RESEARCH FRONTS 2017

Institutes of Science and Development,
Chinese Academy of Sciences

The National Science Library,
Chinese Academy of Sciences

Clarivate Analytics

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中国科学院文献情报中心
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Contents

1. 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, Institutes of Science and Development, CAS, National Science Library, CAS and Clarivate Analytics jointly released the *Research Fronts 2016*. These reports gained widespread attention from around the world.

This year, the same methodology was employed. For the newest edition, *Research Fronts 2017*, 100 hot Research Fronts and 43 emerging Research Fronts were identified based on co-citation analysis that generated 9,690 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, was completed by Institute of Strategic Information of Institutes of Science and Development, Chinese Academy of Sciences. For the 2017 update, the Research Fronts drew on ESI data from 2011 to 2016, which were obtained in March 2017.

2.1 RESEARCH FRONTS SELECTION

Research Fronts 2017 presents a total of 143 Research Fronts, including 100 hot and 43 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 9,690 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 143 Research Fronts is described as follows.

2.1.1 SELECTING THE HOT RESEARCH FRONTS

First, 9,690 Research Fronts in 21 ESI fields were classified into 10 broad research areas. Research Fronts assigned to each of the 10 areas were ranked by total citations, and the Top 10 percent of the fronts in each area were extracted. These Research Fronts were then 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 2015 or more recently were considered, and then these were sorted in descending order by their total citations. There were 43 fronts whose total citations amounted to 100 or more (see appendix). Because the selection was not limited to any research area, the 43 fronts are distributed unevenly in the 10 fields. For example, there are 16 Research Fronts in chemistry and materials sciences but none in ecology and environmental sciences, mathematics, computer science and engineering, 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 43 emerging ones.

2.2 FINAL SELECTION AND INTERPRETATION OF KEY RESEARCH FRONTS

On the basis of 143 Research Fronts provided by Clarivate Analytics, analysts at the Institutes of Science and Development, Chinese Academy of Sciences, conducted a detailed analysis and interpretation to highlight 27 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 in2012, 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 recently.

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 2017*, 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 Science and Development. 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

"Electronic cigarettes, user preferences, and smoking cessation" and "Measurements of economy-wide energy efficiency," it is obvious that the latter is of more practical significance or consequence. Another key hot Research Front was chosen by the indicator CPT.

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, and seven key emerging Research Fronts from the 43 emerging Research Fronts. Thus, we will interpret in detail the selected 27 key Research Fronts from the 143 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 2011 and 2016, 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 deep 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 tables 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.

2. AGRICULTURAL, PLANT AND ANIMAL SCIENCES

1. HOT RESEARCH FRONT

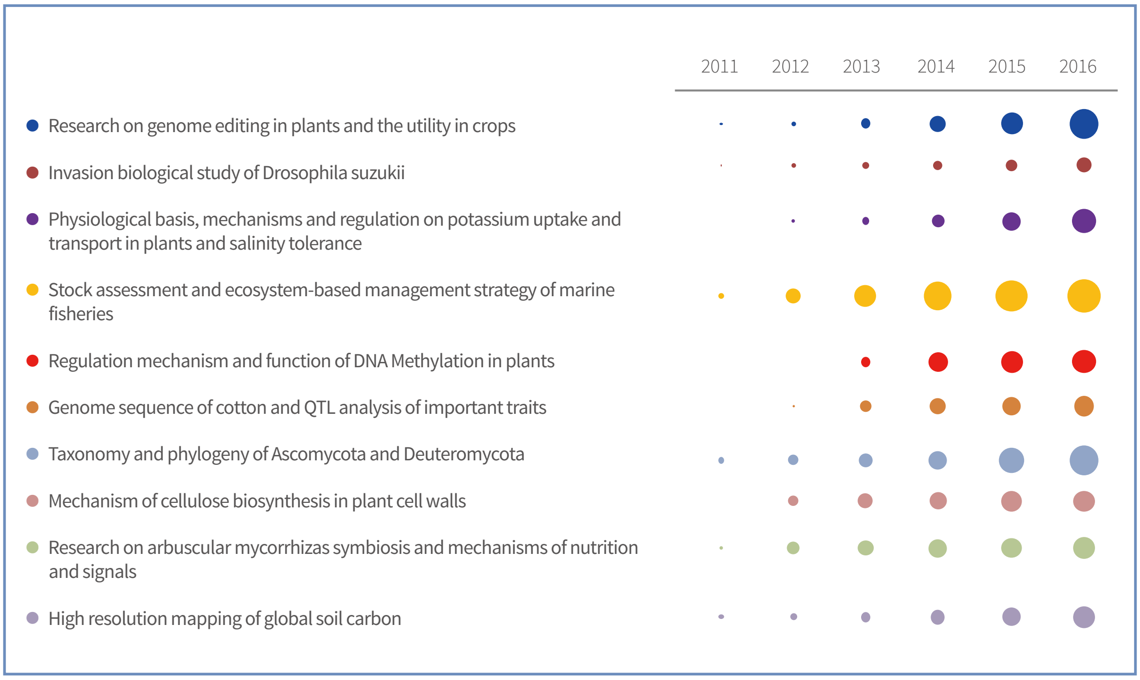
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN AGRICULTURAL, PLANT AND ANIMAL SCIENCES

The Top 10 hot Research Fronts in agricultural, plant and animal sciences mainly cover research on plant genome technology, plant nutrition mechanism, and agricultural resources (Table 1). There are three hot fronts on plant genome technology, including "Research on genome editing in plants and the utility in crops," "Regulation mechanism and function of DNA Methylation in plants," and "Genome sequence of cotton and QTL analysis of important traits." "Research on genome editing in plants and the utility in crops" reflects a major breakthrough in the field of plant biotechnology and is developing rapidly. The fronts related to plant nutrition mechanism include "Research on arbuscular mycorrhizas symbiosis and mechanisms of nutrition and signals" and "Physiological basis, mechanisms and regulation on potassium uptake and transport in plants and salinity tolerance." The latter topic was also featured as an emerging Research Front in 2015. The agricultural-resources-related hot fronts include "Stock assessment and ecosystem-based management strategy of marine fisheries" and "High resolution mapping of global soil carbon." Other hot fronts in botany include "Mechanism of cellulose biosynthesis in plant cell walls," while a Research Front in zoology examines "Invasion biological study of Drosophila suzukii." The hot Research Front in microbiology is "Taxonomy and phylogeny of Ascomycota and Deuteromycota," which was also an area included in the Top 10 hot Research Fronts for two consecutive years.

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

Number	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Research on genome editing in plants and the utility in crops	44	2227	2014.5
2	Invasion biological study of Drosophila suzukii	23	850	2014.2
3	Physiological basis, mechanisms and regulation on potassium uptake and transport in plants and salinity tolerance	18	809	2014.1
4	Stock assessment and ecosystem-based management strategy of marine fisheries	36	2312	2013.9
5	Regulation mechanism and function of DNA Methylation in plants	11	1115	2013.9
6	Genome sequence of cotton and QTL analysis of important traits	7	829	2013.9
7	Taxonomy and phylogeny of Ascomycota and Deuteromycota	33	1933	2013.8
8	Mechanism of cellulose biosynthesis in plant cell walls	23	1163	2013.8
9	Research on arbuscular mycorrhizas symbiosis and mechanisms of nutrition and signals	14	1025	2013.8
10	High resolution mapping of global soil carbon	10	605	2013.8

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



1.2 KEY HOT RESEARCH FRONT – "Research on genome editing in plants and the utility in crops"

As a precise and efficient technology for genome-targeted editing, "Genome editing technology" is widely accepted as a major breakthrough in the field of life sciences. CRISPR technology, in particular, is simpler and cheaper than the earlier ZFN and TALENs technologies and shows its great potential in fundamental research, gene therapy, and genetic improvement. In *Science* magazine, TALENs was listed as 2012 Breakthrough of the Year, and CRISPR/Cas9 as 2013 Breakthrough of the Year. In 2014, genome-editing technology was chosen as one of the ten most influential methods in biological research over the last decade by *Nature Methods*. In 2015, "CRISPR/Cas9 immune mechanism and its application in genome editing" was selected as a Top10 hot Research Front in biology in the Research Fronts report for 2015. In 2016, gene editing in plants was chosen as one of the 10 breakthrough technologies by *MIT Technology Review*. In 2017, there are 44 core papers in the hot Research Front "Research on genome editing in plants and the utility in crops." Most of the core papers focus on the targeted gene mutagenesis and modification of plant genomes. CRISPR/Cas9 was mainly used to carry out genome editing on model plants such as Arabidopsis, tobacco, and important crops such as rice and soybean. In addition, some research focuses on the tools and methods of genome editing for plants.

Table 2 shows the major countries and institutions that contributed to this Research Front. The 44 core papers in this front reflect the participation of 11 countries. The USA is the main country contributing to this hot front, with 25 core papers, accounting for 56.8% of the total. China and Japan contributed to 15 and six core papers, accounting for 34.1% and 13.6% of the total, respectively. The important institutions include the University of Minnesota, the Chinese Academy of Sciences and Iowa State University, with respective totals of eight, seven, and six core papers.

Table 2: Top countries and institutions producing the 44 core papers in the Research Front "Research on genome editing in plants and the utility in crops"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	25	56.8%	1	University of Minnesota Twin Cities	USA	8	18.2%
2	China	15	34.1%	2	Chinese Academy of Sciences	China	7	15.9%
3	Japan	6	13.6%	3	Iowa State University	USA	6	13.6%
4	UK	3	6.8%	4	Southwest University	China	3	6.8%
4	Germany	3	6.8%	4	National Institute of Agrobiological Sciences	Japan	3	6.8%
6	France	2	4.5%	4	Yokohama City University	Japan	3	6.8%
6	South Korea	2	4.5%	4	Cellectis	USA	3	6.8%
8	Philippines	1	2.3%	4	Purdue University	USA	3	6.8%
8	Czech Republic	1	2.3%	4	University of Nebraska Lincoln	USA	3	6.8%
8	Denmark	1	2.3%					
8	Australia	1	2.3%					

In terms of countries that cited the core papers of this hot Research Front (Table 3), the USA contributed to 309 citing papers, accounting for 40.7% of the total. China ranks 2nd with 179 citing papers, or 23.6% of the total. Germany, Japan and the UK have equivalent performance, with 77, 71, and 62 citing papers, respectively. In terms of citing institutions, the Chinese Academy of Sciences contributed to 57 citing papers, followed by the University of Minnesota with 33 and Iowa State University with 27 citing papers.

Table 3: Top countries and institutions producing citing papers in the Research Front "Research on genome editing in plants and the utility in crops"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	309	40.7%	1	Chinese Academy of Sciences	China	57	7.5%
2	China	179	23.6%	2	University of Minnesota Twin Cities	USA	33	4.3%
3	Germany	77	10.1%	3	Iowa State University	USA	27	3.6%
4	Japan	71	9.3%	4	United States Department of Agriculture (USDA)	USA	19	2.5%
5	UK	62	8.2%	4	University of California Davis	USA	19	2.5%
6	Australia	36	4.7%	6	Chinese Academy of Agricultural Sciences	China	18	2.4%
7	Italy	32	4.2%	6	Kyoto University	Japan	18	2.4%
8	India	31	4.1%	6	Cornell University	USA	18	2.4%
9	France	30	3.9%	9	National Institute of Agrobiological Sciences	Japan	15	2.0%
10	Canada	19	2.5%					

Analysis of the core and citing papers in this front shows that the USA is the leading country, with the most core papers and contributing institutions. China also shows good performance in terms of the number of core papers and participating institutions.

1.3 KEY HOT RESRACH FRONT – "Regulation mechanism and function of DNA Methylation in plants"

DNA methylation is a process by which methyl groups are selectively added to the DNA base cytosine to form 5-methylcytosine by the action of DNA methyltransferases. DNA methylation is an epigenetic modification and plays an important role in manipulating gene expression, genome defense, maintaining genome stability, as well as the regulation of plant growth and development. Since DNA-methylation-related enzymes and genes were discovered in 1988, the study of DNA methylation has become more and more popular. Much research has been conducted on the establishment and maintenance mechanism of DNA methylation, the change of DNA methylation under stress and its effects on gene expression, and DNA methylation detection technology.

Eleven papers constitute the core of this hot Research Front. Five papers examine the mechanism of DNA methylation – four reports covering *Arabidopsis thaliana* and one on maize – including identification and function of the factors that regulate DNA methylation, influence of environmental and genetic changes on DNA methylation, and evolutionary patterns and mechanisms of DNA methylation. The other six papers focus on the function of DNA methylation in *Arabidopsis thaliana*. The studies involve transposon regulation, impact on protein modification and small noncoding RNA, the relationship with genetic variation, and influence on complex traits (e.g., flowering time and primary root length).

In terms of countries and institutions (Table 4), 12 countries contributed to the 11 core papers in this Research Front. The USA contributed to 10 reports, accounting for 90.9% of the total. France and Germany contributed to two core papers each. Nine other countries contributed to one core paper each. Important contributing institutions include the National Center for Scientific Research (CNRS), the French National Institute for Agricultural Research, the Max Planck Society, Memorial Sloan Kettering Cancer Center, and the University of California, Los Angeles.

Table 4: Top countries/regions and institutions producing the 11 core papers in the Research Front "Regulation mechanism and function of DNA Methylation in plants"

Country Ranking	Country/ Region	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	10	90.9%	1	Centre National De La Recherche Scientifique (CNRS)	France	2	18.2%
2	France	2	18.2%	1	Institut National De La Recherche Agronomique (INRA)	France	2	18.2%
2	Germany	2	18.2%	1	Max Planck Society	Germany	2	18.2%
4	Japan	1	9.1%	1	Memorial Sloan Kettering Cancer Center	USA	2	18.2%
4	Netherlands	1	9.1%	1	University of California Los Angeles	USA	2	18.2%
4	Spain	1	9.1%					
4	Taiwan	1	9.1%					
4	UK	1	9.1%					
4	Australia	1	9.1%					
4	Austria	1	9.1%					
4	China	1	9.1%					
4	Czech Republic	1	9.1%					

In terms of countries that cited the core papers of this hot Research Front (Table 5), the USA contributed to 314 citing papers, 48.0% of the total. China ranks 2nd with 135 citing papers that account for 20.6% of the total while Germany ranks 3rd with 73 citing papers accounting for 11.2% of the total. In terms of citing institutions, the Chinese Academy of Sciences ranks 1st with 48 citing papers, followed by the Max Planck Society and the University of Georgia, with 35 and 30 citing papers, respectively.

Table 5: Top countries and institutions producing citing papers in the Research Front "Regulation mechanism and function of DNA Methylation in plants"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	314	48.0%	1	Chinese Academy of Sciences	China	48	7.3%
2	China	135	20.6%	2	Max Planck Society	Germany	35	5.4%
3	Germany	73	11.2%	3	University of Georgia	USA	30	4.6%
4	France	68	10.4%	4	Purdue University	USA	25	3.8%
5	UK	59	9.0%	4	University of California Los Angeles	USA	25	3.8%
6	Australia	38	5.8%	6	University of Minnesota Twin Cities	USA	19	2.9%
7	Japan	36	5.5%	7	Salk Institute	USA	18	2.8%
8	Switzerland	32	4.9%	8	China Agricultural University	China	16	2.4%
9	Netherlands	30	4.6%	9	University of Cambridge	UK	15	2.3%
10	Spain	28	4.3%	9	Ohio State University	USA	15	2.3%

The analysis above shows that the USA has the predominant position in this front by contributing the most core papers and citing papers. Although contributing only one core paper, China has followed up actively, producing 135 citing papers to rank 5^{th}.

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, there is one emerging Research Front: "Analysis of tree rings and its application in environment and climate change study."

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

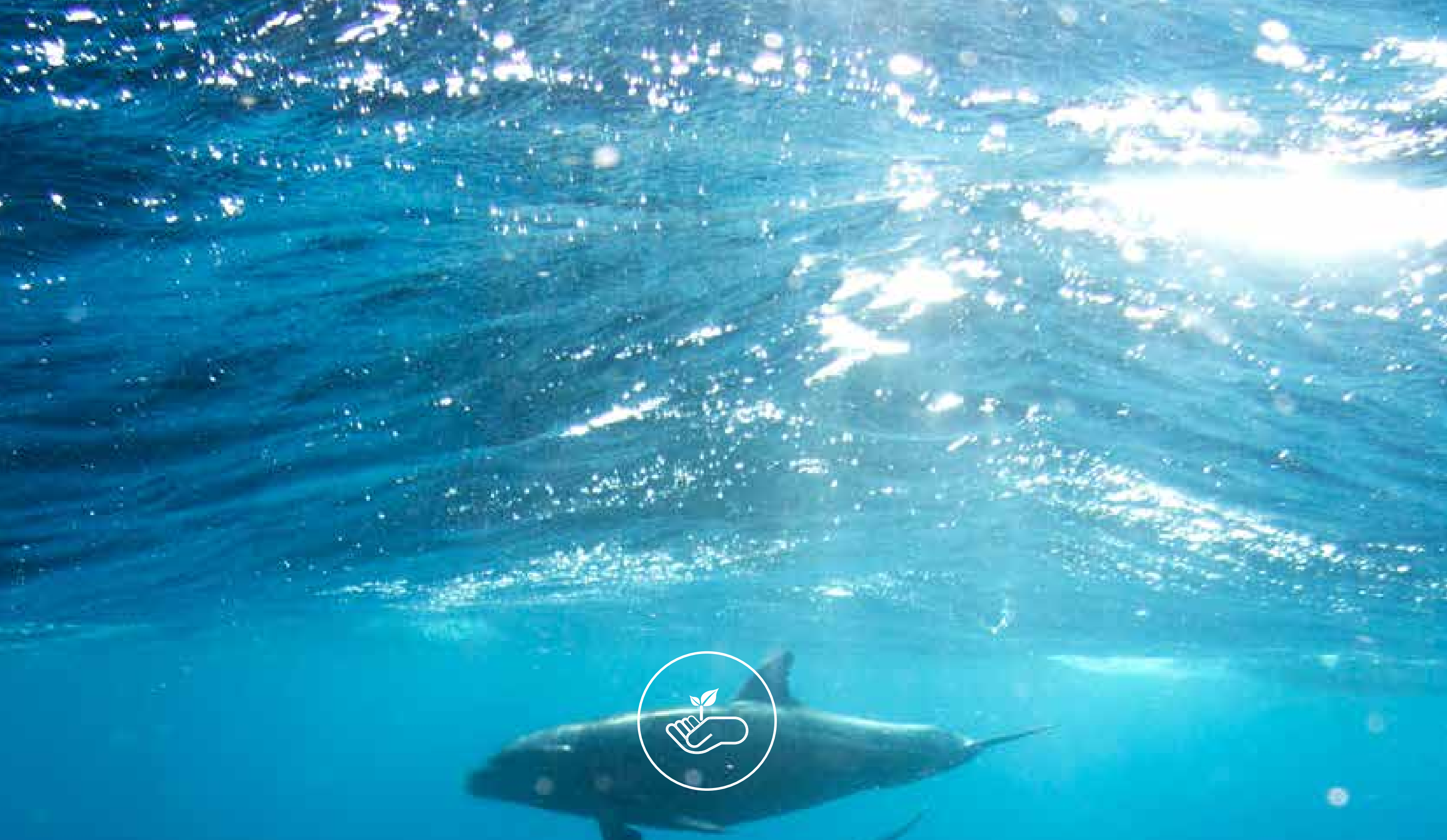
Number	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Analysis of tree rings and its application in environment and climate change study	15	160	2015.7

2.2 KEY EMERGING RESARCH FRONT – "Analysis of tree rings and its application in environment and climate change study"

Dendrochronology, established by the American astronomer A.E. Douglass in the early twentieth century, is a discipline in which tree-ring properties are studied and used to date and analyze past environmental changes. In the field's first 20 years, the study of tree rings was performed only in the USA, where the first tree-ring research laboratory was established at the University of Arizona in 1937. Because tree-ring data has the prominent advantages of accurate dating, long tracing time, high resolution, wide distribution, and on-site sampling, tree-ring analysis has become an important and widely used technology in analyzing global climate change in the past.

In recent years, with more global attention to climate change, tree-ring analysis and its application in the study of environmental and climate change has become one of the emerging fronts in the field of plant science. The content of tree-ring analysis has also been developed from the initial physical analysis of tree-ring width, density and brightness to the molecular analysis of the stability of the rings, stable isotopes, chemical components and anatomical structures. Especially in recent years, with the further development of technology for electronic scanning, signal sensing, and image processing, rapid and accurate ring-recognition technology is showing a strong technological advantage and bright prospects. Observation via the naked eye and hand calculation have been replaced by observation and calculation with instruments. Ring-recognition technology is increasingly automated, computerized, programmed, and visualized, providing an important technical basis for the accurate and reliable study of environmental and climate change.

In the 15 core papers in this emerging Research Front, seven employed new technologies and methods to analyze tree-ring features and to obtain environmental information and carry out climatic reconstructions. The other eight papers focus on the influence of various environmental factors on the formation of tree rings – that is, the association analysis between environmental and climatic variables and tree rings.



3. ECOLOGY AND ENVIRONMENTAL SCIENCES

1. HOT RESEARCH FRONT

1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN ECOLOGY AND EN-VIRONMENTAL SCIENCES

Eight of the Top 10 hot Research Fronts in ecology and environmental sciences in-volve three worldwide environmental problems: environmental pollution, global warming, and soil erosion. Six fronts are related to environmental pollution, a matter that has attracted increasing attention. Three of the hot Research Fronts featured in 2015 related to the topic, with the number increasing to five in 2016. This year there are six hot Research Fronts discussing environmental pollution. “Microplastic pollu-tion in the marine environment" is selected among the Top 10 hot Research Fronts for the third consecutive year, while "Global mercury pollution" and " The impact of or-ganophosphorus flame retardants on the environment and humans" are chosen among Top 10 hot Research Fronts for the second time, having first appeared in 2016. “The formation mechanism of east-central China’s heavy haze pollution in January 2013,” “Degradation of organic pollutants by persulfate activation” and “Adsorption of toxic pollutants from water using metal modified activated carbon” are three new top hot Research Fronts in 2017.

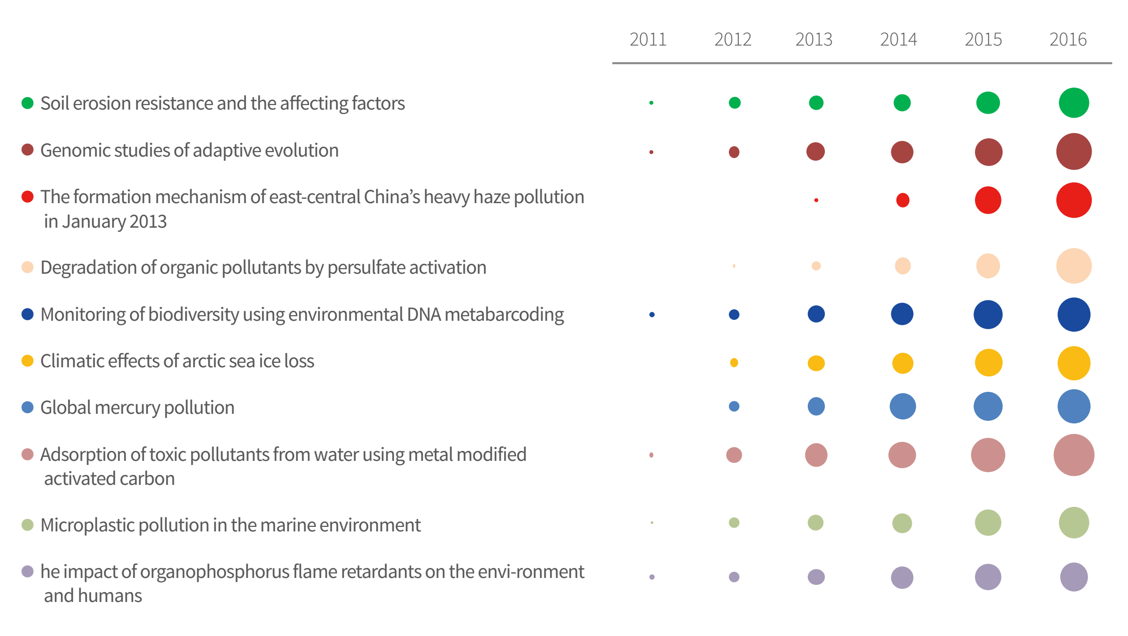
"Climatic effects of arctic sea ice loss" is the only Research Front related to global warming in the Top 10 hot Research Fronts this year. “Soil erosion resistance and the affecting factors” is the youngest hot Research Front on the list (that is, based on the average age of its core papers), focusing on the problem of soil erosion.

"Genomic studies of adaptive evolution" and "Monitoring of biodiversity using envi-ronmental DNA metabarcoding" are two hot Research Fronts in the field of ecology. Injecting fresh technology into the field, the work described in these fronts applies genomics techniques and environmental DNA metabarcoding technology to solve ecological problems.

Table 7: Top10 Research Fronts in ecology and environmental sciences

Number	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Soil erosion resistance and the affecting factors	28	1154	2014.6
2	Genomic studies of adaptive evolution	31	1685	2014.4
3	The formation mechanism of east-central China's heavy haze pollution in January 2013	22	1454	2014.4
4	Degradation of organic pollutants by persulfate activation	31	1370	2014.2
5	Monitoring of biodiversity using environmental DNA metabarcoding	42	2607	2013.9
6	Climatic effects of arctic sea ice loss	32	2329	2013.9
7	Global mercury pollution	27	1731	2013.9
8	Adsorption of toxic pollutants from water using metal modified activated carbon	29	3606	2013.8
9	Microplastic pollution in the marine environment	49	3730	2013.7
10	he impact of organophosphorus flame retardants on the envi-ronment and humans	26	1642	2013.7

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



1.2 KEY HOT RESEARCH FRONT – "The formation mechanism of east-central China's heavy haze pollution in January 2013"

In January 2013, extremely severe and persistent haze pollution swept central and east China, attracting worldwide attention. The most severe haze pollution events occurred in the Beijing-Tianjin-Hebei region and were much more complicated and serious than historical precedents such as the Great Smog of London in 1952 and the Los Angeles photochemical smog episodes in the 1940s and early 1950s

The original research in this hot Research Front focuses on the heavy haze episodes that occurred in east-central China in January 2013 as well as the subsequent haze pollution events. By measuring the chemical composition of haze pollutants, clarify-ing the contribution of various pollutants, and analyzing the formation mechanism of heavy haze episodes, the research provides the basis for formulating effective control measures. The results of these studies revealed that the high-intensity emission of pollution sources from coal, industry (steel, chemical industry, building materials and metallurgy etc.), vehicles and other mobile sources, biomass burning, and dust, are the five main sources of current air pollution in China.

The most-cited paper in this hot Research Front, "High secondary aerosol contribution to particulate pollution during haze events in China," published in *Nature* in 2014, has now received more than 300 citations. For the first time in the world, this paper re-veals that haze pollution in four cities – Beijing, Shanghai, Guangzhou and Xi'an – is largely due to the excessive proportion of secondary aerosols. In secondary aerosols, the proportion of organic aerosol and inorganic aerosol is quite the same. This is closely related to a large number of secondary aerosol precursors (especially volatile organic compounds, or VOCs) emitted from coal combustion and biomass combus-tion. This new discovery deepens the scientific understanding of the causes and sources of haze in China and provides a scientific basis for formulating control poli-cies and governance measures in the future.

Nine countries contributed to the core papers of this hot Research Front. Among them, China participated in all the 22 core papers (Table 8). Six were published jointly with the USA, accounting for 27.3% of the total. Authors affiliated with the Chinese Academy of Sciences were credited on 17 core papers, accounting for 77.3% of the total. Other top institutions contributing to core papers in this hot Research Front include: the China Meteorological Administration, Nanjing University of Information Science and Technology, Peking University, Tsinghua University, and the Paul Scherrer Institute.

Table 8: Top countries and institutions producing the 22 core papers in the Research Front "The formation mechanism of east-central China's heavy haze pollution in January 2013"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	China	22	100.0%	1	Chinese Academy of Sciences	China	17	77.3%
2	USA	6	27.3%	2	China Meteorological Administration	China	4	18.2%
3	Switzerland	3	13.6%	3	Nanjing University of Information Science and Technology	China	3	13.6%
4	Japan	2	9.1%	3	Peking University	China	3	13.6%
4	Germany	2	9.1%	3	Tsinghua University	China	3	13.6%
6	Italy	1	4.5%	3	Paul Scherrer Institute	Switzerland	3	13.6%

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
6	Finland	1	4.5%					
6	Russia	1	4.5%					
6	Sweden	1	4.5%					
6	Canada	1	4.5%					

In terms of countries whose authors cited the core papers of this hot Research Front, China published 662 citing papers, accounting for 86.1% of the total. The USA con-tributed 224 citing papers, or 29.1% of the total. Nine of the Top 10 citing institutions are located in China. The Paul Scherrer Institute is the only non-Chinese facility among the Top 10 citing institutions. The Chinese Academy of Sciences contributed 278 papers, which is 36.2% of the total amount and is far ahead of other institutions. Peking University, Tsinghua University and Nanjing University of Information Sci-ence and Technology rank 2nd to 4th, contributing 87, 81, and 80 citing papers, respec-tively. These institutions are also very active in producing core papers in this hot Re-search Front.

Table 9: Top countries/regions and institutions producing citing papers in the Research Front "The formation mechanism of east-central China's heavy haze pollution in January 2013"

Country Ranking	Country/ Region	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	662	86.1%	1	Chinese Academy of Sciences	China	278	36.2%
2	USA	224	29.1%	2	Peking University	China	87	11.3%
3	Switzerland	52	6.7%	3	Tsinghua University	China	81	10.5%
4	Germany	43	5.6%	4	Nanjing University of Information Science and Technology	China	80	10.4%
5	UK	37	4.8%	5	China Meteorological Administration	China	66	8.6%
6	Japan	34	4.4%	6	Paul Scherrer Institute	Switzerland	47	6.1%
7	Taiwan	24	3.1%	7	Beijing Normal University	China	37	4.8%
8	France	20	2.6%	7	Xi'an Jiaotong University	China	37	4.8%
9	Sweden	17	2.2%	9	Chinese Research Institute of Environmental Sciences	China	36	4.7%
10	Canada	16	2.1%	10	Nanjing University	China	32	4.2%

1.3 KEY HOT RESARCH FRONT – "Monitoring of biodiversity using environmental dna metabarcoding"

The concept of environmental DNA (eDNA), proposed at the end of 1980s, refers to a DNA sample collected from a variety of environmental samples, such as soil, sedi-ment, air, and water. These samples are easy to obtain and will not affect the wildlife itself or destroy the environment. With environmental DNA information, humans can better understand the quantity and survival status of organisms living in different en-vironments. eDNA metabarcoding is an emerging method based on DNA barcoding technology. This method extracts DNA directly from environmental samples. Com-bined with next-generation sequencing technology, this can effectively detect all spe-cies in environmental samples. eDNA overcomes the shortcomings of traditional spe-cies-identification methods. With higher efficiency and lower cost, it greatly expands the application of DNA barcoding in ecology.

Among the 42 core papers in this hot Research Front, 30 focus on the use of eDNA metabarcoding technology for monitoring aquatic ecosystems, evaluating biodiversity in freshwater and marine organisms, and surveying rare aquatic species (endangered species, invasive species, hard-to-trace species, etc.).. The other 12 core papers in-clude the application of this technology to rapidly assess and monitor the biodiversity of arthropod, animal, and bird populations, as well as analyzing the dietary patterns of animals. Other papers examine refinements to the technology itself, exploring the software, the primer specificity, and the sampling condition of eDNA metabarcoding.

Fifteen countries contributed to the 42 core papers. Among them, the USA has 24 core papers, accounting for 57.1% of the total. France and the UK participated in 10 and nine core papers, respectively. Denmark published six core papers while Australia, Canada and China each contributed to three. Seven of the Top institutions are from the USA, two from France, while Denmark, China and the UK can each claim one institution among the most prolific.

Table 10: Top countries/regions and institutions producing the 42 core papers in the Research Front "Monitoring of biodiversity using environmental DNA metabarcoding"

Country Ranking	Country/ Region	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	24	57.1%	1	United States Geological Survey	USA	7	16.7%
2	France	10	23.8%	2	University of Copenhagen	Denmark	6	14.3%
3	UK	9	21.4%	2	University of Grenoble Alpes	France	6	14.3%
4	Denmark	6	14.3%	2	University of Idaho	USA	6	14.3%
5	Australia	3	7.1%	2	University of Notre Dame	USA	6	14.3%
5	Canada	3	7.1%	6	Chinese Academy of Sciences	China	3	7.1%
5	China	3	7.1%	6	Spygen	France	3	7.1%
8	Switzerland	2	4.8%	6	University of East Anglia	UK	3	7.1%
9	Taiwan	1	2.4%	6	Smithsonian Institution	USA	3	7.1%
9	Egypt	1	2.4%	6	U.S. Department of Agriculture (USDA)	USA	3	7.1%
9	Japan	1	2.4%	6	University of Massachusetts Amherst	USA	3	7.1%
9	Malaysia	1	2.4%	6	University of Montana	USA	3	7.1%
9	Netherlands	1	2.4%					
9	Norway	1	2.4%					
9	Spain	1	2.4%					

In analyzing the citing paper, we found that the USA is the most active country, par-ticipating in 356 citing papers, 2.2 times as many as the second-place UK. China ranks 6th with 81 citing papers.

Among the Top 10 citing institutions, Chinese Academy of Sciences ranks 1st with 57 citing papers. The University of Grenoble Alpes and the United States Geological Survey each produced 41 citing papers, and tie for second place. The Centre National de la Recherche Scientifique (CNRS) takes 4th place.

Table 11: Top countries and institutions producing citing papers in the Research Front "Monitoring of biodiversity using environmental DNA metabarcoding"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	356	36.9%	1	Chinese Academy of Sciences	China	57	5.9%
2	UK	161	16.7%	2	University of Grenoble Alpes	France	41	4.3%
3	France	124	12.9%	2	United States Geological Survey	USA	41	4.3%
4	Canada	117	12.1%	4	Centre National de la Recherche Scientifique (CNRS)	France	40	4.1%
5	Australia	114	11.8%	5	University of Notre Dame	USA	34	3.5%
6	China	81	8.4%	6	University of Guelph	Canada	33	3.4%
7	Germany	77	8.0%	6	Natural History Museum in London	UK	33	3.4%
8	Spain	73	7.6%	8	University of Copenhagen	Denmark	27	2.8%
9	Japan	51	5.3%	9	Imperial College London	UK	23	2.4%
9	Switzerland	51	5.3%	9	Smithsonian Institution	USA	23	2.4%

4. GEOSCIENCES

1. HOT RESEARCH FRONT

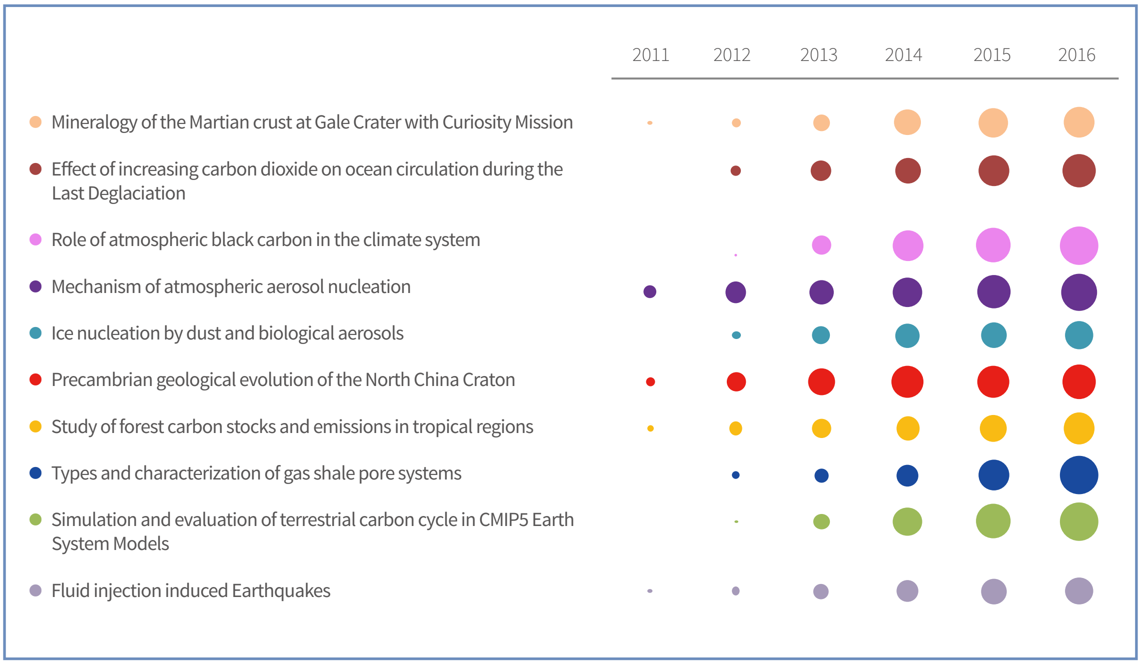
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN GEOSCIENCES

The Top 10 Research Fronts in geosciences mainly focus on climate change, geochemistry, and solid geophysics and geology. Topics examined in fronts related to climate change include the effect of increasing carbon dioxide on ocean circulation during the Last Deglaciation; the role of atmospheric black carbon in the climate system; the mechanism of atmospheric aerosol nucleation; and ice nucleation by dust and biological aerosols. Research Fronts related to geochemistry include the study of forest carbon stocks and emissions in tropical regions, along with the simulation and evaluation of terrestrial carbon cycle in CMIP5 Earth System Models. Research Fronts in solid geophysics and geology examine the mineralogy of the Martian crust at Gale Crater based on samples taken by the Curiosity rover; precambrian geological evolution of the North China Craton, types and characterization of gas shale pore systems; and fluid-injection-induced earthquakes associated with hydraulic fracturing, or fracking.

Table 12: Top10 Research Fronts in geosciences

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Mineralogy of the Martian crust at Gale Crater with Curiosity Mission	24	1496	2013.9
2	Effect of increasing carbon dioxide on ocean circulation during the Last Deglaciation	19	1316	2013.8
3	Role of atmospheric black carbon in the climate system	13	1672	2013.7
4	Mechanism of atmospheric aerosol nucleation	23	2548	2013.6
5	Ice nucleation by dust and biological aerosols	18	1440	2013.6
6	Precambrian geological evolution of the North China Craton	48	4054	2013.5
7	Study of forest carbon stocks and emissions in tropical regions	8	1140	2013.5
8	Types and characterization of gas shale pore systems	40	2743	2013.4
9	Simulation and evaluation of terrestrial carbon cycle in CMIP5 Earth System Models	18	1691	2013.3
10	Fluid injection induced Earthquakes	16	1122	2013.3

Figure 3: Citing papers of the top 10 Research Fronts in geosciences



1.2 KEY HOT RESEARCH FRONT – "Precambrian geological evolution of the North China Craton"

Cratons are the ancient and stable nucleus of the continental crust. Through a series of collisional orogenic events and continuous splicing together with young crust, cratons formed the basis of larger continents. Cratons recorded the early formation and evolution history of the continental crust, which is closely related to ore formation, climate change and biological evolution. Thus, cratons have significant research value.

The North China Craton is one of the oldest in the world, with the age of the old crust estimated at up to ~3.8Ga. Compared with other cratons, its multi-stage formation and evolution history is more complex. It has recorded almost all the important geological events of the Earth, which preserve the evidence for Precambrian crustal evolution history. Because 90% of the crust in the North China Craton was formed in the early Precambrian, mostly in the mid- to late Archeozoic era, the North China Craton offers an important window to investigate the Precambrian crustal evolution and plate movement. Understanding the geological evolution of the North China Craton during the Precambrian period can provide evidence for basic researches, such as the mechanism of early-earth crust formation, and determining when plate-tectonic activities started to play the leading role. These matters have attracted increasing attention in China and throughout the world in recent years.

The core papers of the key hot Research Front "Precambrian geological evolution of the North China Craton" focus on the geological structure, evolution, mineralization, and stitching of the North China Craton during the Precambrian period. The most-cited core paper (519 citations) in this Research Front is a review authored by Zhai Mingguo of the Institute of Geology and Geophysics, Chinese Academy of Sciences. This paper presents the synthesis of geological, geochronological and tectonic information pertaining to the Precambrian evolution and stabilization of the North China Craton.

Analysis of countries and institutions producing core papers (Table 13) shows China's predominance in this field. China-based researchers contributed to all 48 of the core papers, in cooperation with six other countries. Among the top institutions, eight are based in China, while two are in the USA. Japan and Australia are each represented by one institution. China University of Geosciences (Beijing) ranks first and contributed to 27 core papers (roughly 56% of the total), followed by the Chinese Academy of Geological Sciences, the University of Hong Kong, Kochi University, and the Chinese Academy of Sciences.

Table 13: Top countries and institutions producing the 48 core papers in the Research Front "Precambrian geological evolution of the North China Craton"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	China	48	100.0%	1	China University of Geosciences (Beijing)	China	27	56.3%
2	Australia	11	22.9%	2	Chinese Academy of Geological Sciences	China	12	25.0%
3	Japan	10	20.8%	3	University of Hong Kong	China	10	20.8%
4	USA	8	16.7%	3	Kochi University	Japan	10	20.8%
5	UK	2	4.2%	5	Chinese Academy of Sciences	China	9	18.8%
6	Russia	1	2.1%	6	Northwest University	China	7	14.6%

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
6	Germany	1	2.1%	7	Ocean University of China	China	6	12.5%
				8	University of Western Australia	Australia	4	8.3%
				8	Peking University	China	4	8.3%
				10	Shandong Gold Min Stock Co Ltd	China	3	6.3%
				10	Indiana University Bloomington	USA	3	6.3%
				10	United States Geological Survey	USA	3	6.3%

As for countries and institutions producing citing papers, China ranks first with 1,143 citing papers. China University of Geosciences (Beijing), Chinese Academy of Sciences, Chinese Academy of Geological Sciences, China University of Geosciences (Wuhan), and Peking University are the top 5 institutions that published a significant number of citing papers (Table 14). In the Top 10 institutions list, there are eight Chinese institutions, one Japanese institution, and one Australian institution.

Table 14: Top countries and institutions producing citing papers in the Research Front "Precambrian geological evolution of the North China Craton"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	1143	93.2%	1	China University of Geosciences (Beijing)	China	431	35.1%
2	Australia	185	15.1%	2	Chinese Academy of Sciences	China	380	31.0%
3	Japan	115	9.4%	3	Chinese Academy of Geological Sciences	China	289	23.6%
4	USA	70	5.7%	4	China University of Geosciences (Wuhan)	China	130	10.6%
5	India	53	4.3%	5	Peking University	China	113	9.2%
6	Canada	42	3.4%	6	Kochi University	Japan	97	7.9%
7	UK	35	2.9%	7	Northwest University	China	90	7.3%
8	Germany	29	2.4%	8	University of Hong Kong	China	73	5.9%
9	South Africa	20	1.6%	9	China Geological Survey	China	60	4.9%
10	South Korea	16	1.3%	10	University of Adelaide	Australia	51	4.2%

1.3 KEY HOT RESRACH FRONT – "Types and characterization of gas shale pore systems"

Shale gas is the free, adsorbed and dissolved gas accumulated in dark shale beds. Compared with traditional natural gas deposits, gas shales have the advantage of large gas-bearing areas, a long production cycle, and stable output. At the beginning of the twenty-first century, the USA and Canada took the lead in realizing the commercial development of shale gas and achieved great success. Shale gas research and exploration therefore attracted much attention and many investigations, which chiefly focused on the basic geological research, horizontal wells and hydraulic fracturing technology and related new technology development.

Since shale gas is mainly stored in shale pore space, the nature of pores emerged as a key factor in determining the gas reserves of shale gas reservoirs. At present, shale reservoir pores can be divided into five basic types: intergranular pore, mineral pore, organic pore, fossiliferous pore and microchannels. The study of characterization of pores in gas shale reservoir plays a key role in shale gas exploiting.

The 40 core papers of this key hot Research Front focus on the pore system and its structural characterization in gas shale located in Barnett, Texas (USA), Woodford, Oklahoma (USA), and the Sichuan Basin (China). These papers study the impact of pore structure on the capability of methane adsorption.

Among the 10 countries involved in this Research Front, China and the USA are the most active, contributing to 18 and 17 papers, respectively. Researchers based in Australia and Germany, meanwhile, contribute respectively to 10 and seven papers.

In terms of institutions, the Commonwealth Scientific & Industrial Research Organisation (Australia), RWTH Aachen University (Germany), and the University of Texas (UT), Austin (USA) each contribute to six papers, while Chinese Academy of Sciences contributes to five. The most-cited core paper in this Research Front, which was authored by R.G. Loucks from UT Austin, discusses a descriptive classification for matrix-related mudrock pores and has been cited 242 times.

Table 15: Top countries and institutions producing the 40 core papers in the Research Front "Types and characterization of gas shale pore systems"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	China	18	45.0%	1	Commonwealth Scientific & Industrial Research Organisation (CSIRO)	Australia	6	15.0%
2	USA	17	42.5%	1	RWTH Aachen University	Germany	6	15.0%
3	Australia	10	25.0%	1	University of Texas Austin	USA	6	15.0%
4	Germany	7	17.5%	4	Chinese Academy of Sciences	China	5	12.5%
5	Canada	3	7.5%	5	China University of Petroleum(Beijing)	China	4	10.0%
6	UK	2	5.0%	5	Indiana University Bloomington	USA	4	10.0%
6	Norway	2	5.0%	7	Oak Ridge National Laboratory	USA	3	7.5%
8	Poland	1	2.5%	7	Helmholtz Association	Germany	3	7.5%
8	Austria	1	2.5%	7	CONOCOPHILLIPS	USA	3	7.5%
8	France	1	2.5%	7	China University of Mining & Technology	China	3	7.5%
				7	China University of Geosciences (Beijing)	China	3	7.5%

With regard to citing papers, China contributes to more than half the total. The USA ranks 2nd with 281 citing papers. Germany, Australia, and Canada also perform actively in this Research Front and rank from 3rd to 5th respectively. The top three institutions producing citing papers are China University of Petroleum (Beijing), China University of Geosciences (Beijing), and the Chinese Academy of Sciences.

Table 16: Top countries and institutions producing citing papers in the Research Front "Types and characterization of gas shale pore systems"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	488	54.9%	1	China University of Petroleum (Beijing)	China	95	10.7%
2	USA	281	31.6%	2	China University of Geosciences (Beijing)	China	74	8.3%
3	Germany	78	8.8%	3	Chinese Academy of Sciences	China	70	7.9%
4	Australia	77	8.7%	4	University of Texas Austin	USA	61	6.9%
5	Canada	61	6.9%	5	China University of Mining & Technology	China	57	6.4%
6	France	43	4.8%	5	PetroChina	China	57	6.4%
7	UK	39	4.4%	7	RWTH Aachen University	Germany	42	4.7%
8	India	16	1.8%	8	Commonwealth Scientific & Industrial Research Organisation (CSIRO)	Australia	41	4.6%
9	Netherlands	16	1.8%	9	University of Calgary	Canada	33	3.7%
10	Poland	12	1.3%	9	Southwest Petroleum University	China	33	3.7%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN GEOSCIENCES

"Highly siderophile and strongly chalcophile elements in high-temperature geochemistry" was selected as the emerging Research Front of 2017 in Geosciences.

Table 17: Emerging Research Fronts in geosciences

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Highly siderophile and strongly chalcophile elements in high-temperature geochemistry	10	157	2015.8

2.2 KEY EMERGING RESARCH FRONT – “Highly siderophile and strongly chalcophile elements in high-temperature geochemistry”

As platinum-group elements (PGE, including Os, Ir, Ru, Rh, Pt, Pd and Re [Rhenium]) are highly siderophile (i.e,. “iron-loving”) and strongly chalcophile (i.e., having an affinity for sulfur) elements, their abundance in the crust and mantle are relatively low compared to those in the centrosphere. During crust-mantle differentiation, Re, as a moderately incompatible element, is enriched in the crust, while PGE are highly compatible and thus enriched in the mantle.

PGE are similar in physical and chemical properties but differ in melting temperature. Therefore PGE behave differently in the geological evolution process. Accordingly, PGE are an effective tracer of partial melting, core-mantle and crust-mantle interaction, sulfide differentiation, crystallization differentiation, magma evolution, and mineralization, and can offer great insights into the evolution and petrological characteristics of the mantle source.

The Re-Os isotope system (^{187}Re decays to ^{187}Os by β emission), based on its unique geochemical characteristics, has been widely used as a powerful tool for dating melt loss events and tracing crust-mantle interaction. With the continuous improvements in the detection method of Re-Os isotope, the dating and tracing applications of Re-Os isotope system in astrogeochemistry, mantle geochemistry, geology chronology, metal deposits, sediments, and water bodies have developed rapidly in recent years. The Pt-Os isotope system (^{190}Pt decays to ^{188}Os by alpha emission) is often applied in the research of core genesis, core-mantle interaction, mantle evolution, and the dating of sulfide deposit.

The emerging Research Front “Highly siderophile and strongly chalcophile elements in high-temperature geochemistry” focuses on revealing the planetary-evolution process based on the analysis of the distribution of PGE on Earth, Earth’s Moon, Mars, and asteroids. Papers in the front also examine the distributions and geochemical behaviors of highly siderophile and strongly chalcophile elements in lithospheric mantle, volcanics, and mantle rocks via the Re-Os and Pt-Os isotope systems. There are 10 core papers in this emerging front, mainly contributed by Germany, the UK, Canada, France, and the USA.

5.CLINICAL MEDICINE

1. HOT RESEARCH FRONT

1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN CLINICAL MEDICINE

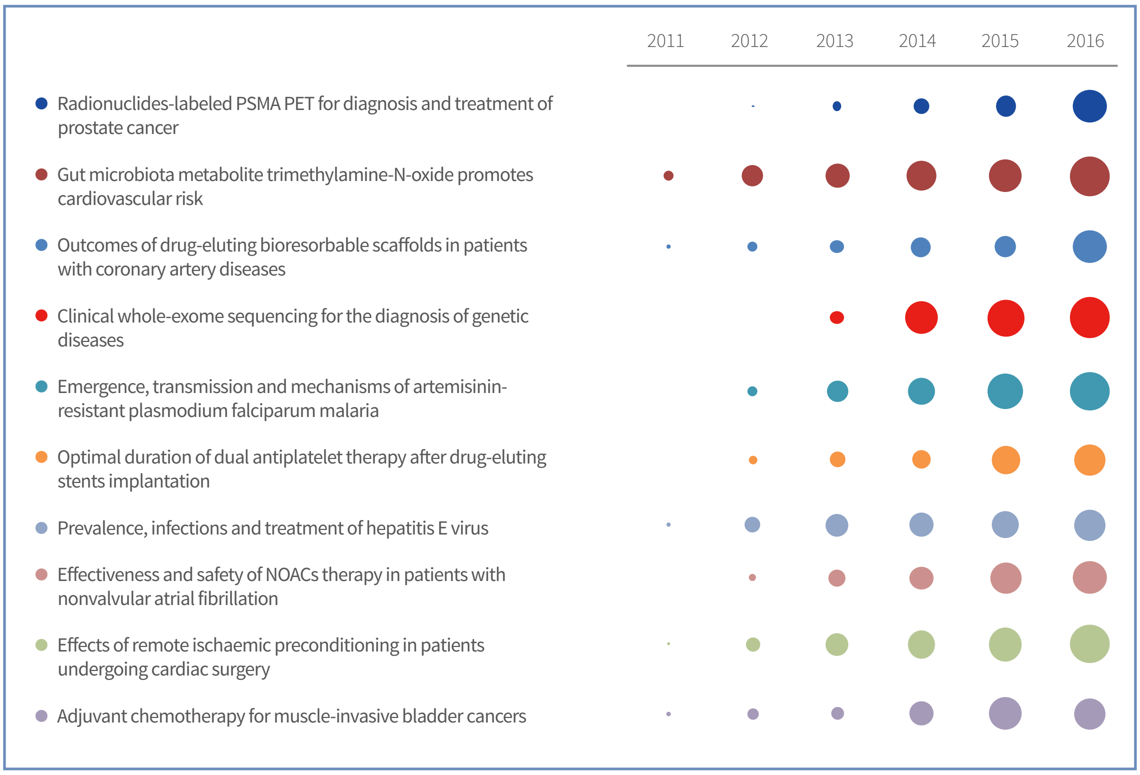
The Top10 Research Fronts in clinical medicine feature four areas: diagnosis and treatment of cardiovascular diseases; diagnosis and treatment of urogenital neoplasms; prevention and control of infectious diseases; and clinical whole-exome sequencing.

Five Research Fronts pertain to cardiovascular disease and its treatment, including drug-eluting bioresorbable scaffolds in coronary artery disease; optimal duration of dual antiplatelet therapy after stents implantation; gut microbiota metabolite trimethylamine-N-oxide (TMAO) and cardiovascular risk; effectiveness and safety of NOACs with nonvalvular atrial fibrillation; and effects of remote ischaemic preconditioning for patients undergoing cardiac surgery. On the topic of urogenital malignancies, the pertinent fronts concern radionuclides-labeled PSMA PET imaging in prostate cancer, along with adjuvant chemotherapy for muscle-invasive bladder cancer. Meanwhile, serious infectious diseases such as artemisinin-resistant plasmodium falciparum malaria and hepatitis E virus have raised great concern among scientists and public-health experts.

Table 18: Top10 Research Fronts in clinical medicine

Number	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Radionuclides-labeled PSMA PET for diagnosis and treatment of prostate cancer	36	1340	2015.2
2	Gut microbiota metabolite trimethylamine-N-oxide promotes cardiovascular risk	17	2333	2014.6
3	Outcomes of drug-eluting bioresorbable scaffolds in patients with coronary artery diseases	30	1582	2014.6
4	Clinical whole-exome sequencing for the diagnosis of genetic diseases	16	1838	2014.4
5	Emergence, transmission and mechanisms of artemisinin-resistant plasmodium falciparum malaria	24	2570	2014.3
6	Optimal duration of dual antiplatelet therapy after drug-eluting stents implantation	17	1867	2014.3
7	Prevalence, infections and treatment of hepatitis E virus	24	1747	2014.2
8	Effectiveness and safety of NOACs therapy in patients with nonvalvular atrial fibrillation	21	1396	2014.2
9	Effects of remote ischaemic preconditioning in patients undergoing cardiac surgery	29	2210	2014.1
10	Adjuvant chemotherapy for muscle-invasive bladder cancers	15	1375	2014.1

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



1.2 KEY HOT RESEARCH FRONT – "Radionuclides-labeled psma pet for diagnosis and treatment of prostate cancer"

Prostate cancer is the most common and the second leading cause of death from cancer in men in the USA. The incidence of prostate cancer in China has continued to rise in recent years, and the proportion of advanced-stage patients is much higher than that in the USA and Europe. Traditional methods such as serum PSA, CT, MRI, and PET-CT/MRI based on choline or fluorodeoxyglucose tracers are not sensitive enough in the diagnosis, staging, and reassessment of prostate cancer.

Prostate-specific membrane antigen (PSMA), an enzyme residing widely in membranes of prostate cancer cells, is playing a vital role in diagnosis and therapy because of its high specificity and reliability. Due to the long half-life of PSMA monoclonal antibodies in vivo, PSMA inhibitors glutamate-urea and its analogues or antibodies combined with radionuclides are most commonly used to improve imaging effects.

The key hot Research Front "Radionuclides-labeled PSMA PET for diagnosis and treatment of prostate cancer" includes 36 core papers, mainly involving radioactive tracers such as Ga-68, F-18, Lu-177, C-11, I-124/131 labeled PSMA PET/CT in the diagnosis, relapse surveillance, and treatment of prostate cancer. Among these papers, 16 concern Ga-68 labelled PSMA PET in prostate cancer recurrence, diagnosis, and treatment. These studies found that Ga-68 labelled PSMA PET could effectively detect lesions even PSA in low levels, showing high sensitivity and specificity in general. In March 2017, the European Association of Nuclear Medicine (EANM) and the Society of Nuclear Medicine and Molecular Imaging (SNMMI) jointly published a guideline for Ga68-PSMA PET/CT prostate-cancer imaging, providing recommendations on this examination.

Among top core-paper-publishing countries and institutions (Table 19), Germany contributes to 70% (25/36) of the total core papers, and six German research institutions are among the top 10, showing the absolute leading role of Germany in this Research Front. The USA ranks second in output of core papers, participating in 30% (11/36) of the core papers, with three institutions listed in the Top 10.

Table 19: Top countries and institutions producing the 36 core papers in the Research Front "Radionuclides-labeled PSMA PET for diagnosis and treatment of prostate cancer"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	Germany	25	69.4%	1	Heidelberg University	Germany	11	30.6%
2	USA	11	30.6%	2	Helmholtz Association of German Research Centres	Germany	10	27.8%
3	Italy	5	13.9%	3	Technical University of Munich	Germany	7	19.4%
4	Netherlands	3	8.3%	4	Johns Hopkins University	USA	5	13.9%
5	Australia	2	5.6%	5	University of Wurzburg	Germany	4	11.1%
6	Austria	1	2.8%	5	University of Bologna	Italy	4	11.1%
6	Belgium	1	2.8%	7	German Cancer Research Center	Germany	3	8.3%
6	Switzerland	1	2.8%	7	University of Munich	Germany	3	8.3%
6	Turkey	1	2.8%	7	Cornell University	USA	3	8.3%
				7	University of California Los Angeles	USA	3	8.3%

Analysis of the citing papers indicates that the USA and Germany are far ahead of the other listed nations, contributing about 40% and 30% of the total, respectively. In a count of the Top 10 institutions in terms of citing papers, almost all are based in Germany and the USA, with four from Germany, five from the USA, with the University of Bologna the sole representative of Italy.

Table 20: Top countries and institutions producing citing papers in the Research Front "Radionuclides-labeled PSMA PET for diagnosis and treatment of prostate cancer"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	Germany	209	39.8%	1	Technical University of Munich	Germany	52	9.9%
2	USA	163	31.0%	2	Heidelberg University	Germany	46	8.8%
3	Italy	50	9.5%	3	Helmholtz Association of German Research Centres	Germany	43	8.2%
4	Netherlands	36	6.9%	4	Johns Hopkins University	USA	37	7.0%
5	Australia	28	5.3%	5	Memorial Sloan Kettering Cancer Center	USA	18	3.4%
6	UK	28	5.3%	6	University of Bologna	Italy	17	3.2%
7	Switzerland	22	4.2%	6	University of California Los Angeles	USA	17	3.2%
8	France	21	4.0%	8	Cornell University	USA	16	3.0%
9	Belgium	19	3.6%	8	National Institutes of Health (NIH)	USA	16	3.0%
10	China	16	3.0%	10	University of Ulm	Germany	14	2.7%

1.3 KEY HOT RESEARCH FRONT – "Clinical whole-exome sequencing for the diagnosis of genetic diseases"

The exome is the part of genome formed by exons. The human exome consists of roughly 180,000 exons, constituting about 1% of the genome, while mutations in the exome are thought to cover 85% of mutations that relate to genetic diseases. Whole-exome sequencing (WES), a transcriptomics technique for sequencing an exome, consists of selecting only the subset of DNA that encodes proteins and sequencing the exonic DNA using high-throughput DNA-sequencing technology. Whole-exome sequencing is more cost-effective and efficient than whole-genome sequencing, therefore, more and more researchers and commercial companies are turning to whole-exome sequencing.

Whole-exome sequencing has been applied in clinical gene diagnosis since 2009. In 2010, whole-exome sequencing was selected as a top scientific breakthrough by *Science*. The 16 core papers in this Research Front record the improvement of whole-exome sequencing's diagnostic rate for different conditions since 2013. These studies confirmed that clinical diagnostic rate of whole-exome sequencing could range from 25% to 41%, which was comparable to or even better than traditional molecular diagnostic techniques. These studies provide strong evidence for the application of whole-exome sequencing in pathogenic gene detection of various Mendelian diseases (single-gene diseases), in the gene-mutation study of complex diseases, and in the genetic diagnosis of clinical diseases. Precision medicine will undoubtedly propel the future development of medical technology. With the rapid development of next-generation sequencing technology, it is foreseeable that whole-exome sequencing will have wider applications in pathogenic gene detection and gene diagnosis.

All 16 core papers in this hot Research Front are swept by the USA, Canada, the UK and Sweden (Table21). The USA contributes 81.3% of the core papers and more than 70% of the top institutions in terms of publishing core papers are located in the USA. Baylor College of Medicine, with a contribution of six core papers, stands out in this Research Front.

Table 21: Top countriesand institutions producing the 16 core papers in the Research Front "Clinical whole-exome sequencing for the diagnosis of genetic diseases"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	13	81.3%	1	Baylor College of Medicine	USA	6	37.5%
2	Canada	3	18.8%	2	University of Texas Health Science Center at Houston	USA	3	18.8%
3	Sweden	1	6.3%	3	McGill University	Canada	2	12.5%
3	UK	1	6.3%	3	McMaster University	Canada	2	12.5%
				3	Memorial University of Newfoundland	Canada	2	12.5%
				3	University of Alberta	Canada	2	12.5%
				3	University of Toronto	Canada	2	12.5%
				3	Duke University	USA	2	12.5%
				3	Harvard University	USA	2	12.5%
				3	Howard Hughes Medical Institute	USA	2	12.5%
				3	Johns Hopkins University	USA	2	12.5%
				3	National Institutes of Health (NIH)	USA	2	12.5%
				3	University of California Los Angeles	USA	2	12.5%
				3	University of Chicago	USA	2	12.5%
				3	University of Minnesota Twin Cities	USA	2	12.5%
				3	University of North Carolina Chapel Hill	USA	2	12.5%
				3	Vanderbilt University	USA	2	12.5%

Analysis of citing papers (table 22) demonstrates that the USA is still the most productive country, with a contribution of 65.4% of the total. Nine out of the Top 10 institutions are based in the USA, which fully reflects the nation's absolute leading position and excellent follow-up trends. Baylor College of Medicine once again proves itself to be the most prominent institution in this front, with participation in 10.1% of the total citing papers.

Table 22: Top countries and institutions producing citing papers in the Research Front "Clinical whole-exome sequencing for the diagnosis of genetic diseases"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	816	65.4%	1	Baylor College of Medicine	USA	126	10.1%
2	Canada	152	12.2%	2	Harvard University	USA	121	9.7%
3	UK	146	11.7%	3	Howard Hughes Medical Institute	USA	99	7.9%
4	Germany	97	7.8%	4	National Institutes of Health (NIH)	USA	81	6.5%
5	Netherlands	94	7.5%	5	University of Pennsylvania	USA	62	5.0%
6	Australia	83	6.7%	6	Columbia University	USA	56	4.5%
7	France	56	4.5%	7	University of North Carolina Chapel Hill	USA	55	4.4%
8	Italy	54	4.3%	8	University of Toronto	Canada	53	4.3%
9	Belgium	46	3.7%	9	Stanford University	USA	51	4.1%
10	China	46	3.7%	10	Johns Hopkins University	USA	46	3.7%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CLINICAL MEDICINE

Nine Research Fronts in clinical medicine have been selected as emerging research fronts this year. These fronts Nine Research Fronts in clinical medicine have been selected as emerging fronts this year. These mainly focus on five areas: diagnosis and treatment of cancer; prevention and control of infectious diseases; cardiovascular diseases treatment; risks of commonly used drugs; and new drug design. Five Research Fronts are related to cancer diagnosis and treatment, including immune-related adverse effects of anti-PD-1, clinical trials of B-cell lymphoma CD19-CART therapy, second generation BTK kinase inhibitors for CLL and their expanding adaptation populations, 21-Gene recurrence score in early stage breast cancer, and MET 14 skipping mutations as target for lung cancers. Besides those, the prevention and control of Zika virus infections, the risks of proton pump inhibitors, the long-term results of stenting versus endarterectomy for carotid-artery stenosis, and the discovery and design of bromodomains (BRDs) inhibitors discovery and drug design, also enter the list of emerging Research Fronts this year.

Table23: Emerging Research Fronts in clinical medicine

Number	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Zika virus infections and prevention	6	372	2016
2	Immune-related adverse events of anti-PD-1 therapy	8	113	2016
3	Clinical trial of CD19 CAR-T cells therapy in b-cell malignancies	7	110	2015.9
4	Long-term results of stenting versus endarterectomy for carotid-artery stenosis	5	128	2015.8
5	BTK inhibitors continue to advance chronic lymphocytic leukemia treatment: selective BTK inhibitors and for treatment-naive older patients	7	202	2015.7
6	Risks of proton pump inhibitors (PPIs) medications	3	109	2015.7
7	21-Gene recurrence score to guide decisions on chemotherapy for early breast cancer	3	104	2015.7
8	MET exon 14 skipping mutations as an important therapeutic target in non-small-cell lung cancer	5	146	2015.6
9	Bromodomains (BRDs) inhibitors discovery and drug design	12	289	2015.6

2.2 KEY EMERGING RESARCH FRONT – “Zika virus infections and prevention”

Zika is a member of the virus family Flaviviridae. It is spread by daytime-active Aedes mosquitoes. In early 2015, a widespread epidemic of Zika fever spread from Brazil to other parts of the Americas. Since then, the virus has continued to spread, posing a threat to global public health. Prevention and control of Zika virus infections has become an important and urgent public-health issue.

Six core papers identify this emerging Research Front. Among them, two reports demonstrate a likely association between Zika virus infections during pregnancy and neonatal microcephaly or fetal death. The United States Centers for Disease Control and Prevention (CDC) detected nucleic acid and antigens of Zika virus in brain and placental tissues from microcephaly and aborted fetuses in Brazil by RT-PCR/immunohistochemistry method in December 2015. Albert Ko, et al., from Yale University, also reported the detection of Zika virus RNA from brain and amniotic fluid of a dead fetus with complications of hydrocephalus, microcephaly and hydranencephaly in a case of a 20-year-old pregnant Salvadoran woman in February 2016.

The other four core papers concern epidemic reports, prevention guidance, and warnings regarding Zika virus for pregnant travelers. The CDC noted that the virus was spreading in 26 American countries and regions as of February 9th 2016, among which Brazil had the worst situation. As estimated by the Ministry of Health in Brazil, there were about 44~130 million suspected cases in Brazil by the end of 2015. Congenital microcephaly increased significantly at the time of Zika virus infection outbreak, and some patients developed Guillain-Barre Syndrome after infection with the virus. Because Zika virus infection during pregnancy might cause neonatal microcephaly or other adverse pregnancy outcomes, in January 2016 the CDC issued travel warnings for pregnant women, advising them to postpone travel to Zika-virus-endemic areas. Shortly after that, the CDC announced interim guidelines for pregnant women with possible Zika virus exposure. In July 2016, the CDC updated the guideline, suggesting those pregnant women who resided in or once travelled to Zika virus epidemic areas or those pregnant women having had unprotected sex with partners resided in or once travelled to Zika virus epidemic areas, to make clinical monitoring plans according to whether they had relevant symptoms, the period of time after exposure, and residence in endemic areas or not.

6. BIOLOGICAL SCIENCES

1. HOT RESEARCH FRONT

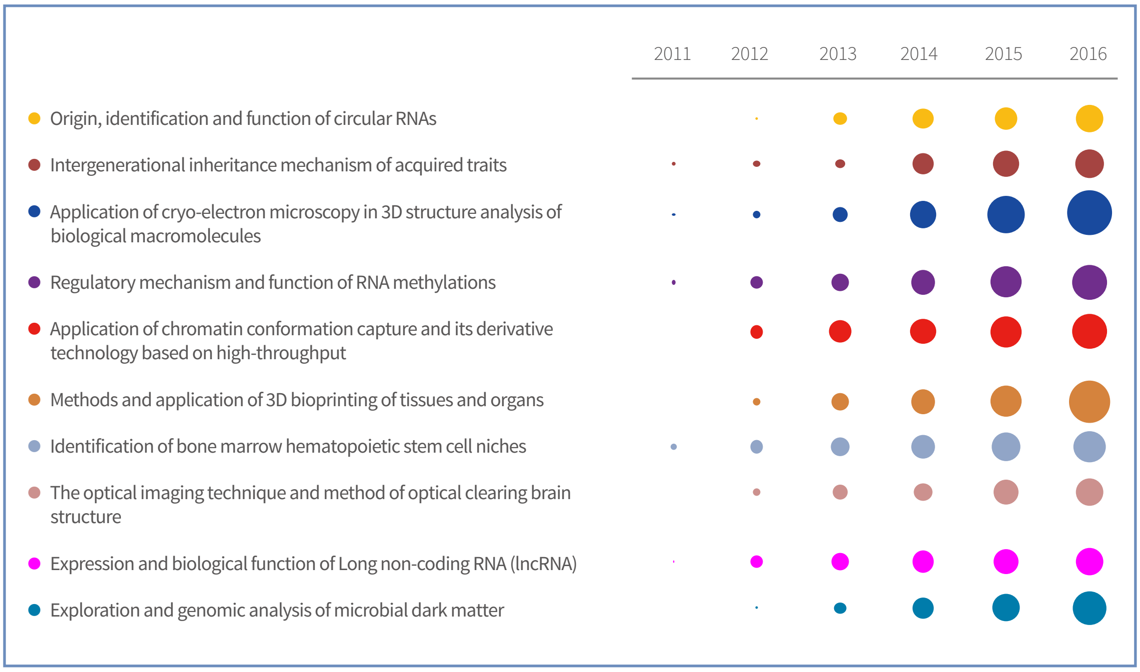
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN BIOLOGICAL SCIENCES

The Top10 Research Fronts in biological sciences focus on RNA research as well as breakthroughs and application of technology and methods, including circular RNAs, mRNA, lncRNA, cryo-electron microscopy, 3D bioprinting, and optical imaging technology of brain structure. Compared with other areas, the mean year of core papers underlying the hot Research Fronts in biological sciences is the youngest. Among them, "Application of cryo-electron microscopy in 3D structure analysis of biological macromolecules" and “Application of chromatin conformation capture and its derivative technology based on high-throughput" were selected as two key Research Fronts in biological sciences.

Table 24: Top10 Research Fronts in biological sciences

Number	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Origin, identification and function of circular RNAs	24	2424	2014.6
2	Intergenerational inheritance mechanism of acquired traits	14	1361	2014.3
3	Application of cryo-electron microscopy in 3D structure analysis of biological macromolecules	38	3834	2014.2
4	Regulatory mechanism and function of RNA methylations	37	3864	2014.1
5	Application of chromatin conformation capture and its derivative technology based on high-throughput	14	3125	2014.1
6	Methods and application of 3D bioprinting of tissues and organs	28	2630	2014.1
7	Identification of bone marrow hematopoietic stem cell niches	14	2179	2014.1
8	The optical imaging technique and method of optical clearing brain structure	15	1717	2014.1
9	Expression and biological function of Long non-coding RNA (lncRNA)	13	1604	2014.1
10	Exploration and genomic analysis of microbial dark matter	14	1543	2014.1

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



1.2 KEY HOT RESEARCH FRONT – "Application of cryo-electron microscopy in 3D Structure Analysis of Biological Macromolecules"

Although cryo-electron microscopy, X-ray crystallography and nuclear magnetic resonance are known as the three major tools for structural biology research, cryo-electron microscopy (Cryo-EM) has been the weakest technique. Although the technique was proposed in the 1970s, there was no breakthrough in the resolution of Cryo-EM until the beginning of the 21st century. This lack of development of Cryo-EM limited its application in the field of structural analysis of biological macromolecules.

In recent years, Cryo-EM has made revolutionary progress. The atomic level of spatial resolution obtained, once impossible, can now be applied to research on the structure of biological macromolecules. More and more breakthroughs in Cryo-EM and the structural analysis of important biological macromolecules have been published in top journals. The 38 core papers of this hot Research Front record these milestones.

One of the most important reasons for the revolutionary progress of Cryo-EM is the development of direct electron-detector (DDD). In October 2013, Yifan Cheng and David Julius's team at the University of California, San Francisco, successfully achieved nearly 90,000 single-particle images by the new generation of DDD camera (Gatan K2 camera). They obtained the 3.4 Å (1 Å is one-tenth of 1 nm) high-resolution three-dimensional structure of transient receptor potential (TRP) channel protein (TRPV1) tetramer, which is near atom-level. Two papers were published in *Nature*, and their citation tallies (384 and 229) are among the Top 5 in this Research Front. The determination of the protein TRPV1 structure marks the "atomic resolution" era of Cryo-EM. Subsequently, Cryo-EM has undergone incredibly rapid development and been widely applied. The structures of many important biomacromolecules and complexes that are difficult to obtain using X-ray crystallography methods are being analyzed.

In 2014, Sjors Scheres at the British Medical Research Council (MRC) Molecular Biology Laboratory successfully obtained the image of a large subunit of yeast mitochondrial ribosomes by improved electron microscopy, with a resolution of 3.2 Å. In 2015, Yigong Shi, a professor at Tsinghua University, published two of this front's core papers. They revealed the electron-microscopic structure of human γ-secretase with a resolution of 3.4 Å for the first time, which provided an important basis for understanding the mechanism of γ-secretase and the pathogenesis of Alzheimer's disease. Subsequent studies gradually improved the resolution to 2.8 Å, 2.6 Å and 2.2 Å. In 2016, Sriram Subramaniam at the National Cancer Institute published the structure of glutamate dehydrogenase, whose resolution even reached 1.8 Å.

The revolutionary progress of Cryo-EM has also benefitted from the development of image-processing software, in addition to breakthroughs in image-processing hardware. In 2012, Sjors Scheres developed the RELION algorithm to more effectively deal with low signal-to-noise ratio image; this advancement could also be used to analyze a single-particle structure. As the most-cited paper in the hot Research Front, this core paper has been cited 414 times.

The analysis of the biological macromolecules structure has not only far-reaching significance, but also wide applications. Researchers can understand the function of nucleic acids, proteins, and their complexes more thoroughly by analyzing their structure. Drug design, gene modification, vaccine development, and artificial protein construction can be carried out based on their functional structure, greatly aiding pharmaceutical development, medicine, disease prevention, biochemical engineering, and other areas.

Nine countries produced the 38 core papers in this Research Front, with notable participation by UK and the USA, which each contributed to 16 core papers each and are far ahead of the other listed countries. China ranks 3rd with five core papers accounting for 13.1% of the total. In terms of institutions, the UK's MRC performs best, with 15 core papers, accounting for 39.5% of all core papers, followed by the University of California ,San Francisco, with eight core papers, constituting 21.1% of the total. Of the five core papers from China, Tsinghua University published four and tied for 3rd place with the Howard Hughes Medical Institute in the USA.

Table 25: Top countries and institutions producing the 38 core papers in the Research Front "Application of cryo-electron microscopy in 3D Structure analysis of biological macromolecules"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	UK	16	42.1%	1	British Medical Research Council (MRC)	UK	15	39.5%
1	USA	16	42.1%	2	University of California San Francisco	USA	8	21.1%
3	China	5	13.2%	3	Tsinghua University	China	4	10.5%
4	Germany	3	7.9%	3	Howard Hughes Medical Institute	USA	4	10.5%
4	Switzerland	3	7.9%	5	Swiss Federal Institute of Technology in Zurich	Switzerland	3	7.9%
6	Netherlands	1	2.6%	5	University of Zurich	Switzerland	3	7.9%
6	Russia	1	2.6%	5	National Institutes of Health (NIH)	USA	3	7.9%
6	Australia	1	2.6%	8	Max Planck Society	Germany	2	5.3%
6	Austria	1	2.6%	8	Harvard University	USA	2	5.3%

The USA published 867 citing papers, or 47.5% of the total, followed by the UK with 315 citing papers, accounting for 17.3%. Germany ranks 3rd with 287 citing papers (15.7%). China produced 189 citing papers to rank 4th. All the Top 10 citing institutions are based within those four countries. The MRC Molecular Biology Laboratory and the Howard Hughes Medical Institute contributed 114 and 112 citing papers, respectively. Two institutions from China, Tsinghua University and the Chinese Academy of Sciences, contributed almost the same number of citing papers as the Max Planck Institute in Germany.

Table 26: Top countries and institutions producing citing papers in the Research Front "Application of cryo-electron microscopy in 3D structure analysis of biological macromolecules"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	867	47.5%	1	British Medical Research Council (MRC)	UK	114	6.3%
2	UK	315	17.3%	2	Howard Hughes Medical Institute	USA	112	6.1%
3	Germany	287	15.7%	3	University of California San Francisco	USA	62	3.4%
4	China	189	10.4%	4	Tsinghua University	China	58	3.2%
5	France	128	7.0%	4	Max Planck Society	Germany	58	3.2%
6	Canada	89	4.9%	6	Chinese Academy of Sciences	China	56	3.1%

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
7	Japan	86	4.7%	7	University of Oxford	UK	53	2.9%
8	Switzerland	85	4.7%	8	Harvard University	USA	52	2.9%
9	Spain	72	3.9%	8	University of California Berkeley	USA	52	2.9%
10	Netherlands	68	3.7%	10	National Institutes of Health (NIH)	USA	48	2.6%

1.3 KEY HOT RESARCH FRONT – "Application of chromatin conformation capture and its derivative technology based on high-throughput"

In recent years, with the evolution of high-throughput sequencing technology, scientists have developed a series of new techniques to study the advanced structure of chromatin in the nucleus at the molecular level, promoting the rapid development of chromatin advanced-structure research. The chromosome conformation capture (3C) and its derivative technology are used widely and promote research into three-dimensional structural reconstruction of chromosome and chromatin regulation function. Work along these lines has now achieved sufficient mass and velocity to become a hot Research Front. This Research Front is closely related to and evolves from an emerging front identified in 2016: "Principles of chromatin looping and evolution of chromosomal domain architecture."

The 3C derivative technology of chromosome conformation capture based on high-throughput includes two technologies: Hi-C and ChIP-PET. They both interpret the spatial conformation of endonuclear chromatin and the relationship between protein and chromatin from the perspective of the whole genome. Among the 14 core papers in this Research Front, 12 are directly related to Hi-C technology. The studies in this front mainly focus on the basic mechanism of chromatin folding and regional formation and its relationship with chromatin function.

Topologically associated domain and chromatin loops are two different phenomena in the study of chromatin conformation. In 2012, four independent research groups analyzed the chromosome conformation information of different species by Hi-C and found the self-interacting genome unit, which is called topological association domain (TAD). Researchers from the Ludwig Cancer Institute have studied the three-dimensional folding structure of DNA in the nucleus chromosome and found that the topological domain is the most basic folding unit. This paper's citation total, now exceeding 900, is the highest among all the 14 core papers. Researchers from the University of Massachusetts Medical School and the Weizmann Institute of Science have found similar topologies in the mouse X chromosome and the *Drosophila* genome, respectively, which supported the aforementioned findings. In addition, the mechanism of chromatin looping and its location and the influence of CTCF protein on the genome structure are also important parts of this Research Front, which establishes an important foundation on which to further understand the structure and function of the three-dimensional genome and the development of disease.

Nine countries participated in the 14 core papers identifying this Research Front. The USA has the strongest showing, with 13 core papers accounting for 92.9% of the total, which is far ahead of the other countries. France has four core papers, ranking 2nd, followed by China and its three core papers. Analyzing the research institutions producing core papers shows that all the top institutions are located in the USA or France. The Massachusetts Institute of Technology contributed five core papers, followed by the Centre National de la Recherche Scientifique (CNRS), Harvard University and the Howard Hughes Medical Institute, contributing to four papers each.

Table 27: Top countries and institutions producing the 14 core papers in the Research Front "Application of chromatin conformation capture and its derivative technology based on high-throughput"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	13	92.9%	1	Massachusetts Institute of Technology (MIT)	USA	5	35.7%
2	France	4	28.6%	2	Centre National de la Recherche Scientifique (CNRS)	France	4	28.6%
3	China	3	21.4%	2	Harvard University	USA	4	28.6%
4	Netherlands	2	14.3%	2	Howard Hughes Medical	USA	4	28.6%
4	Germany	2	14.3%	5	National Institutes of Health (NIH)	USA	3	21.4%
6	Israel	1	7.1%	5	University of California San Diego	USA	3	21.4%
6	Italy	1	7.1%	7	Institut Curie	France	2	14.3%
6	Poland	1	7.1%	7	Institut National de la Sante et de la Recherche Medicale (INSERM)	France	2	14.3%
6	Belgium	1	7.1%	7	Baylor College of Medicine	USA	2	14.3%
				7	Broad Institute	USA	2	14.3%
				7	Ludwig Institute for Cancer Research	USA	2	14.3%
				7	Rice University	USA	2	14.3%
				7	Stanford University	USA	2	14.3%

Analysis of citing papers demonstrates that the USA is still the most productive country, with 810 citing papers, representing more than half the total. Although no UK-based authors are credited in the core papers in this Research Front, the UK had 192 citing papers to rank 2nd. France, Germany, China, and the Netherlands each published more than 100 citing papers. Seven of the Top 10 citing institutions are from the USA, among which Howard Hughes Medical Institute and Harvard University are the most productive with 116 and 99 articles respectively.

Table 28: Top countries and institutions producing citing papers in the Research Front "Application of chromatin conformation capture and its derivative technology based on high-throughput"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	810	54.3%	1	Howard Hughes Medical	USA	116	7.8%
2	UK	192	12.9%	2	Harvard University	USA	99	6.6%
3	France	158	10.6%	3	National Institutes of Health (NIH)	USA	64	4.3%
4	Germany	151	10.1%	4	Centre National de la Recherche Scientifique (CNRS)	France	58	3.9%
5	China	118	7.9%	5	Massachusetts Institute of Technology (MIT)	USA	57	3.8%
6	Netherlands	108	7.2%	6	University of California San Diego	USA	53	3.6%

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
7	Canada	75	5.0%	7	Stanford University	USA	44	2.9%
8	Spain	65	4.4%	8	University of Cambridge	UK	43	2.9%
9	Switzerland	64	4.3%	9	Russian Academy of Sciences	Russia	41	2.7%
10	Italy	61	4.1%	10	New York University	USA	40	2.7%
				10	University of Pennsylvania	USA	40	2.7%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN BIOLOGICAL SCIENCES

Nine emerging Research Fronts have been selected in this biological sciences area. Most of the fronts are closely related to human health, including the pathogenesis of Zika, neutrophils, antibody conjugated drug testing, RAS oncogene, and more. Meanwhile, "The Structure of Zika Virus and Its Pathogenic Mechanism " is also selected as an emerging front in Clinical Medicine, reflecting the concern of the international community on this epidemic.

Table 29: Emerging Research Fronts in biological sciences

Number	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	The Structure of Zika Virus and Its Pathogenic Mechanism	20	359	2016
2	Neutrophil and necroptosis	7	114	2016
3	The method of characterization and detection of antibody-drug conjugates	9	109	2015.9
4	Plasticity of innate lymphoid cell	6	108	2015.8
5	Structural basis and activity of histone methyltransferase	4	107	2015.8
6	Species phylogenetic patterns and gene introgression in mosquito species	6	171	2015.7
7	Dynamics and real-time Imaging of translation of single mRNAs in Live Cells	7	164	2015.7
8	Ensembles and Allostery of Ras Conformation	9	124	2015.7
9	High resolution molecular structure of U4/U6.U5 tri-snRNP	8	215	2015.6

2.2 KEY EMERGING RESEARCH FRONT – "Introgression of Mosquito and its reticular phylogenetic patterns"

Malaria is transmitted exclusively through the bite of Anopheles mosquitoes. However, only a few dozen species among hundreds of species of *Anopheles* can cause malaria in humans, and only a few are very efficient vectors of disease agents. Scientists discovered this selective ability more than a century ago, and explored the biological roots actively. Introgression and reticulation can affect all aspects of phylogenetic development, not limited to similar species. Introgression has important practical significance, especially in the management of transgenic organisms in pest control.

Historically, the lack of genomic resources on *Anopheles* confined investigation to the key characteristic of several genes that affect the ability of *Anopheles* to transmit Plasmodium. In 2015, a research team led by Daniel Deafsey, from the Broad Institute, and Nora Besansky from the University of Notre Dame, sequenced 16 *Anopheles* genomes. Members of the group from around the world examined the reproductive processes of mosquitoes, along with immune response, resistance to insecticide, and genes related to the mechanism of chemoreception. This work revealed significant genetic differences in the life-threatening infections caused by certain species of *Anopheles*. The core paper relating to this research is the most-cited one in this emerging front (76 citations). In 2016, researchers from Rice University designed a new method of quantifying the use of reticular branches in the phylogenetic network for each genomic region in order to elucidate the extent and pattern of introgression. This method was applied to the mosquito dataset and revealed the evolutionary history of all chromosomes.

This emerging Research Front also provides new insights into the genetic relationships of some species and how the evolution of the *Anopheles* genome contributes to their flexibility to adapt to new environments and target human blood. With the development of new sequencing and bioinformatics analysis techniques, these sequenced genomes have made important contribution to enrich scientific resources that will deepen the understanding of the different biological characteristics of mosquitoes and help to eliminate the diseases that have significant impact on global public health.

7.CHEMISTRY AND MATERIALS SCIENCE

1.HOT RESEARCH FRONT

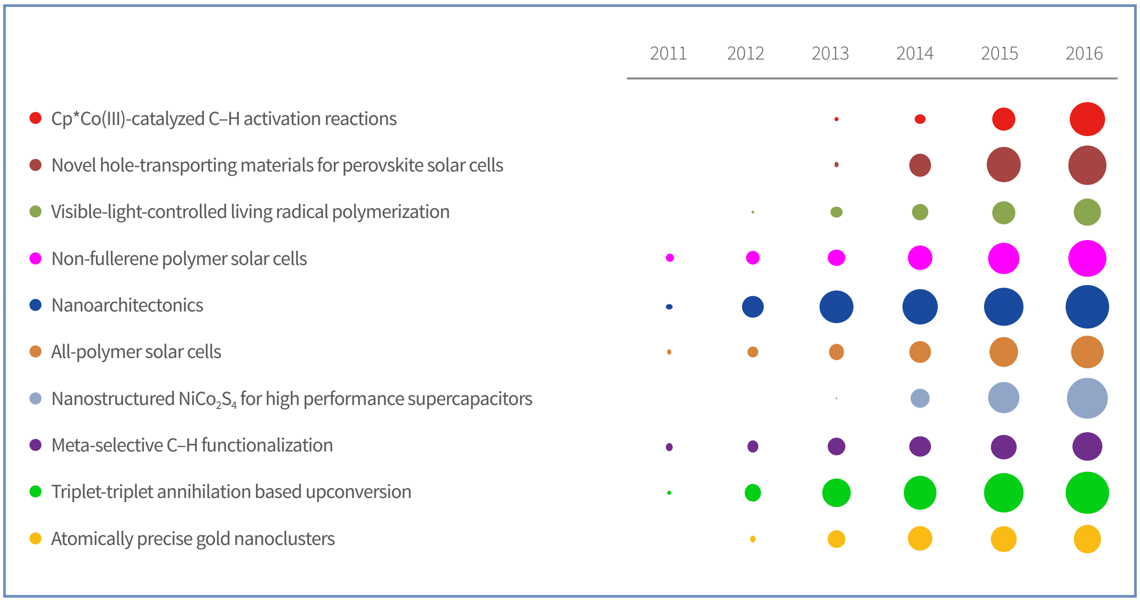
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

The hot Research Fronts in chemistry and materials science cover the topics of solar cells, organic synthesis, nanotechnology, supercapacitors, radical polymerization and upconversion. Compared with the previous years, both consistency and development have been highlighted in the 2017 Top10 hot Research Fronts. In the topic of solar cells, non-fullerene acceptors have been a hot direction in polymer solar cells research for two consecutive years, and novel hole-transporting materials have become a new focus in perovskite solar-cell research. Transition-metal-catalyzed C-H functionalizaiton has always been a hot topic in organic synthesis. In 2013 and 2014, Research Fronts concerning Ru/Rh catalysts were selected. This year, Co catalysts have come to the fore and *meta*-chemoselective functionalization has become a new focus. The topic of nanotechnology accounts for two hot fronts: the concept of nanoarchitectonics, and the precise assembly of Au nanoclusters. High-performance supercapacitors based on nanopore carbon electrode or nanostructured MnO_2 electrode have previously figured among the hot Research Fronts (2014) or emerging Research Fronts (2016). This year, the pertinent front focuses on $NiCo_2S_4$ based supercapacitors. In the topic of radical polymerization, visible-light-controlled polymerization, the subject of one of the emerging Research Fronts in 2014, has become a hot Research Front this year. In the area of upconversion, “Triplet-triplet annihilation based upconversion” is highlighted as one of Top 10 hot Research Fronts.

Table 30: Top10 Research Fronts in chemistry and materials science

Number	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Cp*Co(III)-catalyzed C-H activation reactions	36	2189	2015.1
2	Novel hole-transporting materials for perovskite solar cells	29	2359	2014.7
3	Visible-light-controlled living radical polymerization	30	1873	2014.7
4	Non-fullerene polymer solar cells	44	3532	2014.5
5	Nanoarchitectonics	25	2837	2014.4
6	All-polymer solar cells	22	2146	2014.2
7	Nanostructured $NiCo_2S_4$ for high performance supercapacitors	25	2144	2014.2
8	Meta-selective C-H functionalization	20	1552	2014.2
9	Triplet-triplet annihilation based upconversion	21	2947	2013.9
10	Atomically precise gold nanoclusters	15	1598	2013.9

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



1.2 KEY HOT RESEARCH FRONT – "Cp*Co(III)-catalyzed C–H activation reactions"

Differing from conventional synthetic chemistry based on the transformations among the functional groups, direct C-H functionalization does not require prefunctionalized starting materials, which otherwise have to be prepared in separate steps. This advantage is very attractive in terms of both atom- and step-economy. During the last decade, transition-metal-catalyzed direct C-H functionalization has emerged as a powerful synthetic methodology. Due to the high cost of the more extensively developed catalyst systems based upon precious metals – for example, Ru, Rh, Ir, Pt, Au and Ag – it is not surprising that C-H functionalization employing earth-abundant first-row metals such as Mn, Fe, Co, Ni, and Cu, has increasingly been investigated as an attractive alternative due to availability and cost. This change has also been reflected in the series of Research Fronts reports. "Transition-metal-catalyzed C-H functionalization" has been among the Top 10 Research Fronts in chemistry and materials science several times. Ru/Rh catalysts were selected in 2013 and 2014; this year, Co catalysts have gained prominence.

Co-catalyzed C-H activation reactions can be classified into two categories: low-valent Co catalysis (Co^{II}) and high-valent Co catalysis (Co^{III}). Co^{II}-catalyzed C-H activation pioneered by Nakamura, Ackermann, and Yoshikai has recently been applied in various transformations that were until then dominated by precious Rh, Pd, and Ru catalysts.

Furthermore, high-valent Co catalysts have recently been employed for chemoselective C-H functionalization. In 2013, Kanai from the University of Tokyo and his colleagues reported the utility of a cationic Cp^*Co^{III}/arene complex as a less-expensive alternative to Cp^*Rh^{III}. Since then, researchers have attempted to broaden the scope of Cp^*Co^{III} catalysis and investigate the reaction mechanisms. Reports have demonstrated that Cp^*Co^{III} catalysts could promote some reactions already established with Cp^*Rh^{III} catalysts to access the identical products, and also trigger reactivity differing from that of the related Cp^*Rh^{III} catalysts because of the large difference in electronegativity between Co and Rh.

In terms of contributing countries and institutions (Table 31), Germany, Japan, the USA, South Korea, and China are the main countries producing the core papers. Researchers from the University of Tokyo, the University of Gottingen, the University of Munster, Yale University, and KAIST have made highlighted progress in the field. Zhejiang University, Peking University and the Dalian Institute of Chemical Physics are active Chinese institutions in the field.

Table 31: Top countries/regions and institutions producing the 36 core papers in the Research Front "Cp*Co(III)-catalyzed C–H activation reactions"

Country Ranking	Country/ Region	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country/Region	Core Paper	Proportion
1	Germany	11	30.6%	1	University of Gottingen	Germany	6	16.7%
2	China	10	27.8%	1	University of Tokyo	Japan	6	16.7%
3	Japan	6	16.7%	3	Chinese Academy of Sciences	China	5	13.9%
4	USA	4	11.1%	3	University of Munster	Germany	5	13.9%
5	South Korea	3	8.3%	5	Peking University	China	3	8.3%
6	Taiwan	1	2.8%	5	Institute of Basic Science	South Korea	3	8.3%
6	India	1	2.8%	5	Korea Advanced Institute of Science & Technology (KAIST)	South Korea	3	8.3%
				8	Zhejiang University	China	2	5.6%
				8	Max Planck Society	Germany	2	5.6%

Country Ranking	Country/ Region	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country/Region	Core Paper	Proportion
				8	Hokkaido University	Japan	2	5.6%
				8	Hoshi University	Japan	2	5.6%
				8	University of Houston Clear Lake	USA	2	5.6%
				8	Yale University	USA	2	5.6%

Analysis of the citing papers (Table 32) demonstrates that China is the most productive country that pays close attention to this field. India has made rapid progress in the field, publishing nearly as many citing papers as Germany. The USA, South Korea and Japan are also active. On the list of contributing organizations, the Chinese Academy of Sciences ranks 1st, with the University of Gottingen, Zhejiang University, the University of Munster, the University of Tokyo, KAIST and the Institute for Basic Science all showing continuous interest in the field. In addition, Nanjing University, Lanzhou University, Sungkyunkwan University, and the Indian Institute of Technology make the list.

Table 32: Top countries/regions and institutions producing citing papers in the Research Front "Cp*Co(III)-catalyzed C–H activation reactions"

Country Ranking	Country/ Region	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	250	44.7%	1	Chinese Academy of Sciences	China	64	11.4%
2	India	69	12.3%	2	University of Gottingen	Germany	28	5.0%
3	Germany	66	11.8%	3	Nanjing University	China	23	4.1%
4	USA	53	9.5%	4	Zhejiang University	China	17	3.0%
5	South Korea	38	6.8%	5	Sungkyunkwan University	South Korea	16	2.9%
6	Japan	35	6.3%	6	University of Munster	Germany	15	2.7%
7	Singapore	14	2.5%	6	University of Tokyo	Japan	15	2.7%
8	France	13	2.3%	6	Korea Advanced Institute of Science & Technology (KAIST)	South Korea	15	2.7%
8	UK	13	2.3%	9	Indian Institute of Technology(IIT)	India	14	2.5%
10	Taiwan	10	1.8%	10	Lanzhou University	China	13	2.3%
				10	Institute of Basic Science	South Korea	13	2.3%

1.3 KEY HOT RESRACH FRONT – "Nanoarchitectonics"

The concept of nanoarchitectonics was first proposed by Masakazu Aono at the 1st International Symposium on Nanoarchitectonics Using Suprainterations in 2000. In Aono's opinion, nanotechnology is not only a simple extension of microtechnology in scale. In fact, these two technologies are drastically different, despite their names mistakenly being used interchangeably in some instances. Therefore, a new terminology, "nanoarchitectonics" (nano + architecto +nics), was coined to reflect the paradigm shift. As a new paradigm of materials science and technology on the nanoscale, nanoarchitectonics refers to the technology system aiming at arrangement of nanoscale structural units – a group of atoms, molecules, or nanoscale functional components – into a configuration resulting in a novel functionality through mutual interactions among those units.

Since its first appearance in the title of a scientific paper in 2003, nanoarchitectonics has begun to spread into many fields and has become a well-accepted concept. The broad application can be seen in nanostructured materials, supramolecular self-assemblies, hybrid materials, artificial enzymes, sensors, drug delivery, device and physical application, energy and environmental sciences, as well as biological and medical purposes. In 2016, one of the top materials journals, *Advanced Materials*, published a special issue, *Nanoarchitectonics for Advanced Materials: A Strategy Beyond Nanotechnology*. High-quality reviews from Japan, China, the USA, Germany, France, Netherlands, etc., were invited to illustrate the global progress in this field

Professor Katsuhiko Ariga from the National Institute of Materials Science of Japan has made important contributions to the field of nanoarchitectonics. As seen in Table 33, all 16 of the highly cited papers featuring Japan-based researchers are coauthored by Ariga and his partners. Their major interests include: self-assembly involving layer-by-layer films and Langmuir-Blodgett films; nanostructure assembly; interface chemistry; and so on. China, the Czech Republic, Germany, and other countries/regions (Table 33) also contribute to the field.

Table 33: Top countries/regions and institutions producing the 25 core papers in the Research Front "Nanoarchitectonics"

Country Ranking	Country/ Region	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country/Region	Core Paper	Proportion
1	Japan	16	64.0%	1	National Institute of Materials Science (NIMS)	Japan	16	64.0%
2	China	8	32.0%	2	Chinese Academy of Sciences	China	7	28.0%
3	Czech Republic	2	8.0%	3	Waseda University	Japan	5	20.0%
3	Germany	2	8.0%	4	University of Queensland	Australia	2	8.0%
3	USA	2	8.0%	4	Czech Academy of Sciences	Czech Republic	2	8.0%
3	Australia	2	8.0%	4	Max Planck Society	Germany	2	8.0%
7	France	1	4.0%	7				
7	Taiwan	1	4.0%	7				

According to a count of the citing papers (Table 34), China is the most productive country with 601 citing papers, followed by Japan. On the list of top institutions, NIMS performs best in this Research Front and ranks 1st with 205 citing papers, followed by the Chinese Academy of Sciences, Waseda University, Jilin University, and Taiwan University.

Table 34: Top countries (regions) and institutions producing citing papers in the Research Front "Nanoarchitectonics"

Country Ranking	Country/ Region	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country/ Region	Citing Paper	Proportion
1	China	601	31.0%	1	National Institute of Materials Science (NIMS)	Japan	205	10.6%
2	Japan	463	23.9%	2	Chinese Academy of Sciences	China	144	7.4%
3	India	261	13.5%	3	Centre National de la Recherche Scientifique (CNRS)	France	55	2.8%

Country Ranking	Country/ Region	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country/ Region	Citing Paper	Proportion
4	South Korea	176	9.1%	4	Waseda University	Japan	54	2.8%
5	USA	165	8.5%	5	Jilin University	China	48	2.5%
6	Taiwan	98	5.1%	6	National Taiwan University	Taiwan	43	2.2%
7	Germany	88	4.5%	7	Nanyang Technological University	Singapore	37	1.9%
8	France	72	3.7%	8	National Institute of Advanced Industrial Science & Technology (AIST)	Japan	34	1.8%
9	Australia	71	3.7%	8	Tokyo Women's Medical University	Japan	32	1.7%
10	Singapore	53	2.7%	10	Kyungpook National University	South Korea	32	1.7%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

This year, 16 research topics are selected as emerging Research Fronts in chemistry and materials science, covering the subjects of perovskite solar-cell and luminescent materials, metal-catalyzed chemical reactions, preparation of nanomaterials and devices, photochemistry, and more. Two special themes are prominent: perovskite materials and metal-catalyzed chemical reactions. The former theme – perovskite materials – covers luminescence materials, all-inorganic perovskite absorber-based solar cells, and eco-friendly perovskite absorbers; this same thread, essentially, has constituted an Emerging Research Front from 2014 to this year with slight changes in research emphasis. Metal-catalyzed chemical reactions is the other theme to which about one-third of all the 16 emerging Research Fronts are related. Specifically, two Research Fronts focus on non-noble metal-catalyzed reactions. The Research Fronts related to framework compounds and pillararene are selected as emerging Research Fronts again this year, as they were in 2016. In the topic of nanomaterials, three Research Fronts are selected as emerging fronts this year, including nanosheets, perovskite nanocrystals, and rare-earth-doped nanothermometer.

Table 35: Emerging Research Fronts in chemistry and materials science

Number	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Covalent organic frameworks	9	121	2016
2	High performance Dy(III) single-ion magnets	4	111	2016
3	Rhodium(III)-catalyzed synthesis of Indole Derivatives	9	101	2016
4	All-inorganic perovskite nanocrystals as light emitting materials	8	133	2015.9
5	All-inorganic perovskite absorbers($CsPbX_3$)-based solar cells	4	140	2015.8
6	Self-assembly of pillararene-based host-guest complexes and its application	5	132	2015.8
7	Site-selective protein-modification chemistry	5	117	2015.8

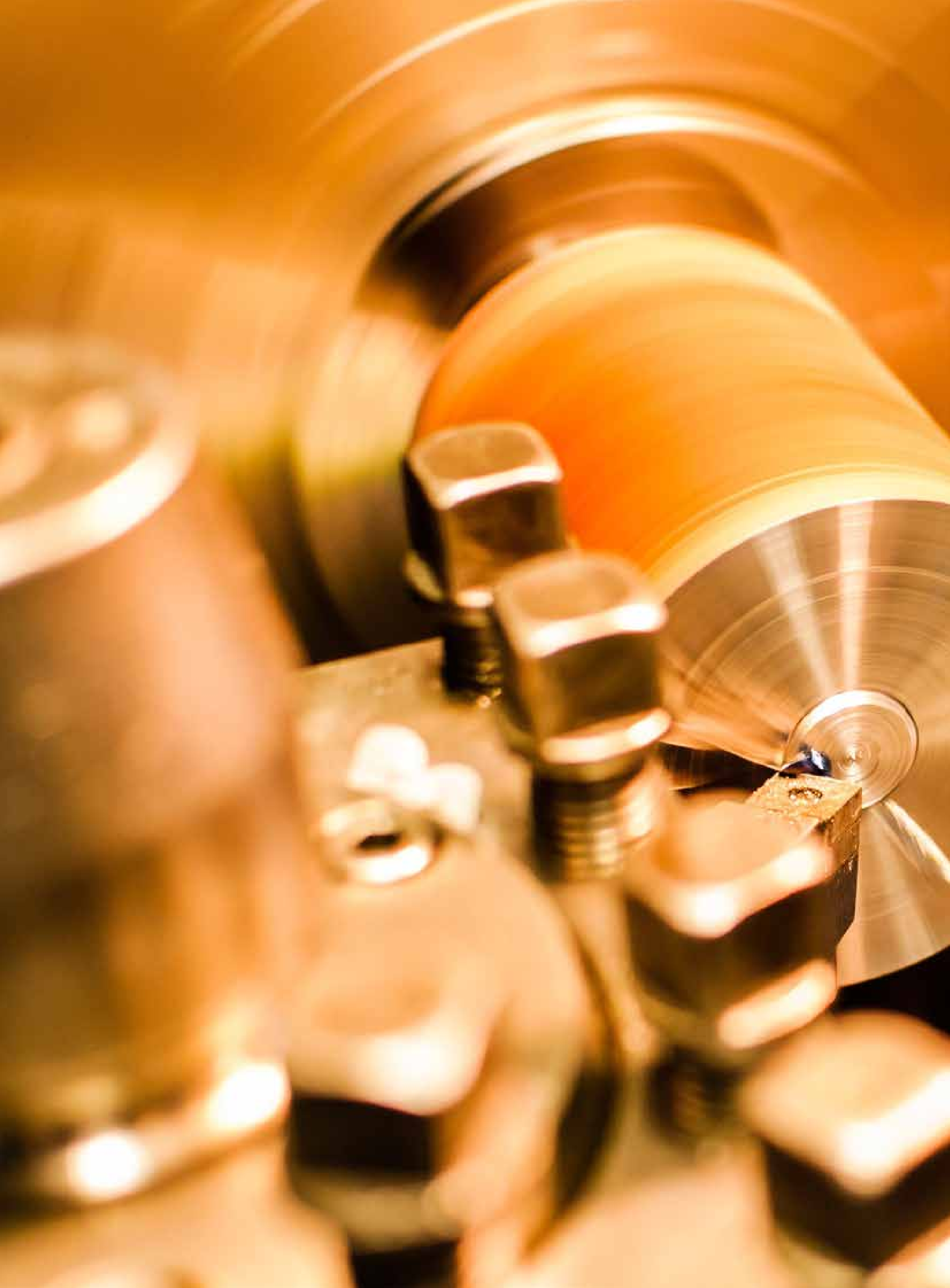
Number	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
8	Continuous-flow photochemistry synthesis	5	109	2015.8
9	Photoredox-catalyzed fluoroalkylation of alkenes	6	170	2015.7
10	Ni-Fe highly-efficient electrocatalysts for the oxygen evolution reaction	6	154	2015.7
11	Production of nanosheets via liquid phase exfoliation	6	144	2015.7
12	Lead-free halide perovskite absorbers	7	141	2015.7
13	Non-noble metal-based bifunctional electrocatalysts for overall water splitting	17	618	2015.6
14	Transition-metal-catalyzed cleavage of amide C-N bonds	7	198	2015.6
15	Non-precious-metal-catalyzed hydrosilylation of alkenes and alkynes	5	116	2015.6
16	Rare earth-doped infrared luminescent nanothermometer	5	102	2015.6

2.2 KEY EMERGING RESARCH FRONT – "Non-noble metal-based bifunctional electrocatalysts for overall water splitting"

Hydrogen generation from water splitting, using electrocatalysts, is an effective way for renewable energy storage and is regarded as the safest and most effective technology to solve the current energy crisis. Water splitting includes two half-reactions: the hydrogen evolution reaction (HER) and the oxygen evolution reaction (OER); these occur, respectively, at the cathode and the anode. Owing to thermodynamic convenience and potential application in proton-exchange membrane or alkaline electrolyzers, most effort in this field has been devoted to developing HER catalysts (usually transition metals) for strong acidic conditions and OER catalysts (usually noble metals) for strong basic conditions. However, pairing the two electrode reactions together in an integrated electrolyser for practical use is difficult, due to the mismatch of pH ranges in which these catalysts are stable and remain most active. In addition, designing different catalysts for OER and HER requires different equipment and processes which can increase the complexity and system costs. It is therefore highly imperative to develop electrocatalysts for both HER and OER in the same electrolyte to achieve efficient overall water splitting.

Water splitting by electrocatalysts for hydrogen production is an old topic. Non-noble metal electrocatalysts applied in water splitting has been a hot topic in recent years, and was selected as an emerging Research Front in chemistry and materials science in 2015, while non-noble metal electrocatalysts with nano structure was a hot Research Front in 2016. This year the interest turns to bifunctional electrocatalysts, which can catalyze the reaction of both hydrogen evolution and oxygen evolution with better performance. Recently, research on bifunctional electrocatalysts for overall water splitting has focused on transition metal phosphide, such as Ni phosphide, Co phosphide, and the oxide/sulfide of the above two metals, while most of the research was carried out under strong basic conditions. Among the institutions that contributed in this emerging Research Fronts, the performance of Utah State University is outstanding. Four of the six core papers from the USA feature authors from this university. The paper titled "Electrodeposited cobalt-phosphorous-derived films as competent bifunctional catalysts for overall water splitting" is the most-cited paper, with citations close to 200.

Follow-up research has further improved the reaction by employing different cobalt composite, phosphide and membrane type bifunctional non-noble metal catalyst. The Chinese Academy of Sciences (CAS) also performs well in this area. Three out of the five core papers from China are affiliated with CAS.



8.PHYSICS

1. HOT RESEARCH FRONT

1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN PHYSICS

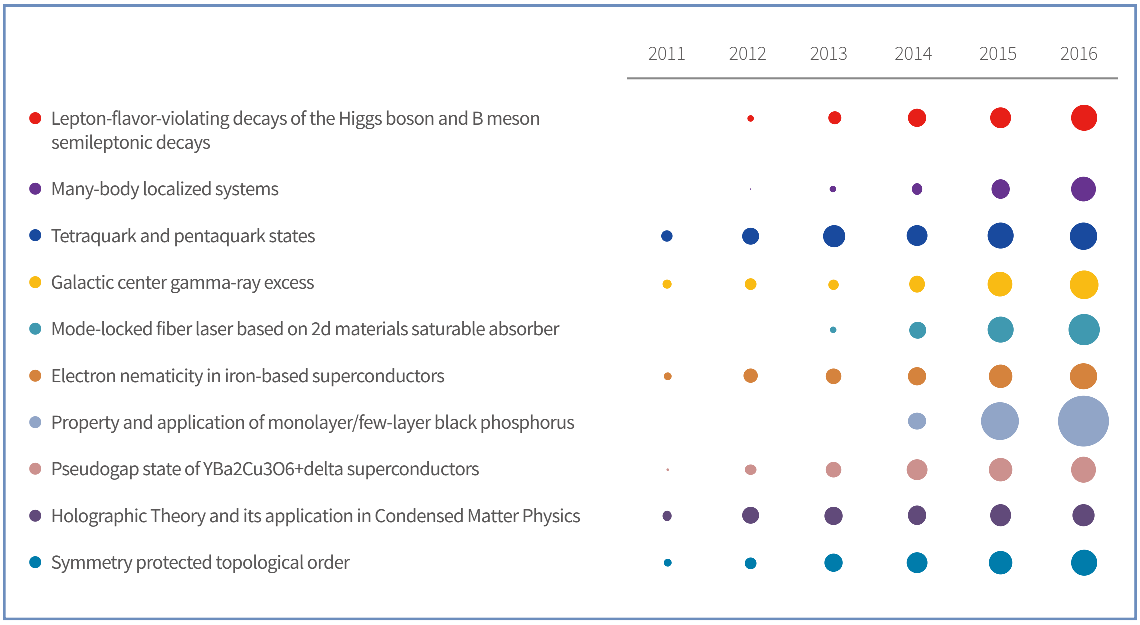
The Top 10 Research Fronts in physics mainly focus on the subfields of condensed matter physics, high-energy physics, and optics. In condensed matter physics, yttrium barium copper oxide (YBCO) is still the hot front this year. Nematicity in iron-based superconductors was an emerging Research Front in 2016 and it emerges as a key hot Research Front this year. Many-body localized systems, the application of holographic theory, and symmetry-protected topological order become new hot fronts. The topic of two-dimensional black phosphorus materials progressed from an emerging Research Front in 2015 to a hot Research Front in 2016. It remains a hot topic this year, and is the most-active front in physics.

In high-energy physics, the indirect detection of dark matter maintains its position on the Top 10 list. The search for new physics based on the lepton-flavor-violating decays of the Higgs boson and B meson semileptonic decays, as well as the study of tetraquark and pentaquark states, have attracted much attention. In optics, mode-locked fiber lasers emerge as a hot Research Front.

Table 36: Top10 Research Fronts in physics

Number	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Lepton-flavor-violating decays of the Higgs boson and B meson semileptonic decays	46	2226	2014.7
2	Many-body localized systems	38	2103	2014.7
3	Tetraquark and pentaquark states	31	2374	2014.5
4	Galactic center gamma-ray excess	49	3630	2014.4
5	Mode-locked fiber laser based on 2d materials saturable absorber	36	2866	2014.2
6	Electron nematicity in iron-based superconductors	25	2052	2014.1
7	Property and application of monolayer/few-layer black phosphorus	13	5173	2014
8	Pseudogap state of YBa2Cu3O6+delta superconductors	28	3045	2013.8
9	Holographic Theory and its application in Condensed Matter Physics	30	2311	2013.8
10	Symmetry protected topological order	26	2407	2013.7

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



1.2 KEY HOT RESEARCH FRONT – "Lepton-flavor-violating decays of the Higgs boson and B meson semileptonic decays"

Great success has been achieved by the Standard Model, although many unsolved problems still exist, indicating the possibility of new physics beyond the Standard Model. Since the discovery of the Higgs boson, searching for new physics has become one of the most important goals in physics. Recently, the Large Hadron Collider (LHC) at the European Center of Nuclear Research (CERN), and the BABAR experiment at Stanford University, have observed some signals of deviations from the Standard Model, including lepton-flavor-violating decays of the Higgs boson and B meson semileptonic decays. The question of whether these deviations will lead to new physics has become a hot topic.

In this Research Front, Germany is the most active country, participating in 19 core papers (Table37), which is 41.3% of the core. The USA, Switzerland, the UK, and Italy also demonstrate excellent performance. The Italian National Institute for Nuclear Physics and CERN contributed to the highest numbers of core papers. On the top-institutions list, three of the top entities are located in Italy, while Switzerland, Germany and the USA each have two, while France and Russia can both claim one.

Table 37: Top countries and institutions producing the 46 core papers in the Research Front "Lepton-flavour-violating decays of the Higgs boson and B meson semileptonic decays"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	Germany	19	41.3%	1	Istituto Nazionale Di Fisica Nucleare	Italy	12	26.1%
2	USA	17	37.0%	2	European Organization for Nuclear Research (CERN)	Switzerland	9	19.6%
3	Switzerland	14	30.4%	3	TU Dortmund University	Germany	8	17.4%
4	UK	13	28.3%	4	University of Cincinnati	USA	7	15.2%
5	Italy	12	26.1%	5	Massachusetts Institute of Technology (MIT)	USA	6	13.0%
6	Spain	11	23.9%	5	University of Paris Sud-Paris XI	France	6	13.0%
7	France	8	17.4%	5	Max Planck Society	Germany	6	13.0%
7	China	8	17.4%	5	Sapienza University of Rome	Italy	6	13.0%
9	Belgium	7	15.2%	5	University of Padua	Italy	6	13.0%
10	Russia	6	13.0%	5	Russian Academy of Sciences	Russia	6	13.0%
10	South Korea	6	13.0%	5	University of Zurich	Switzerland	6	13.0%

Analysis of the citing papers (Table 38) indicates that the USA and Germany published 169 and 161 citing papers, respectively, accounting for 30.1% and 28.6% of the total – shares that are far larger than those of other listed countries. Switzerland, Spain and the UK rank 3rd to 5th. Among the top institutions that cited the core papers of this Research Front, the Italian National Institute of Nuclear Physics and CERN contributed the most, accounting for 13.9% and 12.3% of the total citing papers. Paris-Sud University, the University of Valencia, and the TU Dortmund University rank 3rd to 5th.

Table 38: Top countries and institutions producing citing papers in the Research Front "Lepton-flavour-violating decays of the Higgs boson and B meson semileptonic decays"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	169	30.1%	1	Istituto Nazionale Di Fisica Nucleare	Italy	78	13.9%
2	Germany	161	28.6%	2	European Organization for Nuclear Research (CERN)	Switzerland	69	12.3%
3	Switzerland	101	18.0%	3	University of Paris Sud-Paris XI	France	52	9.3%
4	Spain	88	15.7%	4	University of Valencia	Spain	51	9.1%
4	UK	88	15.7%	5	TU Dortmund University	Germany	46	8.2%
6	France	84	14.9%	6	Johannes Gutenberg University of Mainz	Germany	43	7.7%
7	Italy	81	14.4%	7	Russian Academy of Sciences	Russia	40	7.1%
8	China	75	13.3%	8	University of Cincinnati	USA	38	6.8%
9	India	54	9.6%	9	Univ Savoie Mont Blanc	France	37	6.6%
10	Canada	49	8.7%	10	Massachusetts Institute of Technology (MIT)	USA	35	6.2%
				10	Ruprecht Karl University Heidelberg	Germany	35	6.2%

1.3 KEY HOT RESARCH FRONT–"Tetraquark and pentaquark states"

In addition to the development of new physical models, many problems need to be addressed within the Standard Model – among them, descriptions of Hadron physics. Hadrons are composite particles made of quarks by strong interaction, including baryons and mesons. In the quark model, the hadron is composed of three quarks (i.e., baryons) or quark and antiquark (i.e., mesons). The quark model has achieved great success in that many of its predictions are consistent with experiments. But the quantum chromodynamics (QCD) theory that describes the strong interaction between quarks does not exclude new forms of matter such as tetraquarks and mesonic molecules. Physicists have been trying to find experimental evidence of the exotic hadrons. In June 2013, the tetraquark Zc (3900) was found almost simultaneously by the BES III Collaboration, based in China and the Belle Collaboration, based in Japan.. In August 2015, the LHCb collaboration at CERN reported pentaquark states Pc (4450) and Pc (4380). Therefore, tetraquark and pentaquark states have become a hot topic in high-energy physics.

In this Research Front, China is the most-active country, participating in 20 core papers, which is 64.5% of the total. The USA, Germany, Italy and Russia also perform strongly. The Chinese Academy of Sciences contributes the most core papers, followed by the National Institute of Nuclear Physics and the Russian Academy of Sciences. In terms of institutional contribution to the core papers, five of the top institutions are located in China, four in Russia, and two in Italy, while the USA, the Netherlands, Poland, and South Korea can each claim one institution among the most prolific.

Table 39: Top countries and institutions producing the 31 core papers in the Research Front "Tetraquark and Pentaquark States"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	China	20	64.5%	1	Chinese Academy of Sciences	China	16	51.6%
2	USA	18	58.1%	2	Istituto Nazionale Di Fisica Nucleare	Italy	13	41.9%
3	Germnay	15	48.4%	3	Russian Academy of Sciences	Russia	11	35.5%
4	Italy	14	45.2%	4	Novosibirsk State University	Russia	10	32.3%
5	Russia	12	38.7%	5	Tsinghua University	China	9	29.0%
6	Spain	9	29.0%	6	Lanzhou University	China	8	25.8%
7	South Korea	8	25.8%	6	Alikhanov Institute of Theoretical and Experimental Physics	Russia	8	25.8%
7	Netherlands	8	25.8%	6	National Research Center-Kurchatov Institute	Russia	8	25.8%
9	Poland	7	22.6%	9	Central China Normal University	China	7	22.6%
9	Switzerland	7	22.6%	9	Peking University	China	7	22.6%
				9	Sapienza University of Rome	Italy	7	22.6%

In terms of the citing papers (Table 40), China contributes 455 reports, accounting for 46.2% of the total. The USA, Germany and Russia rank 2nd to 4th. Among the top institutions, the Chinese Academy of Sciences contributed the most citing papers (268), accounting for 27.2% of the total. The Italian National Institute of Nuclear Physics, the Russian Academy of Sciences, and Peking University rank 2nd to 4th.

Table 40: Top countries and institutions producing citing papers in the Research Front "Tetraquark and Pentaquark States"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	455	46.2%	1	Chinese Academy of Sciences	China	268	27.2%
2	USA	314	31.9%	2	Istituto Nazionale Di Fisica Nucleare	Italy	177	18.0%
3	Germany	286	29.0%	3	Russian Academy of Sciences	Russia	171	17.4%
4	Russia	254	25.8%	4	Peking University	China	135	13.7%
5	Italy	192	19.5%	5	Alikhanov Institute of Theoretical and Experimental Physics	Russia	127	12.9%
6	Spain	182	18.5%	6	Novosibirsk State University	Russia	113	11.5%
7	Japan	145	14.7%	7	National Research Center-Kurchatov Institute	Russia	107	10.9%
8	Switzerland	135	13.7%	8	Lanzhou University	China	98	9.9%
9	South Korea	134	13.6%	9	University of Paris Sud-Paris XI	France	97	9.8%
10	France	124	12.6%	10	European Organization for Nuclear Research (CERN)	Switzerland	94	9.5%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN PHYSICS

Five topics in physics are highlighted as emerging Research Fronts, mainly focusing on high-energy physics, condensed matter physics, and optics. These fronts center on research related to Standard Model research based on 750GeV two-photon signal and three-nucleon forces study with chiral effective field theory in high-energy physics; the superconductivity of MoS2 and NbSe2 and nanoconfined 2D ice in condensed matter physics; and, in optics, many-body physics based Rydberg-blockade effect.

Table 41: Emerging Research Fronts in physics

Number	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Standard Model Interpretation of 750 GeV Diphoton	27	1167	2016
2	Superconductivity of MoS_2 and $NbSe_2$	8	168	2015.8
3	Three-Nucleon forces study with chiral effective field theory	11	231	2015.7
4	Structures and phase transitions of nanoconfined 2d ice	3	106	2015.7
5	Many-body physics based rydberg-blockade effect	5	112	2015.6

2.2 KEY EMERGING RESEARCH FRONT – "Standard Model Interpretation of 750 GeV Diphoton"

After the discovery of the Higgs boson, searching for new physics beyond the Standard Model has become one of the most important goals in physics. In December 2015, the LHC collaborations CMS and ATLAS both reported an unexpected excess of pairs of photons with a combined energy of 750 GeV. The excess could have been explained by the production of a new particle, a conclusion potentially pointing to new physics. Therefore, it attracted considerable interest in the scientific community, resulting in a large number of research papers. Published from January to July 2016, the 27 highly cited papers in this emerging Research Front have collectively been cited 1,167 times. These papers mainly focus on extending the Standard Model to explain the excess of pairs of photons. However, in August 2016, new data revealed that the excess was merely a statistical fluctuation. Therefore, all the explanations associated with it proved to be mistaken.

9. ASTRONOMY AND ASTROPHYSICS

1. HOT RESEARCH FRONT

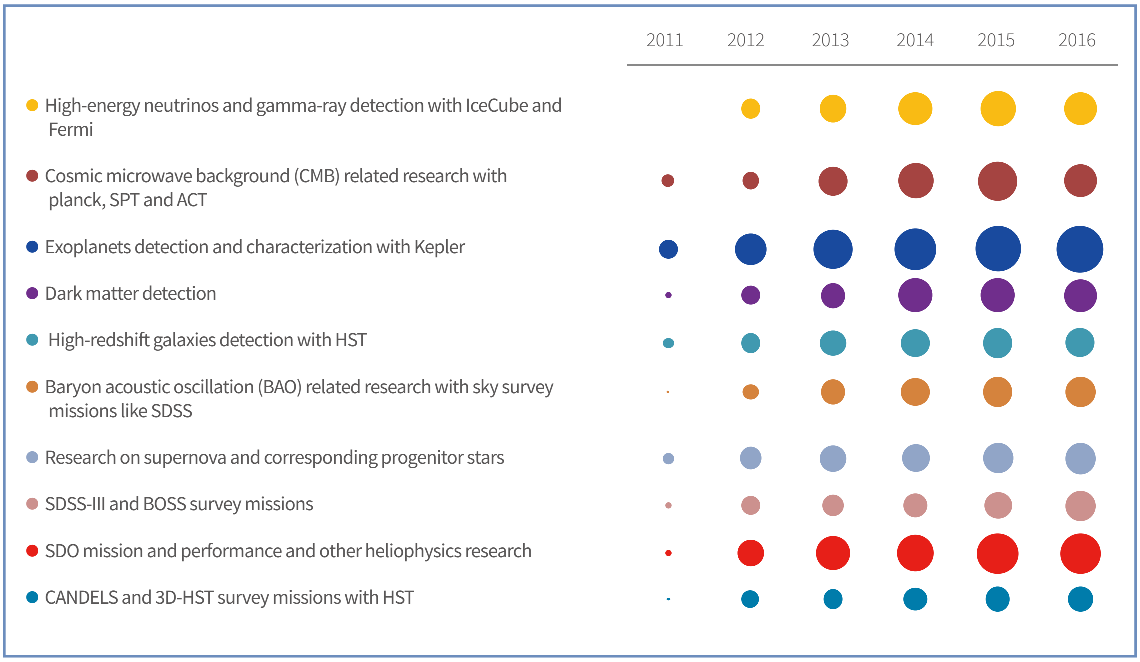
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

The Top 10 Research Fronts in this area focus on several research topics, including the Baryon acoustic oscillation (BAO), high redshift galaxies, solar physics, exoplanets, high-energy neutrinos and gamma-ray detection, cosmic microwave background (CMB), dark matter, and supernova. Most of these topics are closely related to specific space missions and projects. The subject matter in these top Research Fronts has been extensively investigated. For instance, several long-lasting hot research topics in this area, including BAO, high redshift galaxies, solar physics, exoplanets, dark matter, and supernova, are again selected as the top Research Fronts in 2017, just as in 2016 and 2015. The topic of formation and merger of double compact objects, which is closely related to the discovery of ripples in space time – i.e., the gravitational waves whose detection electrified the scientific community in 2016 – come to the fore to be one of the emerging Research Fronts this year.

Table 42: Top10 Research Fronts in astronomy and astrophysics

Number	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	High-energy neutrinos and gamma-ray detection with IceCube and Fermi	19	2517	2013.7
2	Cosmic microwave background (CMB) related research with planck, SPT and ACT	26	3139	2013.5
3	Exoplanets detection and characterization with Kepler	47	7588	2012.9
4	Dark matter detection	27	3701	2012.9
5	High-redshift galaxies detection with HST	18	2524	2012.9
6	Baryon acoustic oscillation (BAO) related research with sky survey missions like SDSS	8	1945	2012.9
7	Research on supernova and corresponding progenitor stars	21	2459	2012.8
8	SDSS-III and BOSS survey missions	4	1498	2012.3
9	SDO mission and performance and other heliophysics research	13	3041	2012.2
10	CANDELS and 3D-HST survey missions with HST	5	1439	2012.2

Figure 8: Citing papers of the top 10 Research Fronts in astronomy and astrophysics



1.2 KEY HOT RESEARCH FRONT – "Exoplanets detection and characterization with Kepler"

Extra-solar planet research has been ranked among the Top 10 Research Fronts in astronomy and astrophysics since 2013. In 2017, "Exoplanets detection and characterization with Kepler" becomes a new iteration of the Research Front. NASA's Kepler Space Telescope, launched in 2009, was the first telescope in space dedicated to finding extra-solar planets. During the mission period, the Kepler telescope will scan about 100,000 stars in two constellations, named Cygnus and Lyra, to search for extra-solar planets.

Thirty-nine out of the 47 core papers in the Research Front reported the observation results of Kepler's main mission and its follow-up mission, K2. Kepler and Kepler-K2 have discovered nearly 5,000 planet candidates and confirmed more than 2,450 planets, including 30 near-Earth-size planets in the habitable zone (as of August 4, 2017). A series of Kepler's milestone discoveries include the detection of the first possible habitable planet (Kepler-22b) in 2011; the confirmation of the planetary system orbiting around binary stars (Kepler-47 and Kepler-34b/35b); the planetary system (Kepler-33) with the most planets in 2012; the discovery of the first Earth-size planet (Kepler-186f) in the habitable zone of its star, and more. Furthermore, the characterization of different types of extra-solar planets, the habitable zone theory, and the Planetary Transits and Oscillations of Stars mission (PLATO) are also matters of central concern in this Research Front. PLATO, developed by the European Space Agency (ESA), is to launch in 2024. Unlike Kepler, which carries only one instrument, PLATO will be equipped with 34 small-aperture telescopes and cameras, and is thus expected to provide a census for small, low-mass planets.

Analysis of countries and institutions producing core papers in this field (Table 43) shows that, as the funding country of Kepler, the USA takes a predominant position in this front. Almost all of the core papers were led or contributed by the USA, and the Top 10 institutions are almost swept by the USA. NASA, as the funding agency of Kepler, decisively produced the most core papers. The Harvard-Smithsonian Astrophysical Center, the University of California-Berkeley, and the California Institute of Technology also perform outstandingly. Denmark also registers strongly in this area; Aarhus University is the only non-US entity on the list of Top10 institutions. The obvious difference in the output of core papers suggests a significant gap in research capacity between the USA and the traditional space research powers such as the UK, France, and Germany.

Table 43: Top countries and institutions producing the 47 core papers in the Research Front "Exoplanets detection and characterization with Kepler"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	46	97.9%	1	National Aeronautics & Space Administration (NASA)	USA	35	74.5%
2	Denmark	23	48.9%	2	Harvard-Smithsonian Astrophysical Center	USA	28	59.6%
3	UK	15	31.9%	3	University of California Berkeley	USA	25	53.2%
4	France	8	17.0%	4	California Institute of Technology	USA	24	51.1%
4	Germany	8	17.0%	5	University of California Santa Cruz	USA	23	48.9%
6	Australia	7	14.9%	6	University of Texas Austin	USA	20	42.6%

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
7	Israel	5	10.6%	7	Seti Institute	USA	17	36.2%
7	Netherlands	5	10.6%	8	Massachusetts Institute of Technology (MIT)	USA	16	34.0%
7	Spain	5	10.6%	9	Aarhus University	Denmark	15	31.9%
10	Portugal	4	8.5%	10	San Jose State University	USA	14	29.8%
10	Switzerland	4	8.5%	10	University of Florida	USA	14	29.8%

Examination of citing papers demonstrates that the USA's predominance extends to the country and institutional levels. The USA contributes to 63.7% of all citing papers, which is 2.45 times that of the second-ranked UK. Five US institutions rank among the Top 10 institutions and three of them sweep the top three positions. The rest of the Top 10 citing institutions are the Max Planck Society (Germany), the French National Center for Scientific Research, Aarhus University (as mentioned, in Denmark), Instituto de Astrofísica de Canarias (Spain), and the University of Porto (Portugal).

Table 44: Top countries and institutions producing citing papers in the Research Front "Exoplanets detection and characterization with Kepler"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	1735	63.7%	1	National Aeronautics & Space Administration (NASA)	USA	504	18.5%
2	UK	707	26.0%	2	Harvard-Smithsonian Astrophysical Center	USA	398	14.6%
3	Germany	546	20.0%	3	California Institute of Technology	USA	360	13.2%
4	France	475	17.4%	4	Max Planck Society	Germany	238	8.7%
5	Spain	337	12.4%	5	Centre National De La Recherche Scientifique (CNRS)	France	202	7.4%
6	Denmark	299	11.0%	6	Aarhus University	Denmark	197	7.2%
7	Australia	268	9.8%	6	University of California Berkeley	USA	197	7.2%
8	Italy	251	9.2%	8	Instituto De Astrofisica De Canarias	Spain	176	6.5%
9	Switzerland	236	8.7%	9	Massachusetts Institute of Technology (MIT)	USA	169	6.2%
10	Canada	192	7.0%	10	Universidade Do Porto	Portugal	162	5.9%

It is expected that, with the successive launches of NASA's Transiting Exoplanet Survey Satellite (TESS) and the James Webb Space Telescope (JWST), as well as ESA's PLATO, extra-solar planet research will continue to be one of the hottest Research Fronts in Astronomy, and America's advantage in this Research Front is unlikely to be challenged in the near future.

1.3 KEY HOT RESARCH FRONT – "SDO mission and performance and other heliophysics research"

As the nearest star to Earth, the Sun is the only such body that can be observed and investigated in certain spatial resolution, and has therefore played an important role in the development of modern astrophysics and astronomy. Meanwhile, the Sun brings us warmth and brightness, and its intense activities also have a profound effect on the terrestrial environment. As an important branch of astrophysics, solar physics specializes in the study of the Sun, including the Sun's structure, composition, energy source and transmission, along with its activities, evolution, and effects on the solar system.

Since 1990s, satellite-based investigation has become a dominant research method in solar investigation, and solar physics research has evolved into a new era. This is evident in a series of solar satellites launched, such as the Yohkoh/Solar-A satellite, the Solar and Heliospheric Observatory (SOHO), the Transition Region and Coronal Explorer (TRACE), the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), the Hinode/Solar-B satellite, the Solar Terrestrial Relations Observatory (STEREO), the Solar Dynamics Observatory (SDO), and the Interface Region Imaging Spectrograph (IRIS). Accordingly, remarkably enhanced space-based solar-detection technologies have opened a new age for solar physics.

Solar physics research based on solar satellites has continued to be one of the Top 10 hot Research Fronts in 2015, 2016, and 2017. While Hinode/Solar-B, SDO, IRIS and STEREO were chiefly involved in 2015 and 2016, SDO, IRIS, and RHESSI are primarily involved in 2017.

There are 13 core papers in this hot Research Front. Eight core papers focus on general discussion, scientific instruments, and observation discoveries of the SDO mission; two core papers describe the CHIANTI spectral code; one core paper, using data from RHESSI, outlines the overview of solar flares and the associated phenomena; one core paper presents the IRIS mission; and one core paper outlines the current understanding of solar flares, mainly focusing on magnetohydrodynamic processes responsible for producing these flares.

The SDO, IRIS and RHESSI missions are all underwritten and directed by NASA. SDO, a large solar-physics space mission costing approximately $850 million, was successfully launched in 2010. SDO's goal is to understand the solar variations that influence Earth and near-Earth space by determining how the Sun's magnetic field is generated and structured and how the stored magnetic energy is converted and released into the heliosphere and geospace in the form of solar wind, energetic particles, and variations in solar irradiance. Six core papers are from a special issue of *Solar Physics* in January 2012, and the other two foundational papers describe the vector magnetic field pipeline as well as the evolution of magnetic field and energy in a major eruptive active region based on observation from the Helioseismic and Magnetic Imager (HMI) instrument aboard SDO.

IRIS and RHESSI are NASA's small missions. IRIS was launched in 2013, and its primary goal is to understand how heat and energy move through the lower levels of the solar atmosphere. RHESSI was launched in 2002, its main mission being to explore the basic physics of particle acceleration and explosive energy release in solar flares.

Two core papers present versions 7 and 7.1 of the CHIANTI spectral code, which consists of an atomic database and a suite of computer programs to calculate the optically thin spectrum of astrophysical objects and carry out spectroscopic plasma diagnostics. CHIANTI is one of the most widespread, complete, and accurate spectral codes available for optically thin emission in the 1–2000Å wavelength range.

Analysis of the top countries and institutions producing the core papers (Table 45), demonstrates that the

USA is the most active country. The USA contributed to 12 of the 13 core papers in this Research Front. The outstanding performance of the USA is related to its investment in the SDO, IRIS, and RHESSI missions. NASA, which led all three missions, ranks 2nd in the list of top institutions. Stanford University and Lockheed Martin, ranking 1st and 3rd respectively, are principal-investigator institutions of the science instruments on SDO. The principal investigator for IRIS is also from Lockheed Martin.

Table 45: Top countries and institutions producing the 13 core papers in the Research Front "SDO mission and performance and other heliophysics research"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	12	92.3%	1	Stanford University	USA	7	53.8%
2	UK	6	46.2%	2	National Aeronautics & Space Administration (NASA)	USA	6	46.2%
3	Germany	2	15.4%	3	Lockheed Martin	USA	5	38.5%
3	Japan	2	15.4%	4	National Center Atmospheric Research (NCAR)	USA	4	30.8%
5	Norway	1	7.7%	5	Lawrence Berkeley National Laboratory	USA	2	15.4%
5	South Korea	1	7.7%	5	E2v Technologies	UK	2	15.4%
5	Ireland	1	7.7%	5	Stfc Rutherford Appleton Laboratory	UK	2	15.4%
5	Austria	1	7.7%	5	University of Cambridge	UK	2	15.4%
5	China	1	7.7%	5	Alias Aerospace, Inc.	USA	2	15.4%
				5	George Mason University	USA	2	15.4%
				5	Harvard-Smithsonian Center for Astrophysics	USA	2	15.4%
				5	University of California Berkeley	USA	2	15.4%
				5	Reflective X-Ray Optics Llc	USA	2	15.4%
				5	University of Michigan	USA	2	15.4%
				5	Max Planck Society	Germany	2	15.4%
				5	Montana State University	USA	2	15.4%

The USA also contributed to the greatest number of citing papers (Table 46), accounting for 53.1 % of the total, followed by China, the UK, and Germany. The Top 10 citing entities include six American institutions, two Chinese institutions, one German institution, and one Russian institution. The Chinese Academy of Sciences produced the most citing papers, followed by NASA and the Max Planck Society.

Table 46: Top countries and institutions producing citing papers in the Research Front "SDO mission and performance and other heliophysics research"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	1046	53.1%	1	Chinese Academy of Sciences	China	266	13.5%
2	China	383	19.4%	2	National Aeronautics & Space Administration (NASA)	USA	251	12.7%
3	UK	359	18.2%	3	Max Planck Society	Germany	133	6.7%
4	Germany	251	12.7%	4	Stanford University	USA	132	6.7%
5	Russia	170	8.6%	5	Russian Academy of Sciences	Russia	127	6.4%
6	France	154	7.8%	6	Harvard-Smithsonian Center for Astrophysics	USA	123	6.2%
7	Japan	136	6.9%	7	Lockheed Martin	USA	117	5.9%
8	South Korea	135	6.8%	8	George Mason University	USA	86	4.4%
9	India	122	6.2%	9	Nanjing University	China	85	4.3%
10	Italy	97	4.9%	10	National Solar Observatory	USA	81	4.1%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

"Initial results from Magnetospheric Multiscale (MMS) mission and related research on magnetic reconnection" and "Formation and merger of double compact objects (e.g., binary black hole)" are selected as the emerging Research Fronts of 2017 in astronomy and astrophysics.

Table47: Emerging Research Fronts in astronomy and astrophysics

Number	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Initial results from Magnetospheric Multiscale (MMS) and related research on magnetic reconnection	16	429	2016
2	Formation and merger of double compact objects (e.g. binary black hole)	8	186	2015.8

2.2 KEY EMERGING RESARCH FRONT – "Formation and merger of double compact objects (e.g. binary black hole)"

Gravitational waves are "ripples" in space-time produced by some of the most violent events in the cosmos, such as the collisions and mergers of massive compact stars. Their existence was predicted by Einstein in 1916. Over the past few decades astronomers amassed strong supporting evidence that gravitational waves exist, chiefly by studying their effect on the motions of tightly orbiting pairs of stars in our Galaxy. Nevertheless, the direct detection of gravitational waves as they reach the Earth had been eagerly anticipated by the scientific community. This would provide new and more stringent ways to test general relativity under the most extreme conditions and open up an entirely novel way to explore the Universe.

In September 2015 the Laser Interferometer Gravitational-Wave Observatory (LIGO) made the first-ever direct detection of gravitational waves from the merger of two massive black holes more than a billion light years away. This discovery event was known as GW150914. It was followed by a second (known as GW151226) in December 2015 and a third confirmed detection (known as GW170104) in January 2017 – again involving the merger of a pair of black holes. The measurements herald the start of the era of gravitational-wave astronomy and multi-messenger astronomy. Gravitational-wave observations can be combined with those made by optical and radio telescopes and other detectors to observe the cosmos.

The discovery of ripples in spacetime – gravitational waves – caused great excitement in the scientific community. The publications *Science* and *Physics World* both named it the 2016 breakthrough of the year. Gabriela Gonzalez, the spokesperson for the LIGO Scientific Collaboration, was honored by *Nature* as one of the top ten scientists of 2016.

At present, the global network of gravitational-waves-detection instruments is forming. After a series of upgrades, LIGO started science observations in November 2016. The VIRGO gravitational wave detector, based in Italy, turned on a 25 days long observing from August 1st 2017. Physicists in Japan are building a detector called the Kamioka Gravitational Wave Detector (KAGRA). LIGO physicists plan to add a detector in India in the early 2020s. Space-based detection of gravitational waves has also made progress. ESA's Laser Interferometer Space Antenna - Pathfinder (LISA Pathfinder) mission, launched in December 2015, has confirmed the technologies to detect gravitational waves from space. In June 2017, ESA announced that LISA will be launched in 2034 to detect gravitational waves. Chinese scientists also have proposed the TaiJi and TianQin space missions to join the hunt for gravitational waves.

The Research Front "Formation and merger of double compact objects," strongly related to the direct detection of gravitational waves from the merger of black holes, stands out as one of the emerging Research Fronts in this area. This front features eight core papers, and the topics include simulating binary black hole formation and thus providing a framework to interpret the results of gravitational-waves detection, predicting the properties of subsequent gravitational-wave events, and prospecting for multiband gravitational-wave astronomy after GW150914. With respect to the reprint authors of the eight core papers, three are from Northwestern University (USA), three from the University of Warsaw (Poland), one from the University of Bonn (Germany), and one from the University of Birmingham (UK).

10 . MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING

1. HOT RESEARCH FRONT

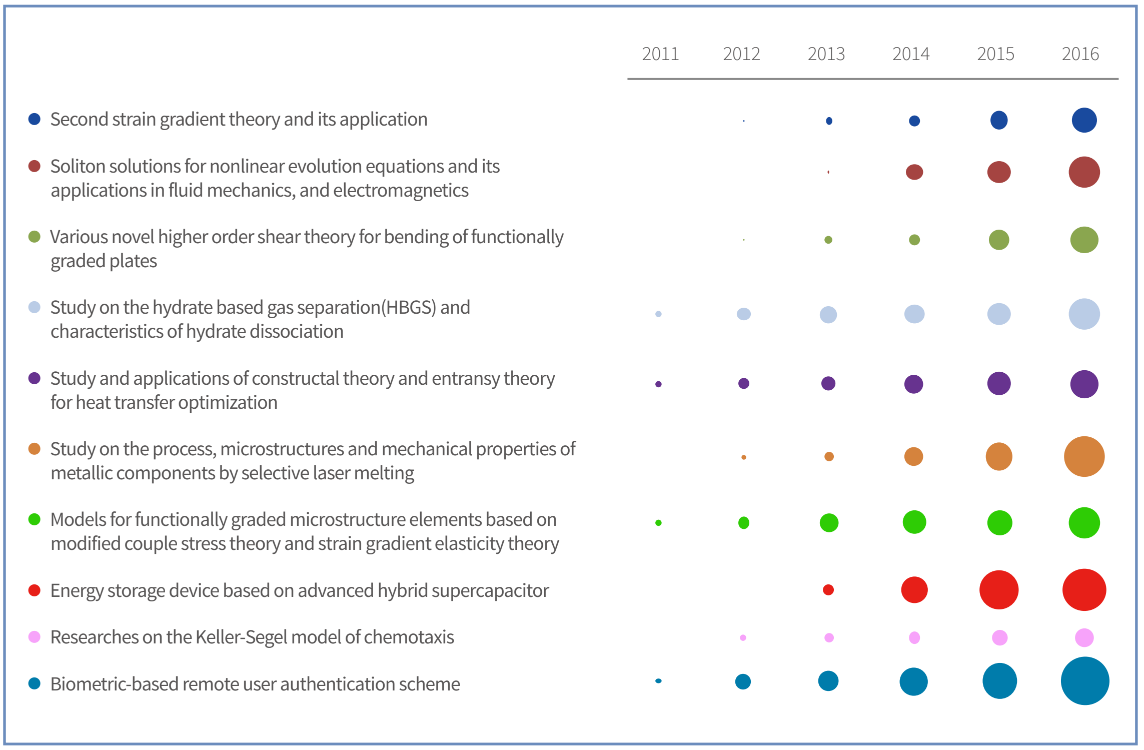
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING

The Top 10 Research Fronts in mathematics, computer science and engineering mainly focus on: the strain gradient theory and its application in material and engineering research; the solutions to several partial differential equations (and equation sets) and their applications; heat transfer optimization theory; supercapacitors; hydrate-based gas separation; selective laser melting; and biometric-based remote authentication. The Top 10 Research Fronts in 2017 show both continuity and development when compared with those fronts selected between 2013 and 2016. The strain gradient theory and its application has been consecutively selected as a hot or emerging Research Front for several years. The solutions of partial differential equations (and equation sets) and their applications have also constituted an important research topic in recent years. In engineering, the constructal theory and heat transfer optimization continues to be a hot Research Front in 2017, and hydrate-based gas separation, selective laser melting, as well as energy-storage devices based on advanced hybrid supercapacitor make the list of hot Research Fronts for the first time in 2017. In computer science, biometrics-based remote authentication is selected as a hot Research Front for the first time.

Table 48: Top 10 Research Fronts in mathematics, computer science and engineering

Number	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Second strain gradient theory and its application	50	1114	2015.1
2	Soliton solutions for nonlinear evolution equations and its applications in fluid mechanics, and electromagnetics	41	1041	2014.9
3	Various novel higher order shear theory for bending of functionally graded plates	35	1575	2014.7
4	Study on the hydrate based gas separation(HBGS) and characteristics of hydrate dissociation	21	947	2014.3
5	Study and applications of constructal theory and entransy theory for heat transfer optimization	29	1004	2014.2
6	Study on the process, microstructures and mechanical properties of metallic components by selective laser melting	16	1000	2014.2
7	Models for functionally graded microstructure elements based on modified couple stress theory and strain gradient elasticity theory	45	2114	2014.1
8	Energy storage device based on advanced hybrid supercapacitor	13	1409	2014
9	Researches on the Keller-Segel model of chemotaxis	45	1156	2014
10	Biometric-based remote user authentication scheme	37	2423	2013.9

Figure 9: Citing papers of the Top 10 Research Fronts in mathematics, computer science and engineering



1.2 KEY HOT RESEARCH FRONT – "Second strain gradient theory and its application"

Microstructure materials have been widely used in various applications. In practical engineering, most of the materials are macroscopically uniform and continuous, but complex microstructures appear at smaller scales. Therefore, understanding and quantifying the relationships between material properties and microstructures have scientific significance and potential in engineering application. The classical continuum theory does not contain any parameter related to the size of the object, and therefore it cannot explain the mechanical property of the microstructure and the size effect of the multi-field coupling performance. Accordingly, establishing a high-order theory based on continuum mechanics to investigate the strain behaviors of materials at micro-scale is very necessary.

Strain gradient theory was first proposed by Mindlin to introduce the size effect on mechanical properties such as elasticity, plastic deformation, and dislocation movement of structures or systems by incorporating high-order strain gradients and/or dislocation densities into the constitutive or evolutionary equations which dominate the behaviors of materials. Strain gradient theory is a complete second-order gradient theory, and thus provides a new idea for the investigation of non-classical continuum mechanics. By the continuous improvement and extension of the theory, researchers have established a variety of strain gradient models applicable to elastic, plastic, elastoplastic, thermoelastic materials and more.

The 50 core papers anchoring the hot Research Front "Second strain gradient theory and its application" in 2017 mainly focus on the use of high-order strain gradient continuum theory, including second-order strain gradient theory, to analyze the strain behaviors in micro-scale of a series of objects such as metamaterial, fabrics, fiber reinforcements, capillary fluids, bone tissue, cantilever beams, curved beams, and carbon nanotubes.

Among the eight countries participating in the Research Front, Italy occupies an absolute dominant position and contributes 48 core papers, accounting for 96.0% of the total (Table 49). France, the USA, Poland, and Germany also show good performance. On the list of the Top 10 institutions in terms of core papers, seven are from Italy. The Sapienza University of Rome and the University of L'Aquila show strong research capability, contributing 28 and 21 core papers to rank 1st and 2nd, respectively. Claude Bernard University Lyon 1 in France is the only non-Italian institution among the Top 5. In addition, the USA, Poland, and Canada each have one placement among the Top 10 institutions.

Table 49: Top countries and institutions producing the 50 core papers in the Research Front "Second strain gradient theory and its application"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	Italy	48	96.0%	1	Sapienza University of Rome	Italy	28	56.0%
2	France	11	22.0%	2	University of L'Aquila	Italy	21	42.0%
3	Poland	6	12.0%	3	Claude Bernard University Lyon 1	France	7	14.0%
3	USA	6	12.0%	4	International Telematic Univ ersity UNINETTUNO	Italy	6	12.0%
5	Germany	4	8.0%	4	Roma Tre University	Italy	6	12.0%
6	Canada	3	6.0%	6	University of Catania	Italy	5	10.0%

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
7	Russia	2	4.0%	6	Warsaw University of Technology	Poland	5	10.0%
8	Estonia	1	2.0%	6	University of California Berkeley	USA	5	10.0%
				9	University of Sassari	Italy	4	8.0%
				10	University of Calgary	Canada	3	6.0%
				10	University of Cagliari	Italy	3	6.0%

Analysis of citing papers demonstrates that Italy's predominance continues, with Italy-based authors contributing to 154 citing papers, accounting for 55.0% of the total. France, Germany, and the USA rank 2nd to 4th. China, although not listed as a core-paper contributor in this field, has actively participated in the follow-up research and ranks 7th in citing papers. China's output of citing papers is close to the volume of Poland, Canada, and Russia. At the institutional level, the Sapienza University of Rome and the University of L'Aquila produce the highest numbers of citing papers, indicating their strength in the follow-up research.

Table 50: Top countries and institutions producing citing papers in the Research Front "Second strain gradient theory and its application"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	Italy	154	55.0%	1	Sapienza University of Rome	Italy	59	21.1%
2	France	66	23.6%	2	University of L'Aquila	Italy	55	19.6%
3	Germany	46	16.4%	3	Claude Bernard University Lyon 1	France	25	8.9%
4	USA	35	12.5%	4	University of Paris-Est	France	19	6.8%
5	Poland	19	6.8%	5	University of Sassari	Italy	17	6.1%
6	Canada	17	6.1%	6	University of Duisburg-Essen	Germany	16	5.7%
7	China	16	5.7%	6	Roma Tre University	Italy	16	5.7%
7	Russia	16	5.7%	8	International Telematic University UNINETTUNO	Italy	14	5.0%
9	Egypt	9	3.2%	9	University of Calgary	Canada	13	4.6%
9	Romania	9	3.2%	9	Otto von Guericke University	Germany	13	4.6%
9	UK	9	3.2%					

1.3 KEY HOT RESARCH FRONT – "Energy storage device based on advanced hybrid supercapacitor"

Supercapacitors, energy-storage devices developed in the 1960s, have received wide attention and developed rapidly due to the appearance of hybrid electric vehicles in the 1990s. Supercapacitors, as the name suggests, possess larger capacity, higher energy, wider operating temperature range, and longer service life compared with conventional capacitors. When compared with batteries, supercapacitors have a higher power density and longer cycle life, and are free of environmental hazards. Therefore, by combining the advantages of traditional capacitors and batteries, supercapacitors show their promising application as a chemical power source. In recent years, supercapacitors have been successfully applied in consumer electronics, transportation energy (electric vehicles, etc.), power compensation, and other fields. The market is rapidly expanding.

According to the mechanism of electric energy storage and conversion, the supercapacitor can be divided into two types: the electric double layer capacitor and pseudocapacitor. Electrode materials for electric double-layer capacitors are mainly carbon-based materials, and those for pseudocapacitors mainly include polymers as well as transition metal oxides and hydroxides. The energy density of a supercapacitor is much higher than that of traditional capacitor, but still remarkably less than that of batteries (such as those combining lithium-ion, nickel-metal hydride batteries, etc.). Recently, an intensively investigated hybrid supercapacitor employing pseudocapacitor materials or battery materials as positive electrode and activated carbon materials as negative electrode appears, such as $Li_4Ti_5O_{12}$/AC and lithium-ion capacitors.

As the core component of supercapacitors, the electrode has always been the focus of research. In this key hot Research Front, the 13 core papers mainly focus on electrode research striving to improve the electrocatalytic performance of supercapacitors. Among these, four core papers investigate the electrode materials of lithium ion capacitors.

Nine countries contributed to the core papers. China, the USA, and South Korea rank in the top three (Table 51). At the institutional level, the University of California, Los Angeles (UCLA), published the largest numbers of core papers. Two of its three core papers have been cited more than 300 times, indicating UCLA's great impact in this Research Front.

Table 51: Top countries and institutions producing the 13 core papers in the Research Front "Energy storage device based on advanced hybrid supercapacitor"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	China	5	38.5%	1	University of California Los Angeles	USA	3	23.1%
2	South Korea	4	30.8%	2	Centre National de la Recherche Scientifique (CNRS)	France	2	15.4%
2	USA	4	30.8%	2	Université6ulouse III	France	2	15.4%
4	France	2	15.4%	2	Nanyang Technological University	Singapore	2	15.4%
4	Singapore	2	15.4%	2	Chonnam National University	South Korea	2	15.4%
6	Germany	1	7.7%	2	Seoul National University	South Korea	2	15.4%
6	Italy	1	7.7%					
6	Japan	1	7.7%					
6	Australia	1	7.7%					

Analysis of the citing papers (Table 52) indicates that China has a high engagement and contributed more than half of the total citing papers. The USA and South Korea continue their leading positions in producing citing papers. Among the Top 10 institutions, Chinese institutions occupy five positions, with the Chinese

Academy of Sciences ranking 1st with 107 citing papers. Nanyang Technological University ranks 2nd with 75 citing papers. Tsinghua University and Huazhong University of Science and Technology also good performance and rank 3rd and 4th, respectively.

Table 52: Top countries and institutions producing citing papers in the Research Front "Energy storage device based on advanced hybrid supercapacitor"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	580	54.9%	1	Chinese Academy of Sciences	China	107	10.1%
2	USA	221	20.9%	2	Nanyang Technological University	Singapore	75	7.1%
3	South Korea	116	11.0%	3	Tsinghua University	China	35	3.3%
4	Singapore	97	9.2%	4	Huazhong University of Science and Technology	China	33	3.1%
5	India	73	6.9%	5	Centre National de la Recherche Scientifique (CNRS)	France	24	2.3%
6	Germany	44	4.2%	5	Drexel University	USA	24	2.3%
7	Australia	41	3.9%	5	University of California Los Angeles	USA	24	2.3%
8	Japan	35	3.3%	8	Nankai University	China	21	2.0%
9	France	28	2.6%	8	Wuhan University of Technology	China	21	2.0%
10	UK	27	2.6%	8	Chonnam National University	South Korea	21	2.0%

11. ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

1. HOT RESEARCH FRONT

1.1 TRENDS INTHE TOP 10 RESEARCH FRONTS IN ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

The top 10 Research Fronts related to the social sciences focus on economics, psychology, sociology, and some instances of interdisciplinary research. The Research Fronts in psychology include “The study of mental health and suicide, alcoholism, drug abuse and other behaviors of soldiers, veterans and other special groups,” “Research on working memory training and its application” and “The impact of bilingualism on cognition.”

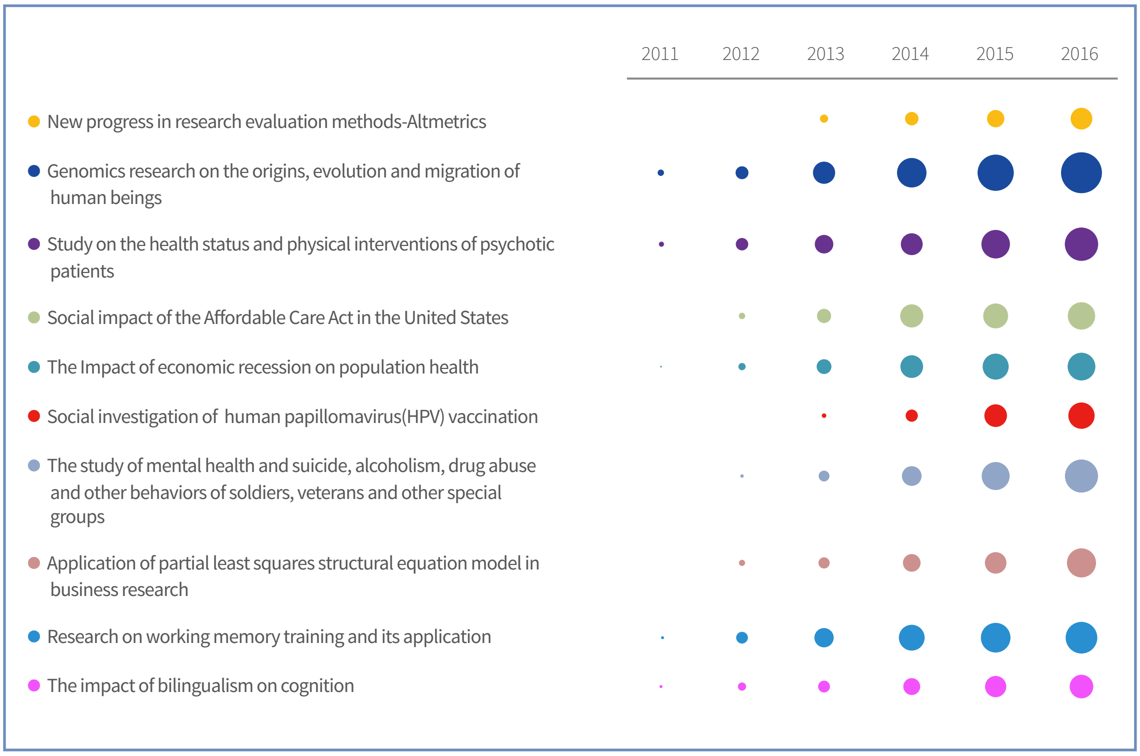
In sociology, “Social impact of the Affordable Care Act in the United States” has continued to be one of the top 10 hot fronts in the successive years of 2015, 2016 and 2017. Some new social researches, such as “Social investigation of human papillomavirus (HPV) vaccination” emerge among the hot Research Fronts in 2017, reflecting increasing attention to the societal aspects of medicine and health. Many hot Research Fronts in recent years involve interdisciplinary research. For example, “Study of the health status and physical interventions of psychotic patients” reflects the interaction between psychology and clinical medicine, while the front “Genomics research on the origins, evolution and migration of human beings” involves both genetics and archeology.

In previous years, various studies on methods and their implication have appeared among the hot Research Fronts. For example: “Multi-regional input-output analysis tools,” and “statistical methods in experimental psychology” in 2014; “Scientificity and repeatability of statistical analysis in experimental psychology” in 2015; and “Data envelopment analysis” in 2016. In this 2017 selection, “Application of partial least squares structural equation model in business research” and “New progress in research evaluation methods - Altmetrics” are among the top 10 hot Research Fronts.

Table 53: Top10 Research Fronts in economics, psychology and other social sciences

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	New progress in research evaluation methods - Altmetrics	26	726	2014.2
2	Genomics research on the origins, evolution and migration of human beings	38	3069	2014.1
3	Study on the health status and physical interventions of psychotic patients	24	1565	2014.1
4	Social impact of the Affordable Care Act in the United States	22	1137	2014.1
5	The Impact of economic recession on population health	29	1260	2014
6	Social investigation of human papillomavirus (HPV) vaccination	9	702	2014
7	The study of mental health and suicide, alcoholism, drug abuse and other behaviors of soldiers, veterans and other special groups	26	1162	2013.9
8	Application of partial least squares structural equation model in business research	12	833	2013.9
9	Research on working memory training and Its application	22	1888	2013.8
10	The impact of bilingualism on cognition	19	1225	2013.7

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



1.2 KEY HOT RESEARCH FRONT – "Genomics research on the origins, evolution and migration of human beings"

In the past, research on the emergence and diffusion of modern humans relied mainly on archaeological and paleontological data. However, it is difficult to determine the genetic relationship among different groups of people based only on these data. Moreover, archaeological research is difficult to interpret as to whether the spread of civilization is due to the migration of people or the dissemination of thought. In the 1980s, the emergence of DNA data made it possible for scientists to use molecular genetic data to do direct testing on different human-origin theories. Genomics research into humanity's origins, evolution, and migration can directly determine the genealogy, migration path, and gene mix of different people.

From the perspective of genetics, the use of gene-sequencing methods, especially research on mitochondrial DNA (mtDNA) and other simple molecular markers, has afforded wide acceptance to the "out of Africa" and "African origin" hypotheses regarding human origin. These theories hold that modern humans originated from Africa and thus expanded outwards. There are 38 core papers in this Research Front, seven of which are directly related to the causes, processes, and changes of the "out of Africa" expansion.

Genome-based evidence suggests that modern humans moving out of Africa encountered Neanderthals and mixed with them. So far, scientists have determined that there is 2% genome sequence of Neanderthals in every modern human individual except those in Africa, indicating that modern humans who were part of the "out of Africa" migration mixed with Neanderthals at the beginning of their exodus from the continent. Thirteen core papers refer to the Neanderthals, and existing studies have established with near certainty that modern people outside Africa are descendants of Neanderthals and African *Homo sapiens*. Of the 13 core papers, four are related to the fossil discoveries of Sima de los Huesos (SH) in Spain. Findings from the SH sites have given scientists a better understanding of the evolution of humankind in the Middle Pleistocene and provided clues to the Neanderthals' origin and evolution.

Other areas of inquiry in this Research Front include: 1) Techniques and methods, such as models of DNA degradation with time, mapDamage, the DNA library preparation method, etc.; the paper that proposed the DNA library preparation method, published in Science in 2012, has the highest number of citations within this Research Front; 2) Other human-origin studies based on genomics, such as the origins of Native American habitants and modern Europeans; 3) Evolutionary aspects of human beings, such as the evolution of innate immune genes, the adaptability of Tibetans to the hypoxic environment of the Tibetan Plateau, etc..

In this Research Front, 27 core papers include authors based in the United States, accounting for just over 71% of the core group. Germany and China take second and third place by contributing to, respectively, 18 and 16 core papers. The UK, Spain, France, and Russia can each claim contributing authors on more than 10 core papers. These are the top-performing countries in this research field. At the institutional level, authors from the Max Planck Society are credited on 15 core papers, the highest total of any organization. The Chinese Academy of Sciences takes second place, contributing to 13 core papers. Five American institutes placed among the top 10: Harvard University, the Broad Institute, the Howard Hughes Medical Institute, the University of California, Berkeley, and Emory University. Besides the Max Planck Society, Germany has another institution – the University of Tubingen – listed in the Top 10. Other countries, including China, Russia, Denmark, Australia and Spain each have only one institution in the Top 10 list.

Table 54: Top countries and institutions producing the 38 core papers in the Research Front "Genomics Research on the origins, evolution and migration of human beings"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	27	71.1%	1	Max Planck Society	Germany	15	39.5%
2	Germany	18	47.4%	2	Chinese Academy of Sciences	China	13	34.2%
3	China	16	42.1%	3	Harvard University	USA	11	28.9%
4	UK	14	36.8%	4	Russian Academy of Sciences	Russia	10	26.3%
5	Spain	12	31.6%	4	Broad Institute	USA	10	26.3%
5	France	12	31.6%	6	Howard Hughes Medical Institute	USA	8	21.1%
7	Russia	10	26.3%	6	University of California Berkeley	USA	8	21.1%
8	Australia	8	21.1%	8	University of Copenhagen	Denmark	7	18.4%
8	Denmark	8	21.1%	8	Eberhard Karls University of Tubingen	Germany	7	18.4%
10	Canada	7	18.4%	10	University of Adelaide	Australia	6	15.8%
				10	Complutense University of Madrid	Spain	6	15.8%
				10	University of Oxford	UK	6	15.8%
				10	Emory University	USA	6	15.8%

From the perspective of citing papers, the United States occupies first place with 712 citing papers, accounting for approximately 45% of the total – nearly twice that of the UK, which ranks second. Germany places third with 276 citing papers, while China ranks eighth with 119 citing papers, a rank much lower than its third place in representation among the core papers.

In regards to the citing institutions, the Max Planck Society has the great number of citing papers, followed by the University of Copenhagen, Oxford University, Harvard University, Cambridge University, and the University of California, Berkeley. The Chinese Academy of Sciences and the Russian Academy of Sciences share seventh place, with 60 citing papers each.

Table 55: Top countries and institutions producing citing papers in the Research Front "Genomics research on the origins, evolution and migration of human beings"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	712	45.5%	1	Max Planck Society	Germany	135	8.6%
2	UK	392	25.0%	2	University of Copenhagen	Denmark	104	6.6%
3	Germany	276	17.6%	3	University of Oxford	UK	99	6.3%
4	France	202	12.9%	4	Harvard University	USA	84	5.4%
5	Spain	201	12.8%	5	University of Cambridge	UK	83	5.3%
6	Australia	166	10.6%	6	University of California Berkeley	USA	77	4.9%
7	Denmark	126	8.1%	7	Chinese Academy of Sciences	China	60	3.8%
7	China	119	7.6%	7	Russian Academy of Sciences	Russia	60	3.8%

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
9	Italy	115	7.3%	9	UCL	UK	59	3.8%
10	Canada	105	6.7%	10	Eberhard Karls University of Tubingen	Germany	49	3.1%
				10	Howard Hughes Medical Institute	USA	49	3.1%

1.3 KEY HOT RESARCH FRONT – "Social investigation of human papillomavirus (HPV) vaccination"

Human papilloma virus (HPV) is an epithelial virus which has a high degree of specificity. HPV can lead to skin infections and mucosal infection of other parts of the body, and is widely distributed in humans and animals. Currently, there are more than 100 different types of HPV which can infect different parts of the body. For example, some types of HPV can lead to genital warts, while other types can cause cellular abnormalities of the cervix, vulva, anus, penis, mouth and throat, sometimes even leading to malignancies, such as cervical cancer. According to data from US Centers for Disease Control and Prevention (CDC), HPV infection is very common in the United States. Approximately 79 million people have been infected with HPV, with about 14 million newly infected individuals each year. HPV is considered the most common sexually transmitted disease in the United States.

Human papillomavirus vaccine was approved for listing by the US Food and Drug Administration (FDA) in 2006 and approved by the World Health Organization (WHO); the vaccine was routinely used in the United States as of 2007. In 2014, WHO issued a guide and called on nations to vaccinate girls against cervical cancer. WHO determined that the vaccine and regular cervical screening are effective measures to prevent cervical cancer. The United States is the first country to carry out HPV vaccination. Moreover, the US CDC recommends that all 11 to 12-year-old boys and girls should be vaccinated with three doses of HPV vaccine, which has a significant effect in the prevention of cancer caused by HPV. *The Journal of Infectious Diseases* published a related study showing that since the introduction of the vaccine in 2006, the incidence of 14-to-19-year-old vaccinated female adolescents infected with HPV has dropped by 56%.

Nine core papers anchor this front. All these core papers include at least one author listing in the United States and mainly focus on the social investigation of HPV vaccination in the USA. The US CDC has 4 core papers, making it is the largest producer of foundational papers, accounting for roughly 44% of the total. Cincinnati Children's Hospital Medical Center, Harvard University, and the University of North Carolina Chapel Hill follow the US CDC in terms of the number of core papers.

Table 56: Top countries and institutions producing the 9 core papers in the Research Front "Social investigation of human papillomavirus (HPV) vaccination"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	9	100.0%	1	Centers for Disease Control & Prevention	USA	4	44.4%
				2	Cincinnati Children's Hospital Medical Center	USA	2	22.2%
				2	Harvard University	USA	2	22.2%
				2	University of North Carolina, Chapel Hill	USA	2	22.2%

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
				5	University of Michigan	USA	1	11.1%
				5	Emory University	USA	1	11.1%
				5	Howard Hughes Medical Institute	USA	1	11.1%
				5	Indiana University-Purdue University Indianapolis	USA	1	11.1%
				5	Johns Hopkins University	USA	1	11.1%
				5	Louisiana State University	USA	1	11.1%
				5	MRC Laboratory Molecular Biology	USA	1	11.1%
				5	University of Cincinnati	USA	1	11.1%
				5	University of South Florida	USA	1	11.1%

All the core papers are from the United States which focus on social survey of the United States HPV vaccination. Not surprisingly, 85% of citing papers are also from the United States. Canada, the UK, France, Australia and Italy are the countries with more than 10 citing papers.

The top 10 citing institutions are all based in the United States. The US CDC has the largest number of citing papers (64 citing papers), accounting for more than 13% of all citing papers. The number of citing papers from US CDC is more than twice that of the University of North Carolina at Chapel Hill, which ranks second in number of citing papers. This confirms that the US CDC is the main contributor and research institution in this area. Harvard University and Indiana University-Purdue University Indianapolis contributed to 28 and 22 citing papers, respectively.

Table 57: Top countries and institutions producing citing papers in the Research Front "Social investigation of human papillomavirus (HPV) vaccination"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	401	85.0%	1	Centers for Disease Control & Prevention	USA	64	13.6%
2	Canada	24	5.1%	2	University of North Carolina Chapel Hill	USA	31	6.6%
3	UK	14	3.0%	3	Harvard University	USA	28	5.9%
4	France	13	2.8%	4	Indiana University-Purdue University Indianapolis	USA	22	4.7%
5	Australia	11	2.3%	5	Emory University	USA	18	3.8%
6	Italy	10	2.1%	5	National Institutes of Health (NIH)	USA	18	3.8%
7	Germany	9	1.9%	7	Boston University	USA	13	2.8%
8	Japan	7	1.5%	7	University of South Florida	USA	13	2.8%
8	Netherlands	7	1.5%	9	Cincinnati Children's Hospital Medical Center	USA	12	2.5%
8	Spain	7	1.5%	9	H Lee Moffitt Cancer Center & Research Institute	USA	12	2.5%

APPENDIX

RESEARCH FRONTS:IN SEARCH OF THE STRUCTURE OFSCIENCE

■ 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 1961and 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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