2019 RESEARCH FRONTS

Institutes of Science and Development,
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Clarivate Analytics

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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 Analytics 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 Analytics 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 Analytics and the National Science Library, Chinese Academy of Sciences (CAS). In 2016, 2017, and 2018, the Institutes of Science and Development, CAS, National Science Library, CAS and Clarivate Analytics jointly released the *Research Fronts 2016, Research Fronts 2017, and Research Fronts 2018*. These reports have gained widespread attention from around the world.

This year, the same methodology was employed. For the newest edition, *Research Fronts 2019*, 100 hot Research Fronts and 37 emerging Research Fronts were identified based on co-citation analysis that generated 10,587 Research Fronts in the Clarivate Analytics database Essential Science Indicators (ESI).

2. METHODOLOGY AND PRESENTATION OF DATA

The study was conducted in two parts. Clarivate Analytics selected Research Fronts and provided data on the core papers and citing papers of the selected 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 Institute of Strategic Information within Institutes of Science and Development, CAS. For the 2019 update, the Research Fronts drew on ESI data from 2013 to 2018, which were obtained in March 2019.

2.1 RESEARCH FRONTS SELECTION

Research Fronts 2019 presents a total of 137 Research Fronts, including 100 hot and 37 emerging ones. As in the previous reports, the Research Fronts are classified into 10 broad research areas in the sciences and social sciences. Starting from 10,587 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 137 Research Fronts is described as follows.

2.1.1 SELECTING THE HOT RESEARCH FRONTS

First, 21 ESI fields were classified into 10 broad research areas. 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 10 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 100 hot Research Fronts. The 10 fronts selected for each of the 10 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 2017 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 research front was selected in an ESI field even if there are only a limited number of research fronts in the field. The selected Research Fronts were delivered to the Institute of Strategic Information where the analysts with domain knowledge made the final selection of emerging Research Fronts and grouped them into 10 broader fields. Thirty-seven fronts were selected as emerging ones and the earliest mean year of the emerging fronts was 2017.6. Because the selection was not limited to any research area, the 37 fronts are distributed unevenly in the 10 fields. For example, there are five emerging Research Fronts in "Chemistry and materials sciences," but only one in “Ecology and environmental sciences," "Geosciences," and "Economics, psychology and other social sciences."

Based on the above two methods, the report presents the Top 10 hot fronts in 10 broad areas (100 fronts in total) and 37 emerging ones.

2.2 FINAL SELECTION AND INTERPRETATION OF KEY RESEARCH FRONTS

On the basis of 137 Research Fronts provided by Clarivate Analytics, analysts at the Institute of Strategic Information, conducted a detailed analysis and interpretation to highlight 30 key Research Fronts (Chapter 2 to Chapter 11) 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 top one percent 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 in 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), is also 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 and 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 demonstrate 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 amount 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 present. For example, if the most-recent citing paper was published in 2016 and the earliest citing paper was published in 2012, 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 impact can also be seen from CPT, 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 bigger C, the bigger CPT, indicating the broader citation influence of the Research Front with bigger C.

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

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

In the *Research Fronts 2019*, for each of the 10 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. Based on their knowledge, the analysts assessed the significance of the key hot Research Front in addressing major issues in the given area. The Top two Research Fronts with the largest numbers of core papers (P) were analyzed to compare their significance. For example, in a comparison of the Research Fronts

“Continuous glucose monitoring and artificial pancreas systems for the management of Diabetes”and "Efficacy and safety of infliximab biosimilar", it is obvious that the latter is of more practical significance or consequence. Another key hot Research Front was chosen by the indicator CPT. As the area of mathematics, computer science and engineering includes three ESI fields, we ensured that one key hot research fornt was selected from each of the ESI field for further interpreatation.

By taking advantage of the above two indicators as well as our domain experts’ judgment, we selected 20 key hot Research Fronts from the 100 hot Research Fronts in the 10 broad research areas. Moreover, based on CPT and experts' judgement, 10 key emerging Research Fronts were selected from the 37 emerging Research Fronts. Thus, we interpret in detail the selected 30 key Research Fronts from the 137 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 10 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 hot Research Fronts which are discussed below the tables are highlighted in green background in the table. Since the papers analyzed in this report were published between 2013 and 2018, 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 amount 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 amount 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 analyze the affiliated countries, institutions of the core papers, which reveal 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 cover research on plant physiological regulation mechanisms, crop trait improvement, herbicide resistance, structure and function of plant active substance, farmland soil pollution restoration, livestock gastrointestinal digestion, and agricultural drones (Table 1).

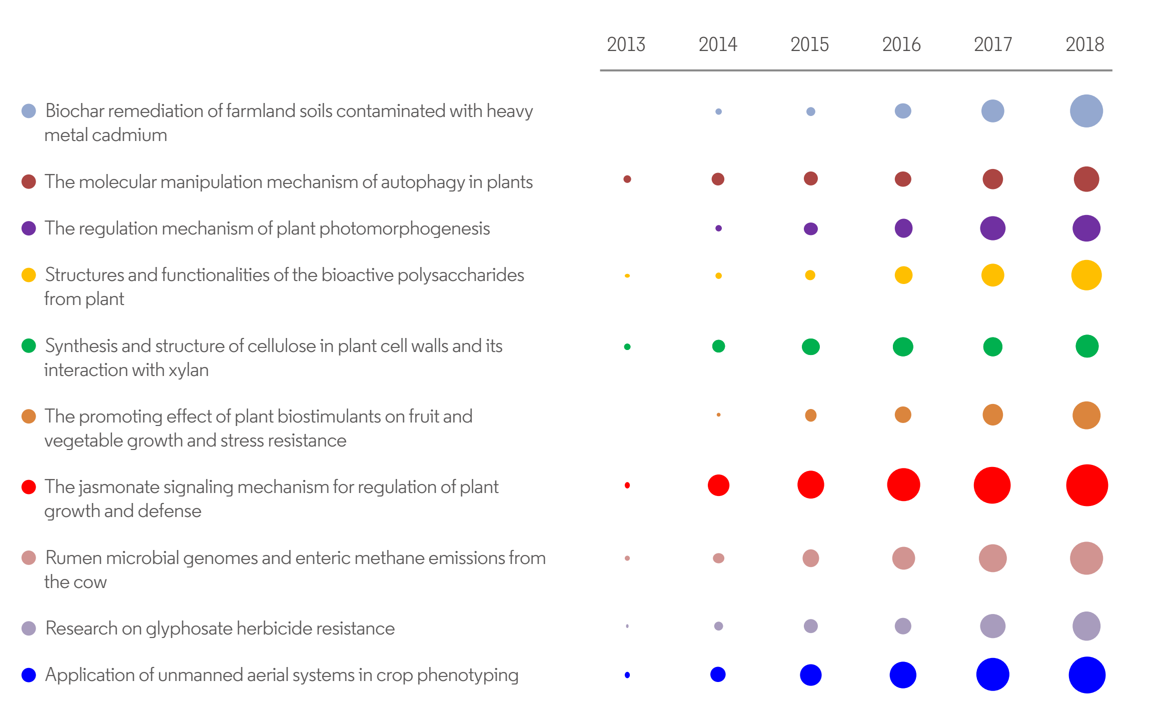
Plant physiological regulation mechanisms have always been a focus in plant science, and related research has continued to enter the Top 10 hot Research Front list every year. This newest listing highlights four hot fronts involve plant physiological regulation mechanisms, including “The jasmonate signaling mechanism for regulation of plant growth and defense”, “The molecular manipulation mechanism of autophagy in plants”, “Synthesis and structure of cellulose in plant cell walls and its interaction with xylan” ,and “The regulation mechanism of plant photomorphogenesis”. Among those hot fronts, jasmonate signaling was previously highlighted in the Top 10 report in 2013, plant autophagy in 2015, and cellulose synthesis in 2017. The topic of crop trait improvement has also received constant attention, and pertinent research has previously figured twice in the Top 10 hot Research Fronts: Improving insect resistance by Bt transgenic crops in 2013, and, in 2018, using CRISPR gene-editing technology for improving crop traits. In 2019, the corresponding research involves using plant biostimulants for crop improvement, as examined in “The promoting effect of plant biostimulants on fruit and vegetable growth and stress resistance”. Herbicide resistance has also been an active focus of agricultural research. In 2015, the front entitled “Herbicide resistance and its genetic causes” made the Top 10, while in 2019 the related front is “Research on glyphosate herbicide resistance.”

Structure and function of plant active substance, farmland soil pollution restoration, livestock gastrointestinal digestion, and agricultural drones emerged as hot topics this year. The four corresponding Top10 hot Research Fronts are, respectively, “Structures and functionalities of the bioactive polysaccharides from plant”, “Biochar remediation of farmland soils contaminated with heavy metal cadmium”, “Rumen microbial genomes and enteric methane emissions from the cow”, and “Application of unmanned aerial systems in crop phenotyping”.

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

Rank	Hot Research Fronts	Core Papers	Citations	Mean Year of Core Papers
1	Biochar remediation of farmland soils contaminated with heavy metal cadmium	21	1095	2016.6
2	The molecular manipulation mechanism of autophagy in plants	27	1038	2016.4
3	The regulation mechanism of plant photomorphogenesis	32	1377	2016.3
4	Structures and functionalities of the bioactive polysaccharides from plant	25	931	2016.3
5	Synthesis and structure of cellulose in plant cell walls and its interaction with xylan	19	1034	2015.9
6	The promoting effect of plant biostimulants on fruit and vegetable growth and stress resistance	15	846	2015.9
7	The jasmonate signaling mechanism for regulation of plant growth and defense	40	2956	2015.8
8	Rumen microbial genomes and enteric methane emissions from the cow	21	1464	2015.6
9	Research on glyphosate herbicide resistance	17	1130	2015.5
10	Application of unmanned aerial systems in crop phenotyping	31	2495	2015.3

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



1.2 KEY HOT RESEARCH FRONT – "The jasmonate signaling mechanism for regulation of plant growth and defense"

Jasmonate is an endogenous growth regulator in plants. It is also a type of defense hormone produced by plants in response to pest and disease invasion, and can help improve plant resistance. Plants generally initiate and cascade the jasmonate signaling pathway through the core transcription factor MYC to protect against pests and diseases, but over-defense will inhibit plant growth and development. Therefore, it is necessary to understand the abatement mechanism of jasmonate signaling and how to appropriately repress the jasmonate signal, and to achieve growth-defense tradeoffs in plants. Understanding the regulation mechanism of jasmonate in plant growth and resistance is a key objective for molecular breeding of new insect-resistant varieties, which has always been a key research topic and central concern for botanists and crop breeders.

Forty core papers underlie this hot Research Front – 13 of them are review articles, focusing on the following: the biosynthesis, metabolism and signal transduction of jasmonate; the redundancy and specificity of signal transduction; the signaling role of transcription factors; the role of jasmonate in plant growth and development; the jasmonate regulation of leaf senescence and cold tolerance; and the application of jasmonate signaling mechanism in balancing plant growth and defense. The remaining 27 research articles mainly examine the new regulatory factors in the jasmonate signaling pathway, such as JAZ protein, bHLH-type transcription factors, and the structural basis and regulatory role of these factors.

In terms of the number of core papers in the front (Table 2), the USA is the main contributor to this hot Research Front, with 17 core papers, accounting for 42.5% of the total. China contributes 10 core papers, or 25.0%. Prolific contributing institutions include Michigan State University in the USA, Spanish National Research Council (CSIC) in Spain, BBSRC John Innes Centre in the UK, Howard Hughes Medical Institute in the USA, the Chinese Academy of Sciences, and Ghent University in Belgium. Among these institutions, Michigan State University can claim eight core papers, while the other institutions each have five.

USA contributes **17** core papers 1

China contributes **10** core papers 2

Table 2 Top countries and institutions producing core papers in the Research Front "The jasmonate signaling mechanism for regulation of plant growth and defense"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	17	42.5%	1	Michigan State University	USA	8	20.0%
2	China	10	25.0%	2	Spanish National Research Council	Spain	5	12.5%
3	UK	7	17.5%	2	BBSRC John Innes Centre	UK	5	12.5%
4	Germany	6	15.0%	2	Howard Hughes Medical Institute	USA	5	12.5%
5	France	5	12.5%	2	Chinese Academy of Sciences	China	5	12.5%
5	Spain	5	12.5%	2	Ghent University	Belgium	5	12.5%
5	Belgium	5	12.5%	7	University of Loire	France	4	10.0%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
8	Canada	4	10.0%	7	University of Confederale Leonard de Vinci	France	4	10.0%
8	Switzerland	4	10.0%	7	University of Tours	France	4	10.0%
10	Netherlands	3	7.5%	10	Leiden University	Netherlands	3	7.5%
10	Czech Republic	3	7.5%	10	Tsinghua University	China	3	7.5%
				10	University of California Berkeley	USA	3	7.5%

In terms of countries that cite the core papers in this hot Research Front (Table 3), the USA is also the main contributing country, with 574 citing papers, or 28.6% of the total. China ranks 2nd with 530 citing papers, or 26.4%, while Germany ranks 3rd with 245. In terms of citing institutions, the Chinese Academy of Sciences ranks 1st with 118 citing papers, followed by the Max Planck Society in Germany (71 papers) and the University of Copenhagen in Denmark (57).

1 USA contributes **574** citing papers

2 China contributes **530** citing papers

3 Germany contributes **245** citing papers

Table 3 Top countries and institutions producing citing papers in the Research Front "The jasmonate signaling mechanism for regulation of plant growth and defense"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	574	28.6%	1	Chinese Academy of Sciences	China	118	5.9%
2	China	530	26.4%	2	Max Planck Society	Germany	71	3.5%
3	Germany	245	12.2%	3	University of Copenhagen	Denmark	57	2.8%
4	UK	172	8.6%	4	French National Centre for Scientific Research	France	52	2.6%
5	Denmark	105	5.2%	4	Spanish National Research Council	Spain	52	2.6%
6	Japan	94	4.7%	6	Technical University of Denmark	Denmark	50	2.5%
7	Netherlands	92	4.6%	6	Michigan State University	USA	50	2.5%
8	France	87	4.3%	8	BBSRC John Innes Centre	UK	48	2.4%
9	Spain	84	4.2%	9	Ghent University	Belgium	47	2.3%
10	India	81	4.0%	9	University of California Berkeley	USA	47	2.3%

1.3 KEY HOT RESEARCH FRONT – "Application of unmanned aerial systems in crop phenotyping"

Field crop phenotype is a visual representation of the characteristics and growth of crop varieties, a key factor reflecting crop yield and quality, and an important basis for revealing the growth and development of crops and their relationship with the environment. Therefore, rapid and accurate field crop phenotyping and monitoring of crop growth are of great significance for crop science research and breeding practice. However, traditional field test sampling and on-board high-throughput platform methods for measuring crop trait parameters are time-consuming and labor-intensive, and the spatial coverage is incomplete, thus greatly limiting the rapid development of crop science research and crop breeding. As a remedy to those limitations, the near-Earth remote-sensing, high-throughput phenotyping platform represented by drones, thanks to its flexibility, low cost, and wide space coverage, has become an important means for obtaining phenotypic information of field crops.

Thirty-one papers constitute the core of this hot Research Front. Twelve of these are review articles. They mainly review the current status and perspectives of unmanned aerial vehicle remote sensing for field-based crop phenotyping, using remote sensing for forestry research and practice, and low-altitude, high-resolution aerial imaging systems used for row and field crop phenotyping. The other 19 research articles focus on using drone-based aerial imaging techniques to image crops or trees in the field, and then combining those images with other methods (such as 3D photo reconstruction) to estimate the phenotype of crops or trees. The main research goals include: estimation of barley biomass; multi-temporal estimation of plant height; high-throughput phenotyping of wheat breeding nursery; the detection and classification of individual trees; phenotypic analysis of field corn; estimation of wheat crop density; and time-series for tracking the seasonal developmental potential of crops.

Analysis of the countries and institutions producing core papers (Table 4) shows that the USA is the most prolific country contributing to this hot Research Front, with 11 core papers, accounting for 35.5% of the total. Germany ranks 2nd with six core papers, followed by China with five. As for the institutions, the United States Department of Agriculture (USDA) and the University of Cologne in Germany are the main contributing institutions, with five and four core papers, respectively.

1 USA contributes **11** core papers

2 Germany contributes **6** core papers

3 China contributes **5** core papers

Table 4 Top countries and institutions producing core papers in the Research Front "Application of unmanned aerial systems in crop phenotyping"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	11	35.5%	1	United States Department of Agriculture	USA	5	16.1%
2	Germany	6	19.4%	2	University of Cologne	Germany	4	12.9%
3	China	5	16.1%	3	Helmholtz Association	Germany	3	9.7%
4	Spain	4	12.9%	3	Spanish National Research Council	Spain	3	9.7%
5	Switzerland	3	9.7%	3	ETH Zurich	Switzerland	3	9.7%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
6	Australia	2	6.5%	6	Royal Melbourne Institute of Technology	Australia	2	6.5%
6	Belgium	2	6.5%	6	China Agricultural University	China	2	6.5%
6	UK	2	6.5%	6	University of Barcelona	Spain	2	6.5%
6	Zimbabwe	2	6.5%	6	University of Santiago De Compostela	Spain	2	6.5%
6	Finland	2	6.5%	6	Cornell University	USA	2	6.5%
6	France	2	6.5%	6	Washington State University	USA	2	6.5%
6	Italy	2	6.5%					

In terms of countries that cite the core papers of this hot Research Front (Table 5), the USA is also the top contributor, with 399 citing papers, accounting for 28.2% of the total. Germany still ranks 2nd, with 197 citing papers, while China ranks 3rd with 187. In regard to the citing institutions, the United States Department of Agriculture (USDA) contributes the most citing papers, with 90. French National Institute for Agricultural Research (INRA) and Helmholtz Association in Germany rank 2nd and 3rd, respectively, with both exceeding 50 citing papers.

USA contributes **399** citing papers 1

Germany contributes **197** citing papers 2

China contributes **187** citing papers 3

Table 5 Top countries and institutions producing citing papers in the Research Front "Application of unmanned aerial systems in crop phenotyping"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	399	28.2%	1	United States Department of Agriculture	USA	90	6.4%
2	Germany	197	13.9%	2	French National Institute for Agricultural Research	France	56	4.0%
3	China	187	13.2%	3	Helmholtz Association	Germany	54	3.8%
4	Australia	121	8.5%	4	Spanish National Research Council	Spain	34	2.4%
5	UK	113	8.0%	5	Chinese Academy of Sciences	China	33	2.3%
6	Spain	112	7.9%	6	Commonwealth Scientific & Industrial Research Organisation	Australia	30	2.1%
7	France	88	6.2%	7	University of Bonn	Germany	28	2.0%
8	Italy	86	6.1%	7	Wageningen University & Research Center	Netherlands	28	2.0%
9	Canada	81	5.7%	9	Swedish University of Agricultural Sciences	Sweden	27	1.9%
10	Finland	48	3.4%	10	French National Centre for Scientific Research	France	26	1.8%
10	Netherlands	48	3.4%	10	Cornell University	USA	26	1.8%
10	Switzerland	48	3.4%					

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: "The mechanism of rice *OsAUX1* gene in promoting root hair elongation under low phosphorus conditions" (Table 6).

Table 6 Emerging Research Fronts in Agricultural, Plant and Animal Sciences

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core papers
1	The mechanism of rice *OsAUX1* gene in promoting root hair elongation under low phosphorus conditions	4	47	2017.8

2.2 KEY EMERGING RESEARCH FRONT – "The mechanism of rice *OsAUX1* gene in promoting root hair elongation under low phosphorus conditions"

Of course, the efficient use of nutrients in farmland soil has always been an important research topic in agriculture. Various root traits, such as root angle and root length, affect the nutrient intake of crops, especially some nutrients (e.g., phosphorus) fixed in the soil. The length of the root hair is affected by the concentration of the plant hormone auxin, and the maintenance of the concentration gradient of auxin depends on the polarity transport. Of the pertinent genes identified so far, *OsAUX1* has proved to be a very important rice auxin transport gene, which can transport auxin under low-phosphorus conditions and promote root hair elongation. Therefore, "The mechanism of rice *OsAUX1* gene in promoting root hair elongation under low-phosphorus conditions" has become a key emerging Research Front.

There are four core papers in this emerging Research Front. Three were published in *Nature Communications* in 2018, the other in the *Proceedings of the National Academy of Sciences of the United States of America (PNAS)* in 2017. These papers report that *OsAUX1* protein moves auxin transport from the root apex to differentiation zone, which promotes root hair elongation and root absorption of phosphorus; the auxin synthesis, transport and response pathways components (e.g., some auxin-induced transcription factors expressed in root hair under low-phosphorus conditions) play key roles in promoting root hair growth; there is a molecular link between auxin and reactive oxygen species (ROS)-mediated polar root hair growth.

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, examination of changes and impacts to ecosystems. Throughout the Top 10, water ecology, and environmental issues, and multidisciplinary solutions to today's pressing concerns are the predominant themes.

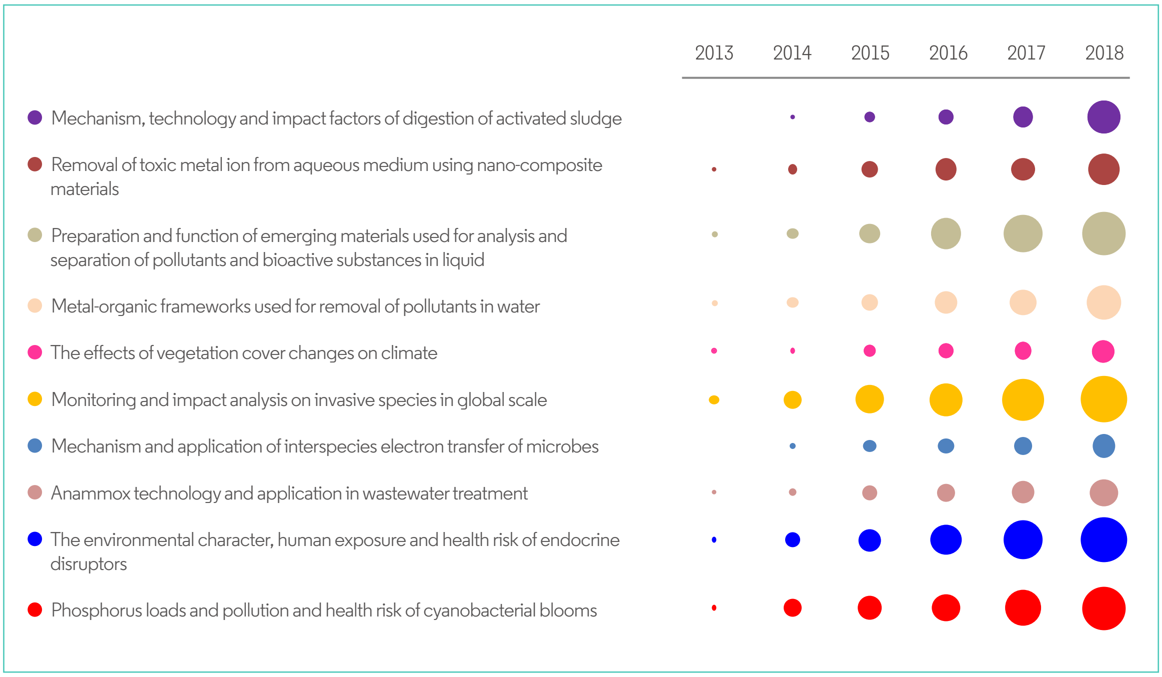
Seven hot Research Fronts (Table 7 and Figure 2) are devoted to the environmental-science subfield and mainly focus on sewage-treatment technology using microbes; water-pollutant analysis and separation technology; and fate and risk studies of environmental pollutants. ("Fate" refers to the life cycle or degradation of pollutants in the environment.) The hot Research Fronts related to sewage treatment include "Mechanism, technology and impact factors of digestion of activated sludge", "Anammox technology and application in wastewater treatment" and "Mechanism and application of interspecies electron transfer of microbes" – the latter pertaining to the process of anaerobic digestion. Technology for analyzing and separating pollutants in water is reflected in the fronts entitled "Removal of toxic metal ion from aqueous medium using nano-composite materials" , "Metal-organic frameworks used for removal of pollutants in water" and "Preparation and function of emerging materials used for analysis and separation of pollutants and bioactive substances in liquid". The hot Research Front on fate and risk studies of environmental pollutants is "The environmental character, human exposure and health risk of endocrine disruptors".

The other three hot Research Fronts, in the ecological science subfield, mainly emphasize macro-scale changes and risks in the biosphere and ecosystems, including "The effects of vegetation cover changes on climate", "Monitoring and impact analysis on invasive species in global scale" and "Phosphorus loads and pollution and health risk of cyanobacterial blooms".

Table 7 Top 10 Research Fronts in ecology and environmental sciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Mechanism, technology and impact factors of digestion of activated sludge	29	1294	2016.7
2	Removal of toxic metal ion from aqueous medium using nano-composite materials	38	1924	2016.1
3	Preparation and function of emerging materials used for analysis and separation of pollutants and bioactive substances in liquid	44	4562	2016
4	Metal-organic frameworks used for removal of pollutants in water	23	1884	2016
5	The effects of vegetation cover changes on climate	11	751	2016
6	Monitoring and impact analysis on invasive species in global scale	41	3434	2015.9
7	Mechanism and application of interspecies electron transfer of microbes	18	1321	2015.9
8	Anammox technology and application in wastewater treatment	16	1214	2015.9
9	The environmental character, human exposure and health risk of endocrine disruptors	44	3043	2015.5
10	Phosphorus loads and pollution and health risk of cyanobacterial blooms	38	2945	2015.5

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



1.2 KEY HOT RESEARCH FRONT – "The environmental character, human exposure and health risk of endocrine disruptors"

Endocrine disrupting chemicals (EDCs), also known as environmental estrogens, are defined as "exogenous agents that interfere with synthesis, secretion, transport, metabolism, binding action or elimination of natural blood-borne hormones that are present in the body and are responsible for homeostasis, reproduction and developmental process." Even at very low levels, EDCs can lead to negative physiological effects, including affecting the reproductive capacity of humans or animals, endangering development or health, and causing imbalances in the endocrine secretion of organisms. EDCs emit into the environment mainly through industrial and agricultural emission and waste combustion. Humans and animals may be exposed to EDCs by intaking food, dust, and water containing EDCs, or by inhaling affected gas or particulate matter, or through the skin by touch. EDCs can also be transferred from pregnant women to fetuses, infants, or children through placenta and breast milk. The main EDCs include pesticides such as insecticides and herbicides, bisphenol A, alkyl phenols, phthalates, brominated flame retardants, and dioxins.

The study of EDCs is mainly carried out in environmental science and biological science. In the former, research includes examination of EDC sources, major environmental processes, fate, and risk. In biological science, the pertinent research covers ecotoxicology, the action mechanism of EDCs on the endocrine system, and impact on disease and health.

Forty-four core papers identified this Research Front, mainly focusing on three areas: (1) Sources, fate, pollution characteristics and ecotoxicology of EDCs in water and soil; (2) Human-exposure monitoring and tracking of EDCs in large-scale population samples; (3) The effects of EDCs on health and development. The main EDCs include phthalates, which is a type of plasticizer, and glyphosate, a variety of herbicide whose toxicity has been globally debated in agricultural, environmental, and chemical industries. Studying EDC-based risks of developmental disorders and diseases in pregnant women, fetuses and infants, and monitoring EDCs exposure in children and mothers are hot topic. In the core literature for this front, "Trends in glyphosate herbicide use in the United States and globally," a 2016 report by C.S. Benbrook, is the most frequently cited paper, with 204 citations.

As for the top countries and institutions in this front (Table 8), 25 core papers list US-based authors, accounting for 56.8% of the total of 44. Germany contributes eight core papers, ranking 2nd, with Canada's six papers placing the nation at 3rd. China, Sweden, and the UK are each represented on four core papers, sharing 6th place. The main contributing institutions in terms of core papers are in the USA, Canada, Germany, and the UK. Among them, US-based institutions such as the Icahn School of Medicine at Mount Sinai, the National Institutes of Health, the Centers for Disease Control and Prevention, and the University of Massachusetts at Amherst are notably active. Therefore, the USA is predominant in this Research Front, with the most core papers and the most participating institutions.

1 — USA contributes **25** core papers

2 — Germany contributes **8** core papers

3 — Canada, France contribute **6** core papers, respectively

6 — China contributes **4** core papers

6 — Sweden contributes **4** core papers

6 — UK contributes **4** core papers

Table 8 Top countries and institutions producing core papers in the Research Front "The environmental character, human exposure and health risk of Endocrine disruptors"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	25	56.8%	1	Icahn School of Medicine at Mount Sinai	USA	5	11.4%
2	Germany	8	18.2%	2	University of British Columbia	Canada	4	9.1%
3	Canada	6	13.6%	2	Ruhr University of Bochum	Germany	4	9.1%
3	France	6	13.6%	2	National Institutes of Health	USA	4	9.1%
5	Denmark	5	11.4%	2	University of Massachusetts Amherst	USA	4	9.1%
6	China	4	9.1%	2	Centers for Disease Control & Prevention	USA	4	9.1%
6	Sweden	4	9.1%	7	Kings College London	UK	3	6.8%
6	UK	4	9.1%	7	Benbrook Consulting Services	USA	3	6.8%
9	Norway	2	4.5%	7	Brown University	USA	3	6.8%
9	South Korea	2	4.5%	7	University of Michigan	USA	3	6.8%
9	Spain	2	4.5%	7	University of Minnesota	USA	3	6.8%

In terms of the countries and institutions that cite the core papers (Table 9), the USA is the most prolific source of citing papers. US-based authors participated in 872 papers, accounting for 39.3% of the total number of citing papers. China has 353 articles, representing 15.9% and ranking 2^{nd}, and Spain has 160 papers, accounting for 7.2%, placing 3^{rd}. As for the Top 10 institutions that cite the core papers in this hot Research Front, six are based in the USA. The top three institutions – the Centers for Disease Control & Prevention (109 papers), Harvard University (107 papers) and the National Institutes of Health (78 papers) – are all in the USA. China ranks 6^{th} by the measure of core papers and 2^{nd} in citing papers, demonstrating a significant presence in this front.

USA contributes **872** citing papers 1

China contributes **353** citing papers 2

Spain contributes **160** citing papers 3

Table 9 Top countries and institutions producing citing papers in the Research Front "The environmental character, human exposure and health risk of endocrine disruptors"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	872	39.3%	1	Centers for Disease Control & Prevention	USA	109	4.9%
2	China	353	15.9%	2	Harvard University	USA	107	4.8%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
3	Spain	160	7.2%	3	National Institutes of Health	USA	78	3.5%
4	Germany	137	6.2%	4	University of Michigan	USA	69	3.1%
5	France	130	5.9%	5	French National Institute of Health and Medical Research	France	66	3.0%
6	Canada	127	5.7%	5	Icahn School of Medicine at Mount Sinai	USA	66	3.0%
7	UK	112	5.0%	7	University of Copenhagen	Denmark	59	2.7%
8	Denmark	101	4.6%	8	CIBER	Spain	57	2.6%
9	South Korea	87	3.9%	9	Chinese Academy of Sciences	China	56	2.5%
10	Italy	81	3.7%	10	State University of New York at Albany	USA	50	2.3%

1.3 KEY HOT RESEARCH FRONT – "Phosphorus loads and pollution and health risk of cyanobacterial blooms"

Bloom is a rapid increase or accumulation in the population of algae in water systems. It is an ecological disaster, indicating eutrophication of water bodies. As large amounts of waste water containing phosphorus and nitrogen from living, industrial, and agricultural production enter a water body, cyanobacteria grow explosively under special environmental and meteorological conditions. This can cause cyanobacterial blooms and make the water body turn blue or green. Toxins produced by cyanobacterial blooms endanger the safety of drinking water and of aquatic plants and animals, causing serious ecological fallout and bringing substantial health risks and economic losses. This makes cyanobacterial blooms one of the major ecological and environmental concerns worldwide. The main cyanobacteria species include Microcystis, Anabaena, and Aphanizomenon flos-aquae. The research concentration on cyanobacterial blooms mainly involves mechanism and causes, ecological and health risks, monitoring and early warning techniques, and control strategies and methods.

38

There are 38 core papers in this Research Front

There are 38 core papers in this Research Front, largely focusing on four aspects: (1) The impact of global or regional nutrient load and other factors on cyanobacterial blooms, especially the production, consumption, transportation, storage, environmental cycling, and impact of phosphorus; (2) Ecological studies on species diversity, growth and metabolism, genetics and toxin production of different cyanobacteria species, especially the ecological study of Microcystis; (3) Health-risk studies of toxic cyanobacteria, especially toxicology, epidemiology, and detection of microcystins; (4) Study of a comprehensive control strategy for cyanobacterial blooms in specific areas such as Lake Erie, with the emphasis on controlling phosphorus.

According to the statistics on top countries and institutions in this front (Table 10), most of the core papers (29) list contributing authors in the USA, accounting for 76.3% of the total of 33 in the core. Eight core papers include authors based in China and the UK, giving both nations a share of 21.1% of the core and tying them for 2nd. The main contributing institutions of the core papers are also in the USA. Among the top 12 institutes, 10 are American. Heidelberg University in Tiffin, Ohio (site of the National Center for Water Quality Research), with eight core papers, and the University of Arkansas at Fayetteville, with seven papers in the core, rank 1st and 2nd, respectively. With four core papers each, the Chinese Academy of Sciences, the UK's Natural Environment Research Council, and four American institutions share 7th place.

USA contributes **29** core papers — 1

China contributes **8** core papers — 2

UK contributes **8** core papers — 2

Table 10 Top countries and institutions producing core papers in the Research Front "Phosphorus loads and pollution and health risk of cyanobacterial blooms"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	29	76.3%	1	Heidelberg University USA	USA	8	21.1%
2	UK	8	21.1%	2	University of Arkansas Fayetteville	USA	7	18.4%
2	China	8	21.1%	3	Ohio State University	USA	6	15.8%
4	Canada	7	18.4%	3	University of North Carolina Chapel Hill	USA	6	15.8%
5	Australia	4	10.5%	5	Oregon State University	USA	5	13.2%
5	Netherlands	4	10.5%	5	National Oceanic and Atmospheric Administration	USA	5	13.2%
7	New Zealand	2	5.3%	7	Chinese Academy of Sciences	China	4	10.5%
7	Austria	2	5.3%	7	Natural Environment Research Council	UK	4	10.5%
				7	Carnegie Institution for Science	USA	4	10.5%
				7	University of Tennessee Knoxville	USA	4	10.5%
				7	Wright State University Dayton	USA	4	10.5%
				7	United States Department of Agriculture	USA	4	10.5%

By the measure of citing papers (Table 11), the USA is still the most important source of papers that cite the core of this front. US-based scholars contributed to 879 citing papers, accounting for 43.1% of the total. China has 419 articles, or 20.5%, ranking 2nd, while Canada posts 257 papers, accounting for 12.6% and ranking 3rd. In terms of institutions that cite the core papers, the Chinese Academy of Sciences ranks 1st with 151 citing papers. The Natural Environment Research Council of the UK ranks 8th with 54 citing papers. Aside from those entities, all the other top citing institutions are in the USA. Among them, the United States Department of Agriculture (108 papers) and Ohio State University (81 papers) rank 2nd and 3rd, respectively. Data analysis shows that the USA is leading the activity in this Research Front, while China is catching up.

USA contributes **879** citing papers — 1

China contributes **419** citing papers — 2

Canada contributes **257** citing papers — 3

Table 11: Top countries and institutions producing citing papers in the Research Front "Phosphorus loads and pollution and health risk of cyanobacterial blooms"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	879	43.1%	1	Chinese Academy of Sciences	China	151	7.4%
2	China	419	20.5%	2	United States Department of Agriculture	USA	108	5.3%
3	Canada	257	12.6%	3	Ohio State University	USA	81	4.0%
4	UK	152	7.5%	4	University of Michigan	USA	74	3.6%
5	Germany	111	5.4%	5	U.S.Geological Survey	USA	71	3.5%
6	Australia	89	4.4%	6	National Oceanic and Atmospheric Administration	USA	68	3.3%
7	Brazil	87	4.3%	7	University of Minnesota	USA	64	3.1%
8	Netherlands	77	3.8%	8	Natural Environment Research Council	UK	54	2.6%
9	France	69	3.4%	9	Michigan State University	USA	46	2.3%
9	Poland	69	3.4%	10	US Environment Protection Agency	USA	44	2.2%

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: "Effects of environmental pollutants on gut microbiota."

Table 12 Emerging Research Fronts in ecology and environmental sciences

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Effects of environmental pollutants on gut microbiota	5	81	2017.6

2.2 KEY EMERGING RESARCH FRONT – "Effects of environmental pollutants on gut microbiota"

Large quantities and species of microbiota inhabit the intestines of humans and animals. The gut microbiota has been proved to be very important for the physical health of humans and animals. It is involved in the regulation of many physiological functions, such as the digestion of food and the synthesis of vitamins and amino acids. The gut microbiota also plays an important role in energy metabolism and storage, immune-system regulation, growth, and neural development. The occurrence of many diseases is associated with the changes in the composition of the gut microbiota – just one of the reasons the topic has become one of the hottest research areas in recent years.

The gut microbiota is very sensitive to drugs, diet, and pollutants in the environment. Recent studies have found that environmental pollutants can enter human or animal's intestines by various ways and interact with gut microbiota. Exposure to different types of pollutants can alter the composition of the gut microbiota, which can further cause energy metabolism disorders, affect nutrient absorption and the function of the immune system, and exert a variety of potential adverse effects on human and animal health, even leading to symptoms of poisoning.

The main contents of this emerging Research Front involve studying the effects of common pesticides such as atrazine (an herbicide) and imazalil (a fungicide) on the gut microbiota of model animals such as mice and zebrafish, with additional focus on the impact on the metabolism and immunity of organisms.

IV. GEOSCIENCES

1. HOT RESEARCH FRONT

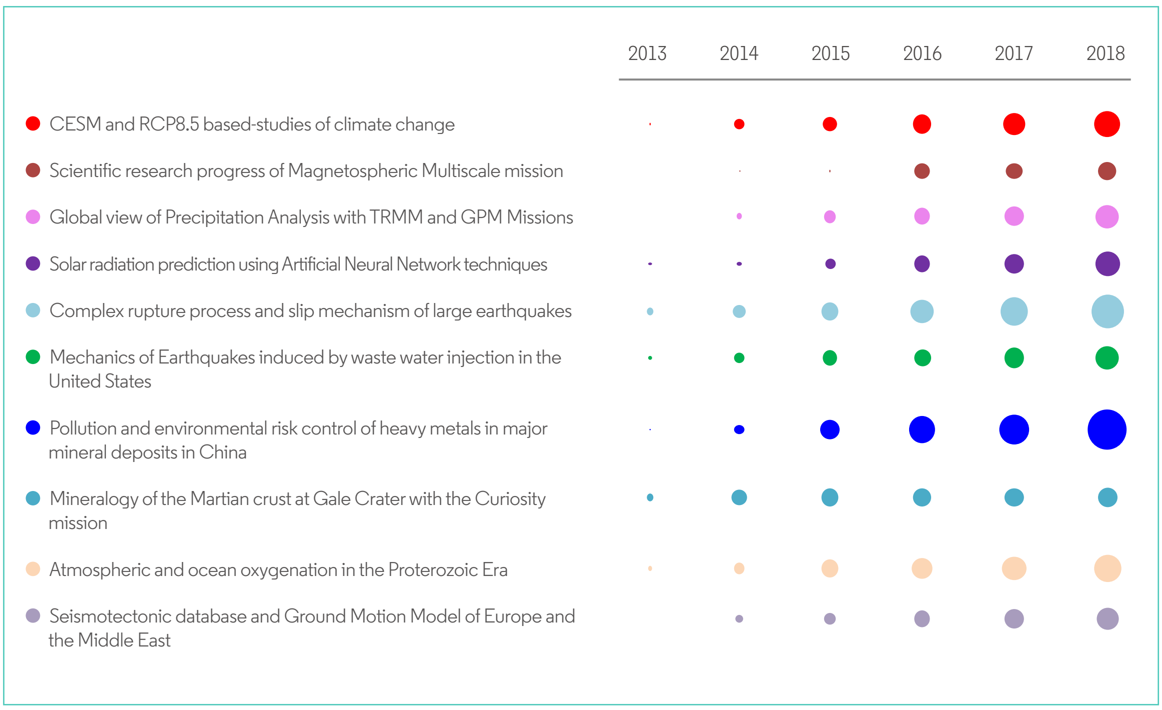
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN GEOSCIENCES

Six of the Top 10 Research Fronts in geosciences focus on solid geophysics, including “Scientific research progress of Magnetospheric Multiscale mission,” “Solar radiation prediction using Artificial Neural Network techniques,” “Complex rupture process and slip mechanism of large earthquakes ,” “Mechanics of earthquakes induced by waste water injection in the United States,” “Mineralogy of the Martian crust at Gale Crater with the Curiosity mission,” and “Seismotectonic database and Ground Motion Model of Europe and the Middle East.” Three fronts pertain to climate change, including “CESM and RCP8.5 based-studies of climate change,” “Global view of precipitation analysis with TRMM and GPM Missions,” and “Atmospheric and ocean oxygenation in the Proterozoic Era.” One Research Front, in geochemistry, “Pollution and environmental risk control of heavy metals in major mineral deposits in China. ”

Table 13 Top10 Research Fronts in geosciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	CESM and RCP8.5-based studies of climate change	8	1212	2016.5
2	Scientific research progress of Magnetospheric Multiscale mission	11	1337	2016.3
3	Global view of Precipitation Analysis with TRMM and GPM Missions	21	1261	2016.3
4	Solar radiation prediction using Artificial Neural Network techniques	25	1216	2016
5	Complex rupture process and slip mechanism of large earthquakes	49	2959	2015.9
6	Mechanics of Earthquakes induced by waste water injection in the United States	26	2290	2015.8
7	Pollution and environmental risk control of heavy metals in major mineral deposits in China	34	2846	2015.7
8	Mineralogy of the Martian crust at Gale Crater with the Curiosity mission	23	1925	2015.7
9	Atmospheric and ocean oxygenation in the Proterozoic Era	29	2601	2015.6
10	Seismotectonic database and Ground Motion Model of Europe and the Middle East	16	1481	2015.5

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



1.2 KEY HOT RESEARCH FRONT – "CESM and RCP8.5-based studies of climate change"

Matching its standing as one of the world's most visible and pressing political issues, climate change ranks among the hottest topics in recent scientific research. The Earth System Model provides an important scientific and quantitative tool for understanding the mechanism behind the past evolution of climate and environmental conditions, as well as for predicting potential global-change scenarios in the future. As one of the most advanced and widely used new-generation earth system models in the world, the Community Earth System Model (CESM) is composed of the Community Atmosphere Model, the Parallel Ocean Program, the Community Land Model, the Los Alamos National Laboratory Sea-ice Model, the Glimmer Ice Sheet Model, and similar tools. It is a flexible and extensible community tool used to investigate a diverse set of earth system interactions across multiple time and space scales.

To improve understanding of the complex interactions of climate, ecosystems, and human activities and conditions, the research community develops and uses scenarios. The Fifth Assessment Report of Intergovernmental Panel on Climate Change (IPCC AR5) developed a set of four new pathways for the climate modeling community as a basis for long-term and near-term modeling experiments. The four Representative Concentration Pathways (RCPs) together span the range of year 2100 radiative forcing values from 2.6 to 8.5 W/m2. RCP 8.5 is the most widely used in the climate change research and assessment.

The core papers in the hot Research Front on "CESM and RCP 8.5-based studies of climate change" focus on research using those specific scenarios to provide new foresight into possible future climates as well as their influences. These latter factors include such variables as climate change in the presence of internal climate variability and external forcing, the roles of greenhouse gas and aerosol, North American climate, heat extremes, cold waves and global drought in the future. The most-cited paper in this Research Front ("The Community Earth System Model: a Framework for Collaborative Research," with 581 citations at this writing) is from a collaborative team of US- and Canada-based authors. This paper describes CEMS and its various possible configurations, highlighting a number of its scientific capabilities.

Among nations, the USA, Canada, China, and Australia are the notable participants in this hot Research Front, with the USA registering as most prolific. In terms of the core papers, 10 of 14 top-producing institutions are in the USA. Among them, the National Center for Atmospheric Research (NCAR) published eight core papers. Authors based at Lanzhou University collaborated with the NCAR, discussing the uncertainty of global drought in the 21st century.

Table 14 Top countries and institutions producing core papers in the Research Front "CESM and RCP8.5 based-studies of climate change"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	8	100.0%	1	National Center for Atmospheric Research	USA	8	100.0%
2	Canada	2	25.0%	2	Department of Energy	USA	2	25.0%
3	China	1	12.5%	2	University of Toronto	Canada	2	25.0%
3	Australia	1	12.5%	4	Lanzhou University	China	1	12.5%
				4	University of Colorado Boulder	USA	1	12.5%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
				4	Colorado State University	USA	1	12.5%
				4	Columbia University	USA	1	12.5%
				4	Cornell University	USA	1	12.5%
				4	National Oceanic and Atmospheric Administration	USA	1	12.5%
				4	University of California, Berkeley	USA	1	12.5%
				4	University of Minnesota	USA	1	12.5%
				4	University of Washington, Seattle	USA	1	12.5%
				4	University of Wisconsin, Madison	USA	1	12.5%
				4	Bureau of Meteorology	Australia	1	12.5%
				4	University of Calgary	Canada	1	12.5%

As for countries and institutions producing citing papers, the USA ranks 1st with 776. China also performs actively in this Research Front and ranks 2nd. Eight US-based entities appear among the Top 10 institutions. The NCAR, the Department of Energy (DOE), and the University of Colorado Boulder are the top three prolific institutions in publishing citing papers.

USA contributes
776 citing papers
1

China contributes
167 citing papers
2

Table 15 **Top countries and institutions producing citing papers in the Research Front "CESM and RCP8.5 based-studies of climate change"**

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	776	77.3%	1	National Center for Atmospheric Research	USA	300	29.9%
2	China	167	16.6%	2	Department of Energy	USA	148	14.7%
3	UK	118	11.8%	3	University of Colorado Boulder	USA	130	12.9%
4	Germany	82	8.2%	4	National Oceanic and Atmospheric Administration	USA	96	9.6%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
5	France	70	7.0%	5	Chinese Academy of Sciences	China	90	9.0%
6	Canada	69	6.9%	6	National Aeronautics and Space Administration	USA	71	7.1%
7	Switzerland	68	6.8%	7	University of Washington, Seattle	USA	64	6.4%
8	Australia	46	4.6%	8	Columbia University	USA	59	5.9%
9	Norway	37	3.7%	9	French National Centre for Scientific Research	France	58	5.8%
10	Netherlands	33	3.3%	10	Princeton University	USA	52	5.2%

1.3 KEY HOT RESARCH FRONT – "Pollution and environmental risk control of heavy metals in major mineral deposits in China"

Mineral resources represent the key material foundation for socio-economic development, rendering the exploitation and utilization of mineral resources essential to modernization. China holds diversified and large-scale mineral resources, proven reserves of mineral resources constitute 12% of the total mineral resources in the world. Nonetheless, despite the importance of mineral resources, mineral extraction has inflicted serious environmental damage, especially in the realm of heavy metal pollution. According to the first soil pollution study led by Ministry of Environmental Protection and Ministry of Natural Resources of China, mines are considered to be one of the most significant sources of heavy metal contamination.

The 34 papers forming the core of the hot Research Front "Pollution and environmental risk control of heavy metals in major mineral deposits in China" mainly focus on the source identification and spatial distribution of soil heavy metals in major mining areas in China, as well as ecological and health risk assessments. Findings deriving from this Research Front will guide the management of mining areas in China, and provide countermeasures and recommendations for the treatment and prevention of heavy metal pollution.

Analysis of the countries and institutions producing core papers (Table 16) shows that China is the prominent country contributing to this hot Research Front, with 26 core papers. In terms of institutions, Beijing Normal University ties for first place, contributing seven core papers, followed by the Chinese Academy of Sciences, Hunan University, and Zhejiang University. The most-cited core paper in this Research Front (with 519 citations to date) is from a research team at State Key Laboratory of Pollution Control and Resource Reuse of Nanjing University. This paper summarizes available data in the literature (2005–2012) on heavy metal polluted soils originating from mining areas in China. The report then evaluates the soil pollution levels of these collected mines and quantifies the risks these pollutants pose to human health.

Table 16 Top countries and institutions producing core papers in the Research Front "Pollution and environmental risk control of heavy metals in major mineral deposits in China"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	26	76.5%	1	Beijing Normal University	China	7	20.6%
2	USA	4	11.8%	2	Chinese Academy of Sciences	China	4	11.8%
3	Spain	2	5.9%	2	Hunan University	China	4	11.8%
3	Colombia	2	5.9%	2	Zhejiang University	China	4	11.8%
3	India	2	5.9%	5	Shiraz University	Iran	2	5.9%
3	Iran	2	5.9%	5	Nanjing University	China	2	5.9%
7	Japan	1	2.9%	5	Northwest A&F University	China	2	5.9%
7	Morocco	1	2.9%	5	China National Environmental Monitoring Centre	China	2	5.9%
7	Netherlands	1	2.9%	5	Hong Kong University of Science and Technology	China	2	5.9%
7	Pakistan	1	2.9%					
7	Poland	1	2.9%					
7	Korea	1	2.9%					
7	France	1	2.9%					
7	Greece	1	2.9%					
7	Bengal	1	2.9%					
7	Canada	1	2.9%					

China contributes **26** core papers 1

USA contributes **4** core papers 2

In terms of the countries producing the citing papers, China is the main contributor (1,208 papers, or 60.3%), reflecting this research topic's central relevance to the nation. The USA ranks 2nd, with 145 core papers. Among the Top 10 institutions, nine are from China. The Chinese Academy of Sciences ties for first place, followed by Beijing Normal University and Hunan University.

Table 17 Top countries and institutions producing citing papers in the Research Front "Pollution and environmental risk control of heavy metals in major mineral deposits in China"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	1208	60.3%	1	Chinese Academy of Sciences	China	262	13.1%
2	USA	145	7.2%	2	Beijing Normal University	China	73	3.6%
3	India	92	4.6%	3	Hunan University	China	57	2.8%
4	Iran	87	4.3%	4	Nanjing University	China	47	2.3%
5	Pakistan	71	3.5%	5	Zhejiang University	China	40	2.0%
6	Australia	61	3.0%	6	China University of Geosciences	China	38	1.9%
7	Spain	51	2.5%	7	Central South University	China	29	1.4%
8	Brazil	48	2.4%	8	Northwest A&F University	China	29	1.4%
9	Italy	45	2.2%	9	Chinese Academy of Agricultural Sciences	China	26	1.3%
10	Germany	43	2.1%	9	French National Centre for Scientific Research	France	26	1.3%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN GEOSCIENCES

"Effects of thermal-damage on mechanical behavior of rock" was selected as the emerging Research Front in geosciences for 2019.

Table 18 Emerging Research Fronts in geosciences

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Effects of thermal-damage on mechanical behavior of rock	9	180	2017.6

2.2 KEY EMERGING RESARCH FRONT – "Effects of thermal damage on mechanical behavior of rock"

Temperature is one of the important factors affecting the mechanical properties of rock. Rock may undergo heating and cooling in projects of high temperature nuclear waste treatment, the development and utilization of geothermal resources, on-site gasification and thermal energy transmission of coal and oil shale, post-disaster reconstruction of rock underground engineering, and development of large depth underground space in metropolitan area. The mesostructure and mineral composition of rock will change in these projects. As a result, the strength and deformation characteristics of rock will also change, potentially posing a real threat to the stability of the project. The related mechanical parameters are the essential basis of underground projects, rock timbering design, and stability analysis of surrounding rock. Studying the effects of thermal-damage on mechanical behavior of rock can provide evidence for the long-term safety assessment of underground shelter projects.

The main research topics in "Effects of thermal-damage on mechanical behavior of rock" include damage investigation of rock under different temperature conditions, micromechanical analysis of mechanical behaviors of thermally damaged rock, and crack propagation testing after processes involving high temperature. All nine of the core papers in this emerging Research Front were contributed by China. Two of the papers involved collaboration with institutions based in the USA and Australia. China University of Mining and Technology contributed six core papers and ranked 1st in terms of the citing papers.

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 the management of chronic diseases, including the application of new technologies; new mechanisms of disease; new technologies for diagnostic imaging and related safety issues; tumor immunotherapy; and clinical application of biotechnological drugs.

The fronts related to managing chronic diseases include studies of achieved blood pressure on cardiovascular outcomes, artificial pancreas systems for type 1 diabetes, pharmacogenomic guided antiplatelet therapy after percutaneous coronary intervention, as well as characteristics and treatment of bronchiectasis.

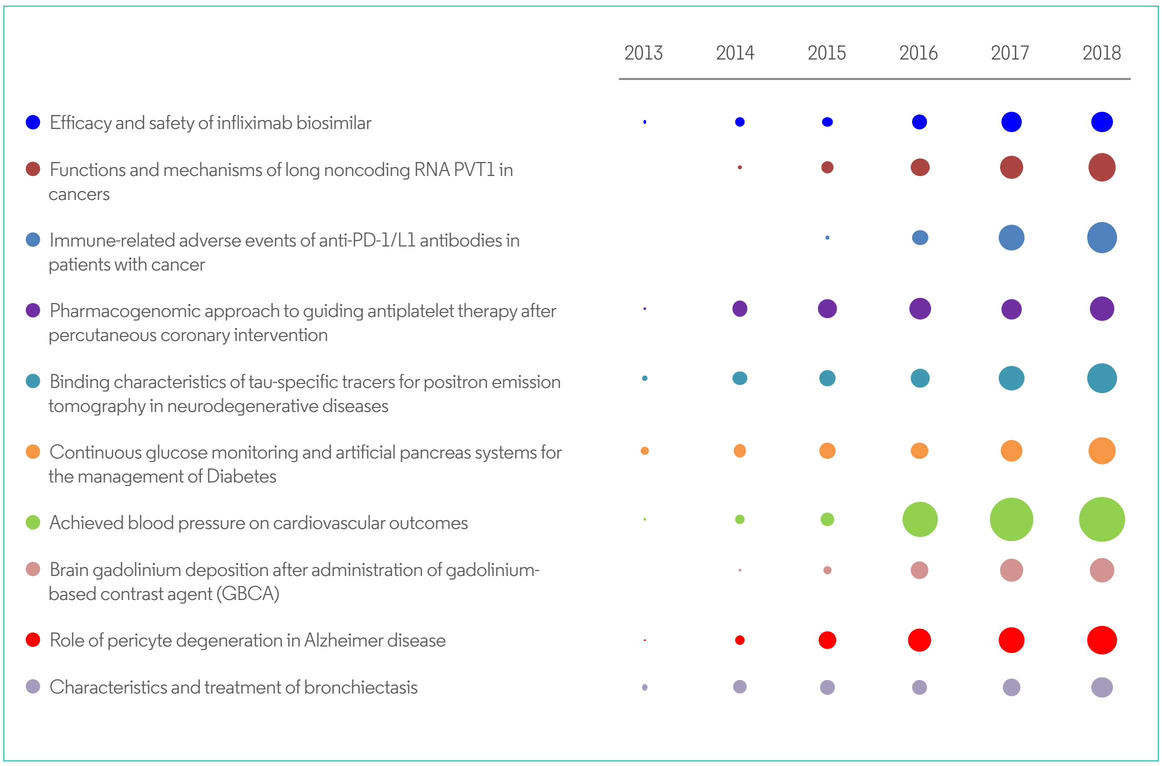
On the topic of new mechanisms of diseases, the pertinent fronts concern functions and mechanisms of long noncoding RNA PVT1 in cancers, and the role of pericyte degeneration in Alzheimer disease. Fronts examining new technologies and safety in diagnostic imaging include tau-specific tracers for positron emission tomography in neurodegenerative diseases, as well as brain gadolinium deposition after administration of gadolinium-based contrast agent. Tumor immunotherapy fronts and clinical application of biotechnological drugs fronts include, respectively, immune-related adverse events of anti-PD-1/L1 antibodies in cancer patients, and efficacy and safety of biosimilar infliximab.

Compared with previous years, the top 10 Research Fronts in clinical medicine in 2019 clearly show the continuity and development of specialty areas from previous reports. Specifically, five fronts – clinical application of infliximab biological analogues, Tau PET imaging in neurodegenerative diseases, artificial pancreas for diabetes mellitus, risks of cardiovascular outcomes after achieved blood pressure, and brain gadolinium deposition – are similar to hot Research Fronts featured in 2018. Meanwhile, the two cancer-related fronts –long noncoding RNA PVT1 in cancers, and adverse events of anti-PD-1/L1 antibodies in cancers – are similar to fronts identified as "emerging" in 2018 ("Long noncoding RNAs as biomarkers in human cancer progression and prognosis") and 2017 ("Immune-related adverse events of anti-PD-1 therapy").

Table 19 Top10 Research Fronts in clinical medicine

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Efficacy and safety of infliximab biosimilar	30	1808	2016.7
2	Functions and mechanisms of long noncoding RNA PVT1 in cancers	23	1447	2016.5
3	Immune-related adverse events of anti-PD-1/L1 antibodies in patients with cancer	19	1467	2016.4
4	Pharmacogenomic approach to guiding antiplatelet therapy after percutaneous coronary intervention	16	1537	2016.3
5	Binding characteristics of tau-specific tracers for positron emission tomography in neurodegenerative diseases	37	3298	2016.2
6	Continuous glucose monitoring and artificial pancreas systems for the management of Diabetes	31	2240	2016.2
7	Achieved blood pressure on cardiovascular outcomes	25	4525	2016
8	Brain gadolinium deposition after administration of gadolinium-based contrast agent (GBCA)	31	3161	2015.9
9	Role of pericyte degeneration in Alzheimer disease	14	1751	2015.8
10	Characteristics and treatment of bronchiectasis	23	1717	2015.8

Figure 4 Citing papers for the top 10 research fronts in clinical medicine



1.2 KEY HOT RESEARCH FRONT – "Efficacy and safety of infliximab biosimilar"

8

Of the top 10 best-selling drugs worldwide in 2018, eight derive from biological medicine.

After decades of development, biopharmaceuticals have become an important part of the global pharmaceutical market. Of the top 10 best-selling drugs worldwide in 2018, eight derive from biological medicine. The biological medicine market is booming, but at the same time the high cost has imposed heavy financial burdens on patients and society. Ideally, ongoing research and development of biosimilars will improve this situation. (A biosimilar is a biologic medical product highly similar to another, already-approved biological medicine -- the "reference medicine.")

Compared with the reference medicine, biosimilars are much cheaper, have good curative effect and low side effects, provide important solutions for reducing burden of diseases, and improve drug accessibility. The expiration of patents on several blockbuster drugs has brought great opportunity for biosimilars. Infliximab, whose patents in Europe and American expired in 2015 and 2018, respectively, was among the top five best-selling antibody drugs globally. This huge market has attracted companies to undertake research and development of infliximab biosimilar.

The "Efficacy and safety of infliximab biosimilar" was among the Top10 hot Research Fronts in 2018 and has been identified again as one of the key fronts in 2019. This Hot Research Front mainly focuses on two main issues: efficacy and safety of infliximab biosimilar CT-P13, as well as safety and efficacy of switching from reference infliximab to biosimilar. CT-P13, developed by the South Korea-based pharmaceutical company Celltrion, is the world's first infliximab biosimilar. CT-P13 was approved by the European Union in 2013 and by the United States in 2016 for use in rheumatoid arthritis, Crohn's disease, ulcerative colitis, ankylosing spondylitis, psoriasis, and other conditions. Among this front's core papers, a report published in *The Lancet* in 2017 (having recorded 189 citations at this writing) announced the findings of the NOR-SWITCH study, funded by the Norwegian government. The NOR-SWITCH study assessed the safety and efficacy of switching from originator infliximab to biosimilar CT-P13, using a randomized, non-inferiority, double-blind, phase 4 trial setting with 52 weeks of follow-up. This study showed that switching from infliximab originator to CT-P13 was not inferior to continued treatment with infliximab originator. Studies such as NOR-SWITCH have provided data support for patients switching from infliximab innovator to biosimilar, thus enhancing the confidence of doctors and patients in the use of infliximab biosimilar. Nevertheless, due to the nature of biosimilars, research will continue to explore the long-term efficacy and safety of infliximab biosimilar in order to dispel all concerns.

11

South Korea contributes 11 core papers, ranks second

In terms of the number of core papers for this front, European countries dominate, thanks to their early start, rich experience, and astute policies in biosimilar research and development. South Korea ranks second, partly owing to the two South Korean companies, Celltrion and Samsung Bioepis, which developed infliximab biosimilars CT-P13 (Remsima®) and SB-2 (Renflexis®), respectively. The United States also stands out with seven papers (or 23.3% of the core).

Table 20 Top countries and institutions producing core papers in the Research Front "Efficacy and safety of infliximab biosimilar"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	Poland	12	40.0%	1	Lithuanian University of Health Sciences	Lithuania	5	16.7%
2	South Korea	11	36.7%	1	Hanyang University	South Korea	5	16.7%
3	Ukraine	8	26.7%	3	Celltrion	South Korea	4	13.3%
3	Germany	8	26.7%	3	Inha University	South Korea	4	13.3%
5	Netherlands	7	23.3%	3	Medical University of Vienna	Austria	4	13.3%
5	USA	7	23.3%	3	University of Banja Luka	Bosnia & Herzegovina	4	13.3%
7	UK	6	20.0%	3	Center of Estudios Reumatol	Chile	4	13.3%
7	Mexico	6	20.0%	8	Charles University Prague	Czech Republic	3	10.0%
9	Norway	5	16.7%	8	Samsung Bioepis Co. Ltd.	South Korea	3	10.0%
9	Lithuania	5	16.7%	8	Diakonhjemmet Hospital	Norway	3	10.0%
9	Austria	5	16.7%	8	Med Pro Familia	Poland	3	10.0%
9	Bulgaria	5	16.7%	8	Poznan University of Medical Science	Poland	3	10.0%
9	Chile	5	16.7%	8	Poznanski Osrodek Medyczny NOVAMED	Poland	3	10.0%
9	Czech Republic	5	16.7%	8	Rheumazentrum Ruhrgebiet	Germany	3	10.0%

As for the citing papers, US-based researchers participated in nearly a quarter of this research (148 articles, or 24.3%), far more than the other countries. Among the Top 10 institutions producing citing papers, eight are based in Europe while the other two are located in South Korea and the United States.

USA contributes **148** citing papers

Table 21 Top countries and institutions producing citing papers in the Research Front "Efficacy and safety of infliximab biosimilar"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	148	24.3%	1	Medical University of Vienna	Austria	27	4.4%
2	UK	91	15.0%	2	French National Institute of Health and Medical Research	France	24	3.9%
3	Italy	89	14.6%	2	Hanyang University	South Korea	24	3.9%
4	Germany	82	13.5%	4	Semmelweis University	Hungary	23	3.8%
5	South Korea	67	11.0%	5	Ku Leuven	Belgium	22	3.6%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
6	France	57	9.4%	5	Charite Medical University of Berlin	Germany	22	3.6%
7	Netherlands	57	9.4%	5	University of Leeds	UK	22	3.6%
8	Spain	48	7.9%	8	Public Hospitals of Paris	France	21	3.5%
9	Canada	43	7.1%	9	Rheumazentrum Ruhrgebiet	Germany	18	3.0%
10	Austria	37	6.1%	9	Pfizer	USA	18	3.0%

1.3 KEY HOT RESARCH FRONT – "Role of pericyte degeneration in Alzheimer disease"

Pericytes are flat cells scattered between vascular endothelial cells and basement membrane. In the central nervous system (CNS), pericytes and vascular endothelial cells, basement membrane, glial cells, and neurons together constitute the neurovascular unit that maintains the system's normal shape and function. Pericytes of the CNS can regulate cerebral blood flow by contraction and relaxation, and play an important role in the formation and maintenance of the blood-brain barrier, stabilization of neovascularization, and phagocytosis of metabolites. Given the importance of pericytes to the neurovascular unit, pericyte dysfunction is closely related to the pathogenesis and prognosis of many kinds of CNS diseases and may become a new target for clinical treatment. Therefore, pericyte dysfunction has become a hot research topic. Alzheimer's disease, as the most common neurodegenerative disease, is also closely related to the dysfunction of peripheral cells in the CNS. The specific mechanisms include impaired blood-brain barrier, decreased regional cerebral blood flow, metabolic abnormality of beta-amyloid protein and tau protein.

The hot Research Front "Role of pericyte dysfunction in Alzheimer's disease" includes 14 core papers, which mainly cover cellular and molecular mechanisms of Alzheimer's, including the important functions and signal pathways of pericytes. Some studies have shown that loss of PDGFRB pericyte in brain tissue of patients with Alzheimer's disease is related to fibrinogen leakage, decreased oxygenation, and abnormal deposition of fibrous beta-amyloid protein. Other studies have shown that pericyte degeneration leads to neurovascular uncoupling, brain oxygen deficiency, and metabolic stress, which are also associated with Alzheimer's disease. Other studies have found that pericyte is the main regulator of cerebral blood flow. Neuronal activity and neurotransmitter glutamate activate signal release to make pericytes relax, thereby expanding capillaries and regulating cerebral blood flow.

Among top countries and institutions producing the 14 core papers, the USA has the highest contribution rate (71.4%), of which the University of Southern California has an obvious leading edge with six core papers, accounting for 42.9% and ranking first among top-producing institutions. The United Kingdom and Serbia rank second and third among top countries producing core papers, with respectively, four and two foundational reports. The only core paper contributed by China is from the Third Military Medical University.

USA contributes **10** core papers 1

UK contributes **4** core papers 2

Serbia contributes **2** core papers 3

China contributes **1** core papers 4

Table 22 Top countries and institutions producing core papers in the Research Front "Role of pericyte degeneration in Alzheimer disease"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	10	71.4%	1	University of Southern California	USA	6	42.9%
2	UK	4	28.6%	2	University College London	UK	2	14.3%
3	Serbia	2	14.3%	2	University of Belgrade	UK	2	14.3%
4	China	1	7.1%	2	University of California San Diego	Serbia	2	14.3%
4	Denmark	1	7.1%	2	California Institute of Technology	USA	2	14.3%
4	Netherlands	1	7.1%					

In terms of the citing papers, the majority of papers are from the USA (567 papers, or 47.3%), followed by the United Kingdom, China, Germany and Canada, with China ranking third with 133 papers. Among the Top 10 institutions producing citing papers, six institutions are based in the United States, with the other four from France and the United Kingdom. Harvard University (54 papers), the University of Southern California (48 papers) and French National Institute of Health and Medical Research (INSERM) (46 papers) constitute the top three.

USA contributes **567** citing papers 1

UK contributes **176** citing papers 2

China contributes **133** citing papers 3

Table 23 Top countries and institutions producing citing papers in the Research Front "Role of pericyte degeneration in Alzheimer disease"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	567	47.3%	1	Harvard University	USA	54	4.5%
2	UK	176	14.7%	2	University of Southern California	USA	48	4.0%
3	China	133	11.1%	3	French National Institute of Health and Medical Research	France	46	3.8%
4	Germany	108	9.0%	4	University College London	UK	38	3.2%
5	Canada	93	7.8%	5	Massachusetts General Hospital	USA	31	2.6%
6	Japan	71	5.9%	6	University of California San Francisco	USA	30	2.5%
7	France	61	5.1%	7	University of Pittsburgh	USA	28	2.3%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
8	Italy	55	4.6%	8	University of Oxford	UK	27	2.3%
9	Sweden	51	4.3%	8	University of California San Diego	USA	27	2.3%
10	Netherlands	47	3.9%	10	French National Centre for Scientific Research	France	26	2.2%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CLINICAL MEDICINE

The Top 11 emerging Research Fronts in clinical medicine mainly focus on tumor immunotherapy; molecular subtypes of tumor and tumor management; risk factors and treatments of cardiovascular diseases; and antiviral treatment of hepatitis C. Among these, immune checkpoint inhibitors for tumor immunotherapy, Ga-68-prostate-specific membrane antigen PET/CT on the management of prostate cancer, and direct acting antivirals treatment for hepatitis C are strongly associated with Research Fronts of previous years.

Table 24 **Emerging Research Fronts in clinical medicine**

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Clinical outcomes of percutaneous coronary intervention in patients with stable coronary artery disease	2	120	2018
2	Impact of Ga-68-prostate-specific membrane antigen (Ga-68-PSMA) PET/CT on the management of prostate cancer	7	114	2018
3	Real world study of cardiovascular events associated with SGLT-2 inhibitors in patients with type 2 diabetes mellitus	9	196	2017.9
4	Genotypes of diffuse large B cell lymphoma	5	113	2017.8
5	Oncolytic viruses promote tumor immunotherapy	5	107	2017.8
6	Cardiovascular risks for metabolically healthy obesity	4	100	2017.8
7	Combination treatment with immune checkpoint inhibitors in renal cell carcinoma in randomized phase 1/2	4	89	2017.8
8	Molecular mechanism for PD-L1 regulation and strategies to enhance cancer immunotherapies	6	137	2017.7
9	Non-statin LDL-lowering medications on cardiovascular outcomes	5	170	2017.6
10	Efficacy and safety of Glecaprevir/Pibrentasvir in patients with chronic HCV with or without cirrhosis	5	164	2017.6
11	Immune-modified response evaluation of cancer immunotherapy	5	147	2017.6

2.2 KEY EMERGING RESARCH FRONT – "Clinical outcomes of percutaneous coronary intervention in patients with stable coronary artery disease"

Percutaneous coronary intervention (PCI) can effectively alleviate symptoms of coronary artery disease and improve clinical outcomes. However, controversy remains over appropriate indications and prognostic benefits of PCI for stable coronary artery diseases, especially as other treatments have made considerable progress in recent years.

Two core papers underlie the emerging Research Front "Clinical outcomes of percutaneous coronary intervention in patients with stable coronary artery disease." Among these, the ORBITA study, a double-blind, randomized controlled trial published in *The Lancet* in February 2018, enrolled 200 patients with severe (>= 70%) single-vessel stenoses. The study aimed to find, for the first time, difference in exercise-time increment between PCI and a placebo procedure in patients with stable angina. After six weeks of follow-up, the study found that PCI did not increase exercise time by more than the effect of a placebo procedure, which was 28.4s and 11.8s respectively. PCI should not be recommended as a first-line therapy for stable coronary artery disease. Although the study has aroused doubts in academia, especially about its sample size, primary endpoint and patient type, this result has undoubtedly had an impact on recommendations of PCI for stable coronary artery disease within relevant guidelines.

VI. BIOLOGICAL SCIENCES

1. HOT RESEARCH FRONT

1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN BIOLOGICAL SCIENCES

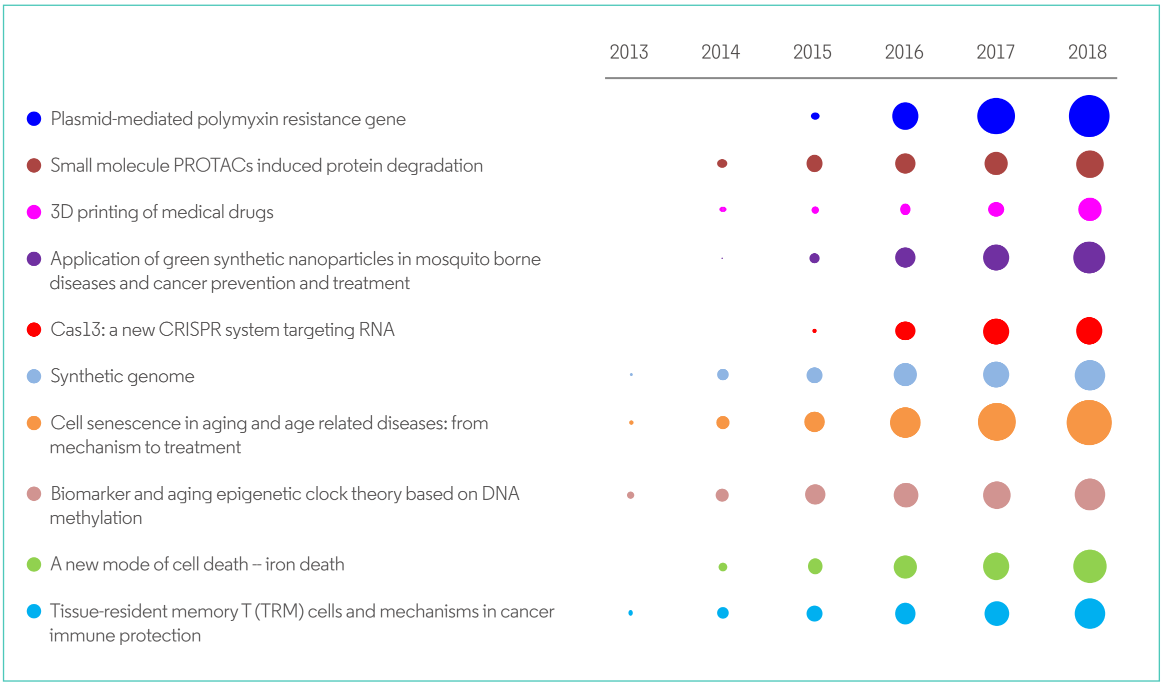
The Top10 Research Fronts in biological sciences include three fronts related to drug development, three devoted to aging, two examining synthetic biology, one exploring the resistance mechanism of bacterial resistance genes, and one on newly discovered T cell lineage with solid tumor immunity.

Specifically, the three specialty areas in drug development are: "Small molecule PROTACs induced protein degradation," "3D printing of medical drugs," and "Application of green synthetic nanoparticles in mosquito borne diseases and cancer prevention and treatment."The three aging-related Research Fronts are: "Cell senescence in aging and age-related diseases: from mechanism to treatment," "Biomarker and aging epigenetic clock theory based on DNA methylation," and "A new mode of cell death -- iron death."Demonstrating the continuity of the latter topic among the hottest fields in the biological sciences, two Research Fronts related to aging appeared in the previous report for 2018 – namely, "Cell senescence" and "Derivation of novel human ground state naive pluripotent stem cells."Rounding out the Top 10 for 2019: The two Research Fronts pertaining to synthetic biology are "Cas13: a novel CRISPR gene editing system targeting RNA" and "synthetic genome." Exploring the resistance mechanism of bacterial resistance genes is the front entitled "Plasmid-mediated polymyxin resistance gene." And a newly identified Research Front examining T cell lineage with solid tumor immunity is "Tissue-resident memory T (TRM) cells and mechanisms in cancer immune protection."

Table 25 Top10 Research Fronts in biological sciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Plasmid-mediated polymyxin resistance gene	50	3689	2016.8
2	Small molecule PROTACs induced protein degradation	27	2571	2016.4
3	3D printing of medical drugs	34	1521	2016.4
4	Application of green synthetic nanoparticles in mosquito borne diseases and cancer prevention and treatment	45	2949	2016.3
5	Cas13: a new CRISPR system targeting RNA	8	1394	2016.3
6	Synthetic genome	17	1736	2016
7	Cell senescence in aging and age-related diseases: from mechanism to treatment	34	5312	2015.9
8	Biomarker and aging epigenetic clock theory based on DNA methylation	20	3011	2015.9
9	A new mode of cell death -- iron death	19	2354	2015.9
10	Tissue-resident memory T (TRM) cells and mechanisms in cancer immune protection	25	2628	2015.8

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



1.2 KEY HOT RESEARCH FRONT – "Plasmid-mediated polymyxin resistance gene"

In recent years, the phenomenon of bacterial resistance has become increasingly serious, posing a major challenge to anti-infective treatment and a significant threat to human health. Polymyxin is the last line of defense against multidrug-resistant gram-negative bacterial infections.

In November 2015, Chinese and British scientists reported a polymyxin resistance gene, mcr-1, in animals and humans in China. This gene is located on the plasmid DNA of bacteria. When different bacteria come into contact, plasmids may spread to each other, leading to the rapid and wide spread of resistance genes. The paper, entitled "Emergence of plasmid-mediated colistin resistance mechanism mcr-1 in animals and human beings in China: a microbiological and molecular biological study," was published in *LANCET INFECTIOUS DISEASES* and is the most frequently cited core paper in this Research Front, with 1,120 citations.

The 50 core papers for this Research Front mainly cover the distribution and epidemiology of mcr-1 in Enterobacteriaceae bacteria from different sources; the mechanism of drug resistance and transmission; the genetic environment and other aspects of research progress; and discussion of its clinical risk and follow-up response measures. In recent years, plasmid-mediated polymyxin-resistant strains carrying mcr-1 gene have been isolated from humans in many countries after the report in China. At the same time, many mutants of mcr-1, such as mcr-2, mcr-3, mcr-4, mcr-5 and mcr-7, have been found.

Drug resistance genes can circulate in humans, animals, and the environment, increasing the risk of human intake of these genes. This risk is not only a medical problem, but also ecological. Its potential threat has attracted wide attentionfe. In the face of such a complex problem, the traditional focus within a single research field has proved inadequate to meet the threat, and the situation calls for multidisciplinary collaboration across the boundaries of research, public health, and policy.

In terms of the number of core papers, the USA, the UK and China are the top three contributors to this hot Research Front. As to the institutions, Delhi University of India, French National Centre for Scientific Research (CNRS) , and the British Ministry of Public Health constitute the top three, respectively. China Agricultural University and Zhejiang University have also made important contributions to this hot Research Front.

Table 26 Top countries and institutions producing core papers in the Research Front "Plasmid-mediated polymyxin resistance gene"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	15	30.0%	1	University of Delhi	India	6	12.0%
2	UK	12	24.0%	2	French National Centre for Scientific Research	France	5	10.0%
3	China	9	18.0%	2	Public Health England	UK	5	10.0%
4	France	8	16.0%	4	US Department Health and Human Services	USA	4	8.0%
5	Netherlands	7	14.0%	4	French National Institute of Health and Medical Research	France	4	8.0%
6	India	6	12.0%	6	China Agricultural University	China	3	6.0%
7	Germany	5	10.0%	6	Zhejiang University	China	3	6.0%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
8	Belgium	4	8.0%	6	Rutgers State University of New Brunswick	USA	3	6.0%
9	Denmark	3	6.0%	6	Heath Park Hospital	UK	3	6.0%
9	Italy	3	6.0%	6	Canisius Wilhelmina Hospital	Netherlands	3	6.0%
9	Spain	3	6.0%	6	Centers for Disease Control & Prevention	USA	3	6.0%

In terms of countries that cite the core papers of this hot Research Front (Table 27), the USA is the main contributing country with 435 citing papers, accounting for 25.6% of the total. China ranks 2nd with 319 citing papers, while the UK ranks 3rd with 206. The top institutions (11 in all) producing citing papers include three institutions based in China, three in France, two in the USA, two in Switzerland, and one in the UK. Zhejiang University, French National Institute of Health and Medical Research (INSERM) and the US Department of Health and Human Services make up the top three.

USA contributes **435** citing papers 1

China contributes **319** citing papers 2

UK contributes **206** citing papers 3

Table 27 Top countries and institutions producing citing papers in the Research Front "Plasmid-mediated polymyxin resistance gene"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	435	25.6%	1	Zhejiang University	China	73	4.3%
2	China	319	18.8%	2	French National Institute of Health and Medical Research	France	60	3.5%
3	UK	206	12.1%	3	US Department Health and Human Services	USA	57	3.4%
4	France	152	9.0%	4	China Agricultural University	China	47	2.8%
5	Switzerland	106	6.3%	5	South China Agricultural University	China	46	2.7%
6	Australia	100	5.9%	5	University of Fribourg	Switzerland	46	2.7%
7	Germany	100	5.9%	7	University of Lausanne	Switzerland	39	2.3%
8	Italy	87	5.1%	7	Centers for Disease Control & Prevention	USA	39	2.3%
9	Spain	78	4.6%	9	French National Centre for Scientific Research	France	35	2.1%
10	Netherlands	76	4.5%	9	University of Bretagne Loire	France	35	2.1%
				9	Public Health England	UK	35	2.1%

1.3 KEY HOT RESARCH FRONT – "Cas13: a new CRISPR system targeting RNA"

At present, the CRISPR/Cas system is the most widely used gene-editing tool. According to the structure and function of Cas, the protein can be divided into six types (Type I-VI), and further divided into several subtypes. Cas9, one of the most familiar proteins, is widely used in genome editing and other work. New CRISPR proteins have been found and applied continuously.

Unlike other members in the CRISPR protein family, Cas13 can target RNA for gene editing. Research has established that Cas13a (also known as C2c2), Cas13b, Cas13c, and Cas13d all have this function. These proteins have been developed as RNA-binding detectors.

This Research Front records the discovery of Cas13, a new targeting RNA CRISPR system. In an article published in the journal *Science* in June of 2016, Zhang Feng and colleagues revealed that C2c2 was the first new CRISPR system targeting only RNA rather than DNA. This finding was included in the 20 most significant scientific advances published in *Science* in 2016. Subsequently, in September 2016, Jennifer Doudna's team expanded the role of C2c2 and found that C2c2 has two different RNA cleavage activities. In 2017, a team led by Wang Yanli of the Institute of Biophysics, Chinese Academy of Sciences, analyzed the structure and mechanism of Cas13a protein and its complexes. In that same year, Zhang Feng's team discovered two new RNA targeting CRISPR systems, Cas13b and Cas13c.

In April 2017, respective teams led by Zhang Feng and Jim Collins developed a highly sensitive detector, "SHERLOCK," based on RNA-targeting CRISPR-Cas13a/C2c2, which can detect the nucleic acid of specific pathogens. At present, this system has been successfully used to detect different strains of the Zika and dengue viruses. DNA editing alone is not enough to treat human diseases with CRISPR technology. Because many diseases are rooted in RNA, the development of CRISPR technology for targeting RNA has expanded the range of applications and prospects for CRISPR technology.

Eight core papers anchor this hot Research Front. The USA is the main contributor to the core papers, with seven, of which all the corresponding authors are based in the USA. The corresponding author of the other paper is from China. Notable atop the institutional distribution of core papers, the National Institutes of Health (NIH) participated in six foundational reports, followed by Harvard University and MIT.

USA contributes **7** core papers — 1

China contributes **1** core papers — 3

Table 28 Top countries and institutions producing core papers in the Research Front "Cas13: a new CRISPR system targeting RNA"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	7	87.5%	1	National Institutes of Health	USA	6	75.0%
2	Russia	4	50.0%	2	Harvard University	USA	5	62.5%
3	Spain	1	12.5%	2	Massachusetts Institute of Technology	USA	5	62.5%
3	UK	1	12.5%	4	Russian Academy of Sciences	Russia	3	37.5%
3	Canada	1	12.5%	4	Rutgers State University of New Brunswick	USA	3	37.5%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
3	China	1	12.5%	6	Howard Hughes Medical Institute	USA	2	25.0%
3	Denmark	1	12.5%	7	University of California Berkeley	USA	1	12.5%
3	France	1	12.5%	7	Chinese Academy of Sciences	China	1	12.5%
3	Germany	1	12.5%					
3	Netherlands	1	12.5%					

Among the 10 countries that cite this Research Front's core papers, the USA is most active, contributing to 367 citing papers. China contributes to 130, indicating that China has carried out more follow-up research in this hot Research Front. In terms of institutions, the USA holds seven places in the Top10. Among them, Harvard University, the National Institutes of Health and the Massachusetts Institute of Technology respectively rank 1st, 2nd and 4th. The Chinese Academy of Sciences places 3rd with 40 citing papers.

USA contributes **367** citing papers 1

China contributes **130** citing papers 2

Table 29 **Top countries and institutions producing citing papers in the Research Front "Cas13: a new CRISPR system targeting RNA"**

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	367	46.7%	1	Harvard University	USA	52	6.6%
2	China	130	16.5%	2	National Institutes of Health	USA	44	5.6%
3	Germany	68	8.7%	3	Chinese Academy of Sciences	China	40	5.1%
4	UK	53	6.7%	4	Massachusetts Institute of Technology	USA	38	4.8%
5	France	45	5.7%	5	Howard Hughes Medical Institute	USA	36	4.6%
6	Canada	35	4.5%	6	University of California Berkeley	USA	33	4.2%
7	Russia	30	3.8%	7	University of North Carolina	USA	29	3.7%
8	Japan	29	3.7%	8	North Carolina State University	USA	26	3.3%
9	Netherlands	27	3.4%	9	French National Centre for Scientific Research	France	22	2.8%
10	Denmark	25	3.2%	9	Russian Academy of Sciences	Russia	22	2.8%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN BIOLOGICAL SCIENCES

Six emerging Research Fronts have been selected in the biological sciences, including three related to cancer, two covering basic biology, and one on tuberculosis detection.

The cancer-related fronts are "Circular RNA as a novel biomarker for cancer," "Tumor near-physiological organoid culture system for disease modeling and drug screening," and "New Role of FOXO Protein Transcription Factor in Cancer."

Circular RNA-related research has been selected among the top Research Fronts for several years. For example, in 2018, the Research Front designated "Using circular RNA as a new biomarker in the diagnosis of cancer" marked the continuation of "Origin, identification and function of circular RNAs," a front identified in 2017.

Two basic biological Research Fronts, "Translation mechanism of Giant viruses" and "Cell lineage tracking at single cell level," discuss the protein translation mechanism and cell development of viruses, respectively. *Science* ranked the single-cell horizontal cell lineage tracking technology as the first of "Ten Breakthroughs in Science" in 2018. The Research Front on tuberculosis detection is " A new generation of Ultrasensitive Xpert MTB RIF Ultra detection method for rapid detection of tuberculosis".

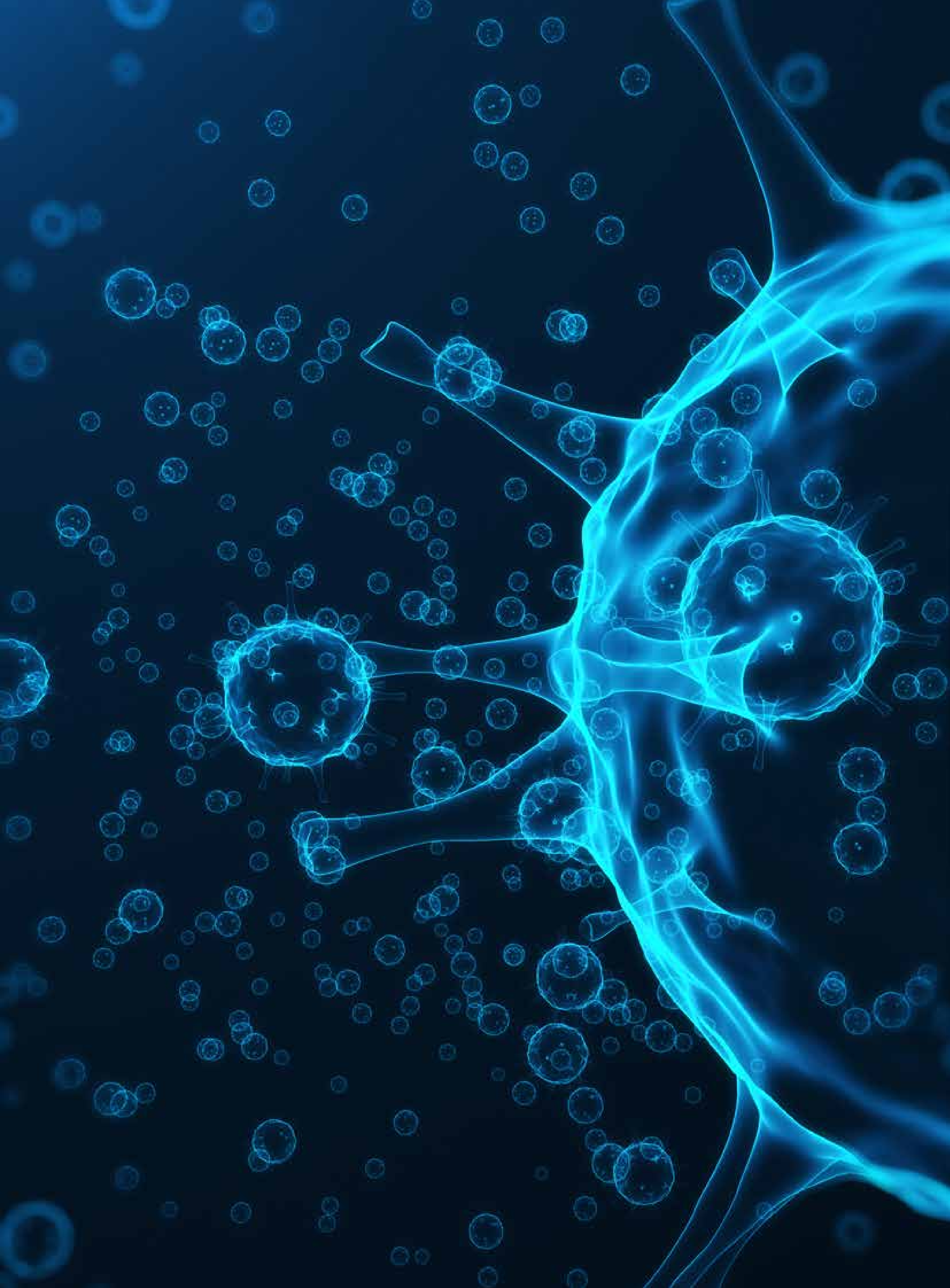
Table 30 Emerging Research Fronts in biological sciences

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Circular RNA as a novel biomarker for cancer	11	185	2018
2	Tumor near-physiological organoid culture system for disease modeling and drug screening	5	137	2017.8
3	The roles of FOXO in neoplasms	6	78	2017.8
4	A new generation of Ultrasensitive Xpert MTB RIF Ultra detection method for rapid detection of tuberculosis	3	86	2017.7
5	Translation mechanism of Giant viruses	3	62	2017.7
6	Building a lineage from single cells: genetic techniques for cell lineage tracking	14	484	2017.6

2.2 KEY EMERGING RESEARCH FRONT – "Circular RNA as a novel biomarker for cancer"

Circular RNAs (circRNAs) are a special kind of endogenous non-coding RNA. They form a closed circular structure, which is more stable than the traditional linear RNA. As early as the 1970s, circRNAs were found in some higher plants. However, due to limited technical means at that time, progress on circRNAs research was very slow. In recent years, with the development of molecular purification and high-throughput sequencing technology, a deeper understanding of circRNAs has emerged. The role of circRNAs in the process of occurrence and development in various chronic diseases, particularly in malignant tumors, has also attracted much attention. Research has demonstrated that circRNAs can regulate the expression of proto-oncogene or anti-oncogene, which may become a diagnostic marker of malignant tumors. However, little is known about its mechanism and mode of action in tumors.

This Emerging Research Front analyzes the expression of different circRNAs in various cancers and their relationship with clinicopathological features. These studies investigate the expression characteristics and possible regulatory mechanisms of circRNAs in osteosarcoma, glioma, lung cancer, cholangiocarcinoma, hepatocellular carcinoma, cervical cancer, oral squamous cell carcinoma, and pancreatic ductal adenocarcinoma.



VII. CHEMISTRY AND MATERIALS SCIENCE

1. HOT RESEARCH FRONT

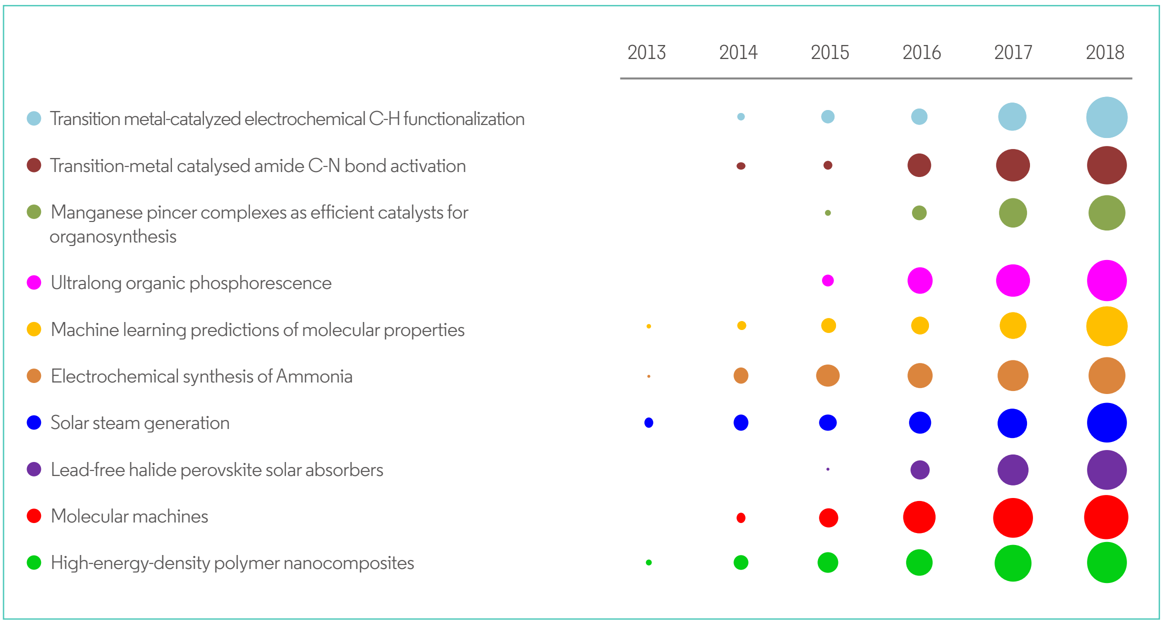
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

The hot Research Fronts in chemistry and materials science cover the topics of organic synthesis, electrochemical synthesis, advanced materials, and application of machine learning in chemistry and materials science. Compared with previous years, both consistency and development are evident in the 2019 Top 10 hot Research Fronts, since half of the fronts are being featured for the first time. The topic of organic synthesis accounts for four distinct avenues of investigation. C-H activation has always been a hot subject, while the combination with organic chemistry and electrochemistry is highlighted this year. Both C-N activation and pincer organic catalysts have been identified among the Top 10 hot Research Fronts for the second time, and "Molecular machines" becomes a new point of focus. In the area of electrochemical synthesis, "Electrochemical synthesis of Ammonia" debuts as a hot Research Front for 2019. In the area of advanced materials, "Lead-free halide perovskite solar absorbers" and "High-energy-density polymer nanocomposites" have been hot specialty areas for two consecutive years, while both "Ultralong organic phosphorescence" and "Solar steam generation" earn distinction as new arrivals to the Top 10. With the rapid development of big data technology and artificial intelligence, "Machine learning predictions of molecular properties" becomes a key hot research front this year.

Table 31 Top 10 Research Fronts in chemistry and materials science

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Transition metal-catalyzed electrochemical C-H functionalization	49	2401	2017.2
2	Transition-metal catalysed amide C-N bond activation	42	2787	2016.7
3	Manganese pincer complexes as efficient catalysts for organosynthesis	36	2221	2016.7
4	Ultralong organic phosphorescence	26	1838	2016.6
5	Machine learning predictions of molecular properties	33	1852	2016.5
6	Electrochemical synthesis of Ammonia	28	2181	2016.4
7	Solar steam generation	30	2934	2016.3
8	Lead-free halide perovskite solar absorbers	24	2562	2016.2
9	Molecular machines	19	2366	2016.1
10	High-energy-density polymer nanocomposites	20	2473	2016

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



1.2 KEY HOT RESEARCH FRONT – "Solar steam generation"

In 2013, Naomi J. Halas, Peter Nordlander, and co-workers at Rice University found that silica-gold coreshell nanoparticles, immersed in water, act as efficient nanoscale generators of steam when illuminated with sunlight. In this steam-formation process, individual nanoparticles act as efficient absorbers of light, heating up and transfering energy to the surrounding water. Some 80% of the absorbed sunlight is converted into water vapor without heating the entire water volume to the boiling point. Steam generated in such an efficient and relatively simple way opens up a wide range of novel compact solar energy applications such as distillation, desalination, and sterilization and sanitation applications in resource-poor locations. Jia Zhu from Nanjing University has made outstanding contributions in this area. He and co-workers have designed and realized a plasmon-enhanced solar desalination device, a 2D water path structure and a 3D artificial transpiration device – as well as making the devices portable, efficient, and low-cost. In 2017, an agreement was signed between Nanjing University and Sheyang Economic Development Area in Jiangsu Province on the technology transfer of solar desalination developed by Jia Zhu, and a desalination line with capacity of 500 t/day was slated for construction.

The quantitative analysis (Table 32) conforms to the description above. Both China and the USA have published several high-impact papers, and some countries pressed by a lack of fresh water, such as Saudi Arabia, have also shown interest in the technology. Researchers from Nanjing University, the King Abdullah University of Science and Technology, Massachusetts Institute of Technology, and Rice University have made significant progress in the field. The U.S. Air Force Research Laboratory has also registered among the major players in this specialty area.

Table 32 Top countries and institutions producing core papers in the Research Front "Solar Steam Generation"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	20	66.7%	1	Nanjing University	China	8	26.7%
2	USA	14	46.7%	2	King Abdullah University of Science and Technology	Saudi Arabia	4	13.3%
3	Saudi Arabia	4	13.3%	3	University of Maryland College Park	USA	3	10.0%
4	Singapore	1	3.3%	3	Massachusetts Institute of Technology	USA	3	10.0%
4	Republic of Korea	1	3.3%	3	Huazhong University of Science and Technology	China	3	10.0%
4	Japan	1	3.3%	6	Rice University	USA	2	6.7%
4	Turkey	1	3.3%	6	Washington University in St. louis	USA	2	6.7%
4	The Netherlands	1	3.3%	6	University of Colorado Boulder	USA	2	6.7%
4	Spain	1	3.3%	6	Air Force Research Laboratory	USA	2	6.7%
4	United Arab Emirates	1	3.3%	6	Peking University	China	2	6.7%
				6	Beijing Institute of Technology	China	2	6.7%
				6	Hubei University	China	2	6.7%

According to a count of the citing papers (Table 33), China, the USA, Japan, Saudi Arabia and Singapore have been actively engaged in the field. In the list of citing institutions, more than a half are based in China, with the Chinese Academy of Sciences ranking 1st in quantity of citing papers.

Table 33 Top countries and institutions producing citing papers in the Research Front "Solar Steam Generation"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	452	48.1%	1	Chinese Academy of Sciences	China	84	8.9%
2	USA	300	31.9%	2	Shanghai Jiao Tong University	China	37	3.9%
3	Japan	47	5.0%	3	Harbin Institute of Technology	China	36	3.8%
4	Germany	39	4.2%	4	Nanjing University	China	31	3.3%
5	UK	36	3.8%	5	Tsinghua University	China	30	3.2%
6	Australia	35	3.7%	6	King Abdullah University of Science and Technology	Saudi Arabia	28	3.0%
7	Saudi Arabia	34	3.6%	7	Massachusetts Institute of Technology	USA	23	2.4%
8	Republic of Korea	34	3.6%	8	Peking University	China	22	2.3%
9	Singapore	31	3.3%	8	Purdue University	USA	22	2.3%
10	Canada	29	3.1%	8	Rice University	USA	22	2.3%

1.3 KEY HOT RESARCH FRONT – "Molecular machines"

The Nobel Prize in Chemistry 2016 was awarded jointly to Jean-Pierre Sauvage, Sir J. Fraser Stoddart and Bernard L. Feringa for the design and synthesis of molecular machines. This Research Front is composed of papers reflecting the contributions made by the 2016 Nobel laureates and the latest developments in the field.

In 1983, Sauvage and co-workers reported a new strategy for making interlocking rings, taking an important step toward molecular machines. Stoddart and colleagues synthesized a degenerate donor–acceptor [2]rotaxane in which it became possible to control the movement of one molecular component with respect to the other, and the term "molecular shuttle" was coined in 1991. Feringa and co-workers synthesized the first light-driven unidirectional rotary motor in 1999, subsequently using an alkene-based rotary molecular motor to rotate a 5-28 mm glass rod in 2006, and realizing a four-wheel drive molecular car based on rotary motors in 2011. In 2017, Feringa and colleagues described the macroscopic contractile muscle-like motion of a supramolecular system formed by the hierarchical self-assembly of a photoresponsive amphiphilic molecular motor.

Many other researchers have also made notable contributions in the field. For example, David A. Leigh and co-workers reported on the use of rotaxanes in the sequence-specific synthesis of peptides, which was a striking example in the field of processive rotaxane catalysts.

The roster of top producers of core papers in the front (Table 34) mirrors the discussion above. The UK, the Netherlands, the USA, and France have published several highly cited foundational papers. The University of Manchester, the University of Groningen, Northwestern University, and the University of Strasbourg are leading institutions in the field.

Table 34 Top countries and institutions producing core papers in the Research Front "Molecular machines"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	UK	9	47.4%	1	University of Manchester	UK	9	47.4%
2	Netherlands	4	21.1%	2	University of Groningen	Netherlands	3	15.8%
3	USA	3	15.8%	3	Northwestern University	USA	2	10.5%
4	France	2	10.5%	3	University of Strasbourg	France	2	10.5%
5	Italy	1	5.3%	5	University of Bologna	Italy	1	5.3%
5	China	1	5.3%	5	Radboud University Nijmegen	Netherlands	1	5.3%
				5	Zhejiang University	China	1	5.3%
				5	University of California, Los Angeles	USA	1	5.3%

According to a count of the citing papers (Table 35), all the member states of G7 are engaged in making molecular machines. China has also been actively involved in the field, publishing the most citing papers. Among the citing institutions, in addition to the leading institutions listed in Table 34, the Chinese Academy of Sciences and French National Center for Scientific Research (CNRS) have been active in making molecular machines.

Table 35 Top countries and institutions producing citing papers in the Research Front "Molecular machines"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	363	27.3%	1	Chinese Academy of Sciences	China	73	5.5%
2	USA	264	19.8%	2	French National Centre for Scientific Research	France	64	4.8%
3	Germany	163	12.2%	3	Northwestern University	USA	47	3.5%
4	UK	142	10.7%	4	University of Groningen	Netherlands	40	3.0%
5	Japan	136	10.2%	5	University of Manchester	UK	34	2.6%
6	France	95	7.1%	6	East China University of Science and Technology	China	30	2.3%
7	Italy	85	6.4%	7	East China Normal University	China	26	2.0%
8	Netherlands	71	5.3%	8	University of Strasbourg	France	25	1.9%
9	Spain	51	3.8%	8	University of Bologna	Italy	25	1.9%
10	Canada	41	3.1%	8	Tokyo Institute of Technology	Japan	25	1.9%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

This year, five research topics are selected as emerging Research Fronts in chemistry and materials science. Within chemistry, the fronts pertain to photo catalysts, Zn/air batteries, semiconducting polymers. Meanwhile, the specialty areas in materials cover the difunctionalization of unactivated alkenes and the synthesis of oxides, related to organic chemistry. For many years, photocatalysts and polymers have been the hot research fields in chemistry and materials science. Between 2013 and 2018, the emerging and hot Research Fronts on the topic of photocatalysts mainly encompassed hydrogen synthesis (2013), photocatalysts with graphen (2014), asymmetric catalytic reactions (2016) and BiOX (X = Cl, Br and I) photocatalysts (2018). For 2019, Research Fronts on photocatalysts are similar to those identified in 2018, in terms of metal Bi 0 – however, the photocatalysts in the current report is $BiV(W)O_4$.

5

Five research topics are selected as emerging Research Fronts in chemistry and materials science

In that six-year period spanning 2013 to 2018, the emerging and hot Research Fronts on the topic of polymers mainly covered two fields: polymers synthesis (2016, 2018) and polymer solar cells (2013-2017). In 2019, the research focus on polymers transfers to the applications of semiconducting polymers in cancer therapy via photoacoustic imaging and photothermal technology. Zn/air batteries, especially with hybrid atoms (N, Co) – doped carbon nanomaterials as electrocatalysts and electrodes is a completely new emerging Research Front. The difunctionalization of unactivated alkenes via distal functional group migration strategy and molecular oxygen as the oxygen source used in the synthesis of oxides are both completely new research fields making their inaugural appearance among the emerging Research Fronts this year.

Table 36 Emerging Research Fronts in chemistry and materials science

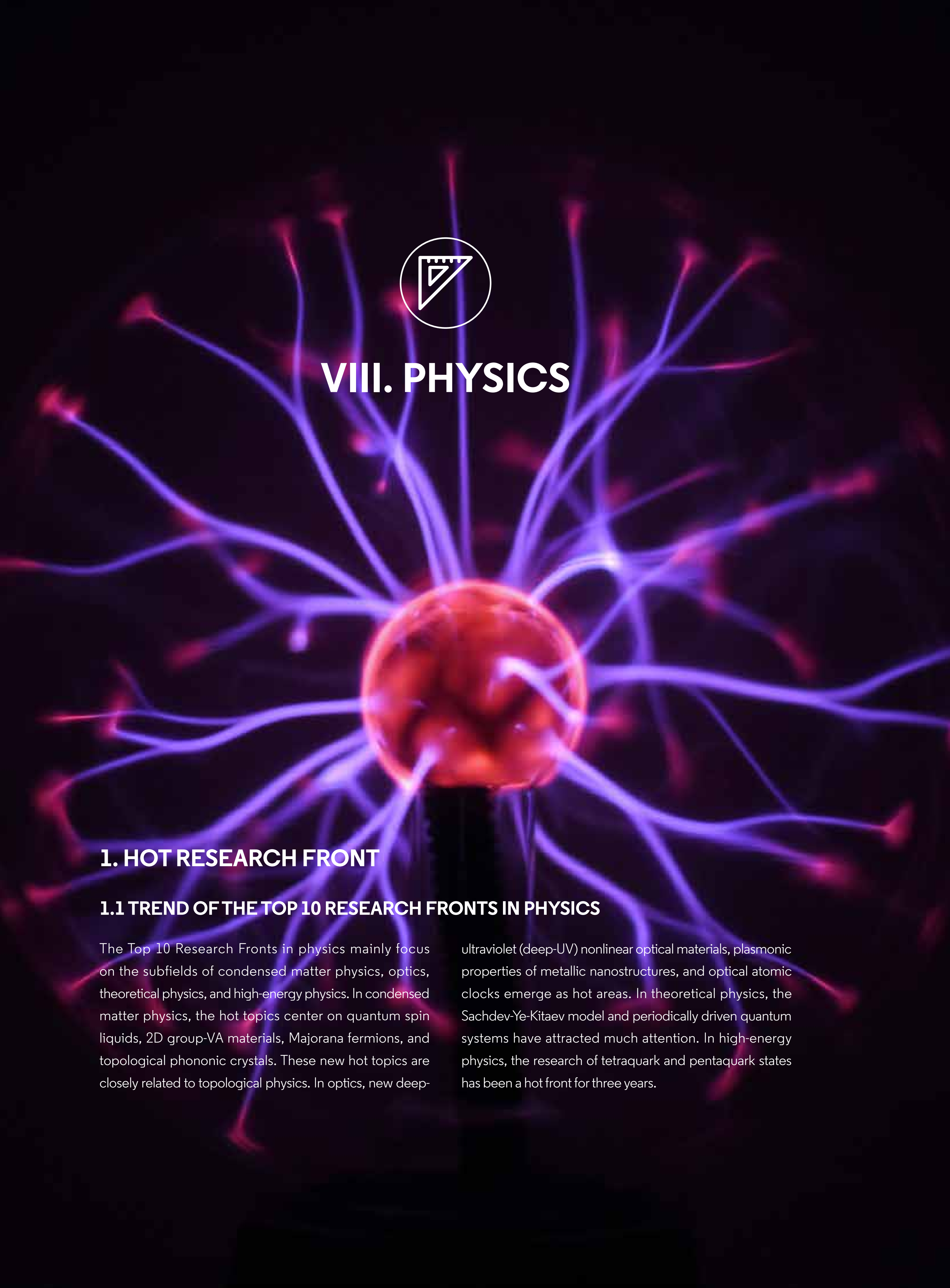
Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Semiconducting polymer for photothermal therapy of cancer	10	274	2017.8
2	Difunctionalization of unactivated alkenes via distal functional group migration strategy	9	256	2017.8
3	$BiV(W)O_4$ photocatalysts	9	229	2017.8
4	Zn/air batteries with hybrid atoms (N, Co) —doped carbon nanomaterials	11	298	2017.7
5	Molecular oxygen as the oxygen source used in the synthesis of oxides	3	133	2017.7

2.2 KEY EMERGING RESEARCH FRONT – "Difunctionalization of unactivated alkenes via distal functional group migration strategy"

Alkenes are widely present in natural products and chemical products, and are extensively used as raw materials in synthetic chemistry. The difunctionalization of alkenes can facilitate the introduction of functional groups into complex molecules, providing more opportunities for alkenes and underlying many industrial applications. However, the difunctionalization of alkenes generally involves activated alkenes having an aryl group, a carbonyl group, or a hetero atom in the ortho position of the double bond. The difunctionalization of unactivated alkenes is still challenging today. The distal functional group migration strategy can reconstruct molecular structures and efficiently synthesize valuable compounds, providing a new scheme for organic synthesis, especially for bifunctionalization of unactivated alkenes. Therefore, the difunctionalization of unactivated alkenes via distal functional group migration strategy has become an emerging research frontier in recent years.

Chinese scientists have displayed outstanding performance in this field. In particular, the team of Professor Chen Zhu at Soochou University has proposed many new and successful strategies in this field, opening up new opportunities for difunctionalization of unactivated alkenes via distal functional group migration strategy. For example, the research group developed intramolecular distal cyano migration combined with alkene difunctionalization for the first time, which realized the selective azidocyanation of unactivated olefins at room temperature. Zhu and colleagues also developed the first distal heteroaryl ipso-migration and synthesized the fluoroalkyl functionalized heteroarenes under mild reaction conditions. In addition, the team proposed the first intramolecularly distal alkynyl migration – which is induced by the addition of a trifluoromethyl radical – and realized radical-mediated trifluoromethyl alkynylation of unactivated olefins. In 2018 this group proposed a new olefin bifunctionalization strategy, the "Docking-Migration" strategy, to synthesize a compound with bifunctional group by introducing a heteroaryl group and a difluoromethyl group on one reaction substrate simultaneously; this advance opens an innovative approach to the difunctionalization of olefins, enriching and further upgrading the reaction mode of the difunctionalization of olefins.


100
75
50



VIII. PHYSICS

1. HOT RESEARCH FRONT

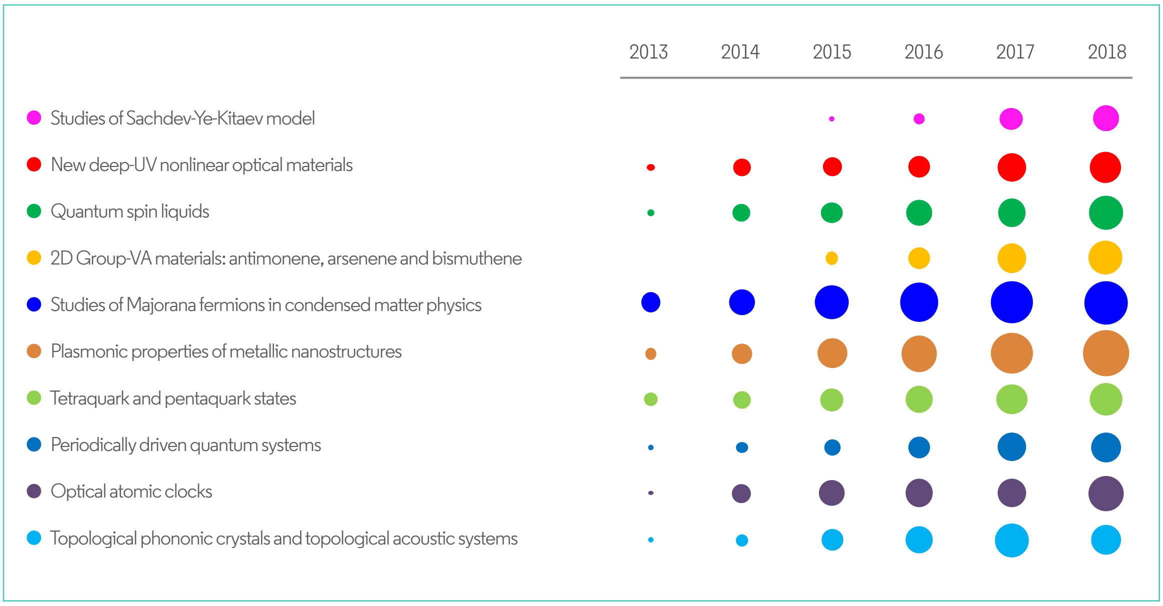
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN PHYSICS

The Top 10 Research Fronts in physics mainly focus on the subfields of condensed matter physics, optics, theoretical physics, and high-energy physics. In condensed matter physics, the hot topics center on quantum spin liquids, 2D group-VA materials, Majorana fermions, and topological phononic crystals. These new hot topics are closely related to topological physics. In optics, new deep-ultraviolet (deep-UV) nonlinear optical materials, plasmonic properties of metallic nanostructures, and optical atomic clocks emerge as hot areas. In theoretical physics, the Sachdev-Ye-Kitaev model and periodically driven quantum systems have attracted much attention. In high-energy physics, the research of tetraquark and pentaquark states has been a hot front for three years.

Table 37 Top10 Research Fronts in physics

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Studies of Sachdev-Ye-Kitaev model	24	1813	2016.5
2	New deep-UV nonlinear optical materials	31	2418	2016.4
3	Quantum spin liquids	40	3383	2016
4	2D group-VA materials: antimonene, arsenene and bismuthene	15	1789	2015.9
5	Studies of Majorana fermions in condensed matter physics	50	6751	2015.7
6	Plasmonic properties of metallic nanostructures	36	3725	2015.7
7	Tetraquark and pentaquark states	40	3635	2015.7
8	Periodically driven quantum systems	23	2597	2015.7
9	Optical atomic clocks	18	2385	2015.7
10	Topological phononic crystals and topological acoustic systems	20	2179	2015.7

Figure 7 Citing papers for the top 10 Research Fronts in physics



1.2 KEY HOT RESEARCH FRONT – "New deep-UV nonlinear optical materials"

Nonlinear optical (NLO) materials can expand the limited and fixed frequency ranges of lasers. A deep-UV laser, with a wavelength below 200 nm, has a wide range of applications such as ultra-high-resolution lithography, biomedical uses, and utility in advanced research equipment. As science and technology have progressed, the needs for deep-UV laser sources is increasing, and this is where deep-UV NLO materials play a critical role. In the early 1990s, a crystal named potassium beryllium fluoroborate (KBBF) was determined by the Chinese Academy of Sciences to have strong NLO effects. Subsequently, KBBF crystals were found to generate UV radiation below 200 nm. A series of instruments based on KBBF, such as the deep-UV laser Raman spectrometer and the deep-UV laser photochemical reactor, have been successfully developed and widely used in groundbreaking scientific research. However, the industrial application of KBBF is largely restricted because of two major disadvantages: KBBF's plate-like growth habit, which limits the quantity of the necessary thin crystals; and the toxicity associated with beryllium. Therefore, the exploration and development of the next-generation deep-UV NLO materials has become a hot topic in laser technology development. The core papers in this Research Front involve discovering new materials based on the structural features of KBBF and exploring new systems of deep-UV NLO materials.

China and the USA are the most active countries in this front (Table 38), respectively participating in 25 core papers (or 80.6% of the total) and 10 core papers (32.3%). In the institutional listing, six of the top entities are based in China, in while the USA has four, South Korea two, and Germany and Australia each claim one. The Chinese Academy of Sciences and Northwestern University contribute to the highest numbers of core papers.

1 China contributes **25** core papers

2 USA contributes **10** core papers

3 South Korea contributes **2** core papers

Table 38 Top countries and institutions producing core papers in the Research Front "New deep-UV nonlinear optical materials"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	25	80.6%	1	Chinese Academy of Sciences	China	23	74.2%
2	USA	10	32.3%	2	Northwestern University	USA	10	32.3%
3	South Korea	2	6.5%	3	University of Houston	USA	3	9.7%
4	Germany	1	3.2%	4	Drexel University	USA	2	6.5%
4	Australia	1	3.2%	5	Henan Polytechnic University	China	2	6.5%
				6	Tongji University	China	1	3.2%
				6	Australian National University	Australia	1	3.2%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
				6	China University of Geosciences - Beijing	China	1	3.2%
				6	University of Science & Technology - Beijing	China	1	3.2%
				10	Yangzhou University	China	1	3.2%
					University of Augsburg	Germany	1	3.2%
					Chung Ang University	South Korea	1	3.2%
					Korea Advanced Institute of Science & Technology	South Korea	1	3.2%
					Johns Hopkins University	USA	1	3.2%

Analysis of the citing papers (Table 39) indicates that China contributes 670 reports, accounting for 78.2% of the total. The USA, India and South Korea rank second to fourth. Among the top institutions, six are in China. The Chinese Academy of Sciences published the most citing papers, accounting for 55.1% of the total.

China contributes
670 citing papers
1

Table 39 **Top countries/regions and institutions producing citing papers in the Research Front "New deep-UV nonlinear optical materials"**

Country Ranking	Country/ Region	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	670	78.2%	1	Chinese Academy of Sciences	China	472	55.1%
2	USA	100	11.7%	2	Northwestern University	USA	53	6.2%
3	India	25	2.9%	3	Xinjiang University	China	29	3.4%
4	South Korea	25	2.9%	4	University of Houston	USA	28	3.3%
5	Russia	23	2.7%	5	Beijing Institute of Technology	China	26	3.0%
6	Taiwan, China	22	2.6%	6	China University of Geosciences- Beijing	China	26	3.0%
7	Germany	19	2.2%	7	Fuzhou University	China	22	2.6%
8	Saudi Arabia	19	2.2%	8	Chung Ang University	South Korea	20	2.3%
9	Czech Republic	17	2.0%	9	Yangzhou University	China	19	2.2%
10	UK	14	1.6%	10	Russian Academy of Sciences	Russia	18	2.1%

1.3 KEY HOT RESARCH FRONT– "Studies of Majorana fermions in condensed matter physics"

In the Standard Model, elementary particles include fermions (quarks and leptons) and bosons (gauge bosons and Higgs bosons). Fermions can be divided into Dirac, Weyl, and Majorana varieties. Majorana fermion is a type whose antiparticle is itself, while Dirac fermions have mass and Weyl fermions have no mass. Studies of Majorana fermions have been an important research topic in particle physics since they were proposed by the Italian physicist Ettore Majorana in 1937. So far, they have not been detected in experiments. In recent years, important progress has been made in studies of Majorana fermions in condensed matter physics. In 2012, the Delft University of Technology in the Netherlands reported evidence for the existence of Majorana fermions in one-dimensional InSb nanowires, a finding that gave a tremendous boost to the research. In 2016, Shanghai Jiao Tong University reported evidence for the existence of Majorana fermions in a 2D system. Studies of Majorana fermions hold promise for the realization of topological quantum computing, and have become a hot topic in condensed matter physics.

The USA is the most active country in this Research Front (Table 40), participating in 29 core papers, or 58.0% of the total. Denmark, Germany, and the Netherlands also perform strongly. In terms of core-paper contribution, six of the top institutions are from the USA, while Netherlands has two. Denmark, Spain, Germany, France, and Switzerland each have one. The University of Copenhagen, Harvard University, Delft University of Technology, and the University of California, Santa Barbara are the top four institutions.

Table 40 Top countries and institutions producing core papers in the Research Front "Studies of Majorana fermions in condensed matter physics"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	29	58.0%	1	University of Copenhagen	Denmark	16	32.0%
2	Denmark	16	32.0%	2	Harvard University	USA	9	18.0%
3	Germany	11	22.0%	3	Delft University of Technology	Netherlands	8	16.0%
4	Netherlands	10	20.0%	4	University of California Santa Barbara	USA	7	14.0%
5	Spain	6	12.0%	5	Spanish National Research Council	Spain	5	10.0%
6	Switzerland	5	10.0%	5	University of Wurzburg	Germany	5	10.0%
6	China	5	10.0%	7	French National Centre for Scientific Research	France	4	8.0%
6	Japan	5	10.0%	7	Eindhoven University of Technology	Netherlands	4	8.0%
6	France	5	10.0%	7	University of Basel	Switzerland	4	8.0%
10	Canada	3	6.0%	7	Microsoft	USA	4	8.0%
10	Sweden	3	6.0%	7	Princeton University	USA	4	8.0%
				7	University of Maryland College Park	USA	4	8.0%
				7	West Virginia University	USA	4	8.0%

In analyzing the citing papers (Table 41), we find that 656 are from researchers based in the USA, accounting for 31.5% of the total. China, Germany and Japan ranked second to fourth. Among the top institutions, French National Centre for Scientific Research (CNRS) has the most citing papers with 134, or 6.4%. The Chinese Academy of Sciences, Copenhagen University and the University of Maryland College Park ranked second to fourth.

USA contributes **656** citing papers 1

China contributes **429** citing papers 2

Germany contributes **374** citing papers 3

Table 41 Top countries and institutions producing citing papers in the Research Front "Studies of Majorana fermions in condensed matter physics"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	656	31.5%	1	French National Centre for Scientific Research	France	134	6.4%
2	China	429	20.6%	2	Chinese Academy of Sciences	China	120	5.8%
3	Germany	374	18.0%	3	University of Copenhagen	Denmark	100	4.8%
4	Japan	163	7.8%	4	University of Maryland College Park	USA	96	4.6%
5	France	156	7.5%	5	University of Basel	Switzerland	82	3.9%
6	Switzerland	151	7.3%	6	Department of Energy	USA	82	3.9%
7	Netherlands	145	7.0%	7	Max Planck Society	Germany	80	3.8%
8	Russia	116	5.6%	8	Russian Academy of Sciences	Russia	74	3.6%
9	Spain	111	5.3%	9	Delft University of Technology	Netherlands	73	3.5%
10	Denmark	109	5.2%	10	National Research Council	Italy	68	3.3%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN PHYSICS

Two topics in physics are highlighted as emerging Research Fronts, focusing on studies of quantum many-body systems in theoretical physics, and the exploration of new physics models in high-energy physics – namely, studies of B-physics anomalies.

2

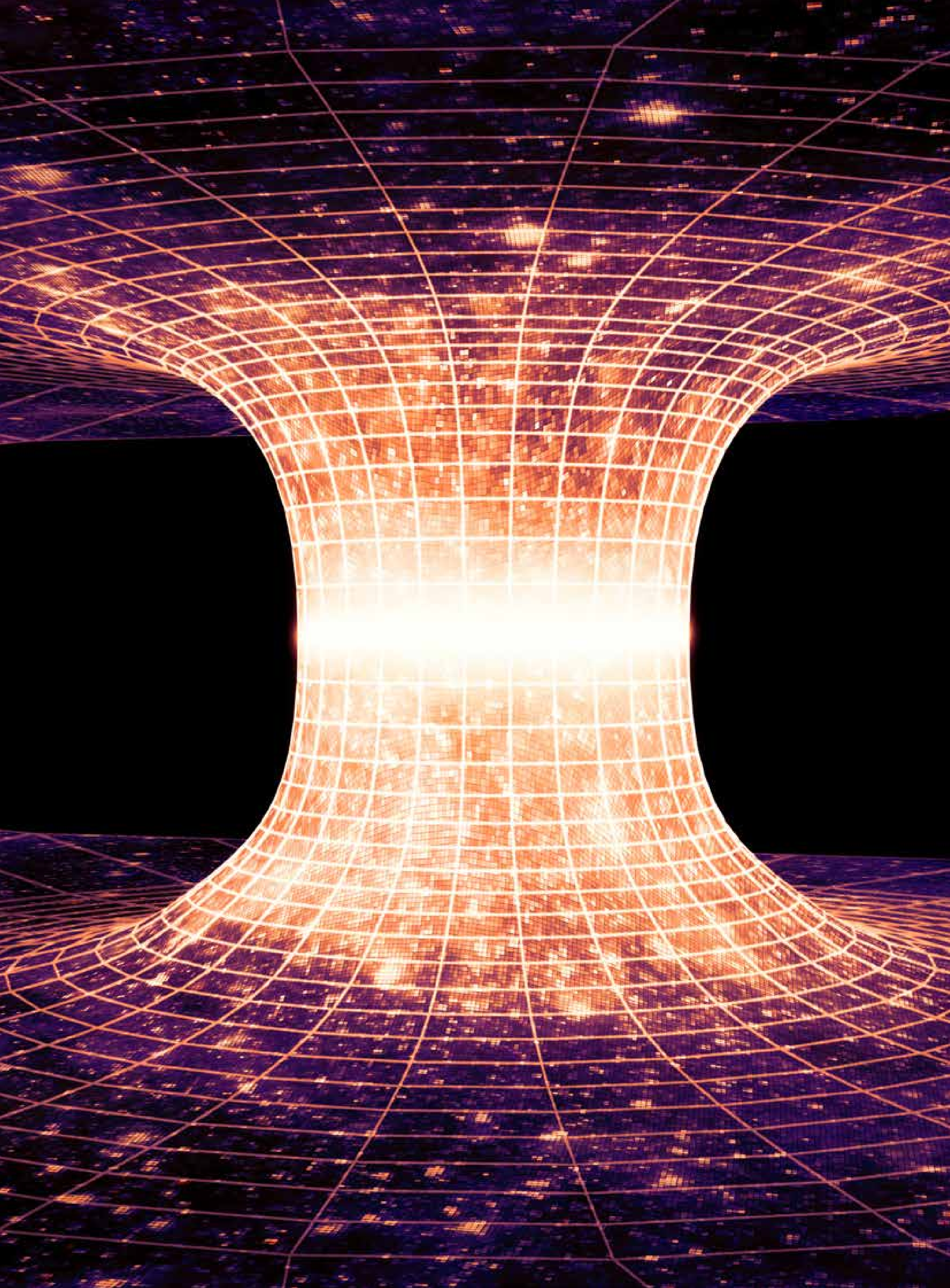
Two topics in physics are highlighted as emerging Research Fronts

Table 42 Emerging Research Fronts in physics

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Studies of quantum many-body systems based on out-of-time-ordered correlators	6	133	2017.8
2	Studies of B-physics anomalies	7	147	2017.7

2.2 KEY EMERGING RESEARCH FRONT – "Studies of B-physics anomalies"

Since the discovery of the Higgs boson, exploring new physics beyond the Standard Model has become one of the most important goals in physics. These explorations include searching for new heavy particles in the Large Hadron Collider (LHC), dark matter detection, neutrino experiments, and precision measurements of flavor physics. In recent years, flavor physics has played an important role in exploring new physics. B mesons are mesons composed of a bottom antiquark and either an up, down, strange, or charm quark. The weak decay of B mesons is a critical topic in flavor physics. Recently, the LCH experiment and the BABAR experiment at Stanford University have observed anomalies in B-meson decays, exhibiting signals of deviation from the Standard Model. Although solutions have been proposed to explain these anomalies, a convincing explanation is still lacking. Hence, many theoretical models have been put forward to explain the anomalies. The core papers in this emerging research front involve recent studies of these theoretical models, which have received much attention in the past two years.



IX. ASTRONOMY AND ASTROPHYSICS

1. HOT RESEARCH FRONT

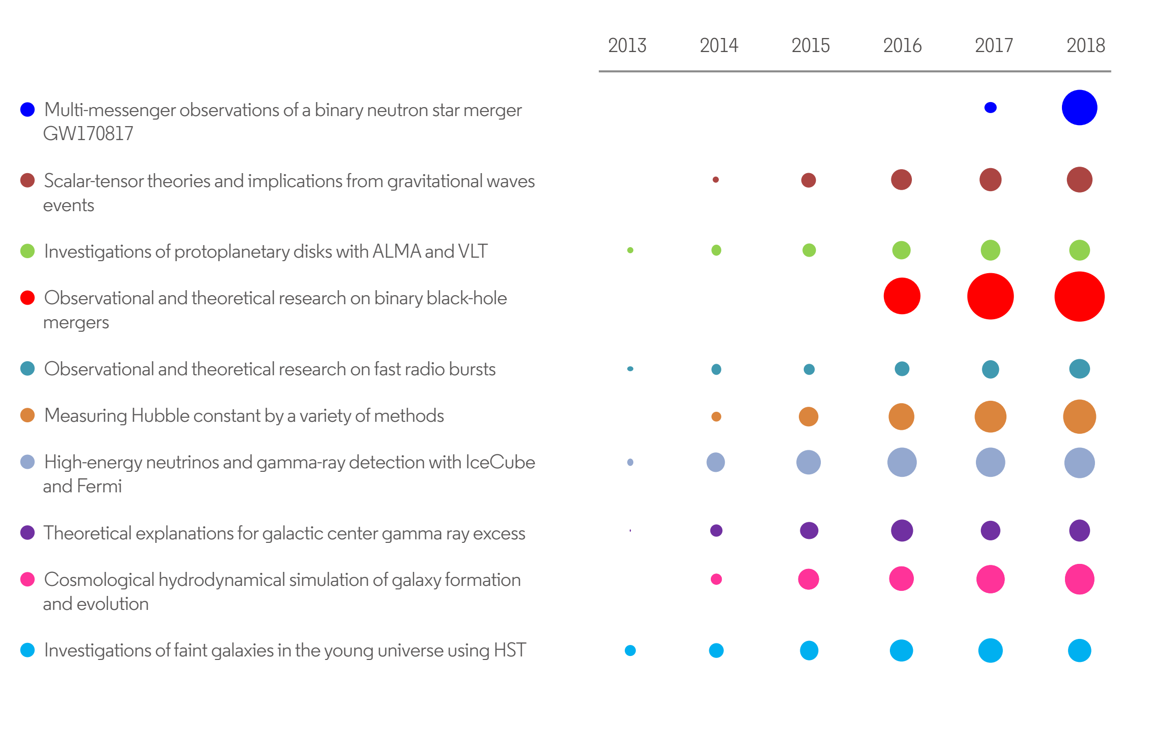
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

The Top 10 Research Fronts in this area focus on diverse topics, including gravitational waves, protoplanetary disks, fast radio bursts, the Hubble constant, high-energy neutrinos and gamma-rays, cosmological hydrodynamical simulation, and faint galaxies in the young universe. Undoubtedly, gravitational waves constitute the most prominent research topic in 2019. The subject appears in three of the Top 10 Research Fronts, i.e., "Multi-messenger observations of a binary neutron star merger GW170817," "Observational and theoretical research on binary black-hole mergers," and "Scalar-tensor theories and implications from gravitational wave events." Several Research Fronts continue to show strong correspondence with specific space-based or ground-based observation platforms, and reflect ongoing focus on the Hubble constant, high-energy neutrinos and gamma-rays, cosmological hydrodynamical simulation, and faint galaxies in the young universe.

Table43 Top 10 Research Fronts in astronomy and astrophysics

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Multi-messenger observations of a binary neutron star merger GW170817	37	2462	2017.3
2	Scalar-tensor theories and implications from gravitational waves events	26	2030	2016.6
3	Investigations of protoplanetary disks with ALMA and VLT	20	1780	2016.1
4	Observational and theoretical research on binary black-hole mergers	6	4614	2016
5	Observational and theoretical research on fast radio bursts	21	2273	2016
6	Measuring Hubble constant by a variety of methods	15	3154	2015.5
7	High-energy neutrinos and gamma-ray detection with IceCube and Fermi	25	3896	2015.1
8	Theoretical explanations for galactic center gamma ray excess	20	2903	2014.8
9	Cosmological hydrodynamical simulation of galaxy formation and evolution	11	3094	2014.7
10	Investigations of faint galaxies in the young universe using HST	16	2736	2014.6

Figure8 Citing papers for the Top 10 Research Fronts in astronomy and astrophysics



1.2 KEY HOT RESEARCH FRONT – "Multi-messenger observations of a binary neutron star merger GW170817"

Dense stars, including white dwarfs, neutron stars, and black holes, have been the main research objects of high-energy astrophysics for decades. In 1974, American scientists Russell A. Hulse and Joseph H. Taylor made the first observation of a binary neutron star system, PSR 1913+16. Long-term observations of the system showed that the variation of the orbital period of the binary system is consistent with the energy loss predicted by general relativity due to the emission of gravitational waves, which are ripples in the fabric of spacetime. This was generally accepted as indirect proof, for the first time, of the existence of gravitational waves. Hulse and Taylor shared the 1993 Nobel Prize in Physics for their discovery.

On August 17, 2017, the Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo collaborations detected a gravitational wave signal with a duration of about 100 seconds. The gravitational wave, which was designated GW170817, was later confirmed as the result of the merger of two neutron stars 140 million light-years away. The aftermath of this merger was also seen by 70 observatories on all seven continents and in space, across the electromagnetic spectrum, marking a significant breakthrough for multi-messenger astronomy. The milestone was selected among *Science* magazine's "Top 10 Science Stories of 2017".

The hot Research Front "Multi-messenger observations of a binary neutron star merger GW170817" includes 37 core papers. The most-cited of these foundational reports, coauthored by almost 4,600 astronomers, highlights the first global multi-messenger observations of the neutron star merger event, and thus led to the research boom on the phenomenon. Other core papers discuss the breakthrough of the gravitational wave and electromagnetic joint observations of the event, including the origin of some short bursts of gamma rays, the existence of "kilonova", and the confirmation of the r-process of neutron star mergers as the major source of heavy elements in the universe.

Analysis of countries and institutions producing core papers in this field (Table 44) shows that, as the funding country of major space- and ground-based observation facilities, the USA takes a predominant position in this front. Nearly 90% of the core papers were led or contributed by the USA, and the Top 10 institutions are almost swept by the USA. The UK, Australia, Italy, Israel, and Germany also register strongly in this area. The Max Planck Society and Tel Aviv University are the only non-US entities on the list of Top 10 institutions. Although China has also participated in the key hot research front, the nation has not made high-impact research contributions in this field.

Table 44 Top countries and institutions producing core papers in the Research Front "Multi- messenger observations of a binary neutron star merger GW170817"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	33	89.2%	1	Department of Energy	USA	17	45.9%
2	UK	15	40.5%	2	Columbia University	USA	13	35.1%
3	Australia	13	35.1%	2	Northwestern University	USA	13	35.1%
3	Italy	13	35.1%	2	Space Telescope Science Institute	USA	13	35.1%
5	Israel	12	32.4%	2	University of California, Berkeley	USA	12	32.4%
6	Germany	10	27.0%	6	National Aeronautics and Space Administration	USA	11	29.7%
6	Chile	10	27.0%	6	Harvard University	USA	11	29.7%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
8	Denmark	9	24.3%	6	Johns Hopkins University	USA	10	27.0%
9	Japan	7	18.9%	9	Smithsonian Institution	USA	10	27.0%
9	India	7	18.9%	9	California Institute of Technology	USA	10	27.0%
9	Netherlands	7	18.9%	9	Max Planck Society	Germany	10	27.0%
9	Spain	7	18.9%	9	Tel Aviv University	Israel	10	27.0%

Examination of citing papers demonstrates that the USA's predominance extends to the country and institutional levels. The USA contributes to more than half (52.3%) of all citing papers, which is 2.5 times that of the second-ranked UK. China, although not listed as a core-paper contributor in this field, has actively participated in the follow-up research, accounting for 20.5% of the total citing papers and ranking 3rd. At the institutional level, four US entities rank among the Top 10, while Italy has two. The National Institute for Nuclear Physics (Italy), the Max Planck Society (Germany) and the French National Center for Scientific Research are the top three institutions in publishing a significant number of citing papers. The Chinese Academy of Sciences and United States Department of Energy both ranked 5th with 62 citing papers.

1
USA contributes
336 citing papers

2
UK contributes
135 citing papers

3
China contributes
132 citing papers

Table 45 **Top countries and institutions producing citing papers in the Research Front "Multi- messenger observations of a binary neutron star merger GW170817"**

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	336	52.3%	1	National Institute for Nuclear Physics	Italy	80	12.4%
2	UK	135	21.0%	2	Max Planck Society	Germany	78	12.1%
3	China	132	20.5%	3	French National Center for Scientific Research	France	71	11.0%
4	Italy	118	18.4%	4	National Institute for Astrophysics	Italy	63	9.8%
5	Japan	115	17.9%	5	Department of Energy	USA	62	9.6%
6	Germany	124	19.3%	5	Chinese Academy of Sciences	China	62	9.6%
7	France	77	12.0%	7	California Institute of Technology	USA	53	8.2%
8	Australia	67	10.4%	9	University of Tokyo	Japan	46	7.2%
9	Israel	66	10.3%	8	National Aeronautics and Space Administration	USA	47	7.3%
10	Spain	60	9.3%	10	Columbia University	USA	43	6.7%

1.3 KEY HOT RESEARCH FRONT – "Observational and theoretical research on binary black-hole mergers"

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

This Research Front brings together six core papers focusing on observations and research on binary black-hole mergers GW150914 and GW151226, including detection, properties, the theoretical-physics implications of the two systems, and tests of general relativity with GW150914. The total citations to the six core papers exceed 4,600, placing this specialty area first by total citations as well as by citations per paper among the Top 10 astronomy and astrophysics Research Fronts featured here.

From the point of view of the countries/regions and institutions contributing to these core papers, this Research Front demonstrates the characteristics of international cooperation in major science programs. LIGO is funded by the U.S. National Science Foundation and operated by the California Institute of Technology and the Massachusetts Institute of Technology. The LIGO Scientific Collaboration (LSC) is a group of scientists focused on the direct detection of gravitational waves, using them to explore the fundamental physics of gravity, and developing the emerging field of gravitational wave science as a tool of astronomical discovery. The LSC is currently made up of more than 1,000 scientists from over 100 institutions worldwide. The Virgo Collaboration also participated in data-analysis work with LIGO; the Virgo team includes more than 300 scientists based at institutes spread across eight European countries. Five of the six core papers were co-authored by the LSC and the Virgo Collaboration, and the other one was co-authored by Montana State University and Princeton University.

Analysis of the citing papers indicates that the USA contributes the most citing reports (1,108) and is far ahead of the UK (530) and Germany (513). China, Italy and Japan rank 4th to 6th respectively. Among the Top 10 citing institutions, there are four institutions in the USA, two in France, and one each in Germany, Italy, China and Japan. The Max Planck Society ranks 1st, followed by the French National Center for Scientific Research, and the National Institute for Nuclear Physics (Italy). The Chinese Academy of Sciences ranks 5th with 156 citing papers.

1

USA contributes
1108 citing papers

2

UK contributes
530 citing papers

Table 46 Top countries and institutions producing citing papers in the Research Front "Observations and theory researches of binary black-hole mergers"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	1108	38.8%	1	Max Planck Society	Germany	286	10.0%
2	UK	530	18.6%	2	French National Center for Scientific Research	France	232	8.1%
3	Germany	513	18.0%	3	National Institute for Nuclear Physics	Italy	221	7.7%
4	China	445	15.6%	4	California Institute of Technology	USA	219	7.7%
5	Italy	354	12.4%	5	Chinese Academy of Sciences	China	156	5.5%
6	Japan	326	11.4%	5	University of Tokyo	Japan	156	5.5%
7	France	280	9.8%	7	National Aeronautics and Space Administration	USA	143	5.0%
8	Canada	234	8.2%	8	Massachusetts Institute of Technology	USA	125	4.4%
9	Spain	215	7.5%	9	University of Paris-Saclay	France	122	4.3%
10	Brazil	194	6.8%	9	University of Maryland, College Park	USA	122	4.3%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

Three emerging Research Fronts distinguish themselves in astronomy and astrophysics: "The Hyper Suprime-Cam Subaru Strategic Program and survey discoveries," "Investigations of dark matter in early universe with 21 cm line observations," and "Constraining the mass, radius and equation of state of neutron stars with multi-messenger observations of gravitational waves." Below, we provide further analysis of the second of these fronts.

Table 47 Emerging Research Fronts in astronomy and astrophysics

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	The Hyper Suprime-Cam Subaru Strategic Program and survey discoveries	16	491	2018
2	Investigations of dark matter in the early universe with 21 cm line observations	8	173	2018
3	Constraining the mass, radius and equation of state of neutron stars with multi-messenger observations of gravitational waves	8	267	2017.8

2.2 KEY EMERGING RESARCH FRONT – "Investigations of dark matter in the early universe with 21 cm line observations"

Our understanding of cosmology has matured significantly in recent decades. In that time, observations of the Universe from its infancy through to the present day have given us a basic picture of how the Universe came to be the way it is today. Despite this progress, much of the first billion years of the Universe, a period when the first stars and galaxies formed, is still an unobserved mystery. The theoretical picture is well established, but the middle phase is largely untested by observations. To improve on this, astronomers are pursuing two main avenues of attack. The first is to extend existing techniques by building larger, more sensitive telescopes at a variety of wavelengths. An alternative approach is based upon making observations of the redshifted 21 cm line of neutral hydrogen.

This 21 cm line is produced by the hyperfine splitting caused by the interaction between electron and proton magnetic moments. Observations of the redshifted 21 cm line offer a new window into the properties of the Universe at redshifts $z = 1–150$, filling in a crucial gap in observations of the period when the first structures and stars formed, with enormous potential to improve our understanding of the Universe.

This Research Front brings together eight core papers focusing on investigations of dark matter in the early universe with 21 cm line observations. The research topics include: possible interaction between baryons and dark-matter revealed by observing 21 cm signal, indicating that 21 cm cosmology can be used as a dark-matter probe; deriving constraints on dark matter annihilation and decay with 21 cm observations; discussion of the modification of the cosmic microwave background spectrum which can be tested by 21 cm signal detection; and the proposal that detailed 21 cm calculations should include a possible early radio background.

X. MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING

1. HOT RESEARCH FRONT

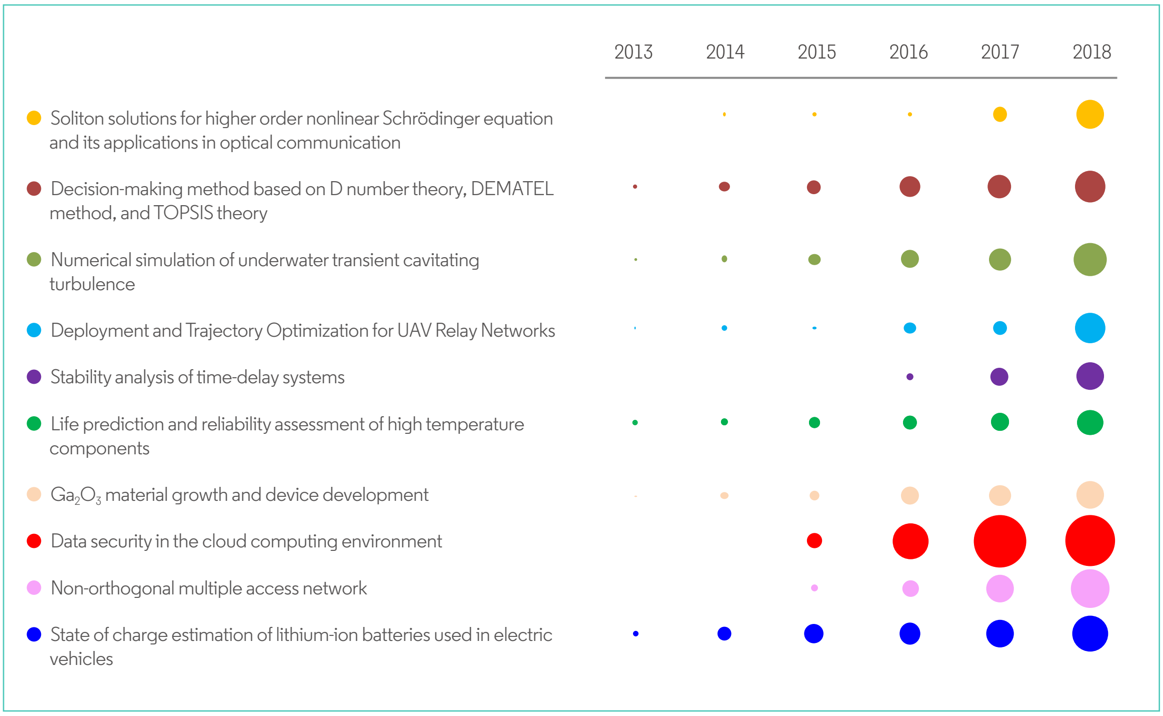
1.1 TREND OF THE TOP 10 RESEARCH FRONTS IN MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING

The Top 10 Research Fronts in mathematics, computer science, and engineering mainly focus on: soliton solutions for higher order nonlinear Schrödinger equation; decision-making method based on D number theory, DEMATEL method, and TOPSIS theory; numerical simulation of underwater transient cavitating turbulence; deployment and trajectory optimization for UAV relay networks; stability analysis of time-delay systems; life prediction and reliability assessment of high-temperature components; Ga_2O_3 material growth and device development; data security in the cloud computing environment; non-orthogonal multiple access network; and state of charge estimation of lithium-ion batteries used in electric vehicles. The Top 10 Research Fronts in 2019 show both continuity and new development when compared with the fronts selected between 2013 and 2018. The solutions for nonlinear equations and their applications have been consecutively selected as a hot or emerging Research Front for years. Decision-making method, stability analysis of time-delay systems, and state of charge estimation of lithium-ion batteries used in electric vehicles have also constituted important research topics in recent years. The remaining research topics are selected as hot Research Fronts for the first time.

Table 48 Top10 Research Fronts in mathematics, computer science and engineering

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Soliton solutions for higher order nonlinear Schrödinger equation and its applications in optical communication	46	1122	2017.3
2	Decision-making method based on D number theory, DEMATEL method, and TOPSIS theory	48	2070	2016.7
3	Numerical simulation of underwater transient cavitating turbulence	32	1233	2016.6
4	Deployment and Trajectory Optimization for UAV Relay Networks	21	1086	2016.6
5	Stability analysis of time-delay systems	22	975	2016.6
6	Life prediction and reliability assessment of high temperature components	21	775	2016.6
7	Ga_2O_3 material growth and device development	32	1901	2016.5
8	Data security in the cloud computing environment	43	7221	2016.1
9	Non-orthogonal multiple access network	47	3525	2016.1
10	State of charge estimation of lithium-ion batteries used in electric vehicles	45	2340	2016.1

Figure 9 Citing papers for the top 10 Research Fronts in mathematics, computer science and engineering



1.2 KEY HOT RESEARCH FRONT – "Data security in the cloud computing environment"

With the development of distributed computing, parallel computing, virtualization, and balanced load, Google first proposed the concept of "cloud computing" in 2006. The US National Institute of Standards and Technology (NIST) defines cloud computing as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service-provider interaction. Since its introduction, cloud computing has received extensive attention and support from many IT companies. With cloud computing services, companies need only apply for resources according to their specific requirements, and can handle their daily business on demand, which greatly reduces their operating costs.

With the maturation of the cloud computing service model, deploying applications on cloud servers has become a trend. However, due to strong dependence on network communication and the inherent vulnerability of these systems, networks face severe security problems, especially for the data resources and private information stored on the cloud server. These threats include illegal copying, forgery or falsification of information, and misappropriation or tampering directed at e-commerce data. In recent years, several top public clouds have been repeatedly hacked, resulting in large-scale incidents of data leakage. Accordingly, the development of methods to ensure the security and reliability of cloud computing has become the core issue in this field.

Forty-three core papers identify this key hot Research Front, mainly focusing on document retrieval based on semantic features, encrypted image retrieval, data storage security, access control schemes, efficient task allocation strategy, and image digital watermarking technology in the cloud computing environment.

As to the top countries and institutions in this front (Table 49), China-based researchers contributed to all 43 core papers. The USA, Canada, and South Korea are ranked 2nd to 4th, respectively, each contributing more than 10% of core papers. Nanjing University of Information Science & Technology, in cooperation with international partners, participated in all the core papers. The Chinese Academy of Sciences and City University of Hong Kong both published three core papers. In addition, several institutions in the USA, Canada, and South Korea rank among Top 10 most prolific in this Research Front.

43

China-based researchers contributed to all 43 core papers

Table 49 Top countries/regions and institutions producing core papers in the Research Front "Data security in the cloud computing environment"

Country Ranking	Country/ Region	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	43	100.0%	1	Nanjing University of Information Science & Technology	China	43	100.0%
2	USA	10	23.3%	2	University of Windsor	Canada	4	9.3%
3	Canada	6	14.0%	3	Chinese Academy of Sciences	China	3	7.0%
4	South Korea	5	11.6%	3	City University of Hong Kong	China	3	7.0%

Country Ranking	Country/ Region	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
5	Taiwan, China	2	4.7%	3	Kyung Hee University	South Korea	3	7.0%
5	UK	2	4.7%	3	New Jersey Institute of Technology	USA	3	7.0%
5	France	2	4.7%	3	University at Buffalo - SUNY	USA	3	7.0%
8	Ireland	1	2.3%	3	University of Central Arkansas	USA	3	7.0%
8	Saudi Arabia	1	2.3%					
8	Australia	1	2.3%					

In terms of papers that cite the core literature for this front, China actively participated in 1,985 citing papers, accounting for 88.3% of the total and ranking 1st (Table 50). The USA, India, Australia, and the UK are ranked 2nd to 5th, respectively. At the institutional level, Chinese entities are also outstanding in terms of carrying forward the work in this Research Front – in fact, institutions based in China sweep the Top 10 positions. Nanjing University of Information Science & Technology, the Chinese Academy of Sciences, Xidian University, Wuhan University, and Nanjing University of Posts and Telecommunications occupy the top five positions in contributing the most citing papers.

China contributes **1985** citing papers 1

USA contributes **366** citing papers 2

Table 50 Top countries/regions and institutions producing citing papers in the Research Front "Data security in the cloud computing environment"

Country Ranking	Country/ Region	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	1985	88.3%	1	Nanjing University of Information Science & Technology	China	621	27.6%
2	USA	366	16.3%	2	Chinese Academy of Sciences	China	206	9.2%
3	India	116	5.2%	3	Xidian University	China	101	4.5%
4	Australia	92	4.1%	4	Wuhan University	China	91	4.0%
5	UK	90	4.0%	5	Nanjing University of Posts and Telecommunications	China	87	3.9%
6	Taiwan, China	82	3.6%	6	Beijing University of Posts and Telecommunications	China	84	3.7%
7	South Korea	80	3.6%	7	Hunan University	China	74	3.3%
8	Canada	77	3.4%	8	China University of Mining & Technology	China	61	2.7%
9	Saudi Arabia	60	2.7%	9	Southeast University	China	52	2.3%
10	Singapore	45	2.0%	10	University of Electronic Science and Technology of China	China	51	2.3%

1.3 KEY HOT RESEARCH FRONT – "State of charge estimation of lithium-ion batteries used in electric vehicles"

As one of the core technologies for the development of electric vehicles, the power battery and its management system (BMS) are the key to the industrialization of electric-powered automobiles and other conveyances. Accurate estimation of battery state of charge (SoC) and efficient battery equalization control are important to maximize battery efficiency, improve battery life, and enhance vehicle performance.

At present, the commonly used SoC estimation method is to perform model-based online iterative estimation using a Kalman filter and to calculate the state of charge by analyzing the external characteristics of the battery by establishing an equivalent circuit model of the battery. Therefore, combining accurate battery models with nonlinear filtering algorithms has become a hot topic and a trend in the study of SoC estimation algorithms. The core papers of this front reflect this trend. On the one hand, these papers consider different factors such as battery aging level, ambient temperature, and charge and discharge efficiency in modeling, and conduct in-depth research on measurement methods and battery model parameter identification methods, such as improving the lumped parameter battery model through an electrochemical equation and establishing a temperature model based open circuit voltage (OCV)-SoC temperature table. On the other hand, in order to improve the performance of Kalman filter in SoC estimation, research has pursued the development of multi-scale extended Kalman filter and adaptive extended Kalman filter employing the covariance matching method, in order to reduce the complexity of the algorithm while ensuring accuracy to facilitate engineering applications.

Among the 10 countries participating in this front, China occupies a dominant position and contributes 45 core papers, accounting for 80.0% of the total (Table 51). The USA and Australia rank 2nd and 3rd, followed by Singapore and Sweden. At the institutional level, Beijing Institute of Technology in China produced the highest number of core papers. Chongqing University and Nanyang Technological University of Singapore rank 2nd and 3rd.

China contributes **36** core papers — 1

USA contributes **13** core papers — 2

Australia contributes **9** core papers — 3

Table 51 Top countries and institutions producing core papers in the Research Front "State of charge estimation of lithium-ion batteries used in electric vehicles"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	36	80.0%	1	Beijing Institute of Technology	China	20	44.4%
2	USA	13	28.9%	2	Chongqing University	China	7	15.6%
3	Australia	9	20.0%	3	Nanyang Technological University	Singapore	6	13.3%
4	Singapore	6	13.3%	4	University of Maryland, College Park	USA	5	11.1%
5	Sweden	5	11.1%	4	University of Michigan	USA	5	11.1%
6	UK	1	2.2%	4	Chalmers University of Technology	Sweden	5	11.1%
6	South Africa	1	2.2%	4	Chinese Academy of Sciences	China	5	11.1%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
6	France	1	2.2%	8	Swinburne University of Technology	Australia	4	8.9%
6	Iran	1	2.2%	9	University of Technology Sydney	Australia	3	6.7%
6	Italy	1	2.2%	10	City University of Hong Kong	China	3	6.7%

Analysis of the citing papers (Table 52) indicates that China is the most active country and contributed to 617 citing papers, accounting for 59.9% of the total. The USA and UK rank 2nd and 3rd. Among the Top10 institutions, Chinese institutions occupy eight positions, with Beijing Institute of Technology ranking 1st. Nanyang Technological University and the University of Michigan also register strong performance.

China contributes **617** citing papers 1

USA contributes **174** citing papers 2

UK contributes **58** citing papers 3

Table 52 Top countries and institutions producing citing papers in the Research Front "State of charge estimation of lithium-ion batteries used in electric vehicles"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	617	59.9%	1	Beijing Institute of Technology	China	121	11.7%
2	USA	174	16.9%	2	Tsinghua University	China	66	6.4%
3	UK	58	5.6%	3	Chinese Academy of Sciences	China	61	5.9%
4	South Korea	49	4.8%	4	Harbin Institute of Technology	China	35	3.4%
5	Australia	44	4.3%	5	Beijing Jiaotong University	China	30	2.9%
6	Canada	42	4.1%	6	Nanyang Technological University	Singapore	28	2.7%
7	Singapore	40	3.9%	7	University of Michigan	USA	27	2.6%
8	Germany	36	3.5%	8	Shanghai Jiaotong University	China	26	2.5%
9	French	31	3.0%	8	Beijing Aerospace University	China	24	2.3%
10	Sweden	26	2.5%	10	Chongqing University	China	23	2.2%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING

"Industrial sensor networks and smart cities," "Application of convolutional neural network in magnetic resonance image processing," "Solutions for time fractional evolution equation," "Least squares based iterative parameter estimation algorithm and its applications," and "H-infinity control of Markov jump system" were selected as the emerging Research Fronts of 2019 in mathematics, computer science and engineering (Table 53). Below, further interpretation of the second front is provided.

Table 53 Emerging Research Fronts in mathematics, computer science and engineering

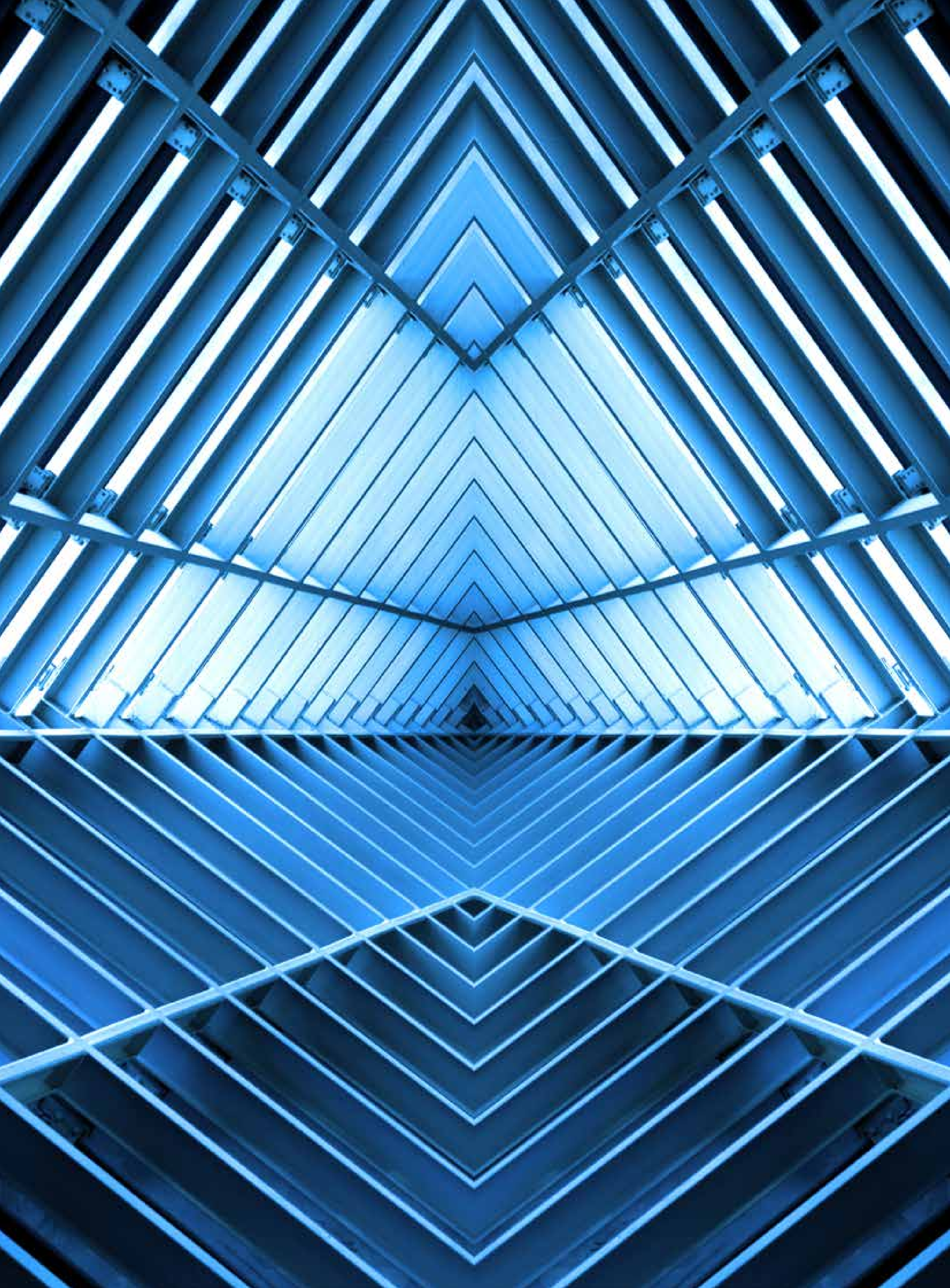
Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core papers
1	Industrial sensor networks and smart cities	45	939	2017.9
2	Application of convolutional neural network in magnetic resonance image processing	9	156	2017.8
3	Solutions for time fractional evolution equation	8	139	2017.8
4	Least squares based iterative parameter estimation algorithm and its applications	22	404	2017.6
5	H-infinity control of Markov jump system	12	357	2017.6

2.2 KEY EMERGING RESEARCH FRONT – "Application of convolutional neural network in magnetic resonance image processing"

Deep Learning has been an emerging machine learning tool in general imaging and computer vision domains, particularly the convolutional neural networks (CNN). The convolutional neural network consists of multiple convolutional layers, which can automatically learn different feature representations from a large amount of data, identify complex data structures, learn nonlinear mapping between input and output data, and no longer use manual extraction of features. Compared with traditional machine learning method, CNN showed more powerful ability of feature learning and feature expression.

Magnetic resonance imaging (MRI) can reveal the structure, metabolism, and function of internal tissues and organs of the body without physical damage. Over the past two decades, MRI has revolutionized diagnostic imaging with its numerous possibilities, offering high-quality, safe medical images. The upsurge of CNN has also swept the field of MRI processing. The application of convolutional neural network in MRI processing has focused on the reconstruction, segmentation, classification of magnetic resonance images, and disease detection and diagnosis, as well as brain medicine research.

The emerging Research Front "Application of convolutional neural network in magnetic resonance image processing" comprises a series of research works, including several new methods of segmentation and correction of magnetic resonance images of brain, musculoskeletal, and nerve based on CNN. Among these studies, the Chinese University of Hong Kong, the Shenzhen Institute of Advanced Technology of the Chinese Academy of Sciences, and the Hong Kong Polytechnic University contributed a core paper and proposed the so-called VoxResNet method, which effectively introduced deep residual learning on the challenging task of volumetric brain segmentation.



XI. 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

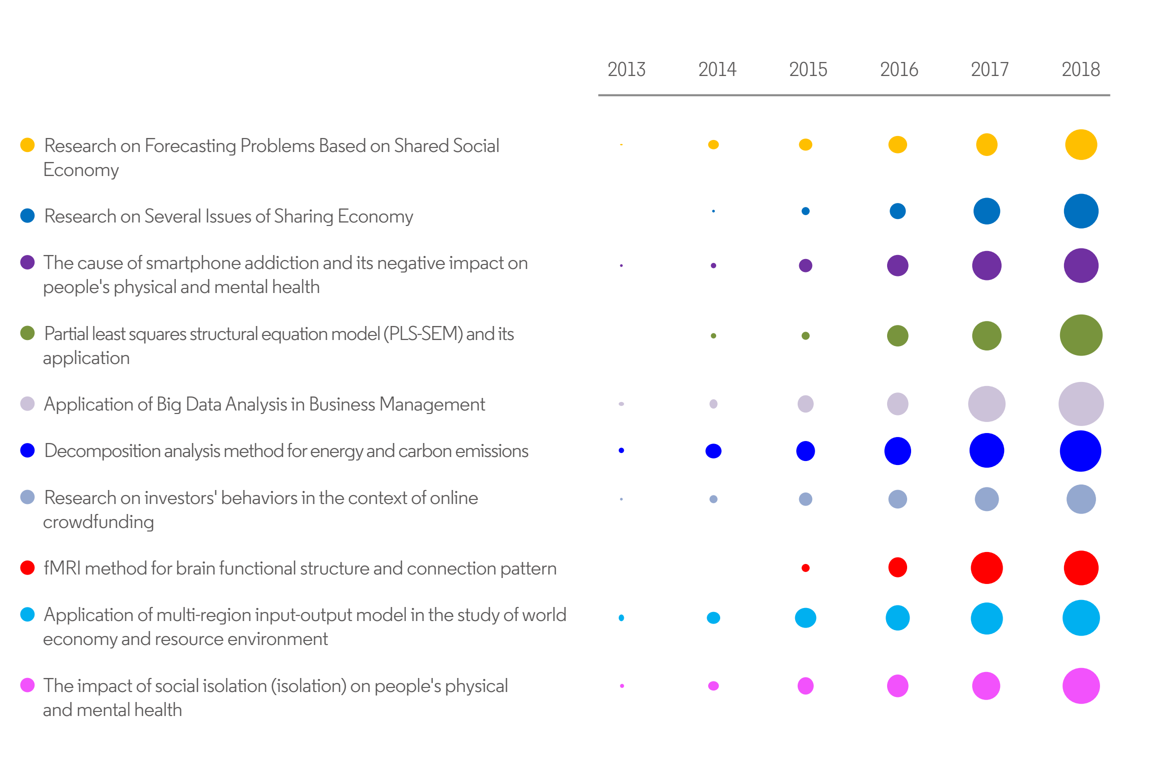
The top 10 Research Fronts of 2019 related to the social sciences focus on economics, psychology, and other social sciences. Psychology accounts for three Research Fronts: “The cause of smartphone addiction and its negative impact on people’s physical and mental health,” “fMRI method for brain functional structure and connection pattern,” and “The impact of social isolation (isolation) on people’s physical and mental health.”

In the field of commercial economy, “Application of big data analysis in business management” repeats its appearance in the Top 10, as in the 2018 Research Front report. In addition, some emerging economic models have become Research Fronts, including “Research on forecasting problems based on shared social economy,” “Research on several issues of sharing economy,” and “Research on investors’ behaviors in the context of online crowdfunding.” In terms of research methods, “Partial least squares structural equation model (PLS-SEM) and its application” makes its third consecutive appearance in this selection of social-science subject fields since 2017. In addition, two other methods-related Research Fronts of 2019 focus on energy and environmental economics: “Structural decomposition analysis method for energy and carbon emissions” and “Application of multi-region input-output model in the study of world economy and resource environment.” This is the third time, including 2013 and 2014, that the input-output method has appeared in the top 10. The field mainly pertains to greenhouse gas emissions and related issues.

Table 54 Top10 Research Fronts in economics, psychology and other social sciences

Rank	Hot Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Research on Forecasting Problems Based on Shared Social Economy	13	893	2016.5
2	Research on Several Issues of Sharing Economy	27	1414	2016.1
3	The cause of smartphone addiction and its negative impact on people's physical and mental health	21	1136	2016
4	Partial least squares structural equation model (PLS-SEM) and its application	14	1479	2015.9
5	Application of Big Data Analysis in Business Management	42	2239	2015.8
6	Decomposition analysis method for energy and carbon emissions	39	2215	2015.8
7	Research on investors' behaviors in the context of online crowdfunding	25	1310	2015.8
8	fMRI method for brain functional structure and connection pattern	10	1147	2015.8
9	Application of multi-region input-output model in the study of world economy and resource environment	21	1723	2015.6
10	The impact of social isolation (isolation) on people's physical and mental health	13	1098	2015.6

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



1.2 KEY HOT RESEARCH FRONT: "Decomposition analysis method for energy and carbon emissions"

Rapid global economic growth has led to increasing emission of greenhouse gases such as carbon dioxide, with a subsequent effect on the environment. This increase has intensified the long-standing conflict between the necessity of fostering economic growth while also protecting the environment (i.e., reducing carbon emissions). Ensuring appropriate climate-mitigation actions under the premise of economic development requires a deep understanding of the key technical and economic factors that drive the growth of greenhouse gas emissions.

The decomposition analysis method of carbon emissions mainly uses technical and economic analysis methods to decompose (i.e., break down) the economic impact of carbon emissions into various aspects, and thus determine some key technical and economic drivers. The Research Front addressing "Decomposition analysis method for energy and carbon emissions" addresses this analytic approach for various energy consumption and carbon emissions. Specifically, these tools include comprehensive decomposition methods, structural decomposition analysis (SDA) methods, data envelopment analysis methods, and Divisia index methods.

Firstly, SDA has been widely used by researchers to study the carbon emissions or total emission intensity of a country over time. Eighteen of the 39 core papers are related to the SDA method. Secondly, the exponential decomposition method is also an important technique, of which the Divisia index method is the most commonly used variant. Ten core papers are related to the Divisia index method.

Twenty-two core papers in this Research Front represent authorship from China-based institutions, accounting for 59% of the core group. Singapore takes the second place by contributing to 14 core papers. At the institutional level, 10 of the 12 top institutions are Chinese, while the other two are the National University of Singapore and the University of Leeds. Singapore's 14 core papers are all from the National University of Singapore, which ranks first among the top organizations. The 10 Chinese institutions contribute almost equally in terms of the core papers. Among them, Shanghai University of Finance and Economics narrowly achieves priority (Table 55).

China contributes **23** core papers 1

Singapore contributes **14** core papers 2

Table 55 Top countries and institutions producing core papers in the Research Front "Decomposition analysis method for energy and carbon emissions"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	China	23	59.0%	1	National University of Singapore	Singapore	14	35.9%
2	Singapore	14	35.9%	2	Shanghai University of Finance & Economics	China	5	12.8%
3	UK	3	7.7%	3	Central South University	China	4	10.3%
4	USA	2	5.1%	4	China University of Mining & Technology	China	3	7.7%
4	Netherlands	2	5.1%	4	China University of Petroleum	China	3	7.7%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
4	Japan	2	5.1%	4	Anhui University of Finance & Economics	China	3	7.7%
7	Montenegro	1	2.6%	4	Shanghai Jiao Tong University	China	3	7.7%
7	Peru	1	2.6%	8	Nanjing University of Aeronautics & Astronautics	China	2	5.1%
7	Spain	1	2.6%	8	Fudan University	China	2	5.1%
7	Australia	1	2.6%	8	Beijing Institute of Technology	China	2	5.1%
7	Austria	1	2.6%	8	University of Leeds	UK	2	5.1%
7	Chile	1	2.6%	8	Chinese Academy of Sciences	China	2	5.1%

In terms of citing papers, China occupies first place with 885, accounting for 75.8% of the total – more than six times that of the United States. The UK places third with 109 citing papers, indicating that China, the United States and the UK are the most prominent countries in this Research Front.

In regard to the citing institutions, eight of the Top10 institutions that cite the most core papers are Chinese institutions, of which the Chinese Academy of Sciences has the highest number of citing papers, accounting for 12.6%. The National University of Singapore and the University of East Anglia are ranked 7th and 8th with, respectively, 55 and 47 papers.

1 China contributes **885** citing papers

2 USA contributes **155** citing papers

3 UK contributes **109** citing papers

Table 56 Top countries and institutions producing citing papers in the Research Front "Decomposition analysis method for energy and carbon emissions"

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	China	885	75.8%	1	Chinese Academy of Sciences	China	147	12.6%
2	USA	155	13.3%	2	Beijing Institute of Technology	China	84	7.2%
3	UK	109	9.3%	3	Beijing Normal University	China	72	6.2%
4	Singapore	57	4.9%	4	China University of Mining & Technology	China	69	5.9%
5	Australia	55	4.7%	5	Tsinghua University	China	68	5.8%
6	Spain	54	4.6%	6	Peking University	China	60	5.1%
7	Japan	46	3.9%	7	National University of Singapore	Singapore	55	4.7%

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
8	Netherlands	23	2.0%	8	University of East Anglia	UK	47	4.0%
9	Germany	22	1.9%	9	North China Electric Power University	China	42	3.6%
10	Norway	21	1.8%	9	Xiamen University	China	42	3.6%

1.3 KEY HOT RESEARCH FRONT – "fMRI method for brain functional structure and connection pattern"

The capacity to identify the unique functional architecture of an individual human brain is a crucial step toward personalized medicine and understanding the neural basis of variation in human cognition and behavior. Abrupt transitions in resting-state functional connectivity (RSFC) patterns can non-invasively identify locations of putative borders between cortical areas, accurately predict individual differences in brain activity, and highlight a coupling between brain connectivity and function that can be captured at the level of individual subjects.

Resting state functional magnetic resonance imaging (fMRI) is an important means by which to study the spontaneous brain function of the human brain at rest by accurately mapping the functional structure and connection mode of the individual brain at the individual level. The core papers of this Research Front examine the use of resting state fMRI research methods to identify brain functional structure and connection patterns, and empirical research on individual cognitive differences and attention.

In this Research Front, nine core papers are from the United States, accounting for 90% of the core literature. The UK takes the second place by contributing three core papers. At the institutional level, most of the institutions are from the United States (one exception being located in the UK), including Yale University, Washington University in St. Louis, Harvard University and Massachusetts General Hospital. Yale University takes first place by contributing 40% of the core papers.

USA contributes **9** core papers 1

UK contributes **3** core papers 2

Table 57 Top countries and institutions producing core papers in the Research Front "fMRI method for brain functional structure and connection pattern"

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
1	USA	9	90.0%	1	Yale University	USA	4	40.0%
2	UK	3	30.0%	2	Washington University in St. Louis	USA	3	30.0%
3	Austria	1	10.0%	3	University of Oxford	UK	2	20.0%
3	China	1	10.0%	3	Harvard University	USA	2	20.0%
3	Germany	1	10.0%	3	Massachusetts General Hospital	USA	2	20.0%

Country Ranking	Country	Core Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Core Papers	Proportion
3	Israel	1	10.0%					
3	Netherlands	1	10.0%					

From the perspective of citing papers, the United States occupies first place with 434, accounting for 57.9% of the total – more than three times that of UK. Germany places third and China takes fourth place with 101 and 96 citing papers, respectively.

As for citing institutions, all the top entities are from the United States, the UK, and Germany, with the United States fielding seven. Harvard University occupies the first place with the greatest number of citing papers, accounting for 8.8%. Six other American institutions register at the top, including Washington University in St. Louis, Yale University, University of Pennsylvania, Stanford University, Massachusetts General Hospital, and the National Institutes of Health.

The University of Oxford, the University of London, and the Max Planck Society of Germany take 4th, 6th and 9th place, respectively.

USA contributes **434** citing papers 1

UK contributes **118** citing papers 2

Germany contributes **101** citing papers 3

China contributes **96** citing papers 4

Table 58 Top countries and institutions producing citing papers in the Research Front “fMRI method for brain functional structure and connection pattern”

Country Ranking	Country	Citing Papers	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Papers	Proportion
1	USA	434	57.9%	1	Harvard University	USA	66	8.8%
2	UK	118	15.7%	2	Washington University in St. Louis	USA	54	7.2%
3	Germany	101	13.5%	3	Yale University	USA	52	6.9%
4	China	96	12.8%	4	University of Oxford	UK	49	6.5%
5	Canada	61	8.1%	5	University of Pennsylvania	USA	47	6.3%
6	Australia	47	6.3%	6	University of London	UK	38	5.1%
7	Netherlands	45	6.0%	6	Stanford University	USA	38	5.1%
8	Italy	34	4.5%	8	Massachusetts General Hospital	USA	32	4.3%
9	France	32	4.3%	9	Max Planck Society	Germany	29	3.9%
10	Japan	25	3.3%	10	National Institutes of Health	USA	27	3.6%

2. EMERGING RESEARCH FRONT

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

Two specialty areas within economics, psychology, and other social sciences have been selected for emerging Research Fronts: "Some new models of multi-attribute decision making" and "Industry 4.0 and its impacts." Below, the latter area is selected for analysis.

Table 59 Emerging Research Fronts in economics, psychology and other social sciences

Rank	Emerging Research Fronts	Core papers	Citations	Mean Year of Core Papers
1	Some new models of multi-criteria decision-making	6	100	2018
2	Industry 4.0 and its impacts	9	152	2017.8

2.2 KEY EMERGING RESARCH FRONT – "Industry 4.0 and its applications"

Combining automation with connectivity and information exchange, the idea of "Industry 4.0" is also known as the "fourth industrial revolution," "smart manufacturing," the "industrial Internet" or "integrated industry." The concept was first proposed by the German federal government at the Hannover Industrial Fair in 2011. Thereafter, Industry 4.0 became one of the ten future projects in the "Germany 2020 high-tech strategy," an initiative intended to increase the competitiveness of German industry and take the lead in the newest round of the industrial revolution.

Industry 4.0 refers to the use of the information system (Cyber-Physical System for short-term CPS) to digitize supply, manufacturing, and sales information in production, and ultimately to achieve intelligent, fast, effective, and personalized product supply. The German federal government is expected to invest 200 million euros in the "Industry 4.0" project, aiming to improve the intelligence level of the manufacturing industry; to establish a smart factory with adaptability, resource efficiency and genetic engineering; and to integrate customers and business partners in the business process and value process, whose technical foundation is the network entity system and the Internet of Things (IoT).

In recent years, Industry 4.0 has attracted increasing attention around the world and has quickly become one of the emerging Research Fronts in this report's grouping of economics, psychology and other social sciences. The core papers in this Research Front mainly focus on the impact of Industry 4.0. Many scholars believe that the implementation of Industry 4.0 has had a profound impact on the creation of industrial value. Their studies, through qualitative and quantitative research methods, have revealed the impacts of Industry 4.0 on business enterprise -- especially small and medium-sized enterprises (SMEs). Industry 4.0 provides a new paradigm for industrial management of SMEs. Scholars have also devoted attention to the comparative study of German Industry 4.0 and China's strategic plan, "Made in China 2025," observing that the two nations have realized the transformation and upgrading of traditional manufacturing industry in combination with the recent emergence of new technologies.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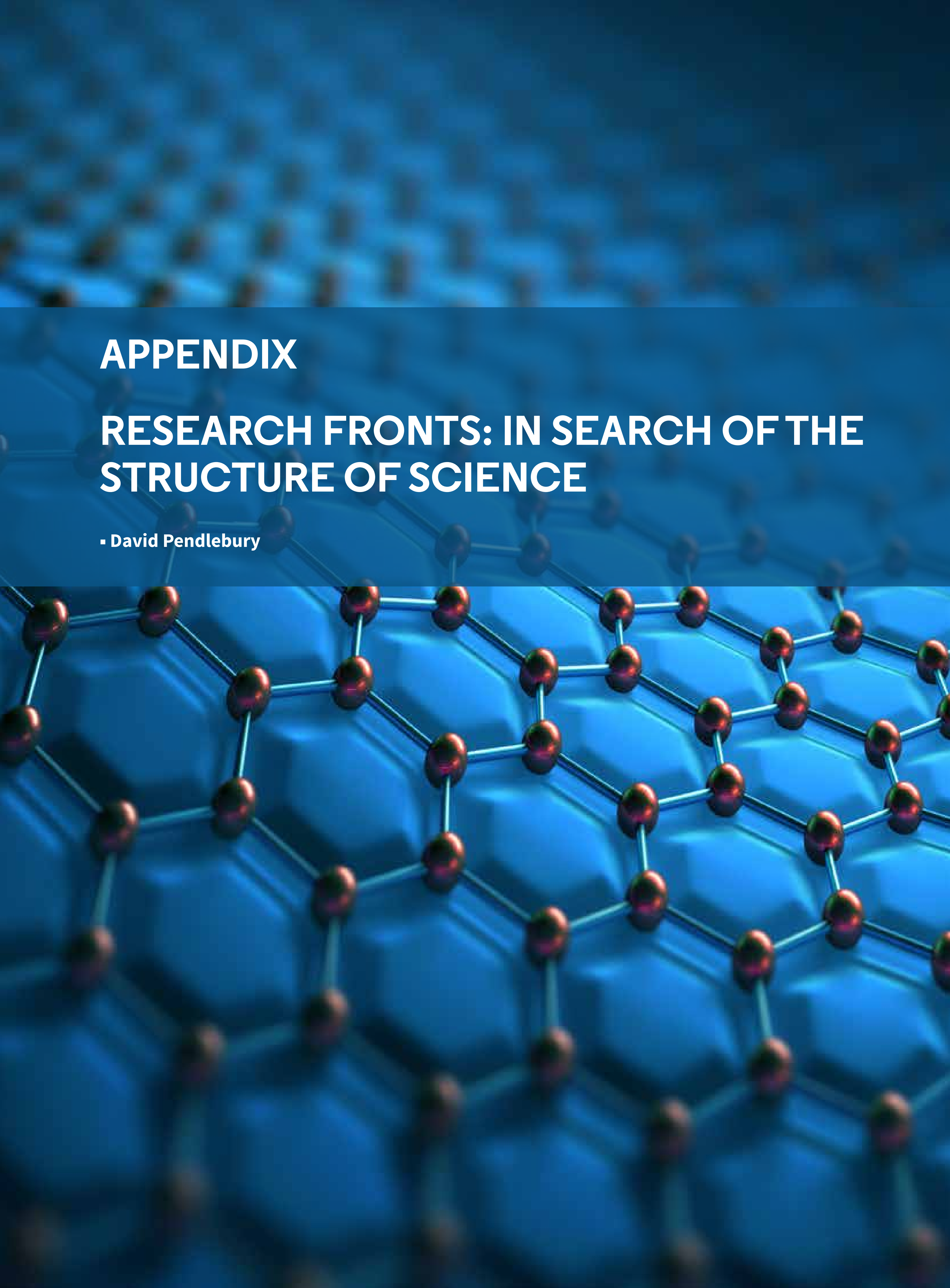

APPENDIX

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 53th 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 Analytics is committed to continuing and advancing the pioneering contributions of these two legends of information science.

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