fronts in chemistry and materials science cover several current topics, showing both consistency and development compared with previous years. The topic of organic synthesis accounts for three directions: C-H activation (“Electrochemical C-H functionalization”, which is identified among the Top 10 hot Research Fronts for the second time); small organic molecular catalysis (“N-heterocyclic carbene catalysis”); and chiral synthesis (“Enantioselective synthesis of atropisomers”). In the area of optical materials, both fluorescent materials (“Near-infrared II fluorophores for biomedical imaging”) and phosphorescent materials (“Pure organic room-temperature phosphorescent materials”) are chosen for 2020, with the latter being a hot direction for two consecutive years. The new area of focus, “Mussel-inspired hydrogel”, represents one of the latest developments of “Molecular machines”, a Top 10 Research Front from last year. As gas separation and purification is of great importance in chemical processes, “Metal-organic frameworks for gas separation and purification” is being featured as a key hot Research Front in 2020. Research on energy storage (“Lead-free ceramics for energy storage applications”), battery materials (“Aqueous zinc-ion battery cathode”), and 2D materials (“Graphdiyne”) are also highlighted in 2020.

Table 31 Top 10 Research Fronts in chemistry and materials science

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Lead-free ceramics for energy storage applications	33	2130	2017.9
2	Near-infrared II fluorophores for biomedical imaging	35	3040	2017.8
3	Enantioselective synthesis of atropisomers	35	2412	2017.6
4	Electrochemical C-H functionalization	37	4868	2017.5
5	Aqueous zinc-ion battery cathode	39	4733	2017.5
6	Pure organic room-temperature phosphorescent materials	44	3750	2017.5
7	Graphdiyne	25	2329	2017.3
8	N-heterocyclic carbene catalysis	19	3865	2016.9
9	Mussel-inspired hydrogel	24	3379	2017
10	Metal-organic frameworks for gas separation and purification	15	2273	2016.9

Figure 6 Citing papers of the Top 10 Research Fronts in chemistry and materials science



1.2 KEY HOT RESEARCH FRONT – "Pure organic room-temperature phosphorescent materials"

Phosphorescence occurs via spin-forbidden transitions: a molecule in the excited singlet state (S_1) undergoes intersystem crossing (ISC) to generate the lowest excited triplet state (T_1), and phosphorescence emission then takes place through a radiative transition from T_1 to the ground state (S_0). Generally, most room-temperature phosphorescent (RTP) materials are inorganic or organometallic complexes containing noble metals. Considering their expense and toxicity, it is indispensable to develop pure organic RTP materials with low cost, versatile molecular design, and good processability. However, production of RTP from pure organic molecules is difficult due to the inefficient ISC from S_1 to T_1, the spin-forbidden radiative transitions from T_1 to S_0, easy nonradiative relaxation from low-lying T_1, and collisional quenching by oxygen. Over the past several years, two approaches have been put forward to obtain RTP from organic molecules: (i) promoting ISC from S_1 to T_1 in organic molecules through efficient spin-orbit coupling, and (ii) the suppression of nonradiative relaxation pathways from T_1 to S_0 as much as possible.

As shown in Table 32, researchers from China, Singapore, the USA, the UK, and Japan have made remarkable progress in this field. Several groups have employed different methodologies, including the introduction of heavy atoms or aromatic carbonyls, rigid crystal formation, polymerization, host-guest doping, metal–organic framework coordination, halogen bonding, and H-aggregation to develop efficient pure organic RTP systems. Wei Huang from Northwestern Polytechnical University, Xi'an, China, and Benzhong Tang from the Hong Kong University of Science and Technology, have made outstanding contributions in this area

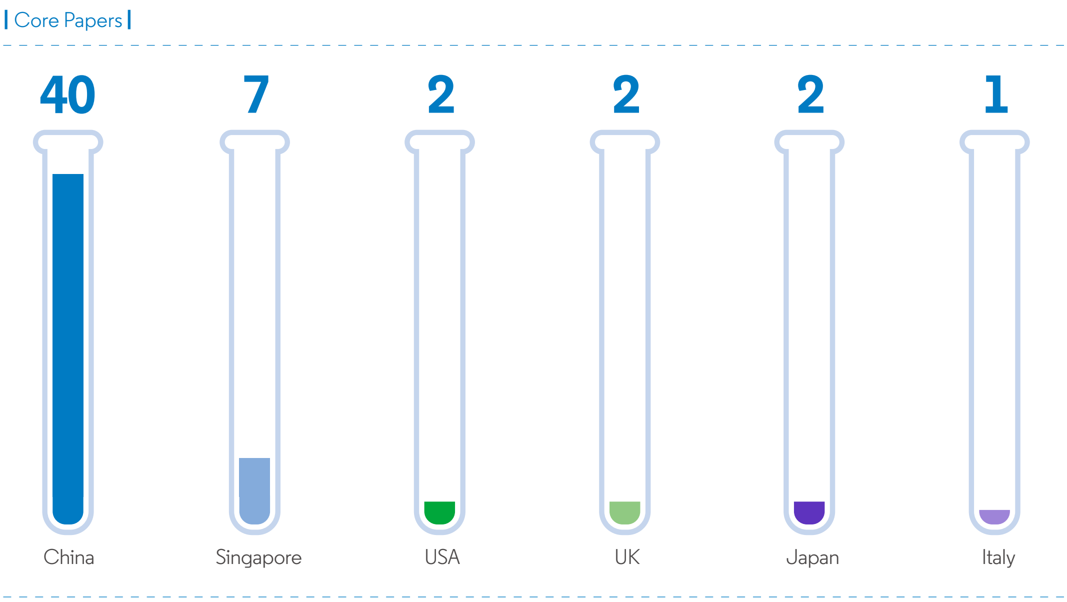


Table 32 Top countries and institutions producing core papers in the Research Front "Pure Organic Room-Temperature Phosphorescent Materials"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	40	90.9%	1	Chinese Academy of Sciences	China	16	36.4%
2	Singapore	7	15.9%	2	Nanjing University of Technology	China	11	25.0%

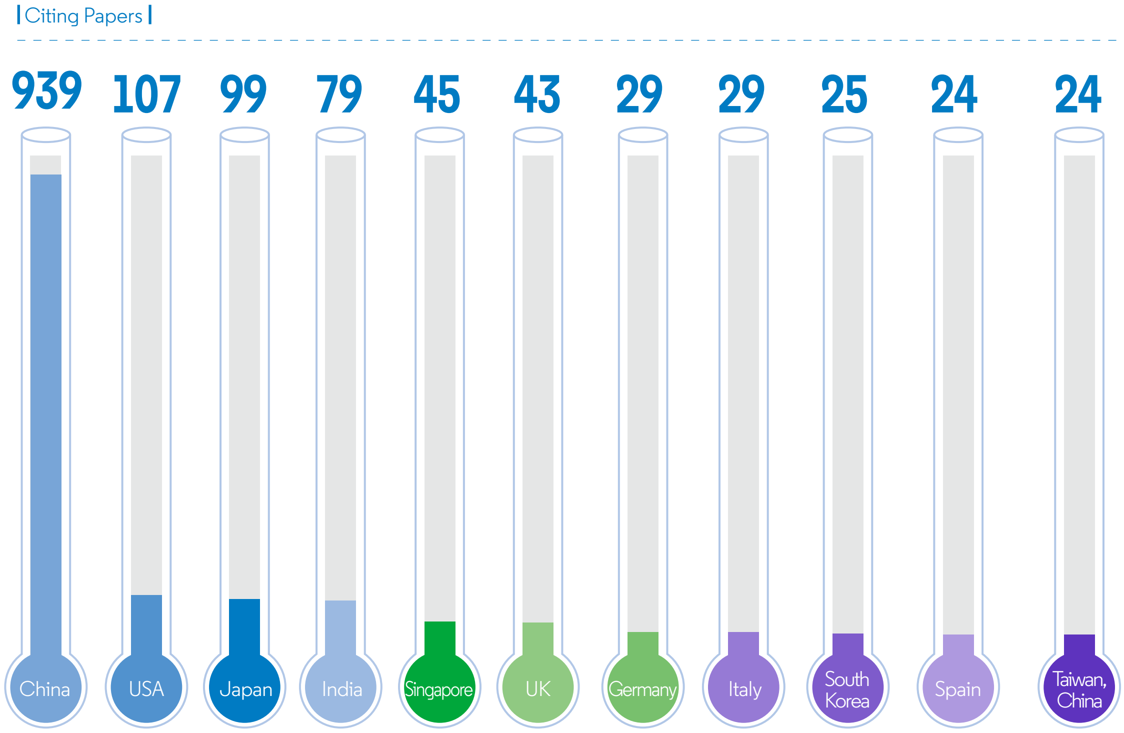
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
3	USA	2	4.5%	3	Northwestern Polytechnical University	China	7	15.9%
3	UK	2	4.5%	4	Tsinghua University	China	6	13.6%
3	Japan	2	4.5%	4	Hong Kong University of Science & Technology	China	6	13.6%
6	Italy	1	2.3%	6	Sun Yat Sen University	China	5	11.4%
				6	Nanjing University of Posts and Telecommunications	China	5	11.4%
				8	South China University of Technology	China	4	9.1%
				8	National University of Singapore	Singapore	4	9.1%
				10	Nanyang Technological University	Singapore	3	6.8%
				10	Harbin Institute of Technology	China	3	6.8%
				10	East China University of Science and Technology	China	3	6.8%
				10	Chongqing University	China	3	6.8%
				10	Beijing Normal University	China	3	6.8%

As for the citing papers (Table 33), researchers from China, the USA, Japan, and other nations or regions have been engaged in designing new types of pure organic RTP materials and exploring their applications. Pure organic RTP materials have been developed toward longer lifetime and higher phosphorescence quantum yield. Applications such as organic light-emitting diodes, photocatalysis, biological imaging, information storage, photodynamic therapy, sensing devices, and security protection have also been actively explored.

Table 33 Top countries/regions and institutions producing citing papers in the Research Front "Pure Organic Room-Temperature Phosphorescent Materials"

Country Ranking	Country /Region	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	939	71.3%	1	Chinese Academy of Sciences	China	184	14.0%
2	USA	107	8.1%	2	Nanjing University of Technology	China	78	5.9%
3	Japan	99	7.5%	2	Jilin University	China	78	5.9%
4	India	79	6.0%	4	Nanjing University of Posts and Telecommunications	China	56	4.3%
5	Singapore	45	3.4%	5	Beijing University of Chemical Technology	China	49	3.7%
6	UK	43	3.3%	6	South China University of Technology	China	46	3.5%
7	Germany	29	2.2%	6	Northwestern Polytechnical University	China	46	3.5%
7	Italy	29	2.2%	6	Hong Kong University of Science & Technology	China	46	3.5%

Country Ranking	Country /Region	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
9	South Korea	25	1.9%	9	Beijing Normal University	China	45	3.4%
10	Spain	24	1.8%	10	Tianjin University	China	42	3.2%
10	Taiwan, China	24	1.8%					



1.3 KEY HOT RESARCH FRONT – "N-heterocyclic carbene catalysis"

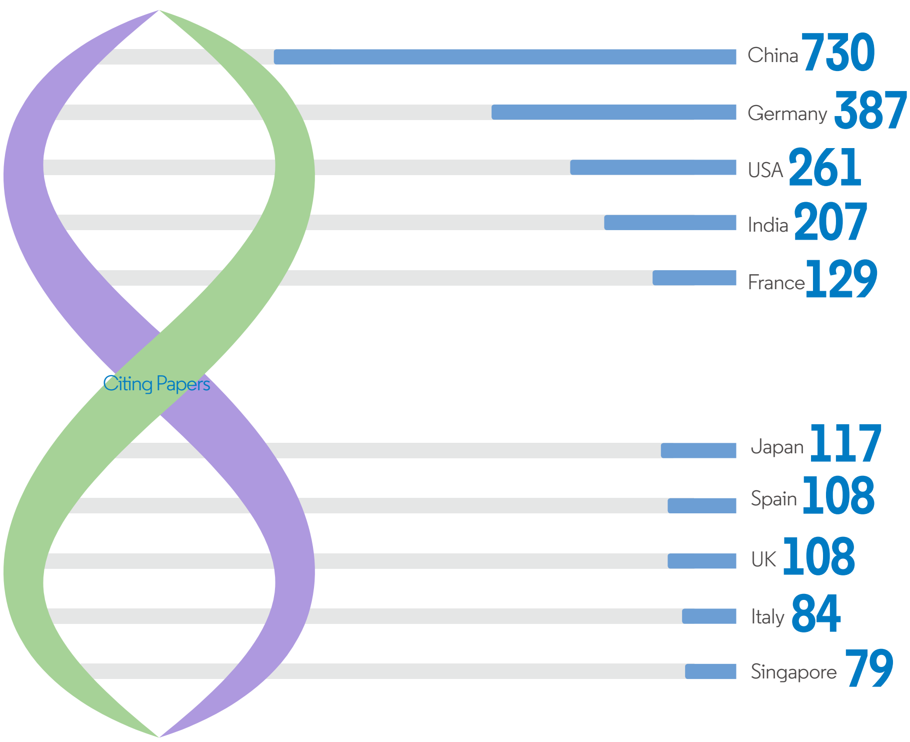
N-heterocyclic carbenes (NHCs) have emerged as a powerful class of organocatalysts that mediate a variety of organic transformations primarily by polarity umpolung approaches. During the course of the reaction of umpolung of aldehydes, the addition of NHCs to aldehydes generates the nucleophilic enaminol intermediates known as the "Breslow intermediates" can be thought of as acyl anion equivalents, causing the innate reactivity of the aldehydes effectively to be inverted with the normally electrophilic carbonyl carbon acting as a transient nucleophile.

The core papers highlight recent advances in types of NHC-catalyzed reactions, such as the benzoin reaction and the Stetter reaction, as well as NHC cooperative catalysis, such as NHC/lewis acid, NHC/brønsted acid, NHC/brønsted base, NHC/hydrogen-bond-donor, and NHC/transition-metal. Frank Glorius from the University of Münster, Germany, and Dieter Enders from RWTH Aachen University, also in Germany, have made outstanding contributions in the field.

According to a count of the citing papers (Table 34), Germany and the USA have kept their advantage in the field. China has paid close attention to NHC catalysis, with a quick increase in the number of published papers; the Chinese Academy of Sciences and Tsinghua University are the leading institutions in China.

Table 34 Top countries and institutions producing citing papers in the Research Front "N-heterocyclic carbene catalysis"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	730	31.5%	1	Chinese Academy of Sciences	China	160	6.9%
2	Germany	387	16.7%	2	French National Center for Scientific Research (CNRS)	France	120	5.2%
3	USA	261	11.3%	3	University of Munster	Germany	73	3.1%
4	India	207	8.9%	4	CSIR India	India	57	2.5%
5	France	129	5.6%	5	Nanyang Technological University	Singapore	55	2.4%
6	Japan	117	5.0%	6	Zhengzhou University	China	51	2.2%
7	Spain	108	4.7%	7	Indian Institute of Technology (IIT)	India	46	2.0%
7	UK	108	4.7%	8	Guizhou University	China	43	1.9%
9	Italy	84	3.6%	9	Rwth Aachen University	Germany	42	1.8%
10	Singapore	79	3.4%	10	Tsinghua University	China	39	1.7%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

Six research specialty areas have been selected as emerging Research Fronts in chemistry and materials science, covering the topics of catalysts, batteries, nano biomaterials, biodegradable materials, chemical techniques and wastewater treatment processes.

Compared with the fronts selected between 2014 and 2019, the emerging Research Fronts in 2020 not only reflect continuity, but also point out some new research directions. The preparation and application of catalysts have repeatedly appeared in the hot Research Fronts and emerging Research Fronts in the field of chemistry and materials. In particular, related research on electrocatalysts for hydrogen evolving by water splitting was highlighted in 2015 (MoS_2 thin film and non-noble metal electrocatalysts), 2016 (non-noble metal nano electrocatalysts), 2017 (non-noble metal dual function electrocatalysts), and 2018 (transition metal nano-array electrocatalysts in neutral environment). This continuity demonstrates that non-noble metal electrocatalysts have always been key research topics in the field of chemistry and materials science.

Battery research has also been identified as one of the important topics in chemistry and materials science. The emerging Research Fronts selected between 2014 and 2019 mainly focused on polymer solar cells, perovskite solar cells, lithium batteries, sodium batteries, etc. In 2020, the research direction shifted to the field of zinc-air batteries, which also appeared in hot Research Fronts in chemistry and materials science, mainly focusing on the research of cathode materials of aqueous zinc ion battery.

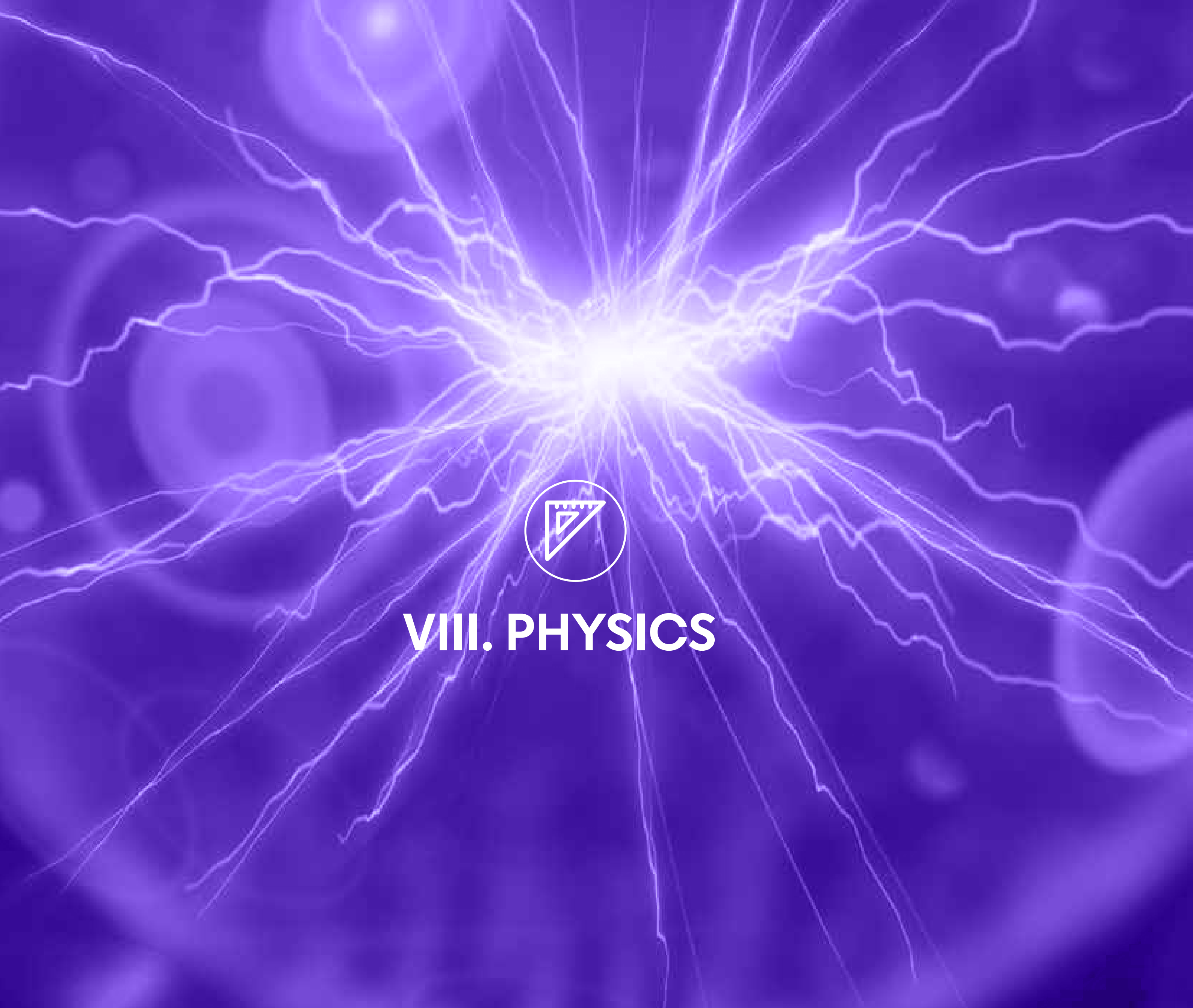
In the area of nanobiomaterials, photoacoustic imaging agent based on the aggregation-induced emission (AIE) of polymer nanoparticles was selected as a hot Research Front in 2015, mainly focusing on the synthesis and property of compounds with AIE characteristics and some application in the field of photoacoustic imaging. In 2020, the research topics now center on its applications in photoacoustic imaging. Furthermore, three new emerging Research Fronts have appeared: the application of biodegradable sensor in biomedical fields, plasma for wastewater treatment, and the extractive distillation process for ternary azeotrope.

Table35: Emerging Research Fronts in chemistry and materials science

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Transition metal phosphides (TMPs) electrocatalysts for the electrocatalytic hydrogen evolution reaction	9	213	2019
2	Nanoparticles with properties of near-infrared aggregation-induced-emission as photoacoustic imaging agent	7	231	2018.9
3	The application of biodegradable pressure sensor material in biomedical fields	6	211	2018.8
4	The extractive distillation process for ternary azeotropes	9	243	2018.7
5	The application of plasma for the disposal of wastewater	18	571	2018.6
6	Rechargeable Zn-air batteries	9	379	2018.6

2.2 KEY EMERGING RESEARCH FRONT – "Transition metal phosphides (TMPs) electrocatalysts for the electrocatalytic hydrogen evolution reaction"

Hydrogen energy represents a potentially abundant and environment-friendly alternative to fossil fuels. Electrochemical hydrogen evolution is the main method to obtain high-purity hydrogen. Pt catalysts are one of the most efficient catalysts for hydrogen evolution reaction. However, due to the high cost, the large-scale application is limited. Transition metal phosphide is a new type of non-noble metal catalysts after the transition metal carbides catalyst and transition metal sulfides catalyst. It has low price, special energy band, good catalytic activity and electrochemical stability in hydrogen evolution. In recent years, it has become the hot research direction in electrochemistry and catalytic materials. The most frequently used transition metal phosphide catalysts include: NiP, Ni_5P_4, CoP, FeP, CuP, MoP and WP. At present, the main methods for improving the catalytic activity of transition metal phosphides are heteroatom doping, vacancy defect, phase structure controlling, multiple component recombination, and heterostructure and hybrid system construction. In this area, many studies have focused on improvement of catalysts with high activity and stability under specific pH conditions, while some concentrate on the preparation of pH-universal catalysts.



VIII. PHYSICS

1. HOT RESEARCH FRONT

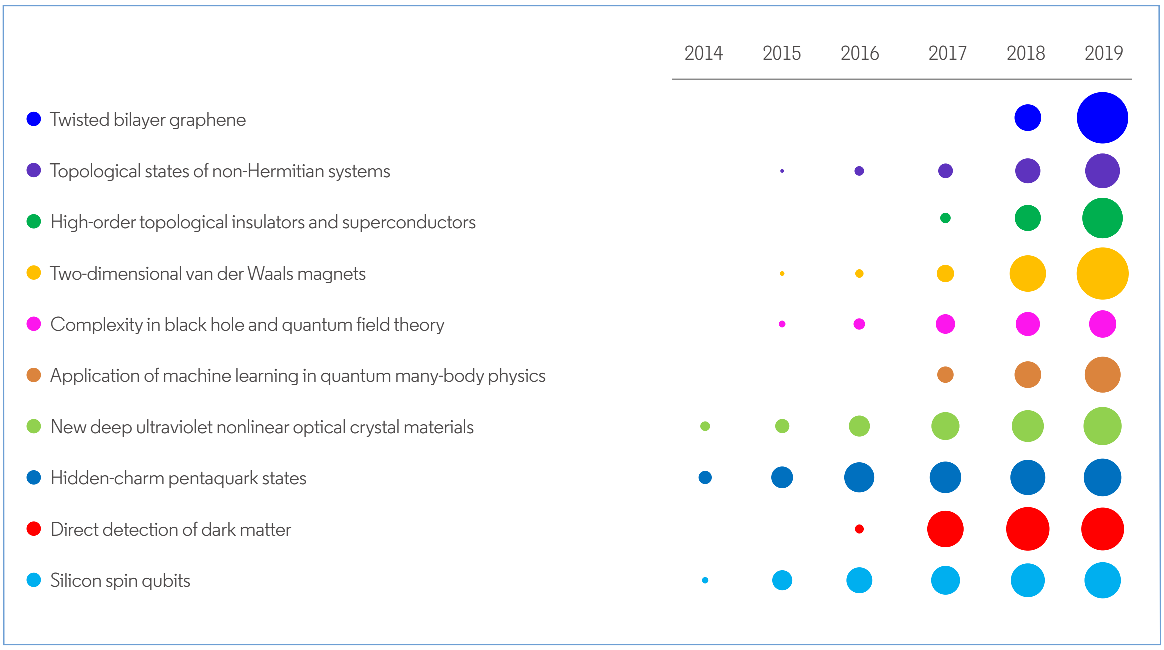
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN PHYSICS

The Top 10 Research Fronts in physics mainly focus on the subfields of condensed matter physics, high-energy physics, quantum physics, theoretical physics, and optics. Eight Research Fronts have newly emerged. In condensed matter physics, the hot topics include twisted bilayer graphene, topological states of non-Hermitian systems, high-order topological insulators and superconductors, and two-dimensional van der Waals magnets. In high-energy physics, the direct detection of dark matter has attracted much attention. Also, research on tetraquark and pentaquark states has been selected as a hot Research Front for four consecutive years, with 2020's selection reflecting a new focus on hidden-charm pentaquark states. In quantum physics, the application of machine learning in quantum many-body physics and silicon spin qubits have become new hot fronts. In optics, new deep-UV nonlinear optical materials remain hot topics. In theoretical physics, complexity in black hole and quantum field theory, which arose in the 2018 report as an emerging Research Front, has become a hot front in 2020.

Table 36: Top 10 Research Fronts in physics

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Twisted bilayer graphene	39	2545	2018.4
2	Topological states of non-Hermitian systems	46	2404	2018.4
3	High-order topological insulators and superconductors	39	2468	2018.2
4	Two-dimensional van der Waals magnets	24	3335	2017.7
5	Complexity in black hole and quantum field theory	43	2568	2017.7
6	Application of machine learning in quantum many-body physics	21	1891	2017.2
7	New deep ultraviolet nonlinear optical crystal materials	32	3094	2017.1
8	Hidden-charm pentaquark states	45	4193	2017
9	Direct detection of dark matter	5	2142	2017
10	Silicon spin qubits	26	2665	2016.8

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



1.2 KEY HOT RESEARCH FRONT – "Twisted bilayer graphene"

The discovery of graphene in 2004 opened the door to the study of novel properties of two-dimensional (2D) materials, which have a thickness consisting of only a few atomic layers. Subsequently, novel 2D materials have been continuously reported, such as transition metal dichalcogenides (TMDs) and phosphorene. These are also called 2D van der Waals (vdW) materials, because van der Waals interaction enables stacking of the layers. While the optical and electrical properties of 2D vdW materials have been widely studied, research on their magnetic properties remains challenging. In 2017, researchers reported the existence of intrinsic magnetism in bilayer $Cr_2Ge_2Te_6$ and monolayer CrI_3, a development that attracted wide interest and led to the emergence of one of 2020's highlighted hot fronts — two-dimensional van der Waals magnets.

In addition to the materials mentioned above, different monolayer 2D materials can be stacked on demand to form a variety of bilayer or multilayer vdW heterostructures, such as graphene heterostructures and TMD heterostructures, which have novel properties and applications. Twisted bilayer graphene (TBG) consists of two sheets of graphene that are twisted relative to each other by a small angle, which can induce new properties. In 2018, a team led by researchers at the Massachusetts Institute of Technology (MIT) discovered that a TBG with a "magic angle" of 1.1° can exhibit Mott insulating state and unconventional superconductivity. This material has attracted a great deal of attention from researchers eager to study the novel electron states and superconductivity in TBG systems. TBG has quickly become a new hot front in condensed matter physics. In 2020, research on TBG was recognized by the Berkeley Prize and the Wolf Prize in Physics.

The USA is the most active country in this front (Table 37), participating in 29 core papers. China, Japan and Germany also contribute notably to the core. Among institutions, MIT registers the highest numbers of core papers, followed by Harvard University, the National Institute of Materials Science of Japan, the Free University of Berlin in Germany, and the Chinese Academy of Sciences. In terms of core paper contribution, five of the top institutions are located in the USA, while Japan, Germany, and China each are host to two. One of the core reports, discussed above, reports the discovery of "magic angle" graphene and currently registers as this front's most-cited core paper, with citations exceeding 900.

Core Papers

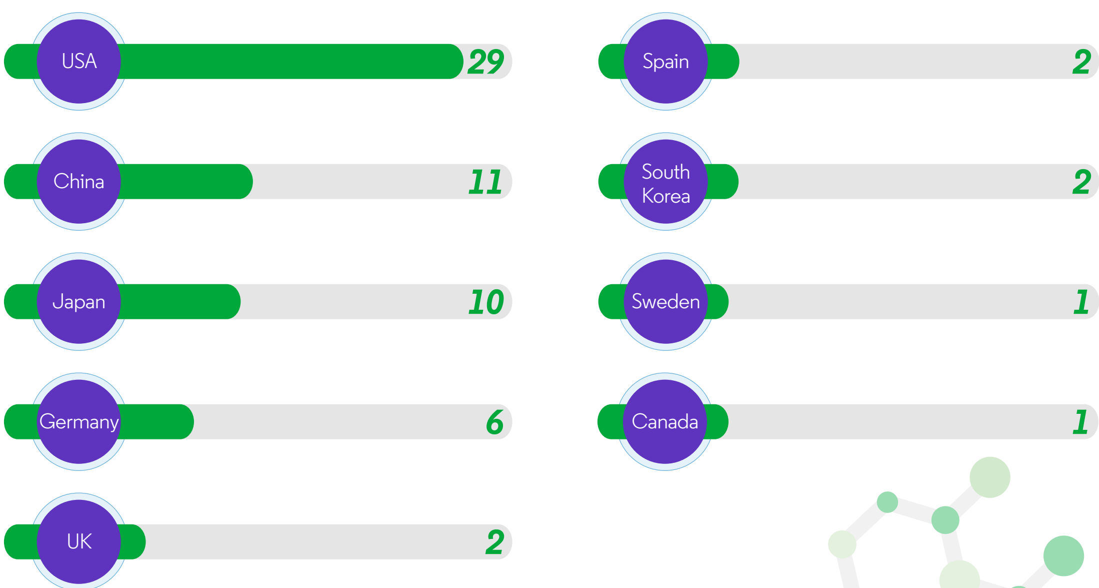


Table 37: Top countries and institutions producing core papers in the Research Front "Twisted bilayer graphene"

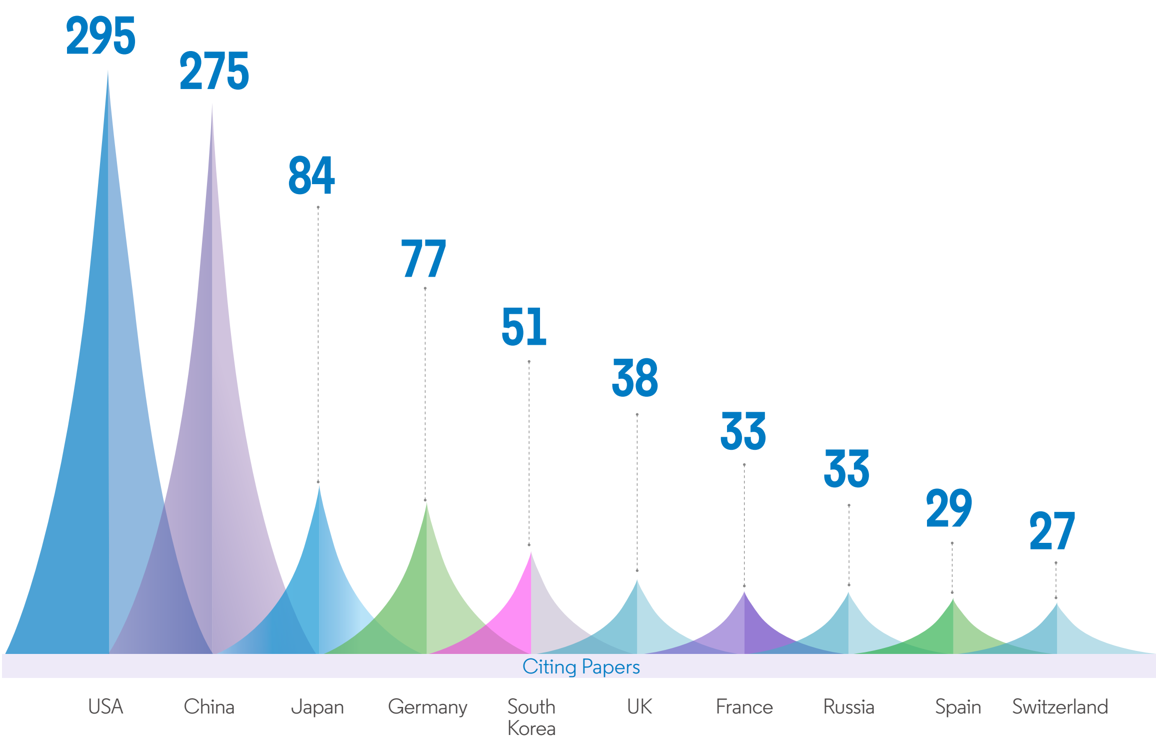
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	29	74.4%	1	Massachusetts Institute of Technology	USA	11	28.2%
2	China	11	28.2%	2	Harvard University	USA	8	20.5%
3	Japan	10	25.6%	3	National Institute of Materials Science of Japan	Japan	7	17.9%
4	Germany	6	15.4%	4	Free University of Berlin	Germany	4	10.3%
5	UK	2	5.1%	4	Chinese Academy of Sciences	China	4	10.3%
5	Spain	2	5.1%	6	United States Department of Energy	USA	3	7.7%
5	South Korea	2	5.1%	6	University of California Santa Barbara	USA	3	7.7%
8	Sweden	1	2.6%	6	Osaka University	Japan	3	7.7%
8	Canada	1	2.6%	6	Max Planck Society	Germany	3	7.7%
				6	Hong Kong University of Science & Technology	China	3	7.7%
				6	Florida State University	USA	3	7.7%

Analysis of the citing papers (Table 38) indicates that the USA has carried out continuous research after the discovery of "magic angle" graphene, and China has quickly caught up with the USA. The citing papers from the two countries far outnumber those by the other listed nations. Among the top institutions, the Chinese Academy of Sciences and the National Institute of Materials Science of Japan account for the most citing papers, followed by the US Department of Energy, MIT and Harvard University.

Table 38: Top countries and institutions producing citing papers in the Research Front "Twisted bilayer graphene"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	295	38.8%	1	Chinese Academy of Sciences	China	77	10.1%
2	China	275	36.2%	2	National Institute of Materials Science of Japan	Japan	51	6.7%
3	Japan	84	11.1%	3	United States Department of Energy	USA	48	6.3%
4	Germany	77	10.1%	4	Massachusetts Institute of Technology	USA	34	4.5%
5	South Korea	51	6.7%	5	Harvard University	USA	30	3.9%
6	UK	38	5.0%	6	French National Center for Scientific Research	France	27	3.6%
7	France	33	4.3%	7	Tsinghua University	China	22	2.9%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
7	Russia	33	4.3%	8	National University of Singapore	Singapore	19	2.5%
9	Spain	29	3.8%	8	Max Planck Society	Germany	19	2.5%
10	Switzerland	27	3.6%	10	Russian Academy of Sciences	Russia	18	2.4%



1.3 KEY HOT RESARCH FRONT– "Direct detection of dark matter"

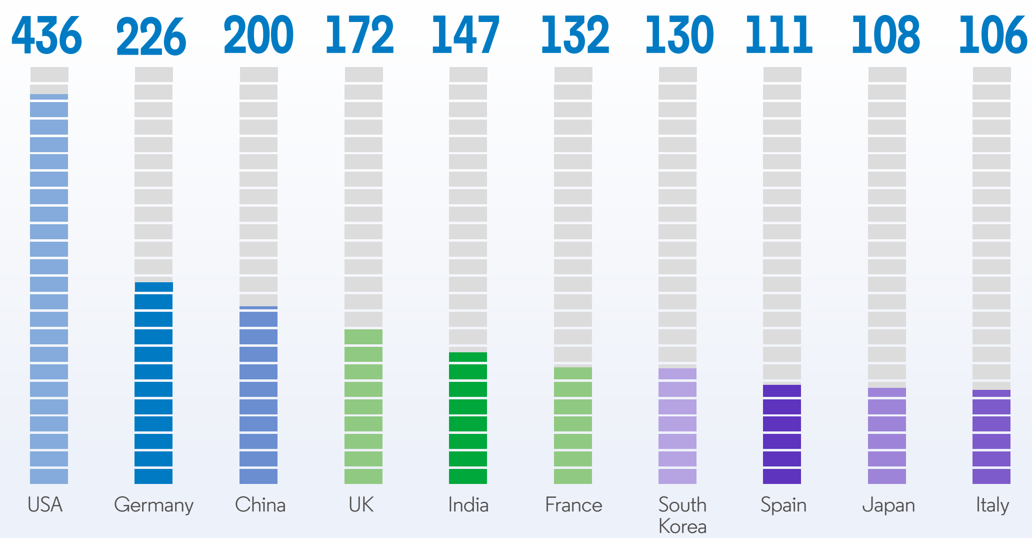
Observational evidence from astronomy and cosmology shows that the main components of the universe are dark matter and dark energy, about which we know little. At present, the detection of dark matter is a hot topic. There are three kinds of dark-matter detection: direct detection, indirect detection, and creating dark matter particles in accelerators. Among these methods, the direct detection of dark matter aims to observe signals induced by the collision of dark matter particles and atomic nuclei. Weakly interacting massive particles (WIMPs) are a class of the proposed candidates for dark matter, and have become the goal of many direct detection experiments using different detectors. Great effort has been made and the sensitivity of the direct detection experiments has been significantly improved, although few promising signals have been found in recent years.

There are only five core papers in this front, but each has collected numerous citations. These highly cited results came from three direct dark matter detection experiments that used liquid xenon detection technology: the Large Underground Xenon (LUX) experiment in the USA (in a report cited 836 times at this writing), the PandaX-II experiment in China (two papers, cited 369 and 387 times, respectively), and the XENON1T experiment in Italy (two reports, respectively cited 420 and 484 times). These results each broke the record of the restriction on the properties of dark matter particles and achieved the highest sensitivity of direct detection experiments at that time. Currently, LUX, PandaX and other experiments are undergoing new upgrades to further improve the sensitivity of the detectors.

By the measure of citing papers (Table 39), the USA is the most active country, followed by Germany, China, and the UK. Among the top institutions, the US Department of Energy and the French National Center for Scientific Research (CNRS) can claim the most citing papers, followed by the University of Chicago, the Chinese Academy of Sciences, the Spanish National Research Council and the Italian National Institute of Nuclear Physics.

Table 39: Top countries and institutions producing citing papers in the Research Front "Direct detection of dark matter"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	436	37.4%	1	United States Department of Energy	USA	144	12.4%
2	Germany	226	19.4%	2	French National Center for Scientific Research	France	122	10.5%
3	China	200	17.2%	3	University of Chicago	USA	98	8.4%
4	UK	172	14.8%	3	Chinese Academy of Sciences	China	98	8.4%
5	India	147	12.6%	5	Spanish National Research Council	Spain	96	8.2%
6	France	132	11.3%	6	National Institute of Nuclear Physics	Italy	91	7.8%
7	South Korea	130	11.2%	7	Helmholtz Association	Germany	80	6.9%
8	Spain	111	9.5%	8	Max Planck Society	Germany	74	6.4%
9	Japan	108	9.3%	9	University of Paris Saclay	France	70	6.0%
10	Italy	106	9.1%	10	Indian Institute of Technology	India	65	5.6%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN PHYSICS

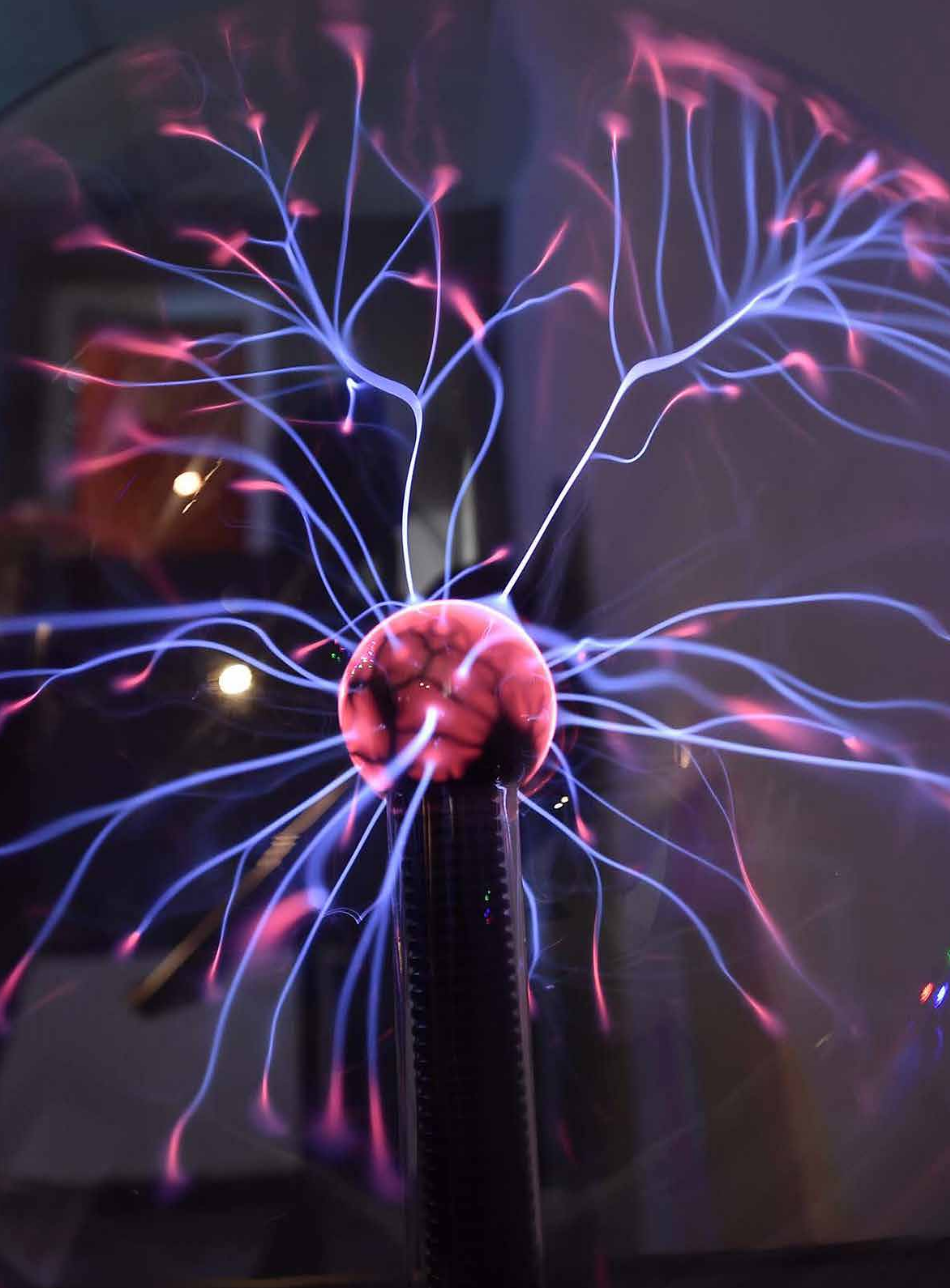
Two topics in physics are highlighted as emerging Research Fronts, with one focusing on studies of theoretical physics, namely “Spontaneous scalarization of black holes in Gauss-Bonnet gravity,” and the other on condensed matter physics: “Moiré superlattices in two-dimensional van der Waals heterostructures”.

Table 40: Emerging Research Fronts in physics

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Spontaneous scalarization of black holes in Gauss-Bonnet gravity	15	444	2018.7
2	Moiré superlattices in two-dimensional van der Waals heterostructures	8	267	2018.6

2.2 KEY EMERGING RESEARCH FRONT – “Moiré superlattices in two-dimensional van der Waals heterostructures”

As is discussed above in section 1.2, vdW heterostructures are bilayer or multilayer artificial structures that can be stacked on demand by monolayer 2D materials, and will enable the realization of high-performance electronic and optoelectronic devices. With the discovery of unconventional superconductivity in twisted bilayer graphene, the novel phenomena induced by the twist angles between the layers in vdW heterostructures have provoked much interest. Lattice mismatch and rotation between the layers can lead to different Moiré superlattices, which are relevant to twist angles. Moiré superlattices can induce structural alteration and band transformations, resulting in new phenomena, including Moiré excitons, Moiré phonons, unconventional superconductivity, and providing new ideas for the development of 2D materials. The core papers in this emerging research front focus on the Moiré superlattice of TMD heterostructures and the optical properties induced by the band structure. The studies of the TMD heterostructures concentrate on bilayers and heterobilayers of MoS_2, $MoSe_2$, WS_2, and WSe_2.



IX. ASTRONOMY AND ASTROPHYSICS

1. HOT RESEARCH FRONT

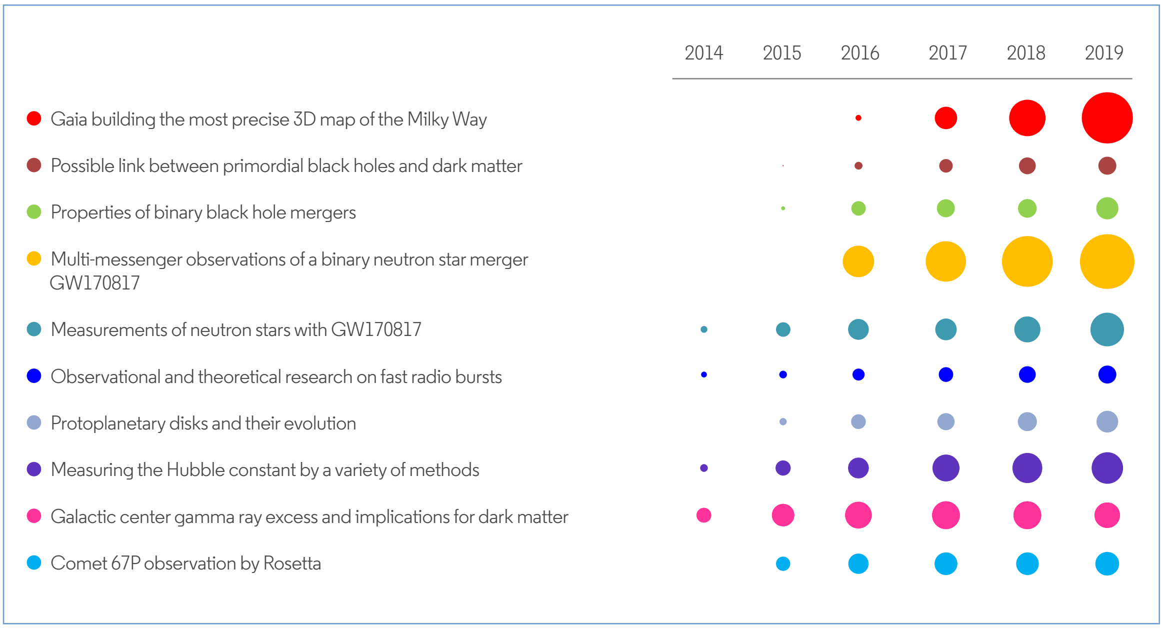
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

The Top 10 Research Fronts in this area continue to focus on a range of topics, including: black holes; dark matter and dark energy; the origin and evolution of the universe, celestial bodies, and extraterrestrial life; and gravitational waves. Among the Top 10 Research Fronts, four involve gravitational wave observations and theoretical studies, as well as related studies on the properties of black holes and neutron stars, including a possible link between primordial black holes and dark matter; properties of binary black hole mergers; multi-messenger observations of a binary neutron star merger GW170817; and measurements of neutron stars using GW170817. The other six fronts pertain to precise mapping of the Milky Way by the Gaia space mission, mysterious fast radio bursts, protoplanetary disks and their evolution, measurement of the Hubble constant, galactic center gamma ray excess, and Comet 67P observation by the Rosetta spacecraft.

Table 41 Top 10 Research Fronts in astronomy and astrophysics

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Gaia building the most precise 3D map of the Milky Way	27	5804	2018
2	Possible link between primordial black holes and dark matter	30	2216	2017.7
3	Properties of binary black hole mergers	35	2754	2017.4
4	Multi-messenger observations of a binary neutron star merger GW170817	48	15751	2017.3
5	Measurements of neutron stars with GW170817	50	5815	2017.3
6	Observational and theoretical research on fast radio bursts	30	3040	2017.2
7	Protoplanetary disks and their evolution	20	1995	2016.8
8	Measuring the Hubble constant by a variety of methods	14	4089	2016.5
9	Galactic center gamma ray excess and implications for dark matter	43	6550	2015.5
10	Comet 67P observation by Rosetta	18	2752	2015.4

Figure 8 Citing papers for the Top 10 Research Fronts in astronomy and astrophysics



1.2 KEY HOT RESEARCH FRONT – "Gaia building the most precise 3D map of the Milky Way"

Until quite recently we knew very little about our galactic home. For us living on Earth, our planet is unique. In fact, Earth is just one of hundreds of billions of planets orbiting the approximately 250 billion stars comprising our galaxy, the Milky Way. It took centuries to discover not only that the Milky Way itself has a spiral structure, but also Earth's position in it. Located some 26,000 light years from the center of the galaxy, Earth sits close to one of the Milky Way's spiral arms. Earth's position inside the Milky Way virtually prevented scientists from seeing the forest for the trees, and that's why it was so difficult to study the Milky Way before Gaia.

Gaia is a European Space Agency (ESA) mission launched in 2013 to survey more than 1 billion stars in our Galaxy and its local neighborhood in order to build the most precise 3D map of the Milky Way and answer questions about its structure, origin and evolution. Gaia is designed to monitor each of its target stars about 70 times over a five-year period to precisely chart their positions, distances, movements, and changes in brightness. This detailed knowledge will promote the discovery of planets around other stars, asteroids in our Solar System, icy bodies in the outer Solar System, brown dwarfs, and far-distant supernovae and quasars. The list of Gaia's potential discoveries makes the mission unique in terms of scope and scientific return. Huge databases of information will be compiled from the Gaia data, allowing astronomers to trawl the archives looking for similar celestial objects, or for events and other correlations that might just provide the clue necessary to solve particular, seemingly intractable, scientific puzzles.

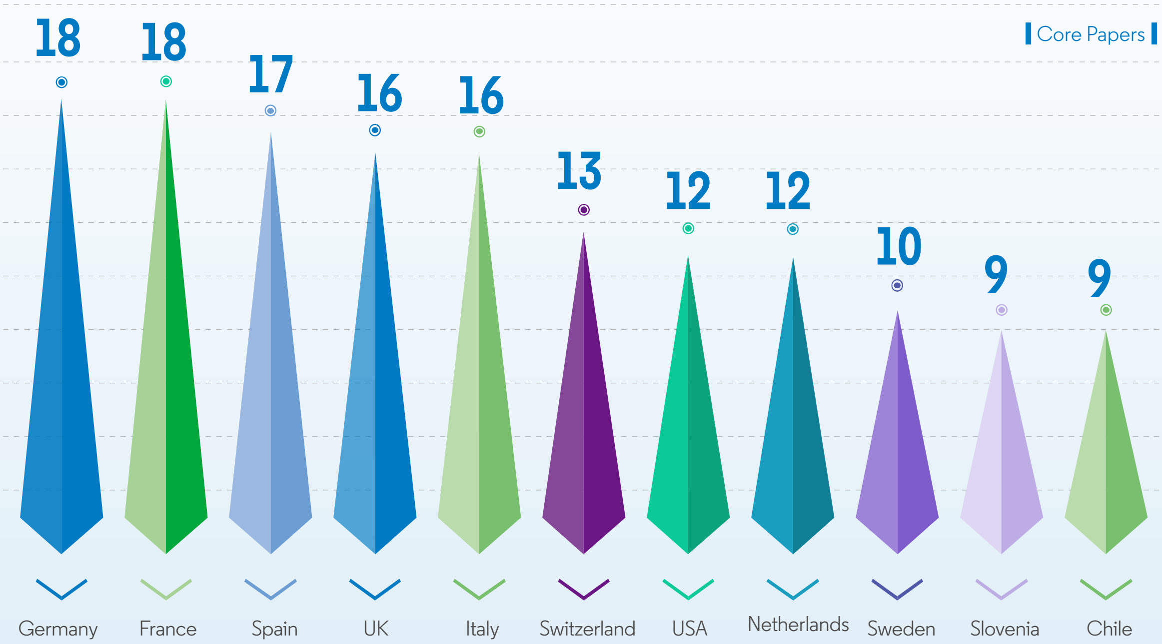
The first data release of Gaia, published in 2016, contained distances and motions of 2 million stars. The second data release was published in 2018, and produced the richest star catalogue to date, including high-precision measurements of nearly 1.7 billion stars. "The observations collected by Gaia are redefining the foundations of astronomy," said Günther Hasinger, ESA Director of Science. Originally designed to operate for five years, until July 2019, Gaia has been extended to 31 December 2022. The final Gaia catalogue will be the definitive stellar catalogue for the foreseeable future and play a central role in a wide range of fields in astronomy. Anthony Brown, the leader of the Gaia Data Processing and Analysis Consortium, was selected by *Nature* as one of the 10 people who mattered in science in 2018.

The hot Research Front "Gaia building the most precise 3D map of the Milky Way" includes 27 core papers, involving overviews of the Gaia mission, the two data releases, and scientific research findings based on Gaia's observational datasets.

As the leading agency for the Gaia mission, several member states of ESA have performed extremely well, both in terms of Top 10 countries and institutions producing core papers in this Research Front. Among the Top 10 countries, only the USA and Chile are not members of ESA, while Slovenia is an associate ESA member, and the other eight are all member nations. All the Top 10 institutions are from ESA member states. Since most of the core papers are the result of multinational cooperation involving many participating countries and institutions, the numbers of core papers produced by top countries and institutions are similar.

Table 42. Top countries and institutions producing core papers in the Research Front "Gaia building the most precise 3D map of the Milky Way"

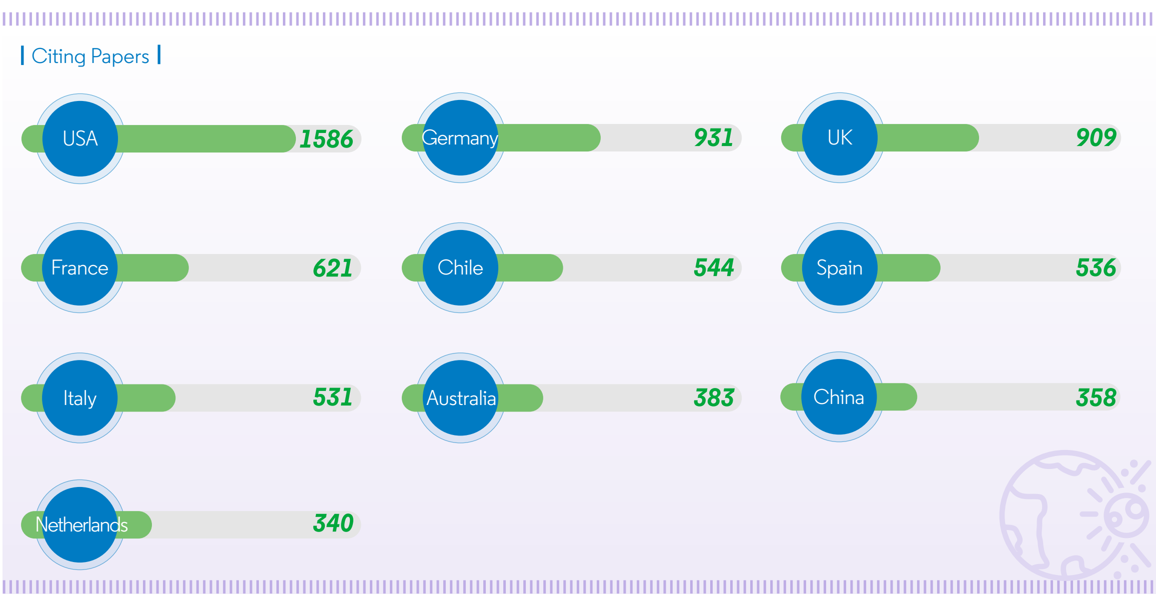
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Germany	18	66.7%	1	French National Center for Scientific Research (CNRS)	France	18	66.7%
1	France	18	66.7%	2	Max Planck Society	Germany	16	59.3%
3	Spain	17	63.0%	3	Université PSL	France	15	55.6%
4	UK	16	59.3%	3	Observatoire de Paris	France	15	55.6%
4	Italy	16	59.3%	3	Italian National Institute for Astrophysics	Italy	15	55.6%
6	Switzerland	13	48.1%	6	University of Bordeaux	France	14	51.9%
7	USA	12	44.4%	7	Université de Paris	France	13	48.1%
7	Netherlands	12	44.4%	7	University of Geneva	Switzerland	13	48.1%
9	Sweden	10	37.0%	7	University of Barcelona	Spain	13	48.1%
10	Slovenia	9	33.3%	10	University of Padua	Italy	12	44.4%
10	Chile	9	33.3%	10	Sorbonne University	France	12	44.4%
				10	The Côte d'Azur Observatory	France	12	44.4%
				10	Institute of Space Studies of Catalonia	Spain	12	44.4%



Gaia's comprehensive datasets provide a wide range of topics for the astronomy community, attracting astronomers from all over the world. Analysis of the citing papers indicates that the USA takes the lead, producing more than half the citing papers. Half the Top 10 institutions producing citing papers are based in the USA. China has also followed up rapidly in this Research Front, ranking 9th in the Top 10 countries in production of citing papers. By that same measure, the Chinese Academy of Sciences ranks 11th among the top institutions.

Table 43 Top countries and institutions producing citing papers in the Research Front "Gaia building the most precise 3D map of the Milky Way"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	1586	54.4%	1	French National Center for Scientific Research (CNRS)	France	579	19.9%
2	Germany	931	32.0%	2	Max Planck Society	Germany	441	15.1%
3	UK	909	31.2%	3	Italian National Institute for Astrophysics	Italy	434	14.9%
4	France	621	21.3%	4	National Aeronautics and Space Administration	USA	297	10.2%
5	Chile	544	18.7%	5	California Institute of Technology	USA	291	10.0%
6	Spain	536	18.4%	6	Smithsonian Institution	USA	278	9.5%
7	Italy	531	18.2%	7	University of Cambridge	UK	273	9.4%
8	Australia	383	13.1%	8	Harvard University	USA	262	9.0%
9	China	358	12.3%	9	Association of Universities for Research in Astronomy	USA	249	8.5%
10	Netherlands	340	11.7%	10	Instituto de Astrofísica de Canarias	Spain	236	8.1%
				11	Chinese Academy of Sciences	China	230	7.9%



1.3 KEY HOT RESEARCH FRONT – "Observational and theoretical research on fast radio bursts"

Fast radio bursts (FRBs) are intense radio pulses from the sky with millisecond-duration and Jansky-level intensity, produced by extremely energetic processes. FRBs were discovered in 2007 by researchers combing through archived data obtained by the Parkes radio telescope in Australia. In subsequent years, FRBs quickly became a subject of intense interest in time-domain astronomy.

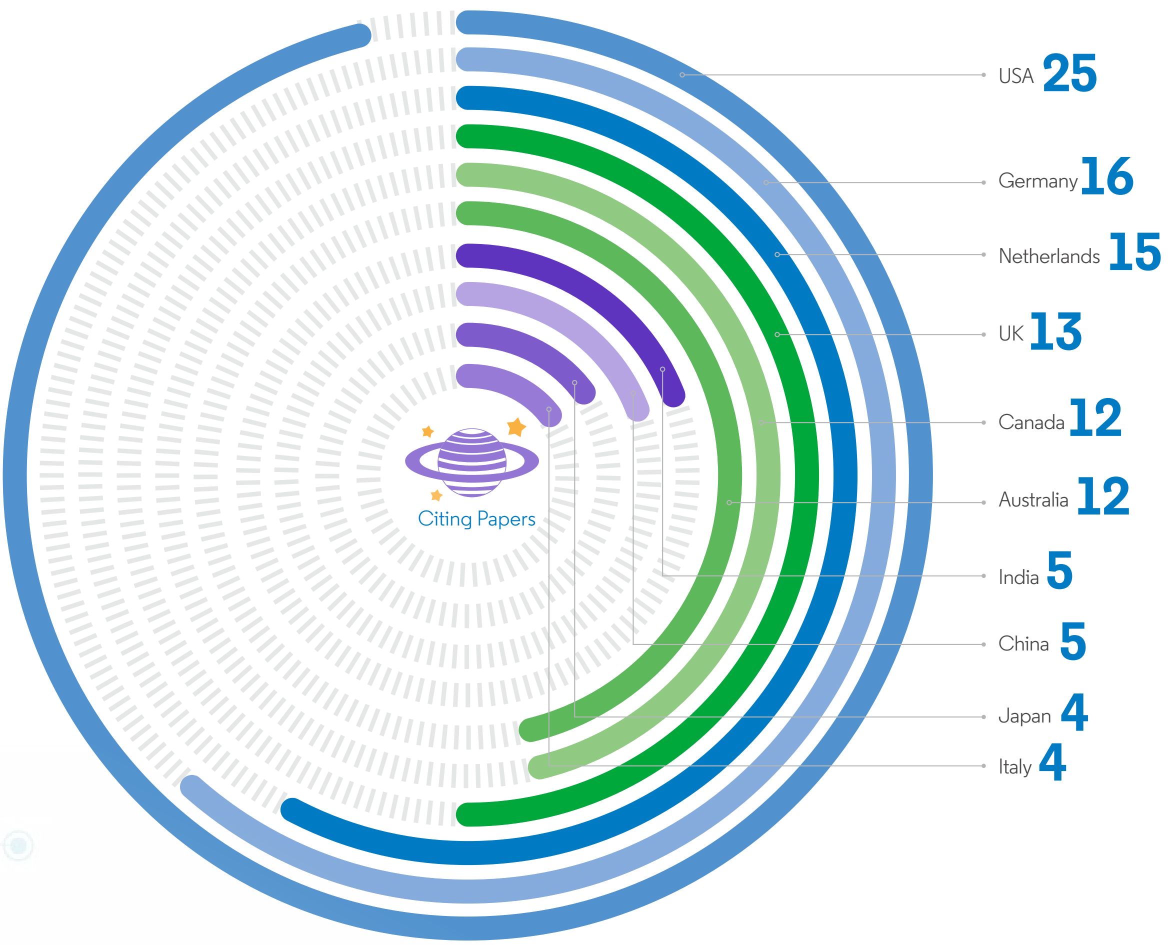
Since the first FRB was observed in 2007, astronomers have cataloged more than 100 FRBs from distant sources scattered across the universe, outside our own galaxy. For the most part, these detections were one-offs, flashing briefly before disappearing entirely. In a handful of instances, astronomers observed FRBs multiple times from the same source. The repeating FRBs rule out cataclysmic origins for those events and could be the key to resolving the mysteries of FRBs, as astronomers anticipated that the upcoming bursts can allow for the preparation extensive follow-up observational campaigns. Following the discovery of the first repeating source FRB 121102 in 2016, several new FRB repeaters were detected, though with no discernible pattern. In 2020, the Canadian Hydrogen Intensity Mapping Experiment (CHIME) telescope FRB collaboration group reported the first source FRB 180916. J0158+65 producing an intriguingly regular pattern of bursts, with a duration of about 16 days. The pattern begins with a noisy, four-day window, during which the source emits random bursts of radio waves, followed by a 12-day period of radio silence. The astronomers observed that this 16-day pattern of FRBs reoccurred consistently over 500 days of observations. As of now, the physical nature of FRBs is still a longstanding mystery in astrophysics, and astronomers have considered a variety of explanations, including: a single compact object, such as a neutron star; a binary system, such as a neutron star orbiting another neutron star or black hole; a radio-emitting source that circles a central star; or a magnetar.

The hot Research Front "Observational and theoretical research on fast radio bursts" includes 30 core papers pertaining to the discovery, observation and localization of singular and repeating FRBs. The Arecibo Observatory of the USA, the Jodrell Bank Observatory of UK, the Parkes Observatory in Australia, the CHIME telescope in Canada, etc., are important observation platforms for FRBs, and associated countries and institutions all perform well in terms of the output of core papers and citing papers in this Research Front.

Table 44: Top countries and institutions producing core papers in the Research Front "Observational and theoretical research on fast radio bursts"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	25	83.3%	1	Max Planck Society	Germany	16	53.3%
2	Germany	16	53.3%	2	National Radio Astronomy Observatory	USA	13	43.3%
3	Netherlands	15	50.0%	3	West Virginia University	USA	12	40.0%
4	UK	13	43.3%	3	Commonwealth Scientific and Industrial Research Organization (CSIRO)	Australia	12	40.0%
5	Canada	12	40.0%	5	University of Manchester	UK	11	36.7%
5	Australia	12	40.0%	5	Netherlands Institute for Radio Astronomy	Netherlands	11	36.7%
7	India	5	16.7%	7	University of Amsterdam	Netherlands	10	33.3%

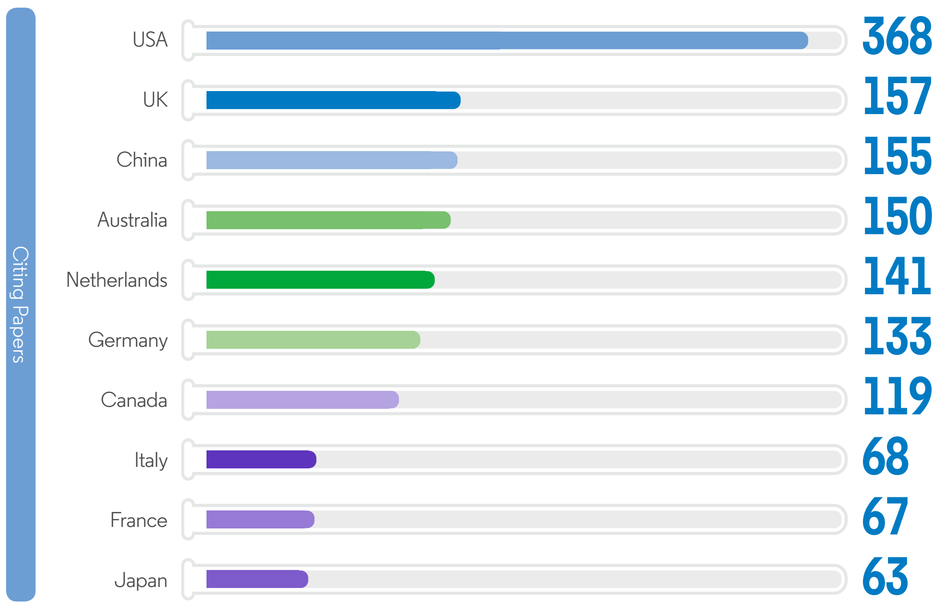
Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
7	China	5	16.7%	7	Swinburne University of Technology	Australia	10	33.3%
9	Japan	4	13.3%	7	McGill University	Canada	10	33.3%
9	Italy	4	13.3%	7	Curtin University	Australia	10	33.3%
				7	California Institute of Technology	USA	10	33.3%



Compared to the output of core papers, China displays better performance in terms of citing papers, showing a robust development trend. In 2019, the Five-hundred-meter Aperture Spherical Radio Telescope (FAST) in China detected multiple bursts from FRB 121102. In the future, FAST will play an important role in the discovery and observation of FRBs.

Table 45: Top countries and institutions producing citing papers in the Research Front "Observational and theoretical research on fast radio bursts"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	368	53.6%	1	Max Planck Society	Germany	108	15.7%
2	UK	157	22.9%	2	University of Manchester	UK	102	14.9%
3	China	155	22.6%	3	Commonwealth Scientific and Industrial Research Organization (CSIRO)	Australia	91	13.3%
4	Australia	150	21.9%	4	Chinese Academy of Sciences	China	89	13.0%
5	Netherlands	141	20.6%	5	West Virginia University	USA	88	12.8%
6	Germany	133	19.4%	6	University of Amsterdam	Netherlands	86	12.5%
7	Canada	119	17.3%	7	National Radio Astronomy Observatory	USA	81	11.8%
8	Italy	68	9.9%	8	Swinburne University of Technology	Australia	76	11.1%
9	France	67	9.8%	9	Curtin University	Australia	68	9.9%
10	Japan	63	9.2%	10	California Institute of Technology	USA	63	9.2%



2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

There is one emerging Research Front in astronomy and astrophysics: "Cosmological implications of the string theory swampland".

Table 46 Emerging Research Fronts in astronomy and astrophysics

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Cosmological implications of the string theory swampland	50	1677	2018.6

2.2 KEY EMERGING RESARCH FRONT – "Cosmological implications of the string theory swampland"

Various theories derived from string theory have described numerous possibilities for a four-dimensional universe, creating a vast string landscape. As early as 2005, a group of string scientists, chiefly represented by Cumrun Vafa of Harvard University, proposed the concept of a "string swampland", which means that many seemingly self-consistent and valid theories are incompatible with string theory and do not belong to the string landscape, and thus have to be excluded into the so-called "string swampland".

Inflation is the most convincing explanation for the existing state and structure of the universe. String theory is regarded as a significant candidate theory for solving the quantum physics and gravity puzzle, but it cannot explain inflation in the development of the universe. In 2018, Vafa et al. proposed the de Sitter swampland conjecture that the difficulties encountered in verifying inflationary models with string theory reflect the impossibility -- that is, inflation may not have occurred in string theory. Any notion that could describe a de Sitter space, i.e., an inflationary universe, would have a theoretical flaw that would plunge the notion into a "swampland" of false theories.

This controversial idea quickly sparked a heated discussion in the string theory and cosmology communities, and the related research papers formed the emerging Research Front of 2020 in astronomy and astrophysics. The emerging front brings together 50 core papers focusing on demonstrating or refuting the validity of the de Sitter swampland conjecture based on various theories, investigating the dynamics of dark energy on the basis of the de Sitter swampland conjecture, providing new theoretical constraints on dark energy combined with cosmological observations, and proposing alternative possibilities for the evolution of the universe beyond the theory of cosmic inflation.

X. MATHEMATICS

1. HOT RESEARCH FRONT

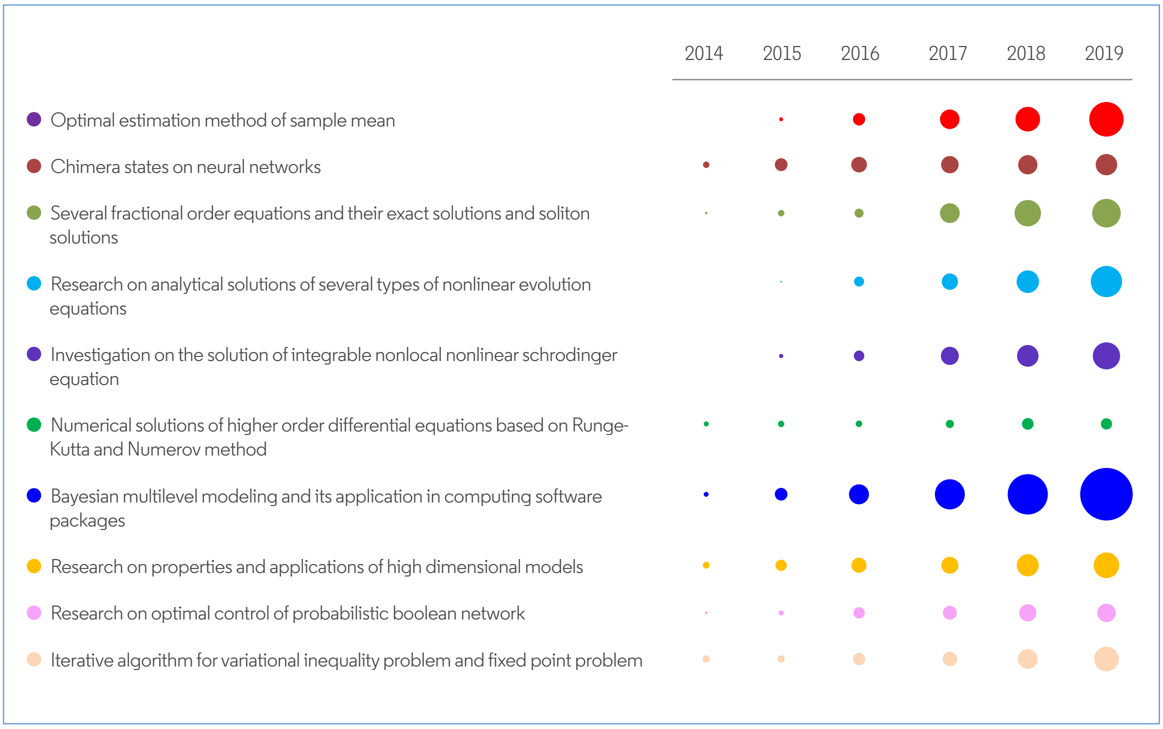
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN MATHEMATICS

The Top 10 Research Fronts in mathematics mainly focus on: optimal estimation method of sample mean; chimera states on neural networks; properties and solutions of partial differential equations; Bayesian multilevel modeling and its application; properties and applications of high dimensional models; optimal control of probabilistic boolean network; and iterative algorithm for the variational inequality problem and the fixed point problem. The Top 10 Research Fronts in 2020 show both continuity and new development when compared with the fronts selected between 2013 and 2019. The solutions for partial differential equations and their applications have been consecutively selected as a hot or emerging Research Front for years. In 2020, optimal estimation method of sample mean, Bayesian multilevel modeling in statistics, and chimera states on neural networks in nonlinear systems have been selected as hot Research Fronts for the first time.

Table 47: Top 10 Research Fronts in mathematics

Rank	Hot Research Fronts	Core papers	Times Cited	Mean Year of Core Papers
1	Optimal estimation method of sample mean	2	830	2016
2	Chimera states on neural networks	11	1344	2015.1
3	Several fractional order equations and their exact solutions and soliton solutions	16	1586	2016
4	Research on analytical solutions of several types of nonlinear evolution equations	28	2271	2017.3
5	Investigation on the solution of integrable nonlocal nonlinear schrodinger equation	40	1596	2017.8
6	Numerical solutions of higher order differential equations based on Runge-Kutta and Numerov method	29	1425	2017.2
7	Bayesian multilevel modeling and its application in computing software packages	9	2477	2016.6
8	Research on properties and applications of high dimensional models	15	1201	2015.7
9	Research on optimal control of probabilistic boolean network	16	814	2016.6
10	Iterative algorithm for variational inequality problem and fixed point problem	47	1664	2017.3

Figure 9: Citing papers for the Top 10 Research Fronts in mathematics



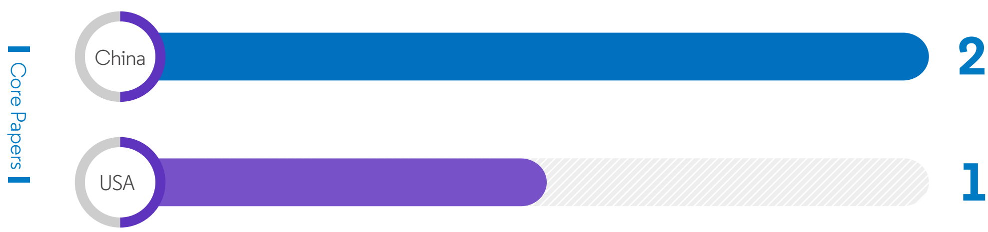
1.2 KEY HOT RESEARCH FRONT – "Optimal estimation method of sample mean"

Meta-analysis refers to the application of specific statistical methods to the overall and systematic qualitative/quantitative analysis of previous research results. In meta-analysis, the more widely used method for continuous outcomes is the calculation of statistics by combining the sample means and standard deviations of multiple studies through Weighted Mean Difference (WMD). However, many studies only report the sample median, maximum, and minimum values, and/or the first and third quartiles. Based on this situation, researchers need to estimate the sample mean and standard deviation based on the aforementioned combined statistics, and then conduct meta-analysis using the transformed sample mean and standard deviation.

Only a few methods are used to estimate the sample mean and standard deviation. The most widely used is the estimation of the sample mean and standard deviation using the sample median, maximum, and minimum as proposed by Stela Hozo, *et al.*, in 2005 (BMC Med Res Methodol 2005, 5:13). Tiejun Tong, Hong Kong Baptist University, and colleagues demonstrated that Hozo's estimation method has a large bias at both the theoretical and practical levels, and proposed an improved method. In fact, Tong and colleagues contributed both of the core papers in this 2020 key hot Research Front, "Optimal estimation method of sample mean". In their core paper published in 2014, Tong and co-authors implemented a conversion method from sample size, median, extremum, or quartile to sample mean and standard deviation. In the other core paper, from 2018, Tong and his research team added weights that flattened out with sample size to the calculation, resulting in more accurate estimation of the sample mean. Researchers from Northwestern University in the USA were involved in one of the papers. The two core papers have received widespread attention since publication, and, at this writing, have been cited 755 and 75 times, respectively.

Table 48: Top countries and institutions producing core papers in the Research Front "Optimal estimation method of sample mean"

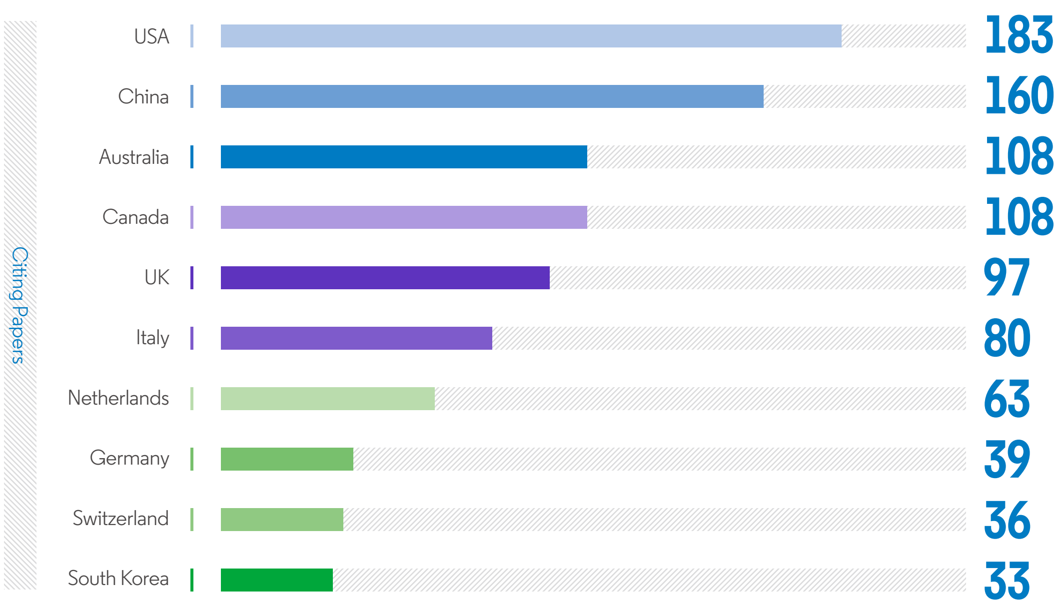
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	2	100.0%	1	Hong Kong Baptist University	China	2	100.0%
2	USA	1	50.0%	2	Northwestern University	USA	1	50.0%



As a statistical method that incorporates independent studies, meta-analysis has demonstrated wide and indispensable utility. Therefore, the research front has been growing rapidly in recent years. The citing papers extend to investigating the optimization of the method and its application in medical research, with the USA and China performing most prominently, and Australia, Canada, and the UK all actively participating in high numbers of citing papers. Most of the Top 10 prolific institutions in terms of citing papers are based in the USA, Canada, and Australia. As the only Chinese institution in Top 10, Sichuan University ranks 4th.

Table 49: Top countries and institutions producing citing papers in the Research Front "Optimal estimation method of sample mean"

Country Ranking	Country/ Regions	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	183	23.0%	1	University of Toronto	Canada	45	5.7%
2	China	160	20.2%	2	McMaster University	Canada	29	3.7%
3	Australia	108	13.6%	3	University of Sydney	Australia	27	3.4%
3	Canada	108	13.6%	4	Sichuan University	China	22	2.8%
5	UK	97	12.2%	5	Harvard University	USA	21	2.6%
6	Italy	80	10.1%	6	University of Western Australia	Australia	19	2.4%
7	Netherlands	63	7.9%	6	Mashhad University of Medical Science	Iran	19	2.4%
8	Germany	39	4.9%	6	Johns Hopkins University	USA	19	2.4%
9	Switzerland	36	4.5%	9	Mayo Clinic	USA	17	2.1%
10	South Korea	33	4.2%	10	University of Melbourne	Australia	15	1.9%
				10	University of New South Wales	Australia	15	1.9%
				10	Erasmus University Rotterdam	Netherlands	15	1.9%
				10	Maastricht University	Netherlands	15	1.9%
				10	University of Amsterdam	Netherlands	15	1.9%



1.3 KEY HOT RESEARCH FRONT – "Bayesian multilevel modeling and its application in computing software packages"

Bayesian analysis provides a method for calculating the hypothesis probability, which is based on the prior probability of a hypothesis, the probability of observing different data under a given hypothesis, and the observed data itself. Hierarchical Bayesian model, known as one of the "landmark buildings" of modern Bayesian method, is a statistical model with structured levels. It estimates the parameters of posterior distribution by Bayesian method, and can be used to establish hierarchical model for complex statistical problems, so as to avoid overfitting problem caused by excessive parameters.

Bayesian network, as an extension of Bayesian method, is one of the most effective theoretical models in the field of uncertain knowledge expression and reasoning. In recent years, the development of artificial intelligence (AI) technology has been on the rise. But more than 30 years ago, a major challenge faced by AI research was figuring out how to program machines. At that time, Judea Pearl, an American computer scientist, found that Bayesian networks can make machines easily infer the relationship between potential causes and observable phenomena. Pearl also won the 2011 Turing Award for his fundamental contribution to AI by virtue of the "calculus model of probabilistic reasoning and causal reasoning", and was called the "father of Bayesian networks".

As the first hot Research Front on Bayesian statistical theory in the field of mathematics in recent years, the front titled "Bayesian multilevel modeling and its application in computing software packages" contains nine core papers. The research focus of this research front is relatively unified. Based on "multi-layer Bayesian modeling as the statistical foundation of machine learning and artificial intelligence", it mainly focuses on Bayesian sampler algorithm design, Bayesian reasoning system development, multi-layer Bayesian model R software package brms, Bayesian modeling and simulation practicality cross validation, Bayesian prediction and distribution model, and the application of Bayesian modeling in the field of ecology.

In terms of the number of core papers in the front (Table 50), the USA and Finland are the main contributors. As for the institutions, Columbia University is the most prolific with six core papers, accounting for 66.7% of the total. It should be noted that these six core papers are all from Columbia's Andrew Gelman and colleagues, as are the top two most-cited core papers in this front. One of these reports, "Stan: a probabilistic programming language", published in 2017, has been cited more than 800 times. Introduced in this paper, Stan is a powerful and efficient probabilistic programming language developed to specify statistical models. It provides complete Bayesian reasoning for continuous variable models through Markov chain Monte Carlo algorithm, which is the cutting-edge fundamental work of Bayesian statistics and modeling.

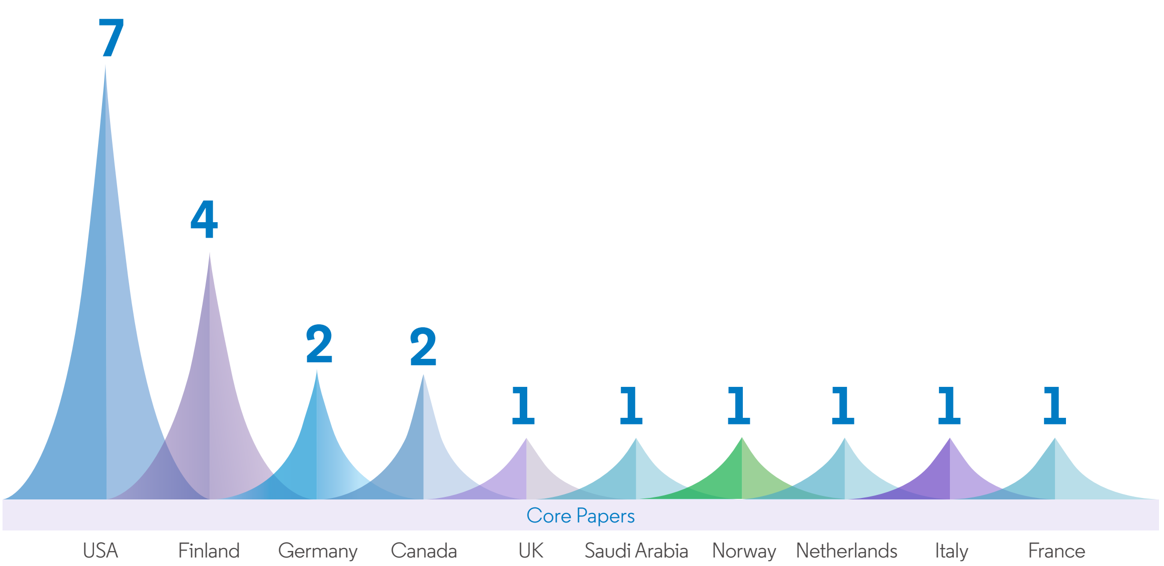


Table 50: Top countries and institutions producing core papers in the Research Front "Bayesian multilevel modeling and its application in computing software packages"

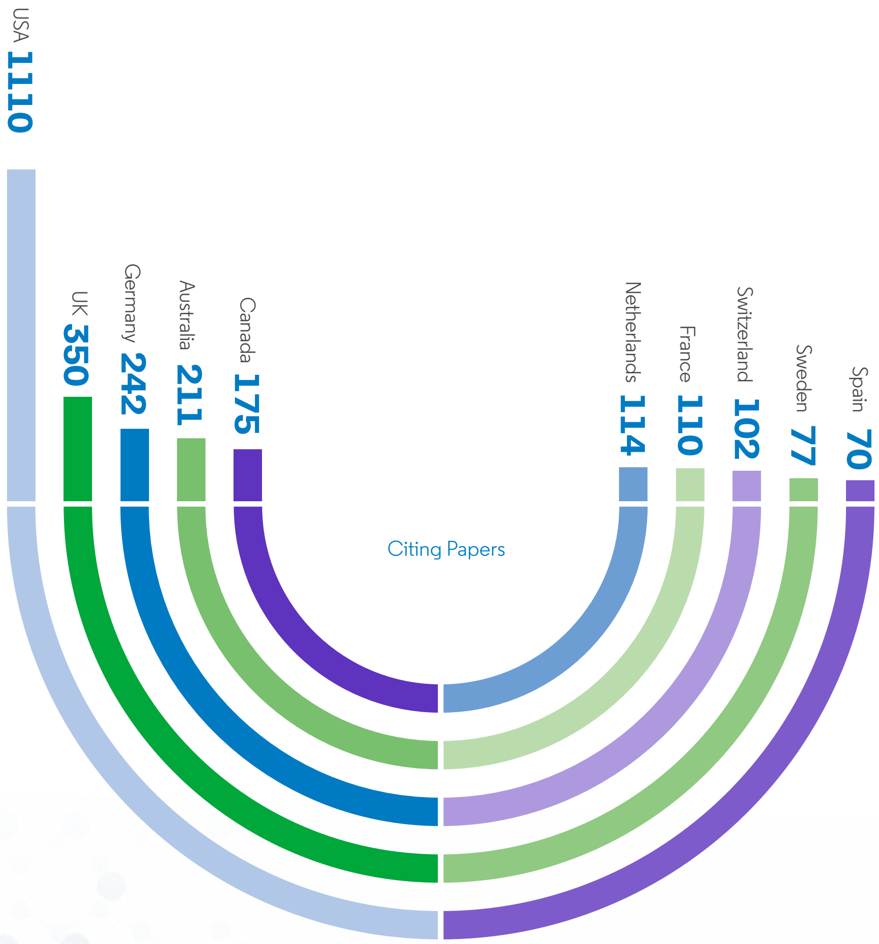
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	7	77.8%	1	Columbia University	USA	6	66.7%
2	Finland	4	44.4%	2	Aalto University	Finland	4	44.4%
3	Germany	2	22.2%	3	University of Munster	Germany	2	22.2%
3	Canada	2	22.2%	3	Harvard University	USA	2	22.2%
5	UK	1	11.1%					
5	Saudi Arabia	1	11.1%					
5	Norway	1	11.1%					
5	Netherlands	1	11.1%					
5	Italy	1	11.1%					
5	France	1	11.1%					

In terms of the citing papers (Table 51), the USA is still the most prolific source of papers that cite the core papers of this front. US-based scholars contributed to 1,110 citing papers, accounting for 55.7% of the total. The UK, Germany, and Australia rank 2nd to 4th. As for the Top 10 citing institutions, seven are based in the USA, including the top three institutions: the U.S. Geological Survey (108 papers), Harvard University (79 papers) and Columbia University (64 papers). Among other national institutions, University College London, the French National Center for Scientific Research (CNRS) in France, and the University of Cambridge all demonstrate a significant presence in following up on this front.

Table 51: Top countries and institutions producing citing papers in the Research Front "Bayesian multilevel modeling and its application in computing software packages"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	1110	55.7%	1	U.S. Geological Survey	USA	108	5.4%
2	UK	350	17.6%	2	Harvard University	USA	79	4.0%
3	Germany	242	12.1%	3	Columbia University	USA	64	3.2%
4	Australia	211	10.6%	4	University College London	UK	57	2.9%
5	Canada	175	8.8%	4	French National Center for Scientific Research (CNRS)	France	57	2.9%
6	Netherlands	114	5.7%	6	University of Washington Seattle	USA	56	2.8%
7	France	110	5.5%	7	Colorado State University	USA	52	2.6%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
8	Switzerland	102	5.1%	8	National Oceanic Atmospheric Admin (NOAA)	USA	49	2.5%
9	Sweden	77	3.9%	9	University of California Davis	USA	47	2.4%
10	Spain	70	3.5%	10	University of Cambridge	UK	46	2.3%

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XI. INFORMATION SCIENCE

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN INFORMATION SCIENCE

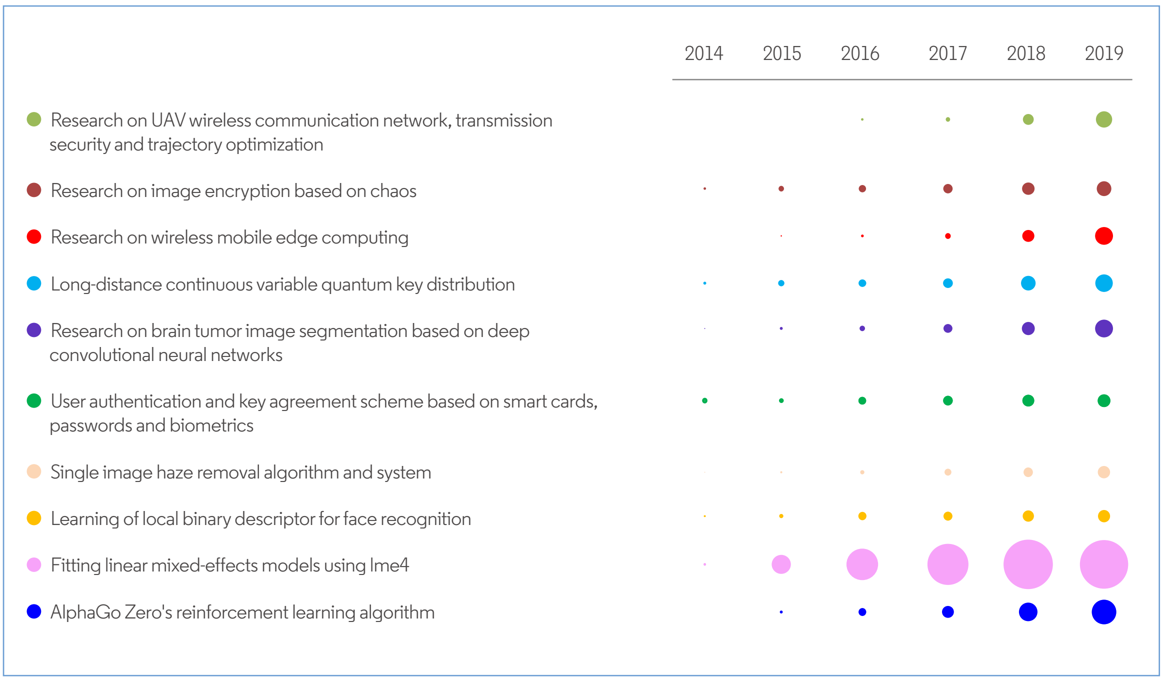
The Top 10 Research Fronts in information science mainly focus on deep learning, reinforcement learning, mobile edge computing, unmanned aerial vehicle (UAV) communications, image processing, and long-distance continuous variable quantum key distribution (Table 52 and Figure 10). Deep learning and reinforcement learning have been consecutively selected as a hot or emerging Research Front for years. "Research on brain tumor image segmentation based on deep convolutional neural networks" was selected as the emerging Research Front in 2019 and the hot Research Front in 2020. "AlphaGo Zero's reinforcement learning algorithm" is selected as the hot Research Front for the first time.

"Research on UAV wireless communication network, transmission security and trajectory optimization" has been a hot front for two years. In the area of image processing, "Research on image encryption based on chaos" was selected as a hot Research Front in 2018 and again in 2020. " User authentication and key agreement scheme based on smart cards, passwords and biometrics" is the continuation of the hot Research Front "Remote user authentication schemes and pertinent technologies based on smart cards, biometrics, etc." in 2018. In this report, "Research on wireless mobile edge computing", "Long-distance continuous variable quantum key distribution", and "Fitting linear mixed-effects models using lme4" are all newly selected into the Hot Research Fronts.

Table 52: Top 10 Research Fronts in information science

Rank	Hot Research Fronts	Core papers	Times Cited	Mean Year of Core Papers
1	Research on UAV wireless communication network, transmission security and trajectory optimization	24	2543	2017.4
2	Research on image encryption based on chaos	45	3303	2016.9
3	Research on wireless mobile edge computing	18	2294	2016.9
4	Long-distance continuous variable quantum key distribution	33	2927	2016.8
5	Research on brain tumor image segmentation based on deep convolutional neural networks	13	2086	2016.7
6	User authentication and key agreement scheme based on smart cards, passwords and biometrics	31	2502	2016.4
7	Single image haze removal algorithm and system	12	1122	2016.4
8	Learning of local binary descriptor for face recognition	17	1366	2016.1
9	Fitting linear mixed-effects models using lme4	3	13035	2016
10	AlphaGo Zero's reinforcement learning algorithm	3	3081	2016

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



1.2 KEY HOT RESEARCH FRONT – "Research on wireless mobile edge computing"

Mobile edge computing (MEC) was originally proposed by the European Telecommunications Standards Institute (ETSI). It is a technology based on the 5G evolution architecture and deep integration of mobile access networks and Internet services. MEC can improve user experience and save bandwidth resources. On the other hand, by sinking computing power to mobile edge nodes and providing third-party application integration, it provides unlimited possibilities for service innovation at mobile edge entrances. MEC will provide a powerful platform to solve the problems of delay, congestion and capacity of future networks. In the 5G era, the application range of MEC will extend to transportation systems, intelligent driving, real-time haptic control, augmented reality and other fields. The main contents of MEC research include task offloading models, computing resource allocation, large-scale MEC system deployment and MEC security issues.

"Research on wireless mobile edge computing" includes 18 core papers, focusing on the following: energy-saving offloading of mobile edge computing in 5G heterogeneous networks; energy-saving resource allocation of mobile edge computing offloading; maximum computing rate of wireless mobile edge computing; and joint offloading and computational optimization in computing systems of wireless mobile edge computing .

China is the main contributor to this hot Research Front (Table 53). In terms of the distribution of core papers, Xidian University, University of Hong Kong, Hong Kong University of Science and Technology, Hamad Bin Khalifa University, Chongqing University of Posts and Telecommunications, and the Chinese Academy of Sciences each contribute three core papers.

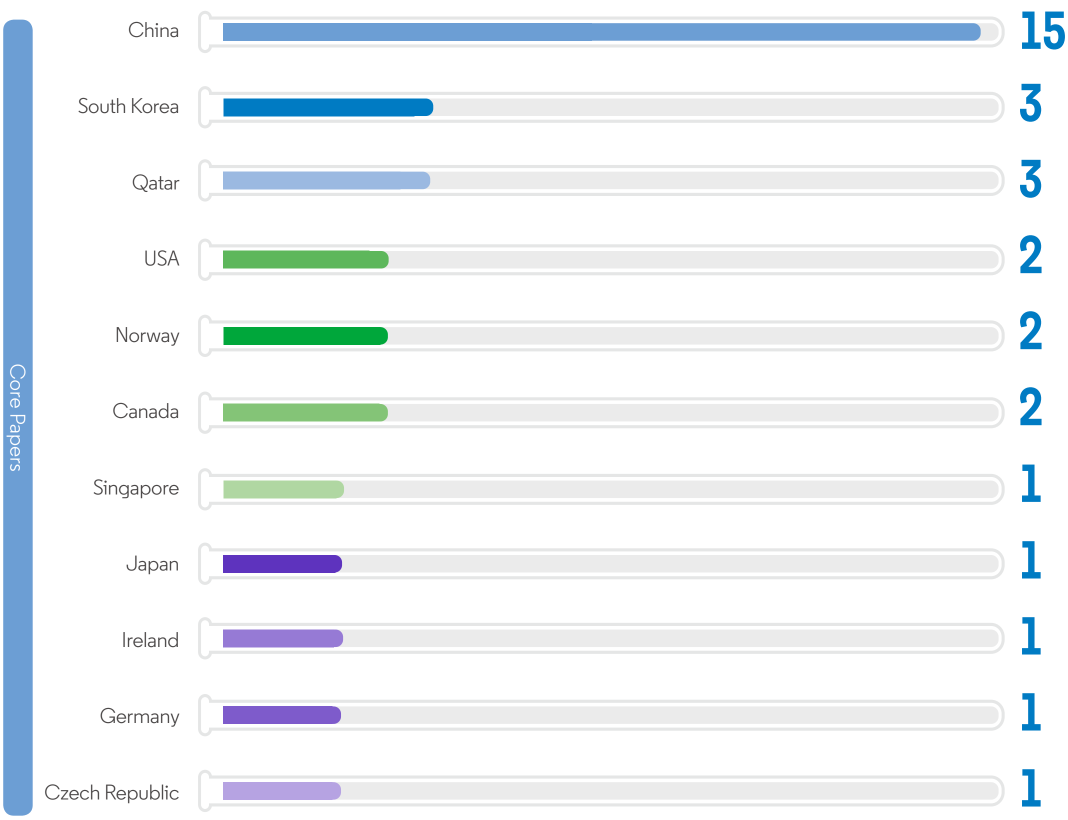


Table 53: Top countries and institutions producing core papers in the Research Front "Research on wireless mobile edge computing"

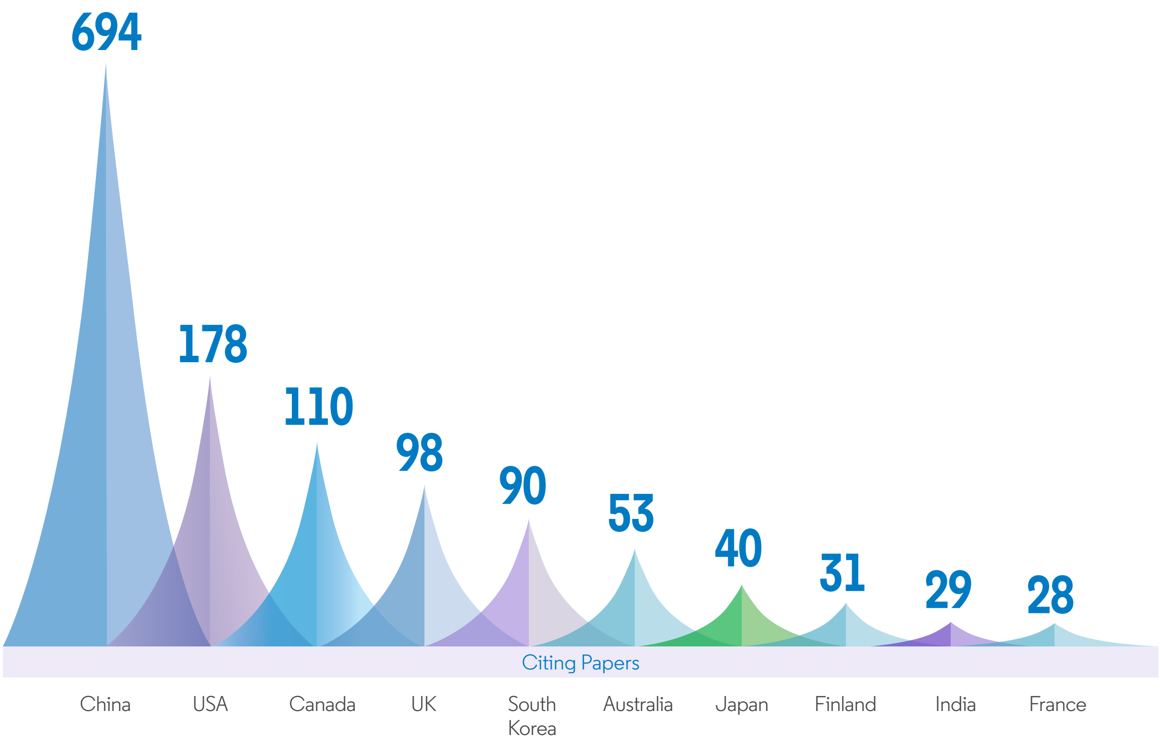
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	15	83.3%	1	Xidian University	China	3	16.7%
2	South Korea	3	16.7%	1	University of Hong Kong	China	3	16.7%
2	Qatar	3	16.7%	1	Hong Kong University of Science & Technology	China	3	16.7%
4	USA	2	11.1%	1	Hamad Bin Khalifa University	Qatar	3	16.7%
4	Norway	2	11.1%	1	Chongqing University of Posts and Telecommunications	China	3	16.7%
4	Canada	2	11.1%	1	Chinese Academy of Sciences	China	3	16.7%
7	Singapore	1	5.6%	7	Simula Research Laboratory	Norway	2	11.1%
7	Japan	1	5.6%	7	LG Electronics	South Korea	2	11.1%
7	Ireland	1	5.6%	7	Carleton University	Canada	2	11.1%
7	Germany	1	5.6%					
7	Czech Republic	1	5.6%					

In terms of papers that cite the core literature for this front, China is also the main contributor (694 papers, or 65.4%). The USA contributes 178 core papers. The Top 10 institutions are all based in China, except for Kyung Hee University in South Korea and Carleton University in Canada.

Table 54: Top countries and institutions producing citing papers in the Research Front "Research on wireless mobile edge computing"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	694	65.4%	1	Beijing University Posts & Telecommunications	China	99	9.3%
2	USA	178	16.8%	2	Chinese Academy of Sciences	China	70	6.6%
3	Canada	110	10.4%	3	Xidian University	China	46	4.3%
4	UK	98	9.2%	4	University of Electronic Science & Technology - China	China	41	3.9%
5	South Korea	90	8.5%	5	Sun Yat Sen University	China	35	3.3%
6	Australia	53	5.0%	6	Tsinghua University	China	32	3.0%
7	Japan	40	3.8%	7	Huazhong University of Science & Technology	China	31	2.9%
8	Finland	31	2.9%	8	Zhejiang University	China	30	2.8%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
9	India	29	2.7%	8	Beijing Jiaotong University	China	30	2.8%
10	France	28	2.6%	10	Southeast University - China	China	25	2.4%
				10	Kyung Hee University	South Korea	25	2.4%
				10	Dalian University of Technology	China	25	2.4%
				10	Carleton University	Canada	25	2.4%



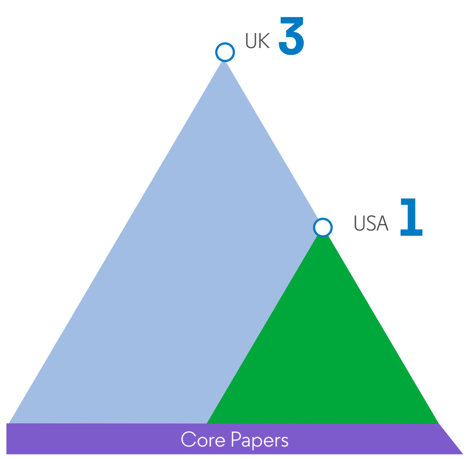
1.3 KEY HOT RESEARCH FRONT – "AlphaGo Zero's reinforcement learning algorithm"

As one of the core technologies of machine learning, reinforcement learning is an important method for solving sequential decision-making problems, in which the agent constantly interacts with the environment and obtains the best strategy through trial and error. This is similar to human experiential learning and decision making. Classic application cases include board games, robots learning to stand and walk, unmanned driving, machine translation, human-machine dialogue, etc. The capacity to learn control strategies directly from high-dimensional sensory inputs such as vision and language is one of the long-term challenges of reinforcement learning. With the breakthrough of deep learning in the fields of vision and speech, the introduction of deep neural networks into reinforcement learning has greatly improved the efficiency and capabilities of reinforcement learning algorithms, and has brought the research of reinforcement learning into a new stage.

Google DeepMind's AlphaGo is a representative of deep reinforcement learning, while AlphaGo Zero, which defeated the former at the board game Go without any input of human expertise, is an outstanding example of pure reinforcement learning. In 2013, DeepMind Technologies first proposed a deep learning model-Deep Q Network (DQN), which functioned by "using reinforcement learning to directly learn control strategies from high-dimensional input". In 2015, personnel at DeepMind published an article, "Human-level control through deep reinforcement learning", in *Nature*, introducing an improved version of DQN. This article is a classic of deep reinforcement learning and one of the three core papers for this Research Front. It has been cited more than 3,000 times in Web of Science. In March 2016, AlphaGo won the game against the world Go champion Lee Sedol by a score of 4 to 1. A Nature article, "Mastering the game of Go with deep neural networks and tree search", published by DeepMind in January 2016, offered the first detailed description of how AlphaGo used the "value networks" to evaluate board positions and "policy networks" to select moves, also using the tree search algorithm to search for the move with the greatest win rate. These deep neural networks were trained by a new combination of supervised learning from human expert games, and reinforcement learning from games of self-play. In 2017, DeepMind published a *Nature* article entitled "Mastering the game of Go without human knowledge", introducing AlphaGo Zero's use of pure reinforcement learning to integrate the "value network" and "strategy network" into an architecture that defeated its predecessor, AlphaGo, by a score of 100 to 0 after three days of training from scratch, and defeated AlphaGo Master 89 to 11 after 40 days of training. The success of this system is also a big step towards the long-term goal of artificial intelligence research to create algorithms that surpass human capabilities in the most challenging areas without human input. The above three articles constitute the core collection of the Research Front.

Table 55: Top countries and institutions producing core papers in the Research Front "AlphaGo Zero's reinforcement learning algorithm"

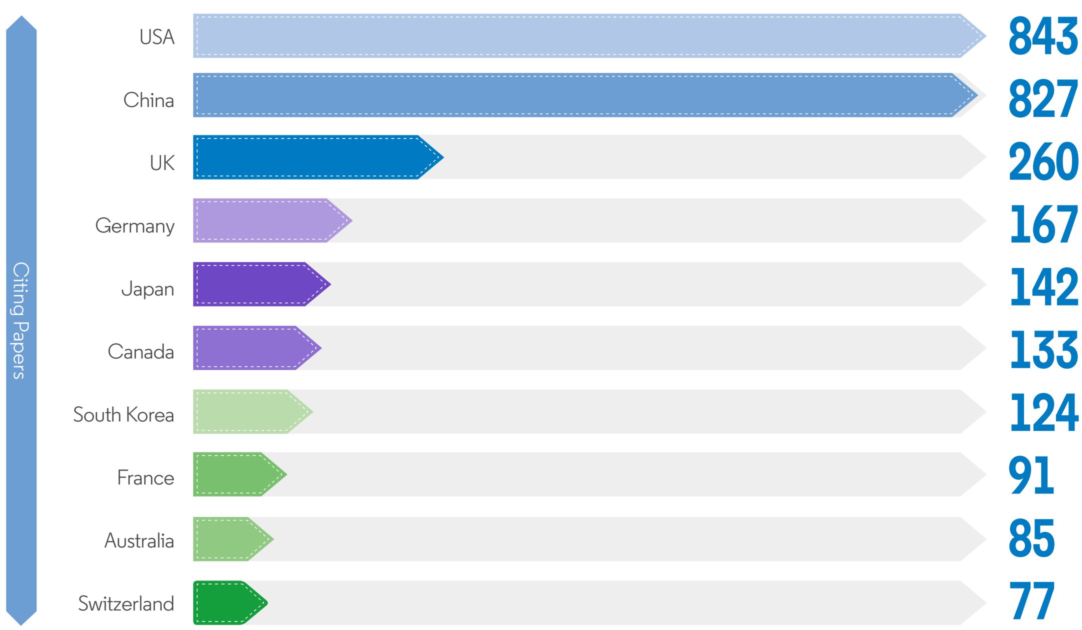
Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	UK	3	100.0%	1	DeepMind	UK	3	100.0%
2	USA	1	33.3%	2	Google Inc	USA	1	33.3%

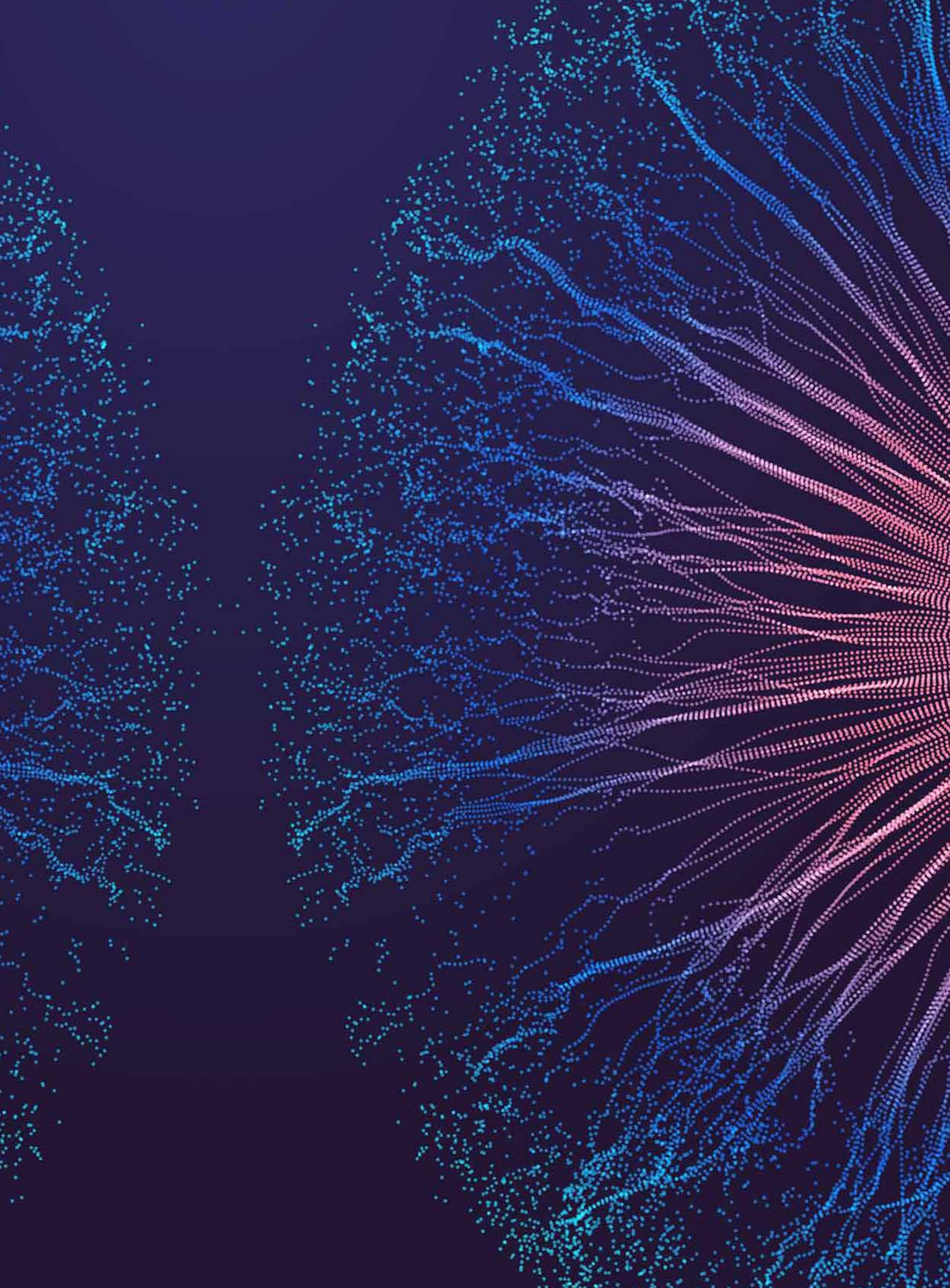


Analysis of the citing papers (Table 56) indicates that the USA and China are the countries with the most active follow-up research on this Research Front. Among the Top 10 citing institutions, research and educational institutions in China and the USA occupy the top five positions, and the Chinese Academy of Sciences is the most active institution.

Table 56: Top countries and institutions producing citing papers in the Research Front "AlphaGo Zero's reinforcement learning algorithm"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	843	34.5%	1	Chinese Academy of Sciences	China	123	5.0%
2	China	827	33.9%	2	Tsinghua University	China	75	3.1%
3	UK	260	10.6%	3	Stanford University	USA	59	2.4%
4	Germany	167	6.8%	4	Harvard University	USA	56	2.3%
5	Japan	142	5.8%	5	Massachusetts Institute of Technology (MIT)	USA	51	2.1%
6	Canada	133	5.4%	6	French National Center for Scientific Research (CNRS)	France	47	1.9%
7	South Korea	124	5.1%	7	Beijing University Posts & Telecommunications	China	44	1.8%
8	France	91	3.7%	8	University College London	UK	40	1.6%
9	Australia	85	3.5%	9	Zhejiang University	China	37	1.5%
10	Switzerland	77	3.2%	10	ETH Zurich	Switzerland	35	1.4%





XII. 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 2020 related to economics, psychology and other social sciences reflect the trend toward economic and social transformation based on digital technology and artificial intelligence (AI). This emphasis differs from previous years, in which hot topics at the frontiers of psychology were predominant. Among the Research Fronts in 2020's social-science grouping, four are related to the digital economy and the impact of AI on society – specifically, "Bitcoin's market efficiency and information efficiency", "The impact of autonomous vehicles on policies and society", "Airbnb consumer assessment and its impact on the hotel industry", and "Consumers' acceptance and use intention of new technologies such as mobile banking". Of those four fronts, three analyze the impact of digitalization on the commercial economy, while "The impact of autonomous driving on policies and society" focuses on the societal impact of AI.

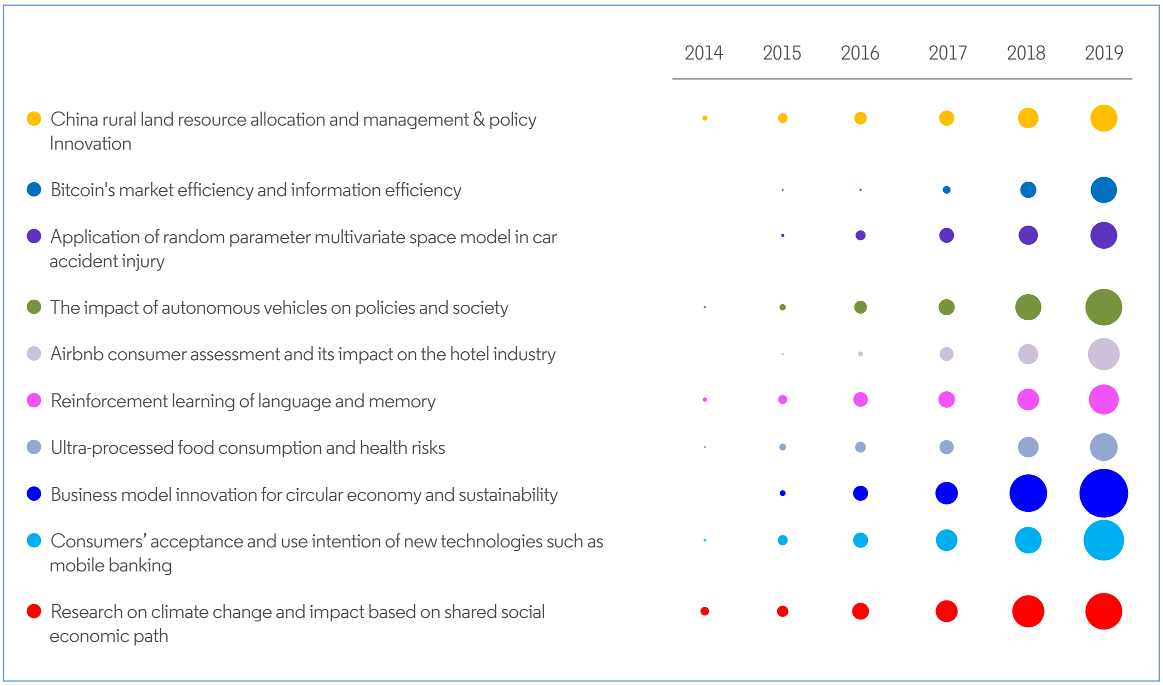
Issues related to resources and the environment constitute another prominent topic in this broad grouping of Research Fronts. Three fronts examine this environmental aspect, including "China's rural land resource allocation and management & policy innovation", "Business model innovation for circular economy and sustainability", and "Research on climate change and impact based on shared social economic path". Only one 2020 Research Front in this report pertains to psychology: "Language and memory reinforcement learning", which focuses on the cognitive field, following "Music training and cognitive ability" in 2016, "Research on the impact of bilingualism on cognition" and "Working memory training and application research" in 2017, and "Sleep and memory consolidation" in 2018.

In terms of research methods, the prominent 2020 Research Front is "Application of random parameter multivariate space model in car accident injury". In contrast with previous years, this method centers on the application of simulation in addressing a societal issue. In addition, the front entitled "Ultra-processed food consumption and health risks", focusing on food and health, has become one of the hot Research Fronts featured among these social-science areas.

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

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	China rural land resource allocation and management & policy Innovation	25	995	2017.6
2	Bitcoin's market efficiency and information efficiency	39	1903	2017.5
3	Application of random parameter multivariate space model in car accident injury	38	1283	2017.5
4	The impact of autonomous vehicles on policies and society	42	2205	2017.4
5	Airbnb consumer assessment and its impact on the hotel industry	33	1670	2017.4
6	Reinforcement learning of language and memory	32	1547	2017.4
7	Ultra-processed food consumption and health risks	29	1426	2017.3
8	Business model innovation for circular economy and sustainability	43	4015	2017.1
9	Consumers' acceptance and use intention of new technologies such as mobile banking	43	2171	2017
10	Research on climate change and impact based on shared social economic path	18	2385	2016.7

Figure 11: Citing papers for the Top 10 Research Fronts in economics, psychology and other social sciences



1.2 KEY HOT RESEARCH FRONT: "Business model innovation for circular economy and sustainability"

The term "circular economy" (CE) often appears in European and Chinese policies and has received increasing attention in the past few years. CE aims to overcome the linear mode of production and consumption on-demand configuration and proposes a closed production cycle system in which resources are reused and kept in the cycle of production and use, thereby generating more value and lasting longer. CE represents the main direction of current world economic development and is the driving force of sustainable development; it has also become one of the new hot topics discussing the latest innovation in sustainable business models.

However, there are still some problems in research on CE. For example, the definition of the term "circular economy" is diverse, resulting in imprecision that may eventually lead to the collapse of the concept. Also, especially at the micro level, there is still a lack of in-depth research on CE evaluation and indicators. Therefore, the core papers in this hot Research Front review, summarize, and comparatively analyze the origin, concepts, basic principles, advantages, disadvantages, and the modeling of CE and CE databases at micro, meso and macro levels.

Forty-three core papers anchor this hot Research Front, to which the UK, the Netherlands, and Sweden have contributed most prolifically. Among the 13 Top institutions, 12 are based in Europe, with the Royal Institute of Technology in Sweden and Delft University of Technology in the Netherlands sharing the top rank, followed by Utrecht University in the Netherlands (Table 58).

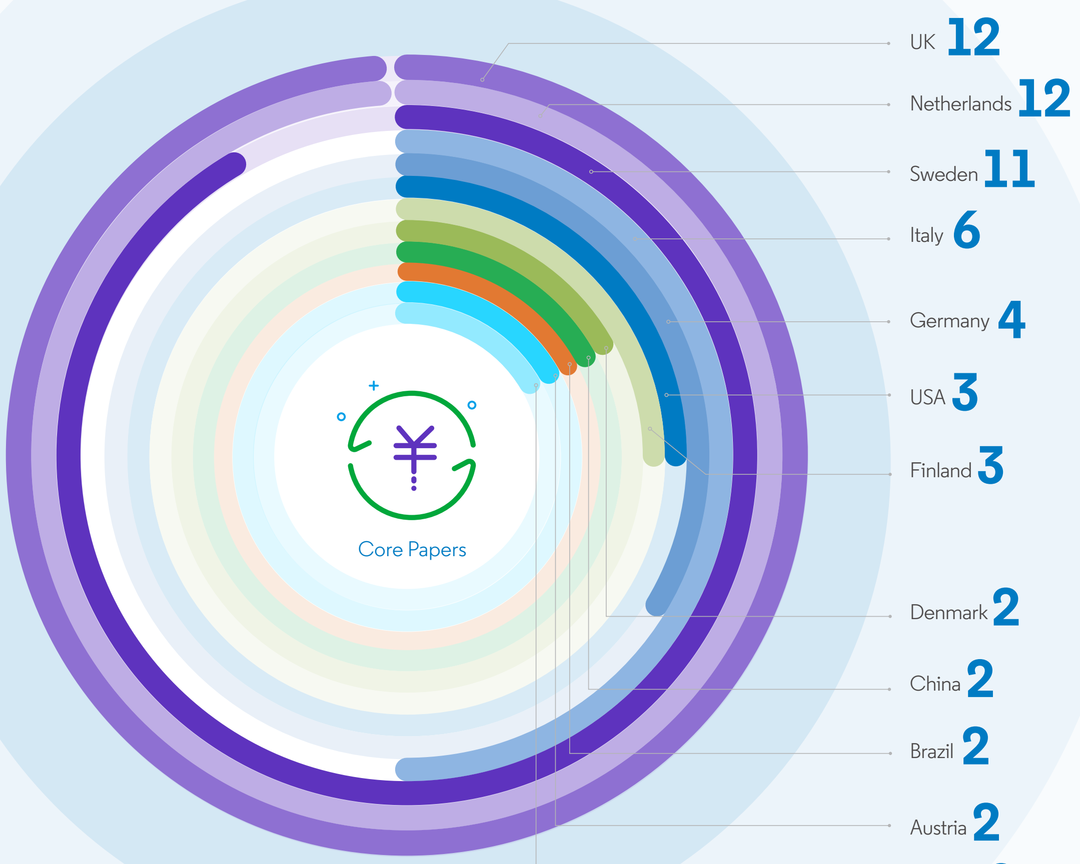


Table 58: Top countries and institutions producing core papers in the Research Front "Business model innovation for circular economy and sustainability"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	UK	12	27.9%	1	Royal Institute of Technology	Sweden	5	11.6%
1	Netherlands	12	27.9%	1	Delft University of Technology	Netherlands	5	11.6%
3	Sweden	11	25.6%	3	Utrecht University	Netherlands	4	9.3%
4	Italy	6	14.0%	4	University of Sheffield	UK	2	4.7%
5	Germany	4	9.3%	4	University of Sao Paulo	Brazil	2	4.7%
6	USA	3	7.0%	4	University of Cambridge	UK	2	4.7%
6	Finland	3	7.0%	4	Technical University of Denmark	Denmark	2	4.7%
8	Denmark	2	4.7%	4	Polytechnic University of Milan	Italy	2	4.7%
8	China	2	4.7%	4	Netherlands Organization for Applied Scientific Research	Netherlands	2	4.7%
8	Brazil	2	4.7%	4	Lund University	Sweden	2	4.7%
8	Austria	2	4.7%	4	Leiden University	Netherlands	2	4.7%
8	Australia	2	4.7%	4	Finnish Environment Institute	Finland	2	4.7%
				4	Chalmers University of Technology	Sweden	2	4.7%

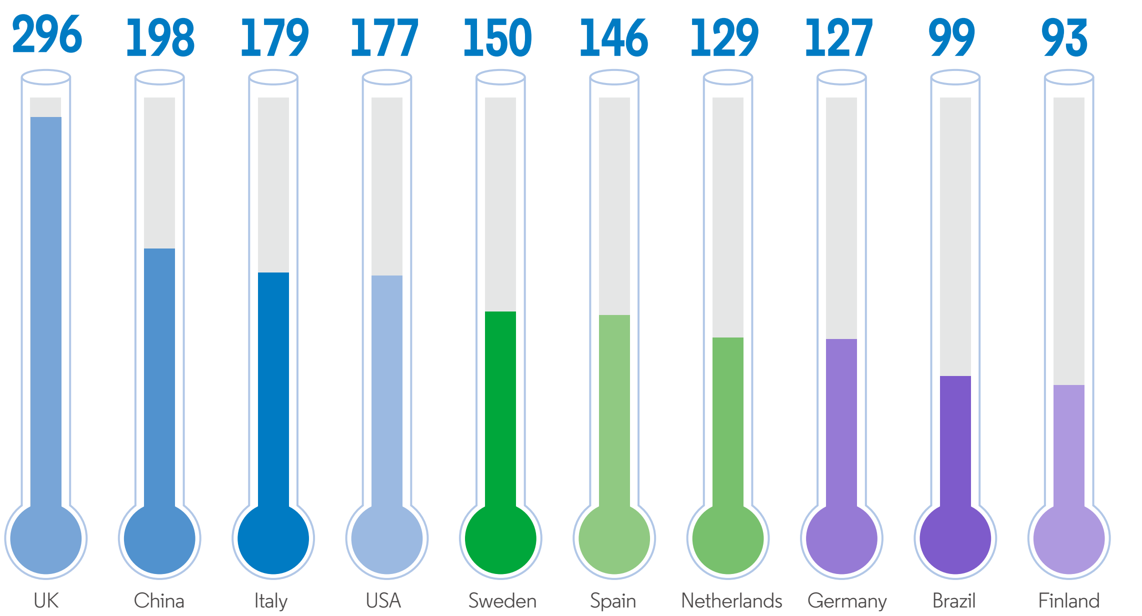
In terms of citing papers, the UK ranks 1st with 296 reports, and China ranks 2nd. The latter placement demonstrates that China has begun to pay attention to research on this frontier. However, ranked on the basis of core papers (Table 58), China is not in the first tier but is in the catch-up stage. At the institutional level, the Top 10 institutions with the highest numbers of citing papers are all Europe-based universities or research installations. Among them, Delft University of Technology in the Netherlands and Lund University in Sweden perform prominently (Table 59), while no Chinese institution was able enter the Top 10 in the production of citing papers.

Table 59: Top countries and institutions producing citing papers in the Research Front "Business model innovation for circular economy and sustainability"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	UK	296	17.9%	1	Delft University of Technology	Netherlands	50	3.0%
2	China	198	11.9%	2	Lund University	Sweden	44	2.7%
3	Italy	179	10.8%	3	Polytechnic University of Milan	Italy	28	1.7%
4	USA	177	10.7%	4	Technical University of Denmark	Denmark	26	1.6%
5	Sweden	150	9.1%	4	Linkoping University	Sweden	26	1.6%
6	Spain	146	8.8%	6	University of Cambridge	UK	24	1.4%
7	Netherlands	129	7.8%	7	University of Vaasa	Finland	23	1.4%
8	Germany	127	7.7%	7	University of Manchester	UK	23	1.4%

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
9	Brazil	99	6.0%	7	Royal Institute of Technology	Sweden	23	1.4%
10	Finland	93	5.6%	10	Norwegian University of Science and Technology	Norway	22	1.3%

| Citing Paper |



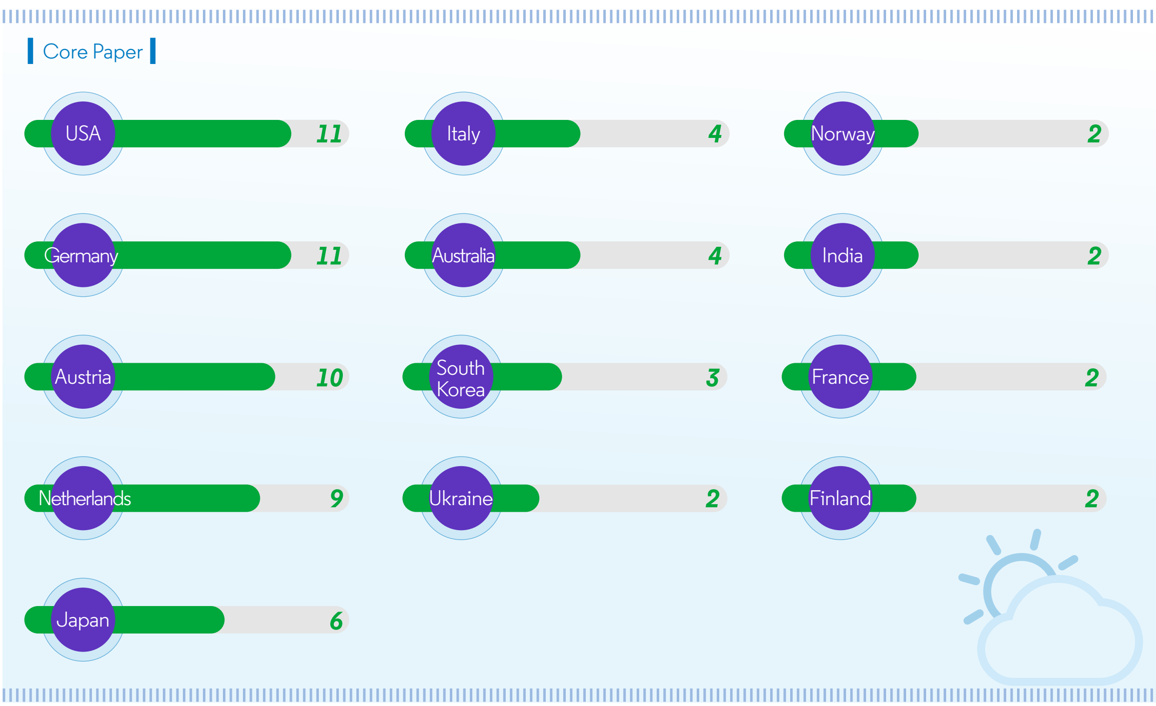
1.3 KEY HOT RESEARCH FRONT – "Research on climate change and impact based on shared social economic path"

Shared socio-economic paths (SSPs) are a powerful tool for describing global socio-economic development scenarios launched by the Intergovernmental Panel on Climate Change (IPCC) in 2010, and are an important part of the new generation of climate change scenario frameworks. These scenarios are developed on the basis of the typical representative concentration path (RCP) scenario, and are used to quantitatively describe the relationship between climate change and socio-economic development paths, with the purpose of promoting a comprehensive analysis of future climate impact, vulnerability, adaptability, and mitigation. Currently, SSPs have five typical paths: SSP1 (Sustainability), SSP2 (Middle of the Road), SSP3 (Regional Rivalry), SSP4 (Inequality) and SSP5 (Fossil-fueled Development). SSPs have been proposed for more than 10 years and have significantly promoted the evaluation of climate change and studies of the impacts on population, land use, agriculture, human development, economy and lifestyle, while also supporting relevant decision-making on climate policies. The core papers of this Research Front mainly use quantitative models to illustrate SSPs and their impact on energy, land use, and emissions, as well as their application in population prediction and urbanization.

In this hot Research Front, the top three countries in the production of core papers are the USA, Germany and Austria. Among the Top 10 institutions, aside from the US National Center for Atmospheric Research, the National Institute for Environmental Research of Japan, and the Australian Federal Scientific and Industrial Research Organization, the entries consist of European universities and scientific research institutions (Table 60).

Table 60: Top countries and institutions producing the core papers in the Research Front "Research on land use and climate change based on shared social economic path"

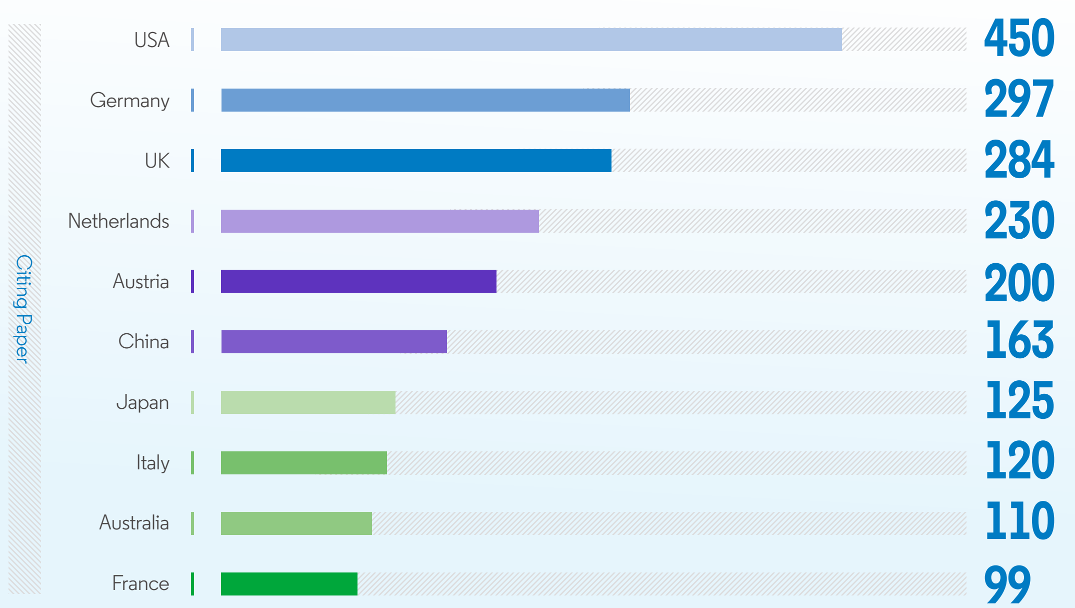
Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	11	61.1%	1	Potsdam Institute for Climate Impact Research	Germany	10	55.6%
1	Germany	11	61.1%	2	Utrecht University	Netherlands	8	44.4%
3	Austria	10	55.6%	2	PBL Netherlands Environment Assessment Agency	Netherlands	8	44.4%
4	Netherlands	9	50.0%	2	International Institute for Applied Systems Analysis	Austria	8	44.4%
5	Japan	6	33.3%	5	National Center for Atmospheric Research (NCAR)	USA	6	33.3%
6	Italy	4	22.2%	5	National Institute for Environmental Studies	Japan	6	33.3%
6	Australia	4	22.2%	7	Wageningen University & Research Center	Netherlands	5	27.8%
8	South Korea	3	16.7%	8	Graz University of Technology	Austria	4	22.2%
9	Ukraine	2	11.1%	8	Foundation Mattei	Italy	4	22.2%
9	Norway	2	11.1%	8	Commonwealth Scientific & Industrial Research Organisation (CSIRO)	Australia	4	22.2%
9	India	2	11.1%					
9	France	2	11.1%					
9	Finland	2	11.1%					



In terms of citing papers, the USA ranks 1st with 450 citing papers, a total 1.5 times that of second-ranked Germany. All of the Top 10 institutions in production of citing papers are based in developed countries, i.e., Europe, the USA, and Japan. Among them, there are eight institutions in Europe. Additionally, the USA and Japan each register one institution in the Top 10.

Table 61: Top countries and institutions producing citing papers in the Research Front "Research on land use and climate change based on shared social economic path"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	450	36.9%	1	International Institute for Applied Systems Analysis	Austria	172	14.1%
2	Germany	297	24.3%	2	Potsdam Institute for Climate Impact Research	Germany	131	10.7%
3	UK	284	23.3%	3	Utrecht University	Netherlands	107	8.8%
4	Netherlands	230	18.8%	4	PBL Netherlands Environment Assessment Agency	Netherlands	89	7.3%
5	Austria	200	16.4%	4	National Institute for Environmental Studies	Japan	89	7.3%
6	China	163	13.3%	6	Wageningen University & Research Center	Netherlands	86	7.0%
7	Japan	125	10.2%	7	Helmholtz Association	Germany	67	5.5%
8	Italy	120	9.8%	8	National Center for Atmospheric Research (NCAR)	USA	62	5.1%
9	Australia	110	9.0%	9	French National Center for Scientific Research (CNRS)	France	54	4.4%
10	France	99	8.1%	10	ETH Zurich	Switzerland	51	4.2%



2. EMERGING RESEARCH FRONT

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

Three specialty areas within economics, psychology and other social sciences have been selected as emerging Research Fronts: "Regional renewable energy and economic development", "Parenting methods and short-term and long-term socialization results", and "The application of artificial intelligence to blockchain smart contracts in supply chain management and smart cities". Among those, the latter front was chosen as the key Emerging Research Front of 2020 in economics, psychology and other social sciences.

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

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Regional renewable energy and economic development	27	605	2018.7
2	Parenting methods and short-term and long-term socialization results	9	242	2018.6
3	The application of artificial intelligence to blockchain smart contracts in supply chain management and smart cities	7	175	2018.6

2.2 KEY EMERGING RESARCH FRONT – "The application of artificial intelligence to blockchain smart contracts in supply chain management and smart cities"

The new generation of information technologies, such as AI, cloud computing, big data, the Internet of Things (IoT), and blockchain, are developing at an astonishing speed Together, they continue to gather innovative resources and elements, interact and integrate with new business forms and new business models, and promote the transformation and upgrading of agriculture, industry, and the service sector. Nowadays, "digital economy", "AI", "smart city", "cross-border integration", and "large platform" have become new trends driving the development of the information industry's next generation.

In the past few years, AI, blockchain technology, and their applications have attracted the attention of more and more scholars around the world, and thus have rapidly become one of the emerging Research Fronts in economics, psychology and other social sciences. Blockchain is a new application mode of computer technology of distributed data storage, point-to-point transmission, consensus mechanism, encryption algorithm, etc. As a distributed digital ledger technology with transparency, traceability and security, blockchain is applied in many aspects of business and economic fields. The smart contract combining AI and blockchain promotes the development and application of blockchain technology.

This emerging research front mainly focuses on the application of enhanced blockchain smart contracts by AI in supply-chain management and smart cities. Blockchain is one of the important underlying supporting technologies for supply chain management and smart city construction. Blockchain enabled the digital transformation of the supply chain, and particularly boosted the key objectives of supply chain management, such as cost, quality, speed, reliability, risk reduction, sustainability, and flexibility. Especially in the IoT ecosystem, blockchain plays an important role in strengthening network security and protecting privacy. Smart contracts improve the efficiency of mining by optimizing energy consumption; improve the scalability of the blockchain through data partitioning; can be used for fraud detection; and will be applied in finance, legal affairs, medical care, logistics, industry, and the urban construction field, speeding the way toward the smart life of the future.

APPENDIX

RESEARCH FRONTS: IN SEARCH OF THE STRUCTURE OF SCIENCE

▪ David Pendlebury

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

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

Garfield was not alone in his vision. During the same era, the physicist and historian of science, Derek J. de Solla Price, was exploring the characteristic features and structures of the scientific research enterprise. The Yale University professor used the measuring tools of science on scientific activity, and he demonstrated in two influential books, of 1961 and 1963, how science had grown exponentially since the late 17th century, both in terms of number of researchers and publications.[6, 7] There was hardly a statistic about the activity of scientific research that his restless mind was not eager to obtain, interrogate, and play with. Price and Garfield became acquainted at this time, and Price, the son of a tailor, was soon receiving data, as he said, “from the cutting-room floor of ISI’s computer room.” [8] In 1965, Price published “Networks of scientific papers,” which used citation data to describe the nature of what he termed “the scientific research front.” [9] Previously, he had used the term “research front” in a generic way, meaning the leading edge of research and including the most knowledgeable scientists working at the coalface. But in this paper, and using the short-lived field of research on N-rays as his example, he described the research front more specifically in terms of its density of publications and time dynamics as revealed by a network of papers arrayed chronologically and their inter-citation patterns. Price observed that a research front builds upon recently published work and that it displays a tight network of relationships.

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

The year is 1972. Enter Henry Small, a young historian of science previously working at the American Institute of Physics in New York City who now joined the Institute for Scientific Information in Philadelphia hoping to make use of the Science Citation Index data and its wealth of title and key words. After his arrival, Small quickly changed allegiance from words to citations for the same reasons that had captivated and motivated Garfield and Price: their power and potential. In 1973, Small published a paper that was as groundbreaking in its own way as Garfield’s 1955 paper introducing citation indexing for science. This paper, “Cocitation in the scientific literature: a new measure of relationship between two documents,” introduced a new era in describing the specialty structure of science.[11] Small measured the similarity of two documents in terms of the number of times they were cited together, in other words their co- citation frequency. He illustrated his method of analysis with an example from recent papers in the literature of particle physics. Having found that such co-citation patterns indicated “the notion of subject similarity” and “the association or co-occurrence of ideas,” he suggested that frequently cited papers, reflecting key concepts, methods, or experiments, could be used as a starting point for a co-citation analysis as an objective way to reveal the social and intellectual, or the socio- cognitive, structure of a specialty area. Like Price’s research fronts, consisting of a relatively small group of recent papers tightly knit together, so too Small found co-citation analysis pointed to the specialty as the natural organizational unit of research, rather than traditionally defined and larger fields. Small also saw the potential for co-citation analysis to make, by analogy, movies and not merely snapshots. “The pattern of linkages among key papers establishes a structure or map for the specialty which may then be observed to change through time,” he stated. “Through the study of these changing structures, co-citation provides a tool for monitoring the development of scientific fields, and for assessing the degree of interrelationship among specialties.”

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

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

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

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

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

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

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

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

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

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

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

REFERENCES

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

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

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

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

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

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

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

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

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

[10] ibid.

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

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

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

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

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

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

[17] Henry Small, Belver C. Griffth. The structure of scientificliteratures i: Identifying and graphing specialties. ScienceStudies, 4 (1):17-40, 1974.

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

[19] ibid.

[20] See note 8 above.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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