



RESEARCH FRONTS 2016

Institutes of Science and Development,
Chinese Academy of Sciences

The National Science Library, Chinese
Academy of Sciences

Clarivate Analytics



中国科学院科技战略咨询研究院
Institutes of Science and Development, Chinese Academy of Sciences



中国科学院
文献情报中心
NATIONAL SCIENCE LIBRARY
CHINESE ACADEMY OF SCIENCES

Clarivate
Analytics

Formerly the IP & Science
business of Thomson Reuters



Table of Contents

1. METHODOLOGY	2
1. BACKGROUND	2
2. METHODOLOGY AND PRESENTATION OF DATA	3
2.1 RESEARCH FRONTS SELECTION	3
2.2 FINAL SELECTION AND INTERPRETATION OF KEY RESEARCH FRONTS	3
2. AGRICULTURAL, PLANT AND ANIMAL SCIENCES	6
1. HOT RESEARCH FRONT	6
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN AGRICULTURAL, PLANT AND ANIMAL SCIENCES	6
1.2 KEY HOT RESEARCH FRONT – “OUTBREAK, PREVENTION AND CONTROL OF MICROBIAL CONTAMINATE OF FRESH PRODUCE”	8
1.3 KEY HOT RESEARCH FRONT – “MECHANISM OF PLANT INNATE IMMUNITY”	10
3. ECOLOGY AND ENVIRONMENTAL SCIENCES	12
1. HOT RESEARCH FRONT	12
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN ECOLOGY AND ENVIRONMENTAL SCIENCES	12
1.2 KEY HOT RESEARCH FRONT – “MICROPLASTIC POLLUTION IN THE MARINE ENVIRONMENT”	14
1.3 KEY HOT RESEARCH FRONT – “BIODIVERSITY LOSS AND ITS IMPACT ON ECOSYSTEM FUNCTIONS AND ECOSYSTEM SERVICES”	15
2. EMERGING RESEARCH FRONT	17
2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ECOLOGY AND ENVIRONMENTAL SCIENCES	17
2.2 KEY EMERGING RESEARCH FRONT – “EFFECTS OF SYSTEMIC INSECTICIDES (NEONICOTINOIDS AND FIPRONIL) ON NON-TARGET ORGANISMS AND ENVIRONMENT”	17
4. GEOSCIENCES	18
1. HOT RESEARCH FRONT	18
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN GEOSCIENCES	18
1.2 KEY HOT RESEARCH FRONT – “GLOBAL WARMING HIATUS”	20
1.3 KEY HOT RESEARCH FRONT – “CARBON CYCLE OF INLAND WATERS AND THE OCEAN”	22
2. EMERGING RESEARCH FRONT	24
2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN GEOSCIENCES	24
2.2 KEY EMERGING RESEARCH FRONT – “ELEMENTAL COMPOSITION OF THE NORTH ATLANTIC OCEAN AND SOUTHERN OCEAN”	24
5. CLINICAL MEDICINE	26
1. HOT RESEARCH FRONT	26
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN CLINICAL MEDICINE	26
1.2 KEY HOT RESEARCH FRONT – “CLINICAL TRIALS OF DIRECT-CATING ANTIVIRALS (DAAS) FOR HEPATITIS C INFECTIONS”	28
1.3 KEY HOT RESEARCH FRONT – “IMMUNE CHECKPOINT INHIBITORS, ANTI-PD-1 ANTIBODIES IN MELANOMA IMMUNOTHERAPY”	30
2. EMERGING RESEARCH FRONT	31
2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CLINICAL MEDICINE	31
2.2 KEY EMERGING RESEARCH FRONT – “PROGRAMMED DEATH 1 (PD-1) INHIBITORS FOR THE TREATMENT OF ADVANCED NON-SMALL-CELL LUNG CANCER”	33

6. BIOLOGICAL SCIENCES	34
1. HOT RESEARCH FRONT.....	34
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN BIOLOGICAL SCIENCES.....	34
1.2 KEY HOT RESEARCH FRONT – “THE MOLECULAR MECHANISM FOR ORIGIN, DEVELOPMENT AND DIFFERENTIATION OF MACROPHAGE”.....	36
1.3 KEY HOT RESEARCH FRONT – “DIFFERENTIATION, FUNCTION, AND METABOLISM OF T CELLS”.....	38
2. EMERGING RESEARCH FRONT.....	40
2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN BIOLOGICAL SCIENCES.....	40
2.2 KEY EMERGING RESEARCH FRONT – “PRINCIPLES OF CHROMATIN LOOPING AND EVOLUTION OF CHROMOSOMAL DOMAIN ARCHITECTURE”.....	41
7. CHEMISTRY AND MATERIALS SCIENCE	42
1. HOT RESEARCH FRONT.....	42
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE.....	42
1.2 KEY HOT RESEARCH FRONT – “PHOSPHORS FOR WHITE LEDS”.....	44
1.3 KEY HOT RESEARCH FRONT – “SODIUM-ION BATTERIES”.....	46
2. EMERGING RESEARCH FRONT.....	46
2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE.....	46
2.2 KEY EMERGING RESEARCH FRONTS: AGGREGATED ANALYSIS OF SIX RESEARCH FRONTS RELATED TO PEROVSKITE.....	48
8. PHYSICS	50
1. HOT RESEARCH FRONT.....	50
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN PHYSICS.....	50
1.2 KEY HOT RESEARCH FRONT – “GALACTIC CENTER GAMMA-RAY EXCESS”.....	52
1.3 KEY HOT RESEARCH FRONT – “PROPERTY AND APPLICATION OF MONOLAYER/FEW-LAYER BLACK PHOSPHORUS”.....	53
2. EMERGING RESEARCH FRONT.....	54
2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN PHYSICS.....	54
2.2 KEY EMERGING RESEARCH FRONT – “EXPERIMENTAL REALIZATION OF FRACTIONAL CHERN INSULATORS”.....	55
9. ASTRONOMY AND ASTROPHYSICS	56
1. HOT RESEARCH FRONT.....	56
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS.....	56
1.2 KEY HOT RESEARCH FRONT – “OBSERVATIONS OF THE COSMIC MICROWAVE BACKGROUND (CMB) BY PLANCK”.....	58
1.3 KEY HOT RESEARCH FRONT – “BARYON ACOUSTIC OSCILLATION (BAO) RELATED RESEARCH BASED ON SKY SURVEY MISSIONS LIKE SLOAN DIGITAL SKY SURVEY”.....	60
2. EMERGING RESEARCH FRONT.....	62
2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS.....	62
2.2 KEY EMERGING RESEARCH FRONT – “STUDIES OF COMET 67P/ CHURYUMOV-GERASIMENKO BY ROSETTA”.....	62

10. MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING	64
1. HOT RESEARCH FRONT.....	64
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING.....	64
1.2 KEY HOT RESEARCH FRONT – “THE INTERNET OF THINGS, CLOUD MANUFACTURING AND RELATED INFORMATION TECHNOLOGY SERVICES”.....	66
1.3 KEY HOT RESEARCH FRONT – “RESEARCH ON MEASUREMENT-DEVICE-INDEPENDENT QUANTUM KEY DISTRIBUTION”.....	68
2. EMERGING RESEARCH FRONT	70
2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING.....	70
2.2 KEY EMERGING RESEARCH FRONT – “ENERGY MANAGEMENT STRATEGIES OF HYBRID ELECTRIC BUS”.....	70
11. ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES.....	72
1. HOT RESEARCH FRONT.....	72
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES.....	72
1.2 KEY HOT RESEARCH FRONT – “IMPACT AND EFFECTS OF U.S. HEALTH CARE REFORMS”.....	74
1.3 KEY HOT RESEARCH FRONT – “DEA (DATA ENVELOPMENT ANALYSIS) BASED ASSESSMENT OF ENVIRONMENTAL AND ENERGY EFFICIENCY”.....	76
12. NATIONAL PERFORMANCE IN RESEARCH FRONTS.....	78
1. INTRODUCTION	78
2. GENERAL PERFORMANCE OF SIX COUNTRIES	79
2.1 STRENGTH AND POTENTIAL DEVELOPMENT.....	79
2.2 COVERAGE PERFORMANCE OF SIX COUNTRIES IN 10 RESEARCH AREAS.....	81
3. PERFORMANCE OF SIX COUNTRIES IN EACH AREA.....	85
3.1 AGRICULTURAL, PLANT AND ANIMAL SCIENCES.....	85
3.2 ECOLOGY AND ENVIRONMENTAL SCIENCES	85
3.3 GEOSCIENCES.....	86
3.4 CLINICAL MEDICINE.....	86
3.5 BIOLOGICAL SCIENCES	87
3.6 CHEMISTRY AND MATERIALS SCIENCES.....	87
3.7 PHYSICS.....	88
3.8 ASTRONOMY AND ASTROPHYSICS.....	88
3.9 MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING	89
3.10 ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES.....	89
APPENDIX	
RESEARCH FRONTS:IN SEARCH OF THE STRUCTURE OF SCIENCE	90
REFERENCES	96
STEERING COMMITTEE	98
WORKING COMMITTEE.....	98



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 (formerly the IP & Science business of Thomson Reuters) 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 (formerly the IP & Science business of Thomson Reuters) 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 (formerly the IP & Science business of Thomson Reuters) and the National Science Library, Chinese Academy of Sciences. The reports gained widespread attention after their release.

This year, the same methodology was employed. For the newest edition, *Research Fronts 2016*, 100 hot research fronts and 80 emerging research fronts were identified based on co-citation analysis that generated 12,188 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 2016 update, the research fronts drew on ESI data from 2009 to 2015, which were obtained in March 2016.

2.1 RESEARCH FRONTS SELECTION

Research Fronts 2016 presents a total of 180 research fronts, including 100 hot and 80 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 12,188 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 180 research fronts is described as follows.

2.1.1 SELECTING THE HOT RESEARCH FRONTS

First, 12,188 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 2014 or more recently were considered, and then these were sorted in descending order by their total citations. There were 80 fronts whose total citations amounted to 100 or more (see appendix). Because the selection was not limited to any research area, the 80 fronts are distributed unevenly in the 10 fields. For example, there are 21 research fronts in biological sciences but none in agriculture, plant and animal sciences.

Based on the above two methods, the report presents the Top 10 hot fronts in 10 broad areas (100 fronts in total) and 80 emerging ones.

2.2 FINAL SELECTION AND INTERPRETATION OF KEY RESEARCH FRONTS

On the basis of 180 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 28 research fronts (Chapter 2 to Chapter 11) of particular interest, including both hot and emerging fronts. In Chapter 12, the current and potential performance of six leading countries in the 180 research fronts was analyzed.

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 1 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. In the current report, 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 2014 and the earliest citing paper was published in 2010, 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 2016*, 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. Research fronts such as "Amazon Mechanical Turk and online experimental behavioral research" were interpreted in *Research Fronts 2015*, therefore the research fronts with the second-largest CPT ("Impact of US health care reforms") is interpreted instead.

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 eight key emerging research fronts from the 80 emerging research fronts. Exceptions exist in some research areas where more weight is given to the professional knowledge of the analysts. For example, in agricultural, plant and animal sciences, although "Outbreak, prevention and control

of microbial contaminants of fresh produce" may not have scored highest in terms of core papers or the CPT indicator, the very important topic related to foodborne diseases and food safety was judged to merit the designation as a "key hot research front." Thus, we will interpret in detail the selected 28 key research fronts from the 180 research fronts. In chemistry and materials science, there are six research fronts related to perovskite materials, and we will interpret them as a whole.

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 blue background in the table. Since the papers analyzed in this report were published between 2009 and 2015, 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

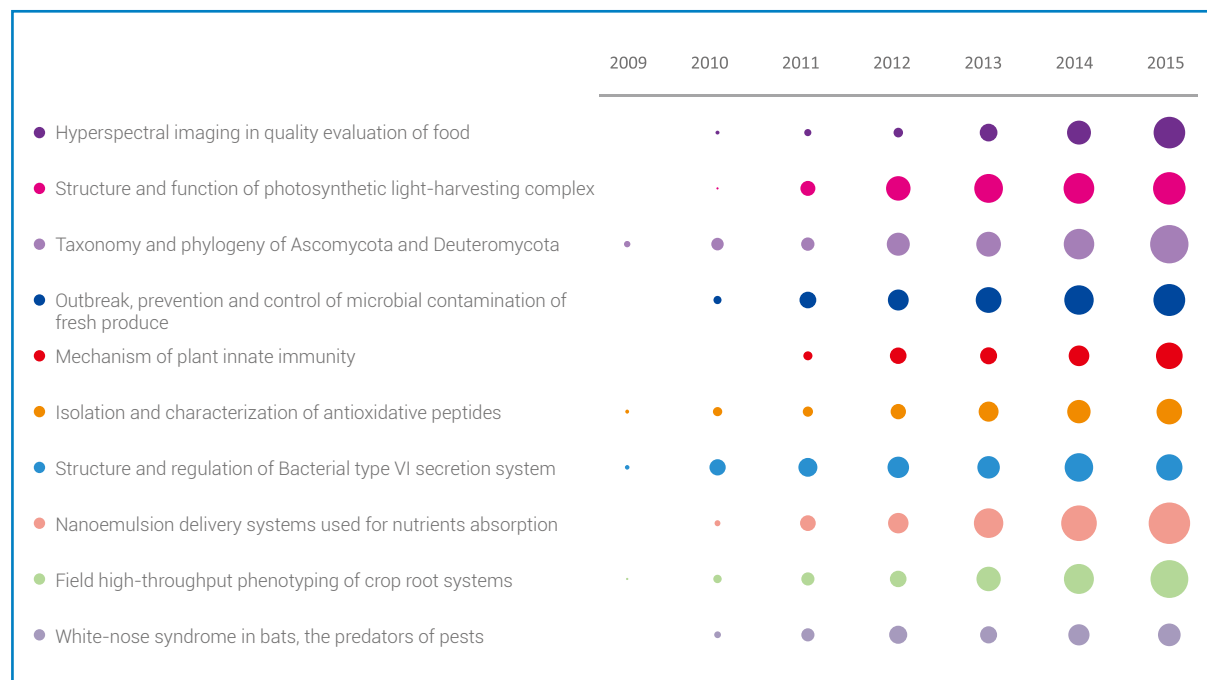
Most of the Top 10 research fronts in agricultural, plant and animal sciences fall into two sub-areas: crop science and food science. Crop science mainly focuses on basic research into pest and disease control and crop improvement. The work on pest and disease control is reflected in four research fronts: "Mechanism of plant innate immunity," "Taxonomy and phylogeny of Ascomycota and Deuteromycota," "Structure and regulation of Bacterial type VI secretion system" and "White-nose syndrome in bats, the predators of pests." Among these research fronts, "Mechanism of plant innate immunity" was also in the Top 10 research fronts in 2015. In addition, two research fronts involving basic research on crop improvement – "Structure and function of Photosynthetic light-harvesting complex" and "Field high-throughput phenotyping of crop root systems" are also among the Top 10 research fronts.

Food science mainly focuses on food safety and food nutrition. Two Top 10 research fronts are related to food safety: "Hyperspectral imaging in quality evaluation of food" and "Outbreak, prevention and control of microbial contamination of fresh produce." The former was also featured as a Top 10 research front in 2015. The research fronts "Isolation and characterization of antioxidative peptides" and "Nanoemulsion delivery systems used for nutrients absorption" are related to food nutrition.

Table 1: Top 10 research fronts in agricultural, plant and animal sciences

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Hyperspectral imaging in quality evaluation of food	40	1645	2012.6
2	Structure and function of photosynthetic light-harvesting complex	30	1756	2012.4
3	Taxonomy and phylogeny of Ascomycota and Deuteromycota	46	2709	2012.3
4	Outbreak, prevention and control of microbial contamination of fresh produce	23	1320	2012.3
5	Mechanism of plant innate immunity	12	1088	2012.2
6	Isolation and characterization of antioxidative peptides	13	857	2012.2
7	Structure and regulation of Bacterial type VI secretion system	20	2000	2012.1
8	Nanoemulsion delivery systems used for nutrients absorption	38	2586	2012.1
9	Field high-throughput phenotyping of crop root systems	30	1851	2012
10	White-nose syndrome in bats, the predators of pests	13	1106	2012

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



1.2 KEY HOT RESEARCH FRONT – “OUTBREAK, PREVENTION AND CONTROL OF MICROBIAL CONTAMINATES OF FRESH PRODUCE”

The contamination of food by microbiological agents is a worldwide public health concern. Many countries have documented significant increases over the past few decades in the incidence of diseases caused by microorganisms in food. Research on the microbial contamination of foodstuffs, including the sources, outbreak, epidemic trend, influence on society and economy, and methods of prevention and control, have recently become a focus of food-safety research.

In this hot research front, the 23 core papers mainly focus on the risk of outbreak, the sources, and the prevention and control strategy for foodborne diseases caused by pathogenic microorganism in fresh food and fresh-cut vegetables. The most important pathogenic microorganism is Salmonella, which is a major cause of foodborne illness throughout the world. The source

analysis of microbial contamination covers the whole food chain, including polluted water and soil, agricultural practices in the field, and the manufacturing process.

Prevention and control methods involve decontamination of the culture environment, optimized production practices, and the disinfection of products during packaging. Conventional measures of food disinfection had a limited effect due to the surface adhesion and internalization of pathogens, while atmospheric pressure cold plasma is viewed as a promising new method, as discussed by several papers in the hot research front. More comprehensive and timely environmental evaluation and more biological and ecological studies of pathogens and agricultural products interaction are needed to better explore prevention and control strategy.

Table 2: Top 5 countries and institutions producing core papers in the research front “Outbreak, prevention and control of microbial contaminants of fresh produce”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	9	39.1%	1	Ghent University	Belgium	5	21.7%
2	Spain	6	26.1%	2	Dublin Institute of Technology	Ireland	4	17.4%
3	Belgium	5	21.7%	3	Centers for Disease Control & Prevention-USA	USA	3	13.0%
4	Ireland	4	17.4%	3	Spanish National Research Council (CSIC)	Spain	3	13.0%
5	South Korea	2	8.7%	5	Chung-Ang University	South Korea	2	8.7%
5	UK	2	8.7%	5	Inagro	Belgium	2	8.7%
				5	Purdue University	USA	2	8.7%

From the perspective of countries and institutions (Table 2), the USA, Spain, Belgium, Ireland, South Korea and the UK contribute the greatest numbers of core papers. The USA is the main country contributing to this hot research front, with nine core papers, which account for 39.1% of the total. In addition, Spain and Belgium are also important countries, contributing six and five core papers, accounting for 26.1% and 21.7% of the total respectively.

In terms of countries that cited the core papers of this hot research front (Table 3), the USA, Spain, South Korea, China, and Belgium are the main players. The USA contributed 375 citing papers, accounting for 39.2% of the total, which is much more than the other countries. Spain ranks 2nd with 101 citing papers, while China ranks 4th with 66 citing papers. In terms of citing institutions,

the United States Department of Agriculture ranks 1st with 91 citing papers, followed by Ghent University (Belgium) with 46 and Spanish National Research Council with 37 citing papers. Among the Top 10 citing institutions, six institutions are located in the USA.

Analysis of the core and citing papers in the hot research front "Outbreak, prevention and control of microbial contaminate of fresh produce" shows that the USA is the leading country in this front. Belgium and Spain also play significant roles. China has been active in doing the follow-up research in this hot research front.

Table 3: Top 10 countries and institutions producing citing papers in the research front "Outbreak, prevention and control of microbial contaminates of fresh produce"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	375	39.2%	1	United States Department of Agriculture (USDA)	USA	91	9.5%
2	Spain	101	10.6%	2	Ghent University	Belgium	46	4.8%
3	South Korea	67	7.0%	3	Consejo Superior de Investigaciones Cientificas (CSIC)	Spain	37	3.9%
4	China	66	6.9%	4	US Food & Drug Administration (FDA)	USA	34	3.6%
5	Belgium	60	6.3%	5	University of Florida	USA	31	3.2%
6	Germany	48	5.0%	6	Chung-Ang University	South Korea	26	2.7%
7	Canada	44	4.6%	6	University of California Davis	USA	26	2.7%
8	Italy	38	4.0%	8	Dublin Institute of Technology	Ireland	25	2.6%
9	UK	38	4.0%	9	University of Maryland College Park	USA	24	2.5%
10	Ireland	36	3.8%	10	Universidad Politecnica de Cartagena	Spain	23	2.4%
				10	Centers for Disease Control & Prevention-USA	USA	23	2.4%

1.3 KEY HOT RESEARCH FRONT – “MECHANISM OF PLANT INNATE IMMUNITY”

Plant innate immunity is an important part of the plant immune system, and is the key natural defense protecting plants from disease. During the immune response, plants can detect pathogen-associated molecules by cell-surface-localized immune receptors and cytoplasmic immune receptor, and can trigger innate immunity to resist the infection of the pathogen. Therefore, research on plant innate immunity can provide important targets for crop disease-resistance breeding. The discovery of specific recognition receptors against various pathogen-associated molecules has long been crucial to understanding plant innate immune response.

Twelve core papers in this hot research front mainly concern the discovery of pattern recognition receptor,

which plays a key role in plant innate immunity, or focus on the study of receptor functional mechanism. Among the 12 core papers, the most-cited paper (179 citations) is “Receptor-like cytoplasmic kinases integrate signaling from multiple plant immune receptors and are targeted by a *Pseudomonas Syringae* effector,” published in *Cell Host & Microbe* by scientists from the National Institute of Biology Science, Beijing (China) in 2010. The team discovered the functional mechanism of host receptor-like cytoplasmic kinase – *Pseudomonas syringae* effector AvrPphB, an important and new signal-transduction element in plant innate immunity. Represented by the core papers, related studies have enriched understanding of the mechanism of plant innate immunity, and provided important theoretical

Table 4: Top countries and institutions producing core papers in the research front “Mechanism of plant innate immunity”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	China	5	41.7%	1	John Innes Center	UK	4	33.3%
2	UK	4	33.3%	2	Chinese Academy of Sciences	China	3	25.0%
2	USA	4	33.3%	2	National Institute of Biology Science	China	3	25.0%
4	Germany	2	16.7%	4	Texas A&M University College Station	USA	2	16.7%
4	Japan	2	16.7%	4	Eberhard Karls University of Tübingen	Germany	2	16.7%
4	Switzerland	2	16.7%	4	University of Basel	Switzerland	2	16.7%
7	Netherlands	1	8.3%					

foundation for disease-resistance breeding.

In terms of countries and institutions (Table 4), seven countries contributed to 12 core papers in this research front. China is the main country, contributing five core papers, accounting for 41.7% of the total. In addition, the USA and the UK contribute four core papers each, accounting for 33.3% of the total. Important contributing institutions include the Chinese Academy of Sciences, the John Innes Center in the UK and Texas A&M University in the USA.

In terms of countries that cited the core papers of this hot research front (Table 5), the USA contributed 169 citing papers, or 34.3% of the total, and ranks 1st. China ranks 2nd with 106 citing papers accounting for 21.5% of

the total. UK ranks 3rd with 86 citing papers accounting for 17.4% of the total. In terms of citing institutions, the John Innes Center (UK) ranks 1st with 54 citing papers, followed by the Max Planck Society (Germany) with 33 and the Chinese Academy of Sciences with 30 citing papers.

The analysis above shows that China, the USA, the UK and Germany are the most important countries producing the core papers for this hot research front, as well as the important countries in terms of the citing papers.

Table 5: Top 10 countries and institutions producing citing papers in the research front “Mechanism of plant innate immunity”

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	169	34.3%	1	John Innes Center	UK	54	11.0%
2	China	106	21.5%	2	Max Planck Society	Germany	33	6.7%
3	UK	86	17.4%	3	Chinese Academy of Sciences	China	30	6.1%
4	Germany	85	17.2%	4	Eberhard Karls University of Tubingen	Germany	26	5.3%
5	Japan	39	7.9%	5	University of California Davis	USA	21	4.3%
6	France	28	5.7%	6	University of Basel	Switzerland	20	4.1%
7	Switzerland	24	4.9%	7	Texas A&M University College Station	USA	19	3.9%
8	Netherlands	23	4.7%	8	Cornell University	USA	16	3.2%
9	South Korea	17	3.4%	9	Wageningen University & Research Center	Netherlands	15	3.0%
10	Spain	15	3.0%	10	National Institute of Biology Science	China	14	2.8%
				10	Institut National de la Recherche Agronomique (INRA)	France	14	2.8%



3. ECOLOGY AND ENVIRONMENTAL SCIENCES

1. HOT RESEARCH FRONT

1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN ECOLOGY AND ENVIRONMENTAL SCIENCES

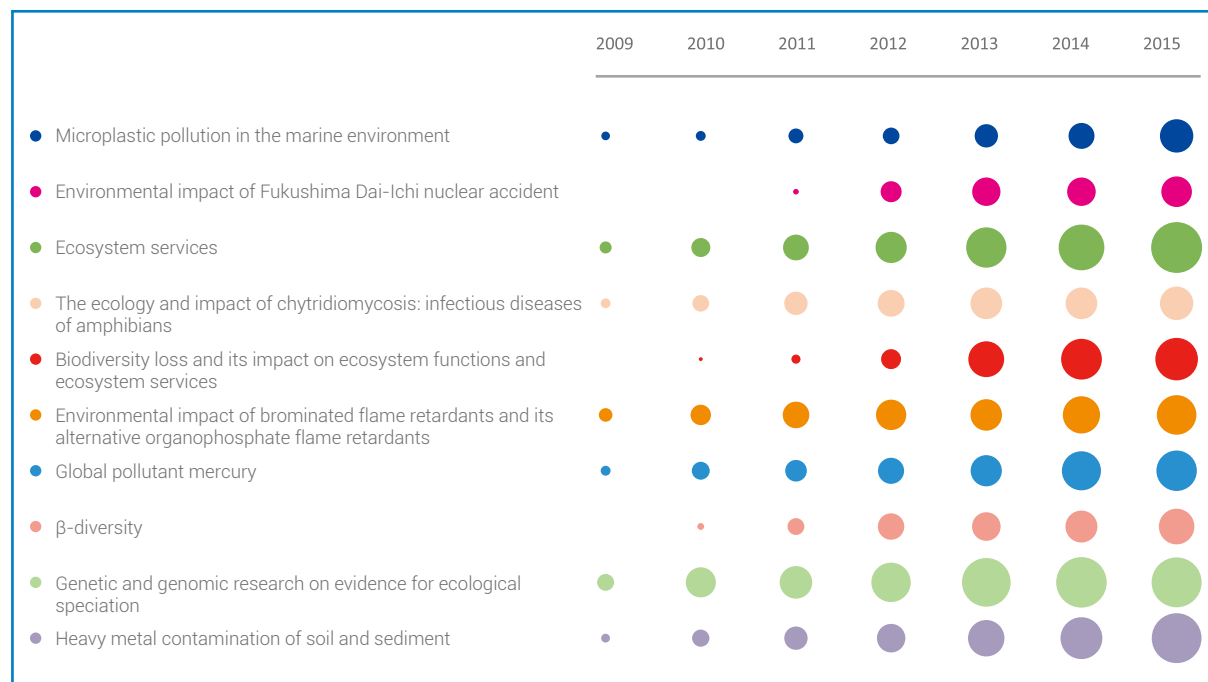
Table 6 shows the Top 10 hot research fronts in Ecology and Environmental Sciences. Environmental pollution problems are the primary research focus of this area. There are five hot research fronts relating to various pollution problems: "Microplastic pollution in the marine environment," "Environmental impact of Fukushima Dai-Ichi nuclear accident," "Environmental impact of brominated flame retardants and its alternative organophosphate flame retardants," "Global pollutant mercury," and "Heavy metal contamination of soil and sediment." The first two fronts mentioned above, on microplastic pollution and the Fukushima Dai-Ichi nuclear accident, are selected as Top 10 hot research fronts in both 2015 and 2016.

Research on amphibian chytrid chytridiomycosis figures once again among the Top 10 hot research fronts, having first been selected in 2013. In 2016, a similar topic, "The ecology and impact of chytridiomycosis: infectious diseases of amphibians," is highlighted as one of the Top 10 hot research fronts. In this area, another hot research front, "Biodiversity loss and ecosystem changes," is a continuation of the hot research fronts "Biodiversity and ecosystem function" and "Functional and phylogenetic diversity as predictors of biodiversity-ecosystem-function relationships," which were covered in 2013 and 2015, respectively. "Ecosystem services", " β -diversity" and "Genetic and genomic research on evidence for ecological speciation" are three new research fronts this year.

Table 6: Top 10 research fronts in ecology and environmental sciences

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Microplastic pollution in the marine environment	43	2789	2013.1
2	Environmental impact of Fukushima Dai-Ichi nuclear accident	20	1739	2012.3
3	Ecosystem services	41	4639	2012
4	The ecology and impact of chytridiomycosis: infectious diseases of amphibians	23	2336	2011.7
5	Biodiversity loss and its impact on ecosystem functions and ecosystem services	8	1954	2011.5
6	Environmental impact of brominated flame retardants and its alternative organophosphate flame retardants	27	2981	2011.4
7	Global pollutant mercury	22	2306	2011.4
8	β -diversity	9	1470	2011.3
9	Genetic and genomic research on evidence for ecological speciation	33	5381	2010.9
10	Heavy metal contamination of soil and sediment	31	2727	2010.9

Figure 2 Citing papers of the Top 10 research fronts in ecology and environmental sciences



1.2 KEY HOT RESEARCH FRONT – “MICROPLASTIC POLLUTION IN THE MARINE ENVIRONMENT”

The term microplastics, or microplastic debris, generally refers to pieces of plastic at the millimeter or even micron level. Microplastics can be suspended in ocean water or deposited on the bottom of the ocean to become a component of sediments. Due to the materials' unique physical and chemical properties, the influence of microplastics pollution on the marine environment is even greater than macroplastics pollution. Microplastics pollution has emerged as one of the new environmental problems that the ocean is facing.

There are 43 core papers in this hot research front, focusing on two topics: geographical investigations of marine microplastic pollution (including 14 core papers) and the influence of marine microplastic and its adsorbed persistent organic pollutants (POPs) on marine organisms (including 23 core papers).

The results of geographical investigations of marine microplastic pollution show that microplastics are ubiquitous throughout the marine environment and can be widely collected on beaches, surface waters, sediments, and even in remote polar glaciers and deep-sea sediments. Collaborating with scientists from six countries, Marcus Eriksen from the Five Gyres Institute published a core paper in *Plos One* in 2014. In this paper, the authors pointed out that large plastic degraded into

microplastics across five sub-tropical gyres and that the smallest particles appeared in remote areas of the oceans.

In research on the impact of microplastics on marine life, the associated ecological effects and health risks are current concerns. Microplastics can easily be ingested by marine life. Twenty-three core papers of this research front documented the occurrence of microplastics in the gastrointestinal tracts of zooplankton, planktonic and benthic fish, crabs and sea birds. In two separate mussel analyses, a marked accumulation of microplastics was observed in cultured mussels compared to mussels living in natural habitats. Several core papers also showed that the observed microplastics contained toxicants or absorbed persistent organic pollutants (POPs), including polychlorinated biphenyls (PCBs), petroleum hydrocarbons, organochlorine pesticides, polybrominated diphenylethers, alkylphenols and bisphenol A. Some papers in this research front demonstrate the transfer of POPs from plastic to organisms. POPs released from microplastics not only induce direct toxic effects on marine organisms, but also can be bio-concentrated through food chains and can ultimately threaten human beings.

These studies indicate that we are facing a very severe

Table 7: Top countries and institutions producing core papers in the research front “The microplastic pollution in the marine environment”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	UK	16	37.2%	1	Plymouth University	UK	10	23.3%
2	USA	14	32.6%	2	University of Exeter	UK	7	16.3%
3	Australia	5	11.6%	3	Sea Education Association	USA	5	11.6%
3	Canada	5	11.6%	3	Algalita Marine Research Foundation	USA	5	11.6%
5	Chile	4	9.3%	5	North Carolina State University	USA	4	9.3%
6	France	3	7.0%	5	5 Gyres Institute	USA	4	9.3%
6	Norway	3	7.0%	7	Woods Hole Oceanographic Institution	USA	3	7.0%
				7	Plymouth Marine Laboratory	UK	3	7.0%
				7	Akvaplan-niva As	Norway	3	7.0%
				7	University of Western Australia	Australia	3	7.0%
				7	Universidad Catolicadel Norte	Chile	3	7.0%

situation with marine microplastic pollution. Therefore, more and more countries are starting to take action. Led by the UK and the USA, 27 countries contributed to core papers (Table 7), while the number of countries that participated in citing papers increased to 76. Analysis shows that many countries have increased their intensity of research on microplastics, and at the same time have formulated a number of regulations or policies to reduce microplastics pollution, such as prohibiting the addition of plastic beads to cosmetic products. Although there is no core paper on the microplastics pollution from China, China contributed 32 citing papers in this area ranking

11th. Among them, a paper with name of "Microplastic Pollution in Table Salts from China" by Huahong Shi's group from East China Normal University published in *Environmental Science & Technology*, has been reported by *Scientific American*. It was then reprinted in all the newspapers and websites nationwide in China causing a fairly strong social reaction. Solving the problem of marine microplastics pollution requires not only effort from scientists, but also attention and advocacy on the part of the general public to reduce the release of plastic products.

Table 8: Top countries and institutions producing citing papers in the research front "The microplastic pollution in the marine environment"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	211	27.4%	1	University of Plymouth	UK	39	5.1%
2	UK	104	13.5%	2	IFREMER	France	23	3.0%
3	Germany	81	10.5%	3	University of Exeter	UK	19	2.5%
4	Australia	68	8.8%	3	National Oceanic and Atmospheric Administration (NOAA)	USA	19	2.5%
5	Canada	53	6.9%	5	Wageningen University and Research Centre	Netherlands	17	2.2%
6	France	49	6.4%	5	Korea Institute of Ocean Science & Technology	South Korea	17	2.2%
7	Brazil	46	6.0%	7	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Australia	16	2.1%
8	Italy	43	5.6%	8	Universidade Federal Rural de Pernambuco	Brazil	15	1.9%
9	Netherlands	35	4.5%	8	Sea Education Association (SEA)	USA	15	1.9%
10	Spain	34	4.4%	8	University of Hawaii	USA	15	1.9%
11	China	32	4.2%					

1.3 KEY HOT RESEARCH FRONT – "BIODIVERSITY LOSS AND ITS IMPACT ON ECOSYSTEM FUNCTIONS AND ECOSYSTEM SERVICES"

With the growth of the human population and the concurrent increase in human activity, biodiversity is being lost at a remarkable rate. More and more evidence shows that multiple ecosystem functions are being negatively affected by biodiversity loss, with manifestations that include decreases in productivity, imbalances in nutrient circulation, and a decrease in pollination. These multiple functions are essential to human beings, since the ecosystem provides the raw

materials for goods and services needed to prosper. In 2007, Hector and Bagchi were first to quantify the impact of biodiversity on several ecosystem processes. Since then, study of the impact of biodiversity on ecosystem functions and ecosystem services has gradually become a hot topic in ecology research. The eight core papers in this research front were all published in top journals. Three core papers were published in *Nature*, another three in *Science*, one in *PNAS*, and the other in

the *American Journal of Botany*. Among these reports, a review published in 2012 by Cardinale (University of Michigan) received 614 citations. The results described in this hot research front indicate that higher species richness is required to provide multiple ecosystem functions over different spatial/temporal scales. On the other hand, research on a single ecosystem may underestimate the role of biodiversity on ecosystem function.

A total of 23 countries contributed to core papers in this hot research front. One hundred and four countries published 1,346 citing papers. The USA participated in all eight core papers and contributed 531 citing papers,

accounting for 39.5% of the total. China participated in one core paper and contributed 102 citing papers. The Chinese Academy of Sciences published 53 citing papers to rank 2nd among the most-prolific institutions producing citing papers.

Many countries are paying close attention to the problems of biodiversity loss and the degradation of ecosystem services. As of now, 124 countries have joined the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, established in 2012 in Panama under the initiative of the United Nations Environment Programme.

Table 9: Top countries and institutions producing core papers in the research front "Biodiversity loss and ecosystem changes"

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	8	100%	1	McGill University	Canada	4	50.0%
2	Canada	4	50.0%	1	College of William & Mary	USA	4	10.0%
3	Sweden	3	37.5%	1	University of Minnesota Twin Cities	USA	4	50.0%
3	Australia	3	37.5%	4	Western Washington University	USA	3	7.5%
5	Switzerland	2	25.0%	4	University of California Santa Cruz	USA	3	37.5%
5	Mexico	2	25.0%	4	University of Michigan	USA	3	7.5%
5	Germany	2	25.0%	4	University of British Columbia	Canada	3	37.5%

Table 10: Top countries and institutions producing citing papers in the research front "Biodiversity loss and ecosystem changes"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	531	39.5%	1	University of Minnesota Duluth	USA	67	5.0%
2	Germany	257	19.1%	2	Chinese Academy of Sciences	China	53	3.9%
3	UK	240	17.8%	3	Institut National de la Recherche Agronomique (INRA)	France	52	3.9%
4	Australia	182	13.5%	3	Wageningen University and Research Centre	Netherlands	52	3.9%
5	France	159	11.8%	5	University of Zurich	Switzerland	44	3.3%
6	Canada	138	10.3%	6	University of Western Sydney	Australia	43	3.2%
7	Switzerland	127	9.4%	6	Centre National de la Recherche Scientifique (CNRS)	France	43	3.2%
8	Spain	123	9.1%	8	University of Gottingen	Germany	42	3.1%
9	Netherlands	115	8.5%	9	German Centre for Integrative Biodiversity Research (iDiv)	Germany	41	3.0%
10	China	102	7.6%	9	Helmholtz-Centre for Environmental Research - UFZ	Germany	41	3.0%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ECOLOGY AND ENVIRONMENTAL SCIENCES

In the area of ecology and environmental sciences, there are two emerging research fronts: “Effects of systemic insecticides (neonicotinoids and fipronil) on non-target organisms and environment” and “Water structure and chaotropy, kosmotropy: their uses, abuses and biological implications.”

Table 11: Emerging research fronts in ecology and environmental sciences

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Effects of systemic insecticides (neonicotinoids and fipronil) on non-target organisms and environment	7	108	2015
2	Water structure and chaotropy, kosmotropy: their uses, abuses and biological implications	9	124	2014.8

2.2 KEY EMERGING RESEARCH FRONT – “EFFECTS OF SYSTEMIC INSECTICIDES (NEONICOTINOIDS AND FIPRONIL) ON NON-TARGET ORGANISMS AND ENVIRONMENT”

Neonicotinoids and fipronil are currently the most common systemic insecticides. Due to the similarities in the binding-site of pests and non-target organisms, systemic insecticides can also have lethal and sublethal impacts on non-target organisms, including insect predators and vertebrates.

In recent years, the sharply reduced number of pollinating insects such as bees has aroused great concern all over the world. Although no consensus has yet been reached on the specific reasons behind the phenomenon, the impact of systemic insecticides on non-target organisms has been widely recognized. The seven core papers in the emerging research front were all published in 2015, providing more evidence that systemic insecticides, including neonicotinoids

and fipronil, not only have the capacity to “accidentally” kill pollinating insects, but can also threaten other non-target organisms such as earthworms, birds and fish, thus contributing to biodiversity loss.

Various countries and regions have undertaken targeted initiatives to prohibit the use of systemic insecticides. In May 2013, the European Union voted to restrict the use of three types of neonicotinoid insecticides (clothianidin, imidacloprid and thiamethoxam) no later than December of that year. The reassessment date has been extended to January 2017. On March 17, 2016, the French National Assembly voted to ban neonicotinoid pesticides. The bill would completely ban all use of neonicotinoid pesticides on crops, including seed treatments, by September 2018 throughout France.



4. GEOSCIENCES

1. HOT RESEARCH FRONT

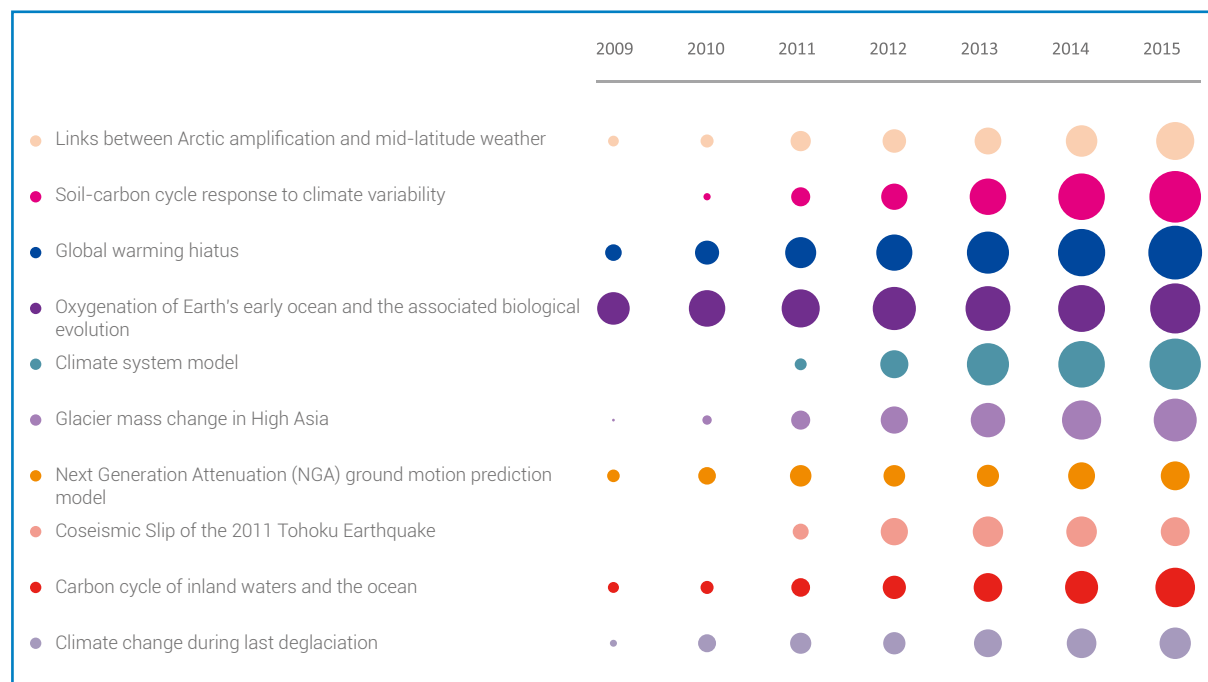
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN GEOSCIENCES

Research fronts in geosciences continue to show a balance between climate change, geochemistry, and solid geophysics and geology. Fronts related to climate change include global warming hiatus; climate system model; glacier mass change in High Asia; soil-carbon cycle response to climate variability; links between Arctic amplification and mid-latitude weather; and climate change during last deglaciation. Research fronts devoted to geochemistry reflect the carbon cycle of inland waters and the ocean, along with the oxygenation of Earth's early ocean and the associated biological evolution. And research fronts in solid geophysics and geology are coseismic slip of the 2011 Tohoku earthquake and Next Generation Attenuation (NGA) ground motion prediction model.

Table 12: Top 10 research fronts in geosciences

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Links between Arctic amplification and mid-latitude weather	40	2700	2012.9
2	Soil-carbon cycle response to climate variability	36	3089	2012.6
3	Global warming hiatus	47	4962	2012.4
4	Oxygenation of Earth's early ocean and the associated biological evolution	50	6328	2012.2
5	Climate system model	31	3793	2012.2
6	Glacier mass change in High Asia	30	3220	2012.1
7	Next Generation Attenuation (NGA) ground motion prediction model	22	2204	2012
8	Coseismic Slip of the 2011 Tohoku Earthquake	22	2391	2011.9
9	Carbon cycle of inland waters and the ocean	13	1861	2011.9
10	Climate change during last deglaciation	16	1746	2011.8

Figure 3: Citing papers of the Top 10 research fronts in geosciences



1.2 KEY HOT RESEARCH FRONT – “GLOBAL WARMING HIATUS”

As a completely new hot topic in global climate change, the notion that global warming has gone on “hiatus” has been the most popular and persistent myth in recent years. Many observations show that despite the continued increase in atmospheric greenhouse gas concentrations, the annual mean global temperature has not risen since the end of twentieth century (i.e., 1998). The phenomenon is called “hiatus.” Since the recent findings of global-warming hiatus may challenge the prevailing belief on human-induced global warming, they have attracted wide attention from the scientific community as well as the general public.

Scientists have carried out numerous calibrations and comparisons of global land-ocean surface temperature,

focusing on the effects of radiation forcing and the natural variability of the climate system, to find the possible mechanisms that might lead to a global-warming hiatus. A general opinion is that a recent global-warming hiatus is part of natural variability and, from a historical perspective, is not surprising. However, the relative importance of various mechanisms has not been quantified. Even though similar global-warming-hiatus events may occur in the future, there is a large probability that the global-warming trend of recent decades will continue.

The first report of the scientific study of the global-warming hiatus was published in 2009. A hot research front on the hiatus has formed since then, with 47 core

Table 13: Top countries and institutions producing core papers in the research front “Global warming hiatus”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	40	85.1%	1	National Center for Atmospheric Research (NCAR)	USA	14	29.8%
2	UK	11	23.4%	2	National Oceanic and Atmospheric Administration (NOAA)	USA	12	25.5%
3	Australia	10	21.3%	3	National Aeronautics and Space Administration (NASA)	USA	10	21.3%
4	Canada	8	17.0%	4	University of Hawaii Manoa	USA	6	12.8%
5	France	5	10.6%	4	California Institute of Technology	USA	6	12.8%
6	Germany	4	8.5%	6	Met Office	UK	5	10.6%
6	China	4	8.5%	7	University California San Diego	USA	4	8.5%
8	Switzerland	3	6.4%	7	Commonwealth Scientific and Industrial Research Organization (CSIRO)	Australia	4	8.5%
8	Japan	3	6.4%					

papers, now ranking 3rd in geosciences. In addition to the special issue of *Nature Climate Change* in March 2014, many top multidisciplinary journals as well as geosciences journals such as *Science*, *Journal of Geophysical Research-Atmospheres*, and *Nature* have published a large number of articles and reviews on the hiatus.

Seventeen countries participated in the 47 core papers of this research front. The USA has the predominant position at the country and institutional levels. China contributed four core papers and tied with Germany to rank 6th. The Chinese Academy of Sciences and Ocean University of China both contributed two papers.

Analysis of the citing papers indicates that the USA

contributed more than half of the total and is far ahead of other countries. The UK ranks 2nd, matching its rank in terms of core papers. China has followed up actively, producing 280 citing papers to rank 5th. The Chinese Academy of Sciences also ranks 5th on the top institution list in producing citing papers.

Table 14: Top 10 countries and institutions producing citing papers in the research front “Global warming hiatus”

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	1408	52.3%	1	National Oceanic and Atmospheric Administration (NOAA)	USA	260	9.7%
2	UK	521	19.4%	2	National Aeronautics and Space Administration (NASA)	USA	242	9.0%
3	Germany	413	15.3%	3	National Center for Atmospheric Research (NCAR)	USA	217	8.1%
4	France	285	10.6%	4	University of Colorado Boulder	USA	145	5.4%
5	China	280	10.4%	5	Chinese Academy of Sciences	China	144	5.3%
6	Australia	256	9.5%	6	Met Office	UK	143	5.3%
7	Canada	197	7.3%	7	California Institute of Technology	USA	135	5.0%
8	Japan	181	6.7%	8	University of Reading	UK	111	4.1%
9	Switzerland	166	6.2%	9	Max Planck Society	Germany	105	3.9%
10	Spain	133	4.9%	10	Swiss Federal Institute of Technology in Zurich	Switzerland	104	3.9%

1.3 KEY HOT RESEARCH FRONT – “CARBON CYCLE OF INLAND WATERS AND THE OCEAN”

Carbon, which continuously cycles in the form of CO₂, carbonates, and organic compounds in the environment, is a key component of living organisms on Earth. Based on numerous studies, the dynamics of global carbon cycle showed a close relationship with climate change and human activities. As an important component of the global carbon cycle, oceanic carbon cycle plays a key role in regulating global climate. Acting as a huge carbon reservoir, the ocean has the ability to absorb and store atmospheric CO₂, therefore significantly affecting the balance of atmospheric CO₂. Accordingly, investigations into the transferring and fate of oceanic carbon are significant in predicting future atmospheric CO₂ levels and even global climate changes. Despite the small fraction of the surface of the earth occupied by

inland waters (rivers, lakes, etc.), they play a major role in the global carbon cycle since they strongly gather the carbon emissions from human activities, and are closely related to the production and decomposition processes of organic carbon.

Understanding carbon-cycle processes and the dynamics of carbon pools –specifically ocean and inland water and their interaction with climate change, ecological systems and human activities through physical, chemical, and biological feedback mechanisms – has become a hot topic in geosciences.

A key hot research front, “Carbon cycle of inland waters and the ocean,” focuses on revealing the degradation and emission of carbon in inland waters and the

Table 15: Top countries and institutions producing core papers in the research front “Carbon cycle of inland waters and the ocean”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	11	84.6%	1	Uppsala University	Sweden	5	38.5%
2	Sweden	5	38.5%	2	Yale University	USA	4	30.8%
2	Brazil	5	38.5%	3	University of Washington Seattle	USA	3	23.1%
4	France	4	30.8%	3	University of Brussels	Belgium	3	23.1%
4	Belgium	4	30.8%					
6	Germany	3	23.1%					
6	Canada	3	23.1%					
6	Netherlands	3	23.1%					

ocean. The offsetting of carbon emission, the human factors affecting the carbon flux from land to ocean, and the changing coastal/marine carbon cycle are also highlighted in this research front.

Analysis of countries and institutions producing core papers in this field (Table 15) shows that the USA takes a leading role in this front, contributing 11 of the core papers. Following the USA, Sweden also performed well in this area. Uppsala University in Sweden published five core papers and ranks 1st as a core-paper producing institution.

As seen in Table 16, the USA produced the most citing papers (554), which accounts for 44.4% of the total. Sweden, the UK, Canada, Germany, and China rank

2nd to 6th, each contributing over 10% of the total citing papers. Four of the top citing institutions are in Sweden, indicating the general interest of Swedish organizations. In contrast, the USA only has two institutions on the list. The Chinese Academy of Sciences published 66 citing papers and ranks 4th on the top-institutions list.

In general, the USA is a leading country in this research front, and Sweden has strong research capabilities. The UK, Canada and Germany are also active participants. China, although not listed as a core paper contributor, follows the studies closely by publishing citing papers, demonstrating the nation's attention to this topic.

Table 16: Top countries and institutions producing citing papers in the research front “Carbon cycle of inland waters and the ocean”

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	554	44.4%	1	The United States Geological Survey	USA	79	6.3%
2	Sweden	190	15.2%	2	Uppsala University	Sweden	77	6.2%
3	UK	160	12.8%	3	Swedish University of Agricultural Sciences	Sweden	69	5.5%
4	Canada	158	12.7%	4	Chinese Academy of Sciences	China	66	5.3%
5	Germany	154	12.3%	5	University of Quebec	Canada	47	3.8%
6	China	140	11.2%	6	Swiss Federal Institute of Technology in Zurich	Switzerland	46	3.7%
7	Switzerland	99	7.9%	7	University of Wisconsin Madison	USA	37	3.0%
8	France	96	7.7%	8	Umea University	Sweden	36	2.9%
9	Australia	70	5.6%	9	University of Vienna	Austria	33	2.6%
10	Brazil	68	5.4%	9	Stockholm University	Sweden	33	2.6%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN GEOSCIENCES

There are two key emerging research fronts in geosciences: "Fault Zone of the 2012 Haida Gwaii earthquake" and "Elemental composition of the North Atlantic Ocean and Southern Ocean."

Table 17: Emerging research fronts in geosciences


Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Fault Zone of the 2012 Haida Gwaii earthquake	8	100	2014.8
2	Elemental composition of the North Atlantic Ocean and Southern Ocean	11	203	2014.5

2.2 KEY EMERGING RESEARCH FRONT – "ELEMENTAL COMPOSITION OF THE NORTH ATLANTIC OCEAN AND SOUTHERN OCEAN"

The important roles of trace elements in marine-ecosystem dynamics and carbon cycles in the marine environment have gradually been realized by the scientific community. Therefore, a systematic investigation of trace elements and their isotopes in global ocean biogeochemical cycles is being considered. The newly established international research program, "An International Study of the Biogeochemical Cycles of the Trace Elements and Their Isotopes" (GEOTRACES), aims to investigate the global oceanic distribution, the source and sink, as well as the internal circulation of specific trace elements (such as aluminum, manganese, iron, zinc, copper, cadmium, thorium, and etc.) and their isotopes. GEOTRACES also studies the response of trace elements and their isotopes to global changes, so as to help understand the evolution of ancient marine environments, as well as to forecast future environments.

Based on recent GEOTRACES measurements, an emerging research front in 2016, "Elemental composition

of the North Atlantic Ocean and Southern Ocean based on GEOTRACES program," has made great progress. Many results were published in top journals such as *Science and Nature*. Countries involved in the 11 core papers include the USA, Switzerland, Germany, the UK, and France. The performance of Switzerland is very impressive in that the two most highly cited core papers both come from researchers based this country. In 2014, researchers from the Swiss Federal Institute of Technology Zurich studied the source of dissolved iron in the North Atlantic Ocean quantitatively as well as the iron fertilization during the last glaciation in the Southern Ocean. Moreover, the elemental composition of primary particles, the concentration, the external sources and the internal circulation, as well as the enrichment process of trace elements in the North Atlantic and the Southern Ocean were analyzed by researchers from University of Hawaii, Woods Hole Oceanographic Institution and the University of Liverpool.

An aerial photograph of a coastline. The land on the left is a mix of golden-brown and tan, showing a rugged, mountainous terrain. The water is a vibrant turquoise color, with swirling patterns and eddies. The sky is a deep, dark blue, occupying the right half of the image. The overall scene is a beautiful natural landscape.

The important roles of trace elements in marine ecosystem dynamics and carbon cycles have been gradually realized by the scientific community.



5. CLINICAL MEDICINE

1. HOT RESEARCH FRONT

1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN CLINICAL MEDICINE

The main field of clinical medicine features three research front groups: “Clinical applications of new drugs,” “Drug resistance mechanisms and genetic monitoring” and “Fatal infectious diseases prevalence and control.”

The first group covers four fronts: “Clinical trials of direct-acting antivirals (DAAs) for hepatitis C infections,” “Immune checkpoints inhibitors anti-PD-1 antibodies in melanoma immunotherapy,” “Effect of monoclonal antibody to PCSK9 on low-density lipoprotein cholesterol in patients with hypercholesterolemia,” and “Anti-Interleukin-17 monoclonal antibody for psoriasis.”

The second group includes three fronts: “Mechanisms of artemisinin resistance plasmodium falciparum malaria in Southeast Asia,” “Circulating tumor DNA for the detection of tumors acquired resistance,” and “Whole-genome sequencing to identify outbreaks of drug-resistant pathogens,” mainly focusing on drug resistance mechanisms and related gene detection methods for falciparum malaria, tumor, tuberculosis and other diseases. The last research front group covers two fronts: “The epidemic and treatment of Ebola virus disease” and “Transmission, epidemiology, and biological features of human-infecting H7N9 influenza viruses.”

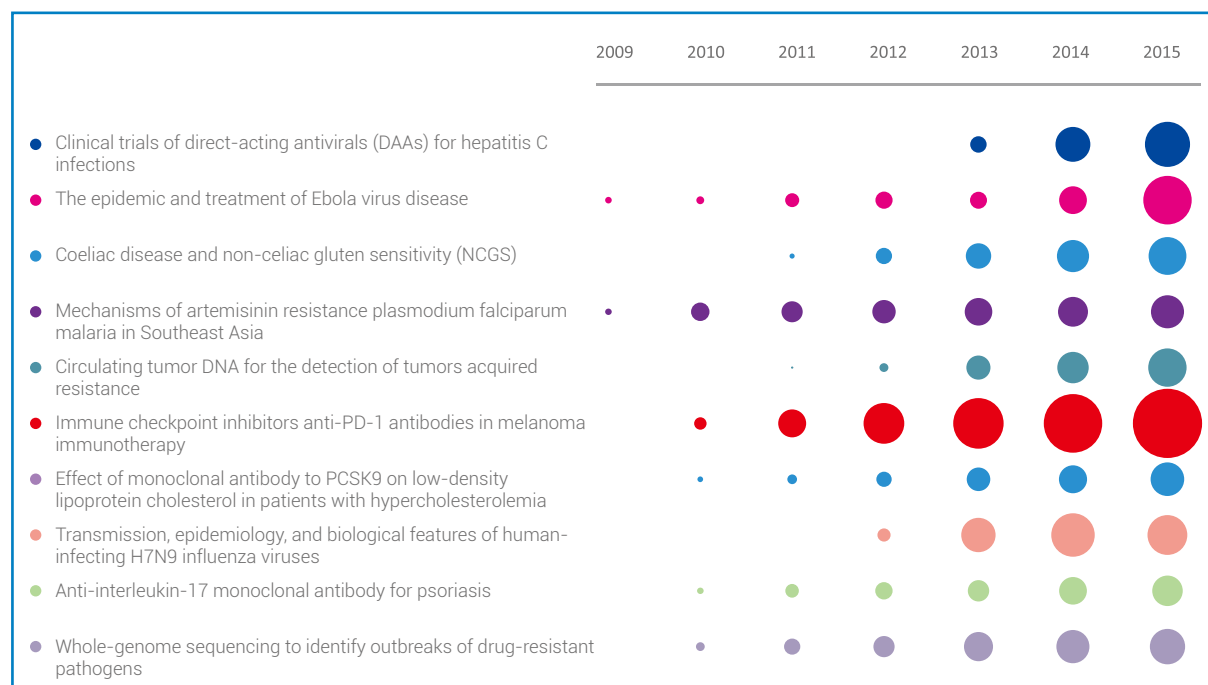
In a survey of research fronts in previous years, three research topics are identified with relatively high research interests: “Direct-acting antivirals (DAAs) for Hepatitis C Infections,” “Effect of Monoclonal Antibody to PCSK9 on lipoprotein cholesterol” and “Fatal infectious diseases (such as Ebola virus, avian influenza, MERS) prevalence and control.”



Table 18: Top 10 research fronts in clinical medicine

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Clinical trials of direct-acting antivirals (DAAs) for hepatitis C infections	38	4743	2014.1
2	The epidemic and treatment of Ebola virus disease	40	2949	2013.8
3	Coeliac disease and non-celiac gluten sensitivity (NCGS)	42	2950	2013.6
4	Mechanisms of artemisinin resistance plasmodium falciparum malaria in Southeast Asia	19	2727	2013.5
5	Circulating tumor DNA for the detection of tumors acquired resistance	17	2070	2013.5
6	Immune checkpoint inhibitors anti-PD-1 antibodies in melanoma immunotherapy	15	10548	2013.4
7	Effect of monoclonal antibody to PCSK9 on low-density lipoprotein cholesterol in patients with hypercholesterolemia	35	3442	2013.3
8	Transmission, epidemiology, and biological features of human-infecting H7N9 influenza viruses	35	5064	2013.1
9	Anti-interleukin-17 monoclonal antibody for psoriasis	18	2189	2013.1
10	Whole-genome sequencing to identify outbreaks of drug-resistant pathogens	21	2458	2012.9

Figure 4: Citing papers of the Top 10 research fronts in clinical medicine



1.2 KEY HOT RESEARCH FRONT – “CLINICAL TRIALS OF DIRECT-ACTING ANTIVIRALS (DAAs) FOR HEPATITIS C INFECTIONS”

Hepatitis C virus (HCV) infection is a global public health problem. According to the World Health Organization (WHO) statistics, the estimated number of infections was 150 million in 2015. Chronic hepatitis C infection (CHC) caused by HCV may be complicated by serious diseases such as cirrhosis or liver cancer. Roughly 500,000 people die from hepatitis C complications every year. The standard treatment regimen for hepatitis C infection was the dual therapy of pegylated interferon-alpha (PegIFN) and ribavirin (RBV) – i.e., “PR” – to remove HCV from body, which requires continuous treatment for 24 to 48 weeks. Most patients were cured by PR, although a substantial portion failed to tolerate or respond, or relapsed after the treatment.

Direct-Acting Antiviral Agents (DAAs) bring new hope for hepatitis C infection antiviral therapy, showing excellent effects even without the use of interferon. Simeprevir and sofosbuvir are two new DAAs drugs. Investigations of their use for initial hepatitis C treatment entered the list of emerging research fronts in 2015. This year, “Clinical trials of direct-acting antivirals (DAAs) for hepatitis C infections” emerges as a key hot research front. Among

the 38 core papers, most focus on sofosbuvir (20 papers, 52.63%), simeprevir (6 papers) and/or Viekira Pak (4 papers) monotherapy or combined therapy for treatment of different genotypes and different treatment status hepatitis C infections in clinical trials. The results clearly demonstrate the advantages of DAAs, such as easier administration, shorter course, higher cure rate, fewer adverse effects, wider applications, and better patient compliance. Therefore, DAAs are very promising as replacements for the conventional interferon injection therapy and to ultimately become the first-line treatment for HCV.

In December 2013, Gilead Sciences announced that the US FDA had approved sofosbuvir (Sovaldi™) 400 mg tablets for the treatment of CHC infection as a component of a combination antiviral treatment regimen – that is: (a) with peginterferon alfa and ribavirin for genotype 1 or 4 CHC; (b) with ribavirin for genotype 2 CHC; and (c) with ribavirin for genotype 3 CHC. Sofosbuvir redefined the standard regime of hepatitis C infection, opened a new era of oral therapy, and has been regarded as a breakthrough for the treatment

Table 19: Top 10 countries and institutions producing core papers in the research front “Clinical trials of direct-acting antivirals (DAAs) for hepatitis C infections”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	35	92.1%	1	Gilead Sciences	USA	17	44.7%
2	France	13	34.2%	1	University of Texas Health Science Center San Antonio	USA	17	44.7%
3	Germany	11	28.9%	3	Cornell University	USA	11	28.9%
3	Spain	11	28.9%	4	Goethe University Frankfurt	Germany	10	26.3%
5	Belgium	10	26.3%	4	Virginia Mason Medical Center	USA	10	26.3%
5	UK	10	26.3%	6	AbbVie Co.	USA	8	21.1%
7	Canada	9	23.7%	6	Johns Hopkins University	USA	8	21.1%
7	Italy	9	23.7%	8	University of Florida	USA	7	18.4%
9	Australia	8	21.1%	8	University of Pennsylvania	USA	7	18.4%
10	New Zealand	6	15.8%	10	University of North Carolina Chapel Hill	USA	6	15.8%

of hepatitis C infection. With Sovaldi having swept across the hepatitis C treatment area, Gilead Sciences holds about 85% of the market share and makes itself a tier-one pharmaceutical company. Prior to Sovaldi, simeprevir capsule (Olysio®), developed by Janssen Pharmaceuticals, was approved by the FDA. However, the requirements for the combination therapy with PegIFN- α and RBV limit its development. In December 2014, the Viekira Pak compound from AbbVie Inc. was approved by the FDA as the first new hepatitis C drug product with breakthrough-therapy designation for genotype 1 CHC, including those with the advanced liver disease cirrhosis. Viekira Pak can be administered orally, offering an interferon-free cocktail therapy for hepatitis C. Viekira Pak has helped AbbVie Inc. achieve great success in the niche market of hepatitis C therapy, blunting the dominant position of Gilead Sciences Inc. and, most importantly, bringing the gospel for patients with hepatitis C.

With the success of numerous clinical trials, more and more DAAs have been approved. DAAs have been recommended as standard therapies for hepatitis C

in the latest clinical guidelines by WHO, Europe, and the USA. In many countries, DAAs have replaced peginterferon-alpha and ribavirin, and have been widely used in clinical treatment. Despite the low cost of producing DAAs, their market price is very high, even for Medicare users in developed countries. More work is needed to assure the worldwide application of DAAs for hepatitis C patients.

The USA stands out as the most active country in this research front (Tables 19 & 20). American researchers took part in 35 core papers (92.1%) and 645 citing papers (48.4%), which is far more than other countries. In a count of the Top 10 institutions in terms of core papers and citing papers, there are nine and six institutions, respectively, based in the USA. This indicates the USA's very active, central and leading position. Gilead Sciences Inc., located in California, which has the reputation of the "world's fastest growing pharmaceutical company," is the top institution based on both core and citing papers.

Table 20: Top 10 countries and institutions producing citing papers in the research front "Clinical trials of direct-acting antivirals (DAAs) for hepatitis C infections"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	645	48.4%	1	Gilead Sciences	USA	65	4.9%
2	France	165	12.4%	2	Johns Hopkins University	USA	54	4.1%
3	Germany	136	10.2%	3	Harvard University	USA	51	3.8%
4	UK	122	9.2%	4	University of Paris Diderot - Paris VII	France	45	3.4%
5	Italy	115	8.6%	4	University of Texas Health Science Center San Antonio	USA	45	3.4%
6	Japan	106	8.0%	6	Goethe University Frankfurt Hospital	Germany	42	3.2%
7	Canada	89	6.7%	6	University of Pennsylvania	USA	42	3.2%
8	Spain	89	6.7%	8	Hannover Medical School	Germany	38	2.9%
9	Australia	56	4.2%	8	Cornell University	USA	38	2.9%
10	Belgium	51	3.8%	10	Institut National de la Sante et de la Recherche Medicale (Inserm)	France	35	2.6%

1.3 KEY HOT RESEARCH FRONT – “IMMUNE CHECKPOINT INHIBITORS, ANTI-PD-1 ANTIBODIES IN MELANOMA IMMUNOTHERAPY”

Melanoma is among the most dangerous types of skin cancer. The incidence is high in Europe and North America, while it is less common in Asia, Africa, and Latin America. Most patients in the early stage can be cured by surgical treatments. However, once distant metastasis occurs, the prognosis is so poor that the five-year survival rate is lower than 10%.

The appearance of immunotherapy has brought hope. Immune checkpoints are molecules in the immune system that take a role of protection. They act as “off switches” that can regulate the immune response and keep T cells from excessive activation. Some cancer cells can take advantage of these off switches to keep the immune system from attacking them. Checkpoint inhibitors that can block these off switches, and thus reactivate the immune response of T cells toward cancer cells, have attracted much attention in recent years. Armed with this knowledge, researchers have identified several immune checkpoints, most notably Cytotoxic T-Lymphocyte-Associated protein 4 (CTLA-4), along with Programmed Cell Death-1 (PD-1) and its ligand (PD-L1).

This year, “Immune checkpoints inhibitors anti-PD-1 antibodies in melanoma immunotherapy” has become a

hot research front, focusing on the treatment of melanoma patients with unresectable or metastatic melanoma or those showing no responses to other drugs.

There are 15 core papers in this research front, and 14 of them were published in the world’s top medical journals, including *Nature*, *Lancet* and the *New England Journal of Medicine*. The highest citation total (2,992) was achieved by a *New England Journal of Medicine* article written by Stephen Hodi of Dana-Farber Cancer Institute June 2010. This study shows for the first time that ipilimumab, a CTLA-4 inhibitor, can prolong overall survival of patients with metastatic melanoma. It also provides crucial support for the approval of Yervoy® (ipilimumab injection) by the FDA. Ipilimumab has become the only FDA approved drug for the treatment of advanced melanoma in the past ten years, ending the period in which there was no effective drug for melanoma patients. A study published in the *New England Journal of Medicine* in June 2011 involved the combination of ipilimumab and dacarbazine. The research was first to prove that dacarbazine, as the standard treatment regimen for melanoma in the past 30 years, can possibly be replaced. Unfortunately, the effective rate for ipilimumab monotherapy is only 10.9%.

Table 21: Top countries and institutions producing core papers in the research front “Immune checkpoint inhibitors anti-PD-1 antibodies in melanoma immunotherapy”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	15	100%	1	Bristol-Myers Squibb Co.	USA	10	66.7%
2	France	10	66.7%	1	Memorial Sloan-Kettering Cancer Center	USA	10	66.7%
3	Canada	7	46.7%	3	Harvard University	USA	9	60.0%
4	Germany	6	40.0%	4	Angeles Clinic and Research Institute	USA	7	46.7%
4	Australia	6	40.0%	4	Gustave Roussy	France	7	46.7%
6	Italy	5	33.3%	6	Melanoma Institute Australia	Australia	5	33.3%
7	Netherlands	4	26.7%	6	University of California Los Angeles	USA	5	33.3%
7	Spain	4	26.7%	6	University of South Florida	USA	5	33.3%
7	UK	4	26.7%	6	University of Sydney	Australia	5	33.3%
10	Israel	3	20.0%	6	Yale University	USA	5	33.3%
10	Belgium	3	20.0%					
10	Denmark	3	20.0%					

and long-term therapy may induce autoimmune or inflammatory immune-mediated adverse reactions.

Anti-PD-1 antibody provides a new choice for malignant melanoma therapy. For advanced melanoma patients with common genetic mutations, the effective rate is around 35% to 47%. This treatment shows high relapse-free survival rate and overall survival rate. In September 2014 and December 2014, the FDA granted pembrolizumab (Keytruda®) and nivolumab (Opdivo®) breakthrough-therapy designations for advanced or unresectable melanoma. Former US president Jimmy Carter announced his cancer was in remission after four months' treatment with Keytruda – a mysterious antibody drug from Merck & Co. Single inhibition of CTLA-4 results in up-regulation of PD-1 and therefore inhibition of T cell immunity, and vice

versa. A collaborative work by Dana-Farber Cancer Institute and Memorial Sloan Kettering Cancer Center showed that nivolumab combined with ipilimumab resulted in significantly longer progression-free survival than monotherapy. Although the occurrence of serious drug-related adverse reaction rate increased, the majority of these adverse reactions can be mitigated by immunomodulatory drugs. Therefore, this therapy's safety is acceptable.

Among the most active countries in this research front, American researchers took part in producing all core papers and more than half (55.2%) of the citing papers, fully reflecting the nation's overwhelming superiority. France, Canada, Germany and Australia are also active in this field (Table 21). China contributes 236 citing papers and ranks 9th on this Top 10 list (Table 22).

Table 22: Top 10 countries and institutions producing citing papers in the research front "Immune checkpoints inhibitors anti-PD-1 antibodies in melanoma immunotherapy"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	2782	55.2%	1	Harvard University	USA	432	8.6%
2	Germany	459	9.1%	2	Memorial Sloan-Kettering Cancer Center	USA	244	4.8%
3	France	444	8.8%	3	Johns Hopkins University	USA	191	3.8%
4	UK	412	8.2%	4	University of Texas MD Anderson Cancer Center	USA	189	3.7%
5	Italy	391	7.8%	5	National Institutes of Health (NIH)	USA	180	3.6%
6	Australia	267	5.3%	6	Gustave Roussy	France	140	2.8%
7	Japan	242	4.8%	7	Yale University	USA	134	2.7%
8	Netherlands	241	4.8%	8	University of Pennsylvania	USA	131	2.6%
9	China	236	4.7%	8	University of Pittsburgh	USA	131	2.6%
10	Canada	181	3.6%	10	Institut National de la Sante et de la Recherche Medicale (Inserm)	France	112	2.2%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CLINICAL MEDICINE

Twenty-one research fronts in clinical medicine have been selected as emerging research fronts this year. These fronts focus on cancer, cardiovascular diseases, infectious diseases, respiratory diseases, and digestive diseases. In terms of cancer, four fronts discuss how to improve the treatment of advanced breast cancer, one

focused on non-small cell lung cancer immunotherapy and one focused on targeted therapy for refractory thyroid cancer. In regard to cardiovascular diseases, the studies focus on the treatment for out-of-hospital cardiac arrest, heart failure and atrial fibrillation. The emerging research fronts in infectious diseases

include the transmission and control of Ebola virus disease, interferon-free antiviral regimens for HCV infection, efficacy of the new vaccine for invasive pneumococcal disease, and the association between acute flaccid myelitis in children and enterovirus D68 outbreak. The topics in respiratory diseases mainly focus on corticosteroid adjunctive therapy for patients

with community-acquired pneumonia, the targeted treatment for eosinophilic asthma, and the relationship between telomere mutations and lung diseases. The key emerging research front, "Programmed death 1 (PD-1) inhibitors for the treatment of advanced non-small-cell lung cancer," was described in depth (see section 2.2).

Table 23: Emerging research fronts in clinical medicine

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Programmed death 1 (PD-1) inhibitors for the treatment of advanced non-small-cell lung cancer	4	146	2015
2	Treatments and outcome of Out-of-Hospital Cardiac Arrest	31	405	2014.9
3	Acute flaccid myelitis in children associated with enterovirus D68 outbreak	7	109	2014.9
4	Interferon-free antiviral regimens prevent recurrence of HCV infection after liver transplantation	8	211	2014.8
5	Regional nodal Irradiation in early-stage breast cancer	4	132	2014.8
6	Benefit of anticoagulation therapy for atrial fibrillation	5	105	2014.8
7	Mechanisms of long non-coding RNA MALAT1 promoting cancer cell proliferation and metastasis	12	181	2014.7
8	Adjuvant ovarian suppression in premenopausal breast cancer	3	149	2014.7
9	Telomere mutations and lung diseases	7	133	2014.7
10	Transmission and control of Ebola virus disease	6	117	2014.7
11	Risk of gastrointestinal bleeding associated with oral anticoagulants	5	250	2014.6
12	Efficacy of 13-valent polysaccharide conjugate vaccine (PCV13) on invasive pneumococcal disease	8	231	2014.6
13	LCZ696 versus enalapril for heart failure	2	222	2014.5
14	Anti-interleukin 5 receptor monoclonal antibody for treatment eosinophilic asthma	6	206	2014.5
15	Inherited mutations in breast cancer	6	182	2014.5
16	Effects of glucose-lowering drugs on cardiovascular outcomes in Type 2 diabetes	6	154	2014.5
17	Intracranial gadolinium deposition after GBCA-enhanced brain MR imaging	6	128	2014.5
18	Sorafenib and lenvatinib in the treatment of radioiodine-refractory thyroid cancer	2	123	2014.5
19	Corticosteroids adjunctive therapy for patients with community-acquired pneumonia	6	117	2014.5
20	Neoadjuvant carboplatin in patients with triple-negative breast cancer	2	110	2014.5
21	Progression of non-alcoholic fatty liver disease using paired biopsies	4	108	2014.5

2.2 KEY EMERGING RESEARCH FRONT – “PROGRAMMED DEATH 1 (PD-1) INHIBITORS FOR THE TREATMENT OF ADVANCED NON-SMALL-CELL LUNG CANCER”

New cases of lung cancer number around 1.8 million per year, which makes it the most common cause of cancer-related death. Patients with non-small cell lung cancer (NSCLC) account for 80% to 85% of newly diagnosed lung cancers. Surgery, radiotherapy, chemotherapy and targeted therapy have had certain effects on NSCLC. However, the 5-year survival rate of patients with advanced NSCLC is still very low, less than 15%. Recently, cancer immunotherapy has become a hot topic. Immune checkpoint inhibitors that have strong targeted effects and mild adverse reaction, has become the new treatment option of lung cancer.

Programmed cell death factor 1 (PD1) is an immune checkpoint, expressed on the surface of T cells. The binding of PD1 with its ligand PDL1 or PDL2 can inhibit the antitumor immune response. Recently, PD1 antibody has played a role not only in treating melanoma and kidney cancer but also in non-small cell lung cancer. The current anti-PD-1 monoclonal antibody drugs are nivolumab and pembrolizumab. On March 4, 2015 and October 9, 2015, the FDA granted approval to nivolumab for the treatment of patients with metastatic squamous NSCLC and non-squamous NSCLC with progression on or after platinum-based chemotherapy. In October 2015, the FDA granted approval for pembrolizumab to treat patients with advanced NSCLC whose disease has progressed after other treatments and with tumors that express a protein called PD-L1. The FDA's approval of the two drugs is based on their clinical trial results that were published in 2015. The research topic therefore becomes one of the emerging research front highlighted this year.

Nivolumab is a humanized IgG4 anti-PD-1 monoclonal antibody. It can reverse tumor immune microenvironment, restore the antitumor activity of T-cells, and inhibit the tumor growth by blocking the interaction between PD1 and its ligands (PD-Ls: PD-L1, PD-L2). Scott N. Gettinger et al conducted a phase I dose escalation study to evaluate the safety and clinical effect of nivolumab, which showed that the 3-mg/kg dose group had the highest objective response rate

(ORR) and the longest overall survival (OS) among all the dose groups. Therefore, 3 mg/kg was chosen as the standard dose in the subsequent clinical trials. Two phase III randomized clinical trials from Johns Hopkins University and the Fox Chase Cancer Center were carried out to compare nivolumab with docetaxel in previously treated patients with advanced squamous NSCLC and non-squamous NSCLC with progression after platinum-based chemotherapy. Their results showed that OS and ORR were longer with nivolumab than with docetaxel. A study from Johns Hopkins University found that progression-free survival (PFS) in the nivolumab group was longer than that in the docetaxel group, while the group from the Fox Chase Cancer Center observed that PFS in nivolumab group was shorter than that in the docetaxel group and one-year PFS rate in nivolumab group was higher than that in the docetaxel group. For the correlation between the expression of PD-L1 and the treatment effect, no correlation was found in the former group, however, a clear correlation was observed in the latter group. The results from the above phase III randomized clinical trials were employed as the evidence by the FDA to approve the use of nivolumab to treat patients with advanced squamous NSCLC and non-squamous NSCLC.

Pembrolizumab is a potent, highly selective, IgG4-kappa humanized monoclonal antibody that prevents PD-1 binding to its ligands. The mechanism of action for pembrolizumab was seen to be similar to that of nivolumab. Edward B. Garon at UCLA carried out a phase I randomized clinical trial to assess the efficacy and safety of pembrolizumab to patients with advanced NSCLC, which showed that pembrolizumab had an acceptable side-effect profile, an objective response rate of 19.4%, a progression-free survival of 3.7 months, an overall survival of 12.0 months, and an association between PD-L1 expression in at least 50% of tumor cells and the improvement of the efficacy of pembrolizumab was observed. These results were used as the evidence by the FDA to approve the use of pembrolizumab to treat patients with advanced NSCLC.



6. BIOLOGICAL SCIENCES

1. HOT RESEARCH FRONT

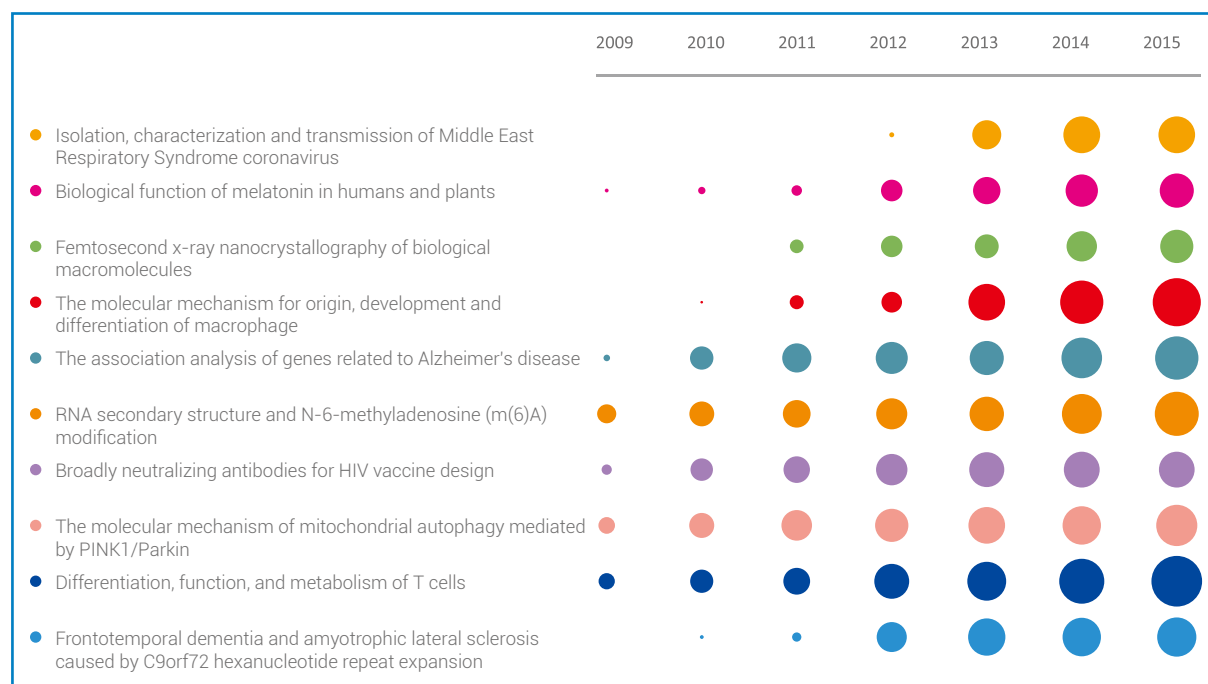
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN BIOLOGICAL SCIENCES

The Top 10 research fronts in biological sciences focus on medical sciences and human health, including virus transmission, crystal structure determination, the mechanism of pathogenicity and immune protection. Among them, "Isolation, characterization and transmission of Middle East Respiratory Syndrome coronavirus" and "Frontotemporal dementia and amyotrophic lateral sclerosis caused by C9orf72 hexanucleotide repeat expansion" had been selected as a Top 10 hot research front in biological sciences multiple times.

Table 24: Top 10 research fronts in biological sciences

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Isolation, characterization and transmission of Middle East Respiratory Syndrome coronavirus	47	3556	2013.6
2	Biological function of melatonin in humans and plants	37	2417	2013.5
3	Femtosecond x-ray nanocrystallography of biological macromolecules	23	2129	2013.5
4	The molecular mechanism for origin, development and differentiation of macrophage	21	3641	2012.9
5	The association analysis of genes related to Alzheimer's disease	21	4815	2012.8
6	RNA secondary structure and N-6-methyladenosine (m(6)A) modification	33	3683	2012.6
7	Broadly neutralizing antibodies for HIV vaccine design	32	6031	2012.5
8	The molecular mechanism of mitochondrial autophagy mediated by PINK1/Parkin	25	5749	2012.5
9	Differentiation, function, and metabolism of T cells	39	5391	2012.5
10	Frontotemporal dementia and amyotrophic lateral sclerosis caused by C9orf72 hexanucleotide repeat expansion	34	5354	2012.5

Figure 5: Citing papers of the Top 10 research fronts in biological sciences



1.2 KEY HOT RESEARCH FRONT – “THE MOLECULAR MECHANISM FOR ORIGIN, DEVELOPMENT AND DIFFERENTIATION OF MACROPHAGE”

Macrophages are a type of immune system cells that are vital to the development of non-specific defense mechanisms in humans. The related publications in this research front mainly focused on the origin of macrophages and the regulation of their development and differentiation.

It had long been assumed that macrophages originate from hematopoietic stem cells (HSCs), until the discovery of new evidence. Recently, several studies suggest that some macrophages develop in the embryo before the appearance of definitive HSCs. In 2010, researchers from Mount Sinai School of Medicine conducted a “fate mapping” analysis to determine the

developmental stage of primitive macrophages by labeling techniques. Their results demonstrated that microglia arise early in mice development and derive from primitive macrophages in the yolk sac. Later, researchers from the UK and Singapore also confirmed the presence of yolk sac derived macrophages.

The mechanism of differentiation and development of macrophages is another hot topic in recent years. Studies have shown that there are many types of macrophages in different parts of the body. For example, protection cells can help blood-vessel growth and tissue regeneration, while inflammatory cells can cause damage. In 2012, researchers from Mount Sinai

Table 25: Top countries and institutions producing core papers in the research front “The molecular mechanism for origin, development and differentiation of macrophage”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	18	85.7%	1	Icahn School of Medicine at Mount Sinai (ISMMS)	USA	7	33.3%
2	UK	7	33.3%	2	Washington University	USA	6	28.6%
2	France	7	33.3%	3	Kings College London	UK	5	23.8%
4	Singapore	6	28.6%	3	Albert Einstein College of Medicine	USA	5	23.8%
5	Switzerland	4	19.0%	5	University of Zurich	Switzerland	4	19.0%
5	Germany	4	19.0%	5	University of Aix-Marseille	France	4	19.0%
5	Belgium	4	19.0%	5	Agency for Science Technology & Research (ASTAR)	Singapore	4	19.0%
5	Netherlands	4	19.0%	8	University of California Santa Cruz	USA	3	14.3%
9	Japan	3	14.3%					
10	Israel	2	9.5%					

School of Medicine and other institutions identified several tissue dendritic cell (DC) subsets and clarified the workings of the transcriptional network and cell lineage. In the same year, researchers from Washington University confirmed that IL-34 specifically directs the differentiation of myeloid cells in the skin epidermis and central nervous system (CNS).

Among the top countries producing the core papers, the USA holds an important position in this research front, with 18 core papers accounting for 85.7% of the total, which is the largest number of core papers (Table 25). The UK and France tied for second place, with 7 core papers accounting for 33.3% of the total. In terms

of institutions, the Mount Sinai School of Medicine performs best in this research front and ranks 1st with 7 core papers, followed by Washington University with 6 core papers.

Analysis of citing papers demonstrates that the USA is still the most productive country, followed by Germany, UK and France. China has made rapid progress in recent years, and ranks 9th with 75 citing papers. On the list of top institutions, Harvard University, Centre National de la Recherche Scientifique (CNRS), Weizmann Institute of Science and Edinburgh University are dominant in this research field, with a considerable amount of paper outputs (Table 26).

Table 26: Top countries and institutions producing citing papers in the research front “The molecular mechanism for origin, development and differentiation of macrophage”

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	800	46.8%	1	Harvard University	USA	86	5.0%
2	Germany	265	15.5%	2	Washington University	USA	68	4.0%
3	UK	238	13.9%	3	Institut National de la sante et de la Recherche Medicale (INSERM)	France	66	3.9%
4	France	141	8.3%	4	Weizmann Institute of Science	Israel	47	2.8%
5	Japan	111	6.5%	5	University of Edinburgh	UK	45	2.6%
6	Canada	90	5.3%	6	Centre National de la Recherche Scientifique (CNRS)	France	37	2.2%
7	Netherlands	90	5.3%	7	University of Bonn	Germany	36	2.1%
8	Australia	89	5.2%	7	University of Freiburg	Germany	36	2.1%
9	China	75	4.4%	7	University of Zurich	Switzerland	36	2.1%
10	Switzerland	69	4.0%	7	University of California San Francisco	USA	36	2.1%

1.3 KEY HOT RESARCH FRONT – “DIFFERENTIATION, FUNCTION, AND METABOLISM OF T CELLS”

The T cell is a type of lymphocyte that plays a central role in cell-mediated immunity. According to different classification rules, T cells can be divided into different subsets, such as T helper cells (Th cells), regulatory T cells (Tr), cytotoxic T cells (CTL), etc. The core papers in this research front mainly discuss the regulation mechanism of differentiation and metabolism of T cells.

Nowadays, researchers are paying very close attention to the analysis of regulatory mechanisms of immune function and differentiation of T cells. In 2009, researchers from Emory University found that mammalian target of rapamycin (mTOR) plays an important regulatory role in the differentiation of memory T cells. In the same year, researchers from

Johns Hopkins University also confirmed that mTOR was involved in the regulation of Th1 cell function. In 2015, American researchers also confirmed that mTORC1 and mTORC2 have different effects on the production of effector T cells and memory T cells.

At the same time, metabolic reprogramming in T-cell fate determination has become a hot topic, and the transcriptional regulation mechanism of metabolism has gradually gained in prominence. Researchers from the University of Pennsylvania and Johns Hopkins University have found that tumor necrosis factor receptor associated factor 6 (TRAF6) and hypoxia induced factor-1 (HIF-1) play important roles in the metabolic regulation process of T cell development

Table 27: Top countries/regions and institutions producing core papers in the research front “Differentiation, function, and metabolism of T cells”

Country Ranking	Country/Region	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	38	97.4%	1	Washington University	USA	9	23.1%
2	Canada	5	12.8%	2	Johns Hopkins University	USA	7	17.9%
3	UK	3	7.7%	3	Harvard University	USA	6	15.4%
4	Ireland	2	5.1%	3	St. Jude Children's Research Hospital - Tennessee	USA	6	15.4%
4	Switzerland	2	5.1%	5	McGill University	Canada	5	12.8%
6	Taiwan	1	2.6%	6	Duke University	USA	4	10.3%
6	Thailand	1	2.6%	7	National Institutes of Health (NIH)	USA	3	7.7%
6	Netherlands	1	2.6%	7	Trudeau Institute	USA	3	7.7%
6	Russia	1	2.6%	7	University of Pennsylvania	USA	3	7.7%
6	France	1	2.6%					
6	Germany	1	2.6%					
6	Australia	1	2.6%					

and differentiation. In 2013, a study from the University of Washington showed that aerobic glycolysis is a necessary metabolic pathway for T cell function. In 2015, researchers from St. Jude Children's Research Hospital explained the mechanism of how regulatory T cells control the production of immunosuppressive factor relying on metabolic pathways rather than conventional immune regulation.

In terms of countries/regions producing core papers, the USA has the strongest advantage in this research front (Table 27). The USA published 38 core papers, accounting for 97.4% of all the 39 core papers, and ranks 1st. Canada has five core papers, ranking 2nd. UK has three core papers, ranking 3rd. Analyzing the

research institutions producing core papers shows that Washington University has nine core papers and ranks 1st, followed by Johns Hopkins University with seven core papers.

According to a count of the citing papers, the USA is still the most productive country with 1,411 citing papers, while China is following the studies closely and ranks 2nd with 250 citing papers. In terms of institutions producing citing papers, Harvard University is the most productive institution (Table 28).

Table 28: Top 10 countries and institutions producing citing papers in the research front "Differentiation, function, and metabolism of T cells"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	1411	57.4%	1	Harvard University	USA	149	6.1%
2	China	250	10.2%	2	University of Pennsylvania	USA	75	3.1%
3	UK	245	10.0%	3	Duke University	USA	68	2.8%
4	Germany	206	8.4%	4	Johns Hopkins University	USA	66	2.7%
5	Canada	128	5.2%	5	National Institutes of Health (NIH)	USA	58	2.4%
6	France	120	4.9%	6	St. Jude Children's Research Hospital - Tennessee	USA	56	2.3%
7	Japan	110	4.5%	7	Yale University	USA	52	2.1%
8	Italy	108	4.4%	8	Washington University	USA	51	2.1%
9	Netherlands	81	3.3%	9	University of California San Francisco	USA	49	2.0%
10	Australia	73	3.0%	10	Institut national de la sante et de la recherche medicale (INSERM)	France	46	1.9%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN BIOLOGICAL SCIENCES

There are 18 emerging research fronts in biological sciences, covering a series of topics, such as the genetic mechanism and diagnosis of important disease, the application of nanotechnology in biomedicine, the detection and sequencing of the genome, etc. Among these topics, the very active study of the CRISPR/Cas genome-editing technique is sustained and diversified.

CRISPR/Cas genome-editing technique was selected as key emerging research front and key hot research front in 2014 and 2015, respectively. "Genome-wide identification of CRISPR RNA-guided nucleases (RGNs) off-target effects" and "Genome-scale transcriptional activation by CRISPR-Cas9" enter the list of emerging research fronts this year (Table 29).

Table 29: Emerging research fronts in biological sciences

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Genome-wide identification of CRISPR RNA-guided nucleases (RGNs) off-target effects	4	152	2015
2	Botanical extracts and nanoparticles for mosquito control	12	132	2015
3	Genome-wide association studies of obesity	3	119	2015
4	Activation of mechanistic target of rapamycin complex 1 (mTORC1)	3	106	2015
5	Nanopore sequencing	9	155	2014.8
6	Dendrimer-based nanovectors for tumor-targeted drug and gene delivery	4	112	2014.8
7	Prediction for structure and function of proteins using pseudo amino acid composition (PseAAC)	9	236	2014.7
8	Genetic diagnosis using the human phenotype ontology	6	152	2014.7
9	Type-2 innate lymphoid cells and regulation of beige fat biogenesis	5	197	2014.6
10	Nanotechnological carriers for cancer chemotherapy	5	109	2014.6
11	Genome-scale transcriptional activation by CRISPR-Cas9	2	168	2014.5
12	The interplay of autophagy and apoptosis	2	154	2014.5
13	Principles of chromatin looping and evolution of chromosomal domain architecture	2	142	2014.5
14	Actin assembly and network homeostasis	4	129	2014.5
15	Fluorogenic probes for live-cell imaging of the cytoskeleton	4	126	2014.5
16	Characterization of highly pathogenic avian influenza viruses (H5N8 and H5N6)	6	108	2014.5
17	The impact of genetic structure and diet on the gut microbiota	2	103	2014.5
18	Regeneration and gene expression of cochlear hair cell	4	102	2014.5

2.2 KEY EMERGING RESEARCH FRONT – “PRINCIPLES OF CHROMATIN LOOPING AND EVOLUTION OF CHROMOSOMAL DOMAIN ARCHITECTURE”

The genome inside every cell of the body is identical, but the body needs each cell to be different – an immune cell fights off infection, a cone cell helps the eye detect light, the heart's myocytes must beat endlessly, etc. Over the past 100 years, genome looping has been a blind spot for modern biology. Scientists have known that DNA forms loops in cells and that knowledge of where the loops are is incredibly important. But mapping the positions of all those loops was long thought to be an insurmountable challenge.

In 2009, Job Dekker first proposed the concept of Hi-C technique. By employing the technique, the researchers analyzed the spatial interactions of loci in the chromosome of normal human lymphoblastoid cell. Hi-C is a derivative technique of chromosome conformation capture which represents chromosome conformation capture based on high-throughput. It can capture the spatial interaction between the different loci throughout a genome and can help study the DNA elements of regulator gene in three-dimensional space.

For decades, scientists have examined the regions in the close vicinity of a gene to understand how it is regulated. But as the genome folds, sequences far from

a gene loop back and come in contact with those nearby elements. In December 2014, scientists from Baylor College of Medicine, Rice University, the Broad Institute and Harvard University described the results of a five-year effort to map, in unprecedented detail, how the two-meter long human genome folds inside the nucleus of a cell. Their results showed that the cell modulates its function by folding the genome into an almost limitless variety of shapes. A centerpiece of the study is the first reliable catalog of loops spanning the entire human genome. The team also discovered a series of rules about how and where loops can form.

In March 2015, Hadjur and colleagues from University College London, employing the Hi-C method, revealed the important role of CTCF (CCCTC-binding factor) in promoting changes in genomic structure. The study compared CTCF sites of four mammalian species and revealed a direct link between insulator site divergence and the evolution of chromatin domain structure, which brings new ideas and methods to research on transcription factors.



7. CHEMISTRY AND MATERIALS SCIENCE

1. HOT RESEARCH FRONT

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

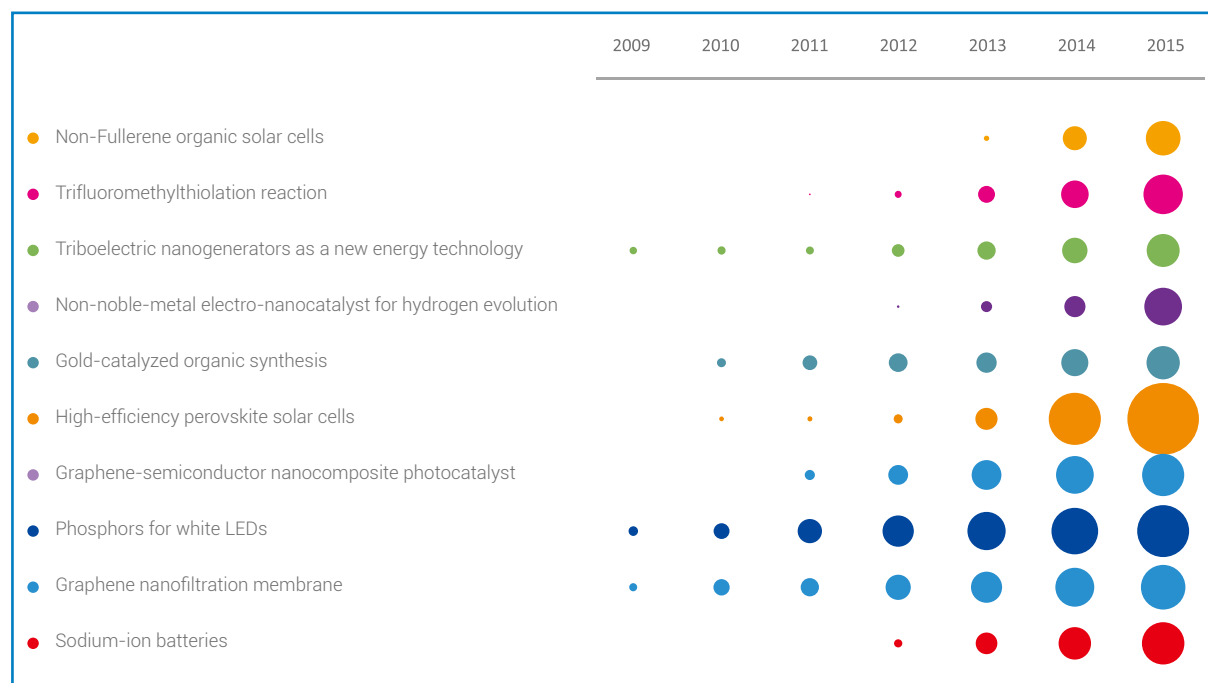
The *Research Fronts 2016* in chemistry and materials science cover the topics of nanomaterials, batteries, organic chemistry and luminescent materials. “Phosphors for white LEDs” has been listed as Top 10 research front for two consecutive years. In the topic of nanomaterials, there are three related research fronts: graphene, nanocatalysts and triboelectric nanogenerators. A particularly hot direction for graphene is its application in photocatalysis and membrane filtration. Fronts pertaining to electro-nanocatalysts and photo-nanocatalysts both appear in the Top 10 due to the excellent performance of nanocatalysts based on their size effect. A front on triboelectric nanogenerators is a newcomer. In the topic of batteries, non-fullerene acceptors have become a new focus in organic solar cells research. Sodium-ion batteries have replaced lithium-ion batteries from last year’s listings. Perovskite solar cells, subject of one of the emerging research fronts last year, has become a hot research front this year. Noble-metal catalyzed organic synthesis has always been a hot topic in organic chemistry. Although copper catalysts were selected last year, this year gold catalysts have come to the fore. Trifluoromethylthiolation is another research front in organic chemistry, which is a succession of last year’s front on “Copper-catalyzed trifluoromethylation of alkenes.”



Table 30: Top 10 research fronts in chemistry and materials science

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Non-Fullerene organic solar cells	41	2249	2014.2
2	Trifluoromethylthiolation reaction	47	3158	2013.8
3	Triboelectric nanogenerators as a new energy technology	43	2846	2013.7
4	Non-noble-metal electro-nanocatalyst for hydrogen evolution	26	2427	2013.7
5	Gold-catalyzed organic synthesis	23	2062	2013.2
6	High-efficiency perovskite solar cells	30	16471	2013.1
7	Graphene-semiconductor nanocomposite photocatalyst	21	3176	2012.6
8	Phosphors for white LEDs	44	4690	2012.5
9	Graphene nanofiltration membrane	22	3125	2012.5
10	Sodium-ion batteries	4	1998	2012.5

Figure 6: Citing papers of the Top 10 research fronts in chemistry and materials science



1.2 KEY HOT RESEARCH FRONT – “PHOSPHORS FOR WHITE LEDs”

Phosphor-converted white light-emitting diodes (pc-WLEDs) are emerging as an indispensable solid-state light source for the next-generation lighting industry and display systems, thanks to their unique properties including but not limited to energy savings, environmental friendliness, small volume, and long life. pc-WLEDs have been considered another revolution in the human development of lighting technology, after the conventional incandescent lamp and the fluorescent lamp. The phosphor-converted method – namely, coating LED chips with phosphors – is the principal technology in the commercialization of WLEDs. Specifically, there are two approaches: blue-LED chips+ yellow phosphor and ultraviolet LED chips coated with red-green-blue phosphors, or white light-emitting single-phased phosphors. In 1996, a totally new lighting device was invented by Shuji Nakamura

from Nichia Chemical Co. (Japan) by means of a blue InGaN LED chip coated with yttrium aluminum garnet yellow phosphor. Later, he became one of the three recipients of the 2014 Nobel Prize in Physics for this invention. Until now WLEDs based on blue-LED chips have been commercialized, although major challenges come from poor luminous efficacy and color-rendering indexed. White UV LEDs with red-green-blue phosphors conquer the aforementioned disadvantages and have currently become the industry's key direction, although the blending of different phosphors may complicate their fabrication and cost. Therefore, white light-emitting single-phased phosphors have attracted much attention recently and become hot research topics.

The 44 core papers reflect the aforementioned trends in terms of both the content and topic distribution. Twelve countries/regions participated in the core papers of

Table 31: Top countries/regions and institutions producing core papers in the research front “Phosphors for white LEDs”

Country Ranking	Country/Region	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country/Region	Core Paper	Proportion
1	China	26	59.1%	1	Chinese Academy of Sciences	China	12	27.3%
2	Taiwan	11	25.0%	2	National Taiwan University	Taiwan	8	18.2%
3	Germany	6	13.6%	3	China University of Geosciences	China	6	13.6%
4	USA	5	11.4%	4	National Chiao Tung University	Taiwan	3	6.8%
5	Japan	3	6.8%	4	Philips Technol GmbH	Netherlands	3	6.8%
5	Netherlands	3	6.8%	4	Russian Academy of Sciences	Russia	3	6.8%
5	Russia	3	6.8%	4	University of Munich	Germany	3	6.8%
8	South Korea	2	4.5%					
9	India	1	2.3%					
9	Italy	1	2.3%					
9	Estonia	1	2.3%					
9	Belgium	1	2.3%					

this research front. China ranks 1st with 26 (59.1%) core papers, and is 2.4 times that of Taiwan which ranks 2nd on the list (Table 31). Germany and USA rank 3rd and 4th. When we analyze the institutions, we see that the Chinese Academy of Sciences published far more core papers than others. National Taiwan University and China University of Geosciences rank 2nd and 3rd.

Analysis of the citing papers demonstrates that China published 1,641 (61.8%) to rank 1st on the list. South Korea contributed 339 citing papers to rank 2nd (Table 32). The citing papers contributed by the USA, Japan, India, Taiwan and Germany are between 128 and 172, placing these countries on the third tier of the list. On the list of contributing organizations, nine out of ten citing organizations are from China and Taiwan while the other one is Pukyong National University in South Korea. Among the eight organizations from Mainland China,

the Chinese Academy of Sciences published 366 citing papers and ranks 1st.

In the “12th National Five-year Plan” for Science and Technology Development implemented from 2011, the independent development of key technologies of WLED was highlighted. It is not surprising to find that most of the core papers as well as citing papers from China were published during 2011-2015. China is an important contributor in this research front not only in terms of the research output but also research impact. Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, published a review in the top journal, Chemical Society Reviews. Another review, from South China University of Technology, received over 500 citations, which is the highest among all the core papers.

Table 32: Top 10 countries/regions and institutions producing citing papers in the research front “Phosphors for white LEDs”

Country Ranking	Country/Region	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country/Region	Citing Paper	Proportion
1	China	1641	61.8%	1	Chinese Academy of Sciences	China	366	13.8%
2	South Korea	339	12.8%	2	Pukyong National University	South Korea	134	5.0%
3	USA	172	6.5%	3	China University of Geosciences	China	115	4.3%
4	Japan	158	5.9%	4	Sun Yat-sen University	China	100	3.8%
5	India	148	5.6%	5	Lanzhou University	China	88	3.3%
6	Taiwan	144	5.4%	6	Jilin University	China	56	2.1%
7	Germany	128	4.8%	7	South China University of Technology	China	55	2.1%
8	Netherlands	73	2.7%	7	Suzhou University	China	55	2.1%
9	Russia	55	2.1%	9	National Taiwan University	Taiwan	54	2.0%
10	France	52	2.0%	10	University of Science and Technology Beijing	China	52	2.0%

1.3 KEY HOT RESEARCH FRONT – “SODIUM-ION BATTERIES”

Sodium-ion batteries are not a novel type of chemical power source. From the 1970s to the 1980s, sodium-ion and Li-ion batteries were investigated in parallel. At one point, research on sodium-ion batteries was slowed down due to the commercialization of lithium ion batteries by Sony (Japan) in the early 1990s. With the emergence of electric vehicles and the smart grid, the development of lithium ion batteries was constrained by the lack of lithium resources. Compared with lithium, sodium resources are abundant, widely distributed and easy to extract. The chemical properties and charging mechanism of sodium and lithium are similar. Therefore, research on sodium-ion batteries is back on the agenda. The number of publications on sodium-ion batteries has drastically increased since 2010. The USA and Japan both set up special initiatives for exploratory research on sodium-ion batteries. Sodium-ion is heavier and has a larger radius than lithium ion, which confines its reversible insertion in the electrode materials and in turn influences the electrochemical performance of batteries. Therefore, the key challenge in the application

of sodium-ion batteries is the invention of advanced electrode materials. This is also the focus of the four core papers. Since the energy density of sodium-ion batteries is lower than that of lithium-ion batteries, sodium-ion batteries are more applicable in scenarios where the energy density and size requirement is less critical, while lithium-ion batteries are more applicable to small, portable electronic devices and electric vehicles.

Two topics related to “Sodium-ion batteries” appear both in hot research fronts and emerging research fronts. Statistics show that the contribution mainly comes from China, the USA, South Korea and Japan in terms of both core papers and citing papers. Top institutions on the lists include: the Chinese Academy of Sciences, Kyoto University in Japan, Central South University in China and Korea Advanced Institute of Science and Technology (KAIST) in South Korea. Important Chinese contributing institutions include the Chinese Academy of Sciences, Central South University, and Nankai University. One of the core papers is from Yongsheng Hu’s group at the Institute of Physics, Chinese Academy of Sciences (Table 33).

Table 33: Top 10 countries and institutions producing citing papers in the research front “Sodium-ion batteries”

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	455	41.7%	1	Chinese Academy of Sciences	China	92	8.4%
2	USA	249	22.8%	2	Kyoto University	Japan	46	4.2%
3	South Korea	121	11.1%	3	Central South University	China	40	3.7%
4	Japan	96	8.8%	4	Korea Advanced Institute of Science and Technology (KAIST)	South Korea	39	3.6%
5	Australia	75	6.9%	5	University of Wollongong	Australia	33	3.0%
6	Germany	66	6.0%	5	Wuhan University	China	33	3.0%
7	Spain	57	5.2%	5	University of Texas at Austin	USA	33	3.0%
8	Singapore	45	4.1%	8	University of Science and Technology of China	China	30	2.7%
9	France	32	2.9%	9	University of Maryland College Park	USA	27	2.5%
10	India	28	2.6%	10	Nankai University	China	26	2.4%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN CHEMISTRY AND MATERIALS SCIENCE

This year, 22 research topics are selected as emerging research fronts in chemistry and materials science, covering the subjects of perovskite-type materials, battery research, organic chemistry, nanomaterials, and more. Research on perovskite-type materials occupies five positions in the emerging research fronts. Besides applications in solar cells, perovskite materials also have great potential in the preparation of luminescent materials and photoelectric detectors. In the topic of battery research – besides perovskite solar cells – lithium-oxygen batteries, lithium-sulfur batteries, sodium-ion batteries, polymer solar cells and dye-sensitized solar cells have all constituted important avenues. Asymmetric catalysis and transition metal

catalysis have always been cutting-edge research in organic chemistry, while metal-organic frameworks and pillararene-related topics have also achieved prominence. In the topic of nanomaterials, whether in zero-dimensional carbon quantum dots, two-dimensional MnO_2 , transition metal dichalcogenide or three-dimensional core-shell structures, the research directions have shown a focus on the optical and electrochemical properties and the corresponding applications. The research front "The effects of nanoparticles on cell biology" reflects the fact that with the rapid development of nanomaterials, more attention has been devoted to the attendant bio-safety issues.

Table 34: Emerging research fronts in chemistry and materials science

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Organolead trihalide perovskite single crystals with long carrier diffusion lengths	2	225	2015
2	Methylammonium lead iodide perovskite degradation by water	7	160	2015
3	Lead halide perovskites luminescent nanomaterials	7	121	2015
4	Fluorescent carbon quantum dots	3	101	2015
5	Core-shell composites with electromagnetic absorption performance	12	200	2014.8
6	Ortho-quinone methides as reactive intermediates in asymmetric catalysis	8	165	2014.8
7	Organolead trihalide perovskite photodetectors	6	123	2014.8
8	Nickel-catalyzed activation of aryl ethers via C-O bond cleavage	6	112	2014.8
9	Asymmetric catalysis activated by visible light	5	111	2014.8
10	Lanthanide metal-organic frameworks for luminescence thermometry	6	160	2014.7
11	The mechanism of Li_2O_2 formation in non-aqueous lithium-oxygen batteries	3	117	2014.7
12	High efficiency single-junction polymer solar cells	5	662	2014.6
13	The origin of high-performance in perovskite solar cells	12	641	2014.6
14	Two-dimensional transition metal dichalcogenide nanomaterials	5	286	2014.6
15	MnO_2 -based nanostructures for high-performance supercapacitors	9	131	2014.6
16	Sodium-ion batteries	2	198	2014.5
17	Pillararene-based supramolecular polymers	4	135	2014.5
18	Transition metal-catalyzed direct (hetero) arylation reactions of heteroarenes	2	122	2014.5
19	Porphyrins for dye-sensitized solar cells	2	112	2014.5
20	The effects of nanoparticles on cell biology	4	106	2014.5
21	Rhodium(III)-catalyzed C-H activation of arenes	4	106	2014.5
22	High-performance lithium-sulfur batteries	4	102	2014.5

2.2 KEY EMERGING RESEARCH FRONTS: AGGREGATED ANALYSIS OF SIX RESEARCH FRONTS RELATED TO PEROVSKITE

One hot front and five emerging fronts pertain to research on perovskite-type materials.

Perovskite solar cells have become a rising star in third-generation photovoltaics. The achievements in perovskite solar cells research have exceeded that of the new generation thin-film batteries (including amorphous silicon, dye sensitized solar cells and polymer solar cells) accumulated in recent decades. These advancements were highlighted as one of the Top 10 scientific breakthroughs in 2013 by *Science* magazine. Perovskite is an organometallic halide absorber based on a specific crystal structure that adopts the same crystal structure as calcium titanate, namely, ABX_3 , where $A = CH_3NH_3$, $B = Pb$, and $X = Cl$, Br or I . The most common perovskite is $CH_3NH_3PbI_3$. The first peer-reviewed journal publication of a perovskite-sensitized solar cell came in 2009, written by Tsutomu Miyasaka from Tooin University of Yokohama, where the $CH_3NH_3PbI_3$ absorber-based solar cells yielded a solar-energy conversion efficiency of 3.8%. In 2011, Nam-Gyu Park from Sungkyunkwan University further improved this by employing $CH_3NH_3PbI_3$ quantum dots on nanocrystalline TiO_2 surface, reporting a 6.5% efficiency liquid electrolyte solar cell. In 2012, Henry J. Snaith from Oxford University constructed meso-superstructured perovskite solar cells, leading to 10.9% efficiency. Michael Grätzel from the Swiss Federal Institute of Technology improved the efficiency to 15% in 2013, and Sang Il Seok from the Korea Research Institute of Chemical Technology increased efficiency to 20.1% in 2014. In 2015, scientists from China, Japan and Switzerland successfully prepared a piece of perovskite solar cells over 1 cm^2 that have a power conversion efficiency larger than 15%, as certified by an accredited photovoltaic calibration laboratory. For the first time, this allows the comparison of perovskite solar cells with other types of solar cells under the same standard. Recently, Michael Grätzel further improved the certified power-conversion efficiency to 19.6%. This series of dazzling progressions in photoelectric

conversion efficiency reflects the leading positions of Switzerland, the UK and South Korea in this research area: an observation consistent with the statistics of the core papers. China made a great effort to catch up and now takes a place in the top countries according to production of core papers, also assuming a leading position among the countries producing citing papers. The Chinese Academy of Sciences and Huazhong University of Science and Technology have become the R&D bases in China recognized for their excellence.

Although developing rapidly, perovskite solar cells still present challenges for ongoing development. In terms of working principles, unraveling the mechanisms of photo-induced charge-transfer processes is crucial for further studies; in terms of the fabrication, greater carrier diffusion length reduces recombination rate, resulting in higher power-conversion efficiency, and is therefore promising for the future of perovskite solar cells. In terms of stability: To achieve successful commercialization, it is necessary to consider the effects of interference from the environment. Along with the directions listed above, other topics such as novel perovskite without lead and low-cost transport layers materials are also very important.

Due to its excellent photoelectric properties, the applications of perovskite not only involve solar cells but also include other fields, such as light-emitting diodes and photodetectors discussed in emerging research fronts as well as fuel cells, lasers, and memory storage.

Statistics show that, in the five perovskite-related emerging research fronts, China is gaining ground among the leading countries. China contributed one core paper in "Lead halide perovskites luminescent nanomaterials," and two core papers in "The origin of high-performance in perovskite solar cells." In terms of citing papers, the USA takes the first place, and China ranks 2nd in each of the five related emerging research fronts.



8. PHYSICS

1. HOT RESEARCH FRONT

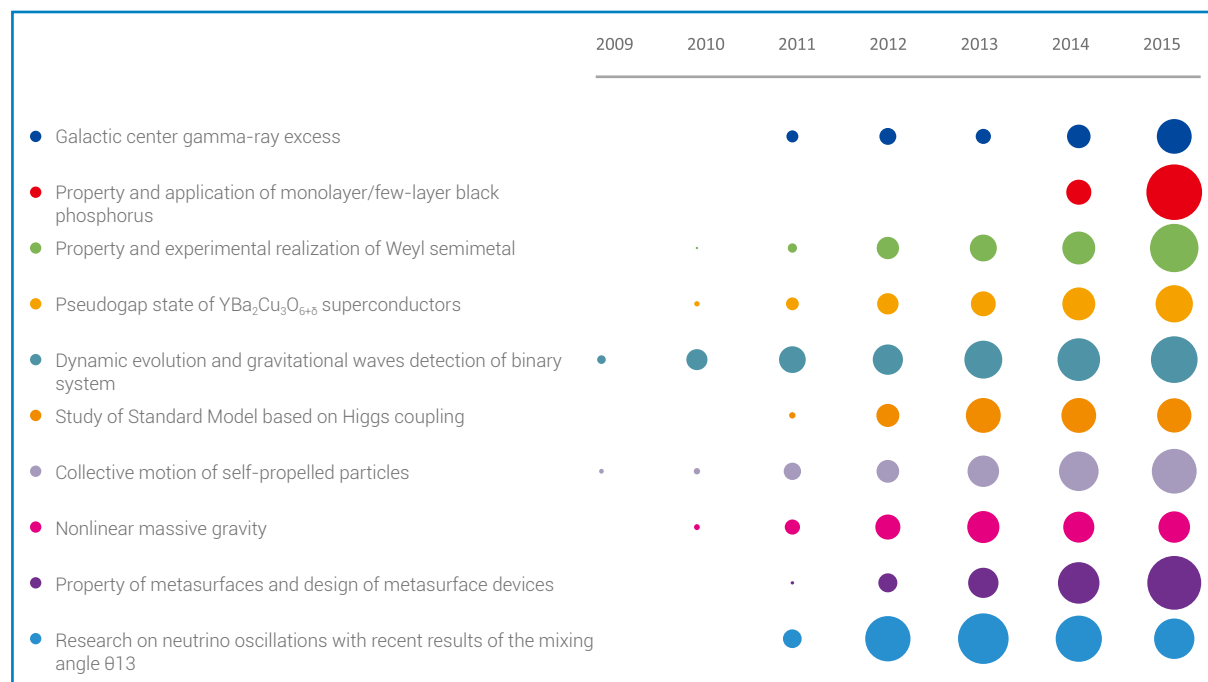
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN PHYSICS

The Top 10 research fronts in physics mainly focus on the subfields of high-energy physics, condensed matter physics, theoretical physics and optics. In high-energy physics, neutrino oscillation and gravitational wave detection are still hot topics this year. The indirect detection of dark matter has also attracted much attention. In condensed matter physics, the study of correlated quantum phenomena is highlighted, including two-dimensional black phosphorus materials, Weyl semimetal, and yttrium barium copper oxide (YBCO) superconductors. In theoretical physics, self-propelled particles and nonlinear massive gravity remain hot topics, as well as the research on the Standard Model. In optics, metasurfaces emerges as a hot topic.

Table 35: Top 10 research fronts in physics

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Galactic center gamma-ray excess	49	2111	2014.2
2	Property and application of monolayer/few-layer black phosphorus	25	3270	2014
3	Property and experimental realization of Weyl semimetal	43	3604	2013.7
4	Pseudogap state of $\text{YBa}_2\text{Cu}_3\text{O}_{6+\delta}$ superconductors	34	2406	2013.5
5	Dynamic evolution and gravitational waves detection of binary system	26	2798	2013.2
6	Study of Standard Model based on Higgs coupling	36	2386	2013.1
7	Collective motion of self-propelled particles	33	2786	2012.9
8	Nonlinear massive gravity	30	3437	2012.7
9	Property of metasurfaces and design of metasurface devices	22	3152	2012.6
10	Research on neutrino oscillations with recent results of the mixing angle θ_{13}	18	4682	2012.3

Figure 7: Citing papers of the Top 10 research fronts in physics



1.2 KEY HOT RESEARCH FRONT – “GALACTIC CENTER GAMMA-RAY EXCESS”

Dark matter is one of the most important topics in physics in the 21st century. The existence of dark matter has been proved by astronomical observation, yet the exact nature of dark-matter particles remains a question. At present, the detection of dark matter is a hot topic in physics. The experiments can be divided into three classes: direct detection, indirect detection, and using accelerators to create dark-matter particles. Among them, the indirect detection explores dark matter from the annihilation or decay products, such as gamma rays, neutrinos, positrons and antiprotons. The Galactic Center is expected to be the brightest source of dark matter, and is one of the most promising targets of indirect detection. In recent years, data from the Fermi Gamma Ray Space Telescope demonstrated a gamma-ray emission that is highly concentrated around the Galactic Center. The most plausible astrophysical explanation for this observation is dark-matter annihilation.

In this research front, the USA is the most active country, participating in 33 core papers (Table 36), which is 67.3% of the total amount and is far ahead of other countries. France, the Netherlands, India and

China also demonstrate excellent performance. Fermi National Accelerator Laboratory and the University of Chicago contributed the highest numbers of core papers as individual organizations. In terms of core paper contribution, five of the top institutions are located in the USA, while the Netherlands, China, Italy and the United Kingdom can each claim one institution among the most prolific. According to a count of the reprint authors of core papers, 25 are from the USA, followed by India (4), while China and Netherlands each has three.

In analyzing the citing papers (Table 37), we found that the USA is still the most active country, participating in 230 citing papers and accounting for 54.5% of the total, followed by Germany with 64 citing papers (15.2%). France, China and Italy rank 3rd to 5th. Among the top institutions that cited the core papers of this research front, Fermilab National Accelerator Lab and the University of Chicago contributed the most, 67 and 57 respectively, accounting for 15.9% and 13.5% of the total citing papers. Italy's National Institute for Nuclear Physics, the University of California Santa Cruz, and the Chinese Academy of Sciences rank 3rd to 5th.

Table 36: Top countries and institutions producing core papers in the research front “Galactic center gamma-ray excess”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	33	67.3%	1	Fermi National Accelerator Laboratory (Fermilab)	USA	14	28.6%
2	France	5	10.2%	2	University of Chicago	USA	11	22.4%
2	Netherlands	5	10.2%	3	University of Amsterdam	Netherlands	5	10.2%
4	India	4	8.2%	3	University of California Irvine	USA	5	10.2%
4	China	4	8.2%	5	SLAC National Accelerator Laboratory	USA	4	8.2%
6	Australia	3	6.1%	5	University of California Santa Cruz	USA	4	8.2%
6	Italy	3	6.1%	7	Chinese Academy of Sciences	China	3	6.1%
6	UK	3	6.1%	7	Durham University	UK	3	6.1%
9	Switzerland	2	4.1%	7	Istituto Nazionale di Fisica Nucleare	Italy	3	6.1%
9	New Zealand	2	4.1%					
9	Canada	2	4.1%					
9	Germany	2	4.1%					

Table 37: Top countries and institutions producing citing papers in the research front “Galactic center gamma-ray excess”

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	230	54.5%	1	Fermi National Accelerator Laboratory (Fermilab)	USA	67	15.9%
2	Germany	64	15.2%	2	University of Chicago	USA	57	13.5%
3	France	51	12.1%	3	Istituto Nazionale di Fisica Nucleare	Italy	38	9.0%
4	China	50	11.8%	4	University of California Santa Cruz	USA	37	8.8%
5	Italy	48	11.4%	5	Chinese Academy of Sciences	China	35	8.3%
6	UK	39	9.2%	6	Max Planck Society	Germany	25	5.9%
7	Spain	31	7.3%	7	University of Amsterdam	Netherlands	22	5.2%
8	Canada	28	6.6%	7	University of California Irvine	USA	22	5.2%
9	Japan	27	6.4%	9	Durham University	UK	19	4.5%
10	Netherlands	24	5.7%	9	Stanford University	USA	19	4.5%
10	Switzerland	24	5.7%					

1.3 KEY HOT RESEARCH FRONT – “PROPERTY AND APPLICATION OF MONOLAYER/FEW-LAYER BLACK PHOSPHORUS”

In recent years, graphene-like, two-dimensional materials, such as transition metal sulfide (MoS₂) and silicene, have become a hot topic for their unique microstructure and physical properties. However, most of the 2D materials have certain drawbacks. In 2014, Xianhui Chen from the University of Science and Technology of China and Yuanbo Zhang from Fudan University prepared a field-effect transistor based on two-dimensional black phosphorus single-crystal. Two weeks after that work appeared, Peide Ye at Purdue University and colleagues claimed success in producing field-effect transistors by phosphorene, which is the 2D counterpart of layered black phosphorus. 2D black phosphorus materials have advantages similar to graphene and transition metal sulfide, and have emerged as promising candidates for future nano-electronic technologies. “Property of phosphorene” was one of the emerging research fronts in 2015. This year, “Property and application of monolayer/few-layer black phosphorus” emerges as a key hot research front.

In the 25 core papers underlying the research front, the most-cited paper (466) was published by China-based scientists, followed by another highly cited paper (406) from a US team. The citations for these two reports far exceed those of other core papers. The USA is the most active country, producing most of the core papers in this research front (Table 38). Researchers from the USA published 17 core papers, which accounts for 68.0% of the total followed by China and the Netherlands.

In analyzing the citing papers (Table 39), we found that China is very active. Chinese scientists published 283 (43.6%) citing papers, followed by the USA (238; 36.7%) and Singapore (78; 12%). All the top institutions are from these three countries, among which Chinese Academy of Sciences has the most citing papers (64), counting for 9.9% of the total. The National University of Singapore, University of Science and Technology of China and Nanyang Technological University rank 2nd to 4th.

Table 38: Top countries and institutions producing core papers in the research front “Property and application of monolayer/few-layer black phosphorus”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	17	68.0%	1	Delft University of Technology	Netherlands	3	12.0%
2	China	6	24.0%	1	Michigan State University	USA	3	12.0%
3	Netherlands	4	16.0%	1	Washington University	USA	3	12.0%
4	Singapore	2	8.0%	4	Arizona State University	USA	2	8.0%
5	Spain	1	4.0%	4	Boston University	USA	2	8.0%
5	UK	1	4.0%	4	International Business Machines (IBM)	USA	2	8.0%
5	Brazil	1	4.0%	4	National University of Singapore	Singapore	2	8.0%
				4	Purdue University	USA	2	8.0%
				4	University of Nebraska Lincoln	USA	2	8.0%
				4	University of Science and Technology of China	China	2	8.0%
				4	Xidian University	China	2	8.0%

Table 39: Top 10 countries and institutions producing citing papers in the research front “Property and application of monolayer/few-layer black phosphorus”

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	283	43.6%	1	Chinese Academy of Sciences	China	64	9.9%
2	USA	238	36.7%	2	National University of Singapore	Singapore	43	6.6%
3	Singapore	78	12.0%	3	University of Science and Technology of China	China	23	3.5%
4	South Korea	44	6.8%	4	Nanyang Technological University & National Institute of Education (NIE)	Singapore	22	3.4%
5	Japan	33	5.1%	5	Peking University	China	20	3.1%
6	Germany	27	4.2%	6	Nanjing University	China	19	2.9%
7	UK	25	3.9%	7	Agency for Science, Technology and Research (ASTAR)	Singapore	19	2.9%
8	Netherlands	19	2.9%	8	Massachusetts Institute of Technology (MIT)	USA	18	2.8%
9	Australia	16	2.5%	9	Boston University	USA	17	2.6%
10	Spain	15	2.3%	10	Rice University	USA	14	2.2%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN PHYSICS

Ten topics in physics are highlighted as emerging research fronts, mainly focusing on high-energy physics, condensed matter physics and theoretical physics. These fronts center on research related to the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) and cosmic inflation models in high-energy

physics; properties of transition metal sulfides, FeSe superconductors and fractional Chern insulators in condensed matter physics; and, in theoretical physics, research on the graviton theorem, periodically driven quantum systems, and superstring theory.

Table 40: Emerging research fronts in physics

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Advanced LIGO and related tools and simulations	4	129	2015
2	Torsional Newton-Cartan geometry	10	132	2014.9
3	Property of periodically driven quantum systems	7	120	2014.9
4	Valleytronics of MoS ₂ and WSe ₂	5	363	2014.6
5	Integrability of the AdS(5)×S(5) superstring	10	210	2014.6
6	Study of inflationary models based on the 2013 Planck data	8	178	2014.6
7	Nematicity of FeSe superconductors	8	171	2014.6
8	New soft graviton theorem	14	297	2014.5
9	Experimental realization of fractional Chern insulators	2	202	2014.5
10	Spin-orbit coupling ultracold atomic systems	2	119	2014.5

2.2 KEY EMERGING RESEARCH FRONT – “EXPERIMENTAL REALIZATION OF FRACTIONAL CHERN INSULATORS”

Discovered in the 1980s and subsequently awarded the Nobel Prize in Physics, the fractional quantum Hall Effect has always been a hot topic in condensed matter physics. However, the requirements of an extremely high magnetic field and low temperature limit its application. In recent years, theoretical studies showed that the fractional quantum Hall effect can be realized in a system with topological flat bands where an external magnetic field is not necessary. This effect is known as quantum anomalous Hall Effect, and the system in which the effect can be realized bears the collective name of fractional Chern insulators. Fractional Chern insulators have the potential to be employed in future topological quantum computation.

Recently, considerable research has focused on experimental realization of fractional Chern insulators. Tilman Esslinger of the Swiss Federal Institute of Technology Zurich reported experimental realization of the Haldane model and the characterization of its topological band structure using ultracold fermionic atoms in a periodically modulated optical honeycomb lattice. Immanuel Bloch of the University of Munich claimed realization of the Hofstadter model using ultracold fermionic atoms in 2D optical superlattices. Both works are very important to the experimental realization of fractional Chern insulators, and have therefore drawn great attention.



9. ASTRONOMY AND ASTROPHYSICS

1. HOT RESEARCH FRONT

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

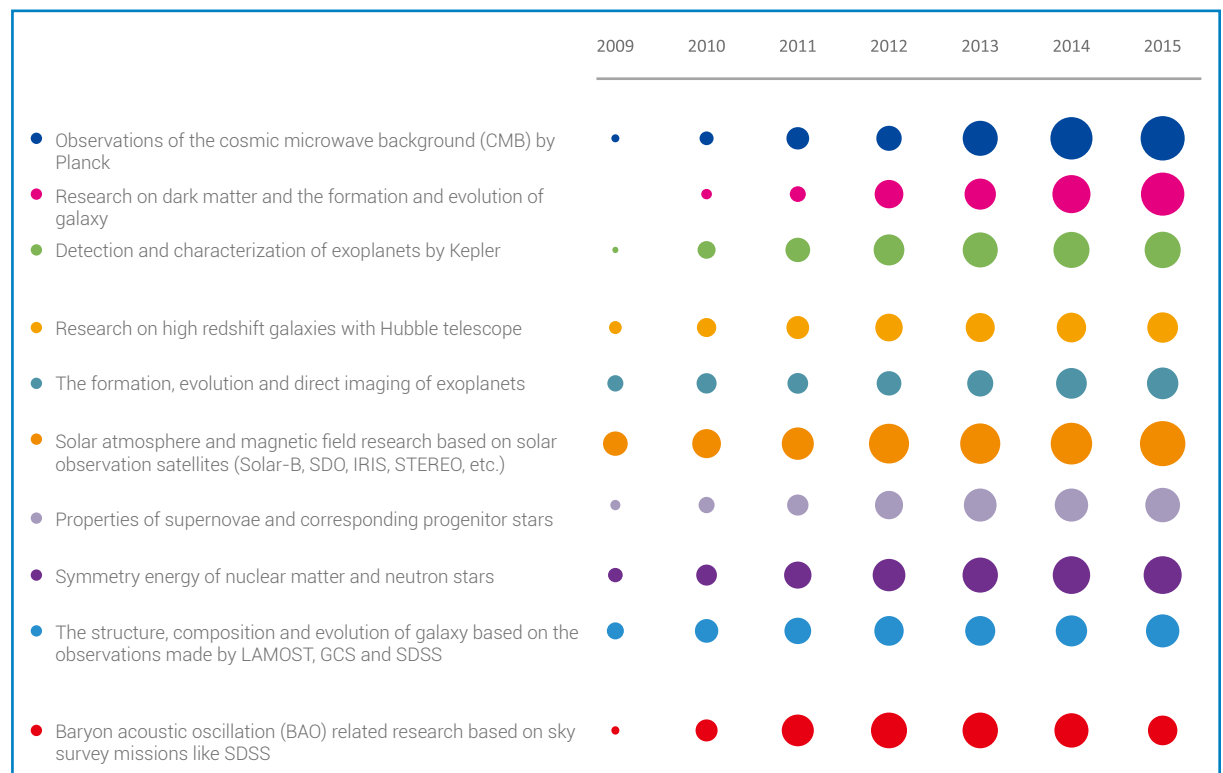
The Top 10 research fronts in astronomy and astrophysics focus on several research topics, including the origin and evolution of the universe, exoplanets, and solar physics. As one of the key questions of modern astronomy and astrophysics, seven out of the Top 10 research fronts focus on the origin and evolution of the universe, including the structure, formation and evolution of the galaxy, the cosmic microwave background (CMB), baryon acoustic oscillation (BAO), supernovae, the property of dark matter particles, high redshift galaxies, the physics of strong fields around compact objects, and so on. Two hot research fronts are related to the detection and research of exoplanets, which is a very hot research topic in this area. Another hot research front focuses on the origin of solar activities. It is notable that most of the Top 10 research fronts directly relate to specific satellite missions for space exploration. This demonstrates that the hot research fronts in this area depend strongly on space-based platforms.

Compared with the research fronts in 2015, two new hot topics enter the Top 10 list (research front 1 and 8): "Observations of the cosmic microwave background (CMB) by Planck" and "Symmetry energy of nuclear matter and neutron stars." Voted one of the top ten scientific breakthroughs by *Science* in 2014, "Studies of comet 67P/Churyumov-Gerasimenko by Rosetta" is selected as an emerging research front this year.

Table 41: Top 10 research fronts in astronomy and astrophysics

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Observations of the cosmic microwave background (CMB) by Planck	42	4532	2013.1
2	Research on dark matter and the formation and evolution of galaxy	35	3993	2012.7
3	Detection and characterization of exoplanets by Kepler	24	4244	2012.1
4	Research on high redshift galaxies with Hubble telescope	26	3390	2012
5	The formation, evolution and direct imaging of exoplanets	17	2839	2011.6
6	Solar atmosphere and magnetic field research based on solar observation satellites (Solar-B, SDO, IRIS, STEREO, etc.)	24	4612	2011.3
7	Properties of supernovae and corresponding progenitor stars	28	2663	2011.2
8	Symmetry energy of nuclear matter and neutron stars	25	4235	2011.1
9	The structure, composition and evolution of galaxy based on the observations made by LAMOST, GCS and SDSS	18	2939	2011
10	Baryon acoustic oscillation (BAO) related research based on sky survey missions like SDSS	7	3126	2010.7

Figure 8: Citing papers of the Top 10 research fronts in astronomy and astrophysics



1.2 KEY HOT RESEARCH FRONT – “OBSERVATIONS OF THE COSMIC MICROWAVE BACKGROUND (CMB) BY PLANCK”

Since the discovery of the cosmic microwave background (CMB) in 1965, scientists have obtained significant results: the 1978 Nobel Prize was awarded to the two discoverers of CMB; the Cosmic Background Explorer (COBE) satellite, launched in 1989, demonstrated for the first time that the CMB has a thermal black body spectrum at a temperature of 2.73 K; two of COBE's principal investigators received the Nobel Prize in Physics in 2006; the Wilkinson Microwave Anisotropy Probe (WMAP), launched in 2001, measured the temperature differences across the sky in the CMB, thus constraining the parameters of the current Standard Model of Cosmology; the Lambda Cold Dark Matter (Λ CDM) model opened the era of precision cosmology. As the third generation of CMB-observation satellites, Planck was launched in May 2009 and scanned the sky continuously in the spectrum of microwave and infrared waves to detect the CMB with higher precision. Observation data was released in 2011,

2013 and 2015, and related publications dominate the hot research fronts in astronomy and astrophysics in 2016.

Twenty-seven out of the 42 core papers of this research front reported the observation results of Planck in 2013. In March 2013, the European Space Agency (ESA) released the most accurate and detailed map ever obtained by the Planck space mission, which refreshed the cosmological parameters obtained by WMAP (including the age of the Universe, the composition proportion of normal matter, dark matter and dark energy, the expansion rate of the universe or Hubble's constant, etc.). Results from Planck in 2015 confirmed these parameters of the cosmic model. In addition, using data from Planck, X-ray Multi Mirror Mission (XMM-Newton), the South Pole Telescope (SPT), Atacama Cosmology Telescope (ATC) and other missions, scientists explored the gravitational lensing effect and Sunyaev–Zel'dovich effect of the CMB. This

Table 42: Top countries and institutions producing core papers in the research front “Observations of the cosmic microwave background (CMB) by Planck”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	40	95.2%	1	University of California Berkeley	USA	38	90.5%
2	Canada	38	90.5%	2	Max Planck Society	Germany	37	88.1%
3	Germany	37	88.1%	3	California Institute of Technology	USA	34	81.0%
4	UK	36	85.7%	3	University of Illinois Urbana-Champaign	USA	34	81.0%
5	France	32	76.2%	5	McGill University	Canada	33	78.6%
6	Italy	31	73.8%	5	University of California Davis	USA	33	78.6%
7	Netherlands	30	71.4%	7	Cardiff University	UK	32	76.2%
7	South Africa	30	71.4%	7	University of Toronto	Canada	32	76.2%
9	Spain	29	69.0%	9	Princeton University	USA	31	73.8%
9	Norway	29	69.0%	9	University of British Columbia	Canada	31	73.8%
9	Poland	29	69.0%					

provides observational proof to studies of the formation of galaxies and helps in understanding the interaction of dark matter and baryonic matter in the process of galaxy formation.

The observation of CMB by Planck also helps close the debate on the discovery of gravitational waves in 2014. In March 2014, a team announced that they had detected B-mode polarization of CMB photon based on the data collected by the BICEP2 telescope in Antarctica. This observation has great potential for being direct evidence of cosmic inflation. This seemingly Nobel Prize-worthy research rapidly attracted wide attention in the astronomical community. Subsequently, however, scientists cast increasing doubt on the experiments. A joint analysis based on the data from Planck and BICEP2 finally concluded that there is no conclusive evidence of primordial gravitational waves. Related research article served as core papers in the emerging research front reported in last year's survey.

The member states and collaborators of the ESA and the USA, who jointly led the Planck mission, published most of the core papers in this research front. In all, 95.2 % of the core papers were contributed by US-based institutions. The University of California Berkeley and the California Institute of Technology rank 1st and 3rd among all the institutions in terms of core papers. Following the USA, Canada, Germany and the UK all participated in more than 85 % of the core papers, indicating close international cooperation in this research front.

The USA also contributed the highest number of citing papers in this research front, followed by UK and Germany. Canada ranks 2nd in terms of the core papers, but 6th in terms of the citing papers. The Max Planck Society contributed the most numerous citing papers, followed by the California Institute of Technology, the University of California Berkeley and Harvard University.

Table 43: Top 10 countries and institutions producing citing papers in the research front "Observations of the cosmic microwave background (CMB) by Planck"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	996	52.3%	1	Max Planck Society	Germany	339	17.8%
2	UK	582	30.6%	2	California Institute of Technology	USA	287	15.1%
3	Germany	519	27.3%	3	University of California Berkeley	USA	257	13.5%
4	Italy	426	22.4%	4	Harvard University	USA	200	10.5%
5	France	369	19.4%	5	University of Cambridge	UK	194	10.2%
6	Canada	345	18.1%	6	National Institute for Nuclear Physics	Italy	193	10.1%
7	Spain	255	13.4%	7	National Institute for Astrophysics	Italy	189	9.9%
8	Netherlands	199	10.5%	8	University of Paris Diderot - Paris VII	France	183	9.6%
9	Chile	198	10.4%	9	Princeton University	USA	181	9.5%
10	Japan	175	9.2%	10	University of Toronto	Canada	178	9.3%

1.3 KEY HOT RESEARCH FRONT – “BARYON ACOUSTIC OSCILLATION (BAO) RELATED RESEARCH BASED ON SKY SURVEY MISSIONS LIKE SLOAN DIGITAL SKY SURVEY”

Baryon acoustic oscillation (BAO) is a popular research topic in astronomy and astrophysics these days. “Sloan Digital Sky Survey (SDSS)-III baryon oscillation spectroscopic survey” has continued to be one of the Top 10 hot research fronts in the successive years of 2014, 2015 and 2016.

BAOs are the regular and periodic fluctuations of visible matter density in large-scale structure resulting from sound waves propagating in the early universe. BAO matter clustering provides a “standard ruler” for length scale. By measuring the location of the peak at various redshifts, scientists can probe the accelerating expansion of the universe and the properties of dark energy. The Dark Energy Task Force, a joint sub-committee formed to advise the National Science

Foundation, the National Aeronautics and Space Administration, and the Department of Energy on the future of dark-energy research, published a report in 2006, recommending BAO as one of four methods for dark-energy detection and highlighting BAO as being less affected by astrophysical uncertainties compared to other methods.

BAO signals were first directly detected by the Sloan Digital Sky Survey (SDSS) in 2000 and the 2-degree Field Galaxy Redshift Survey (2dFGRS) in 2001. Later, other survey projects, such as the WiggleZ Dark Energy Survey and the 6-degree Field Galaxy Redshift Survey also detected BAO. From 2009 to 2014, the Baryon Oscillation Spectroscopic Survey (BOSS), one of SDSS-III projects, mapped the spatial distribution of luminous red galaxies

Table 44: Top countries and institutions producing core papers in the research front “Baryon acoustic oscillation (BAO) related research based on sky survey missions like Sloan Digital Sky Survey”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	7	100%	1	Swinburne University of Technology	Australia	4	57.1%
2	UK	4	57.1%	2	New York University	USA	3	42.9%
2	Australia	4	57.1%	2	University of Arizona	USA	3	42.9%
4	Spain	3	42.9%	2	University of Barcelona	Spain	3	42.9%
5	Canada	2	28.6%	2	University of California Berkeley	USA	3	42.9%
5	France	2	28.6%					
5	Germany	2	28.6%					
5	Japan	2	28.6%					

and quasars to detect the characteristic scale imprinted by BAOs in the early universe. In July 2016, hundreds of scientists collaborated to make the largest-ever, three-dimensional map of distant galaxies, which can be used in precise measurement of dark energy. The core papers of this research front are involved in the above projects, and the research topics include discovering BAO signals, sharpening BAO features to improve distance measurements, and mapping the distance-redshift relation with BAO.

Based on the analysis of the top countries and institutions producing the core papers (Table 44), the USA is the most active country. All seven of the core papers have authors affiliated with US-based institutions. Swinburne University of Technology in

Australia takes first place on the top-institutions list. New York University, the University of Arizona, the University of California Berkeley and the University of Barcelona in Spain tie for second place.

American researchers also contributed the greatest number of citing papers (Table 45), which account for 33.6 % of the total, followed by researchers from the UK, China and Germany. Five American institutions are among the Top 10 citing institutions, and the University of California Berkeley ranks 1st. The Max Planck Society and the Chinese Academy of Sciences take second and third place respectively.

Table 45: Top 10 countries and institutions producing citing papers in the research front “Baryon acoustic oscillation (BAO) related research based on sky survey missions like Sloan Digital Sky Survey”

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	621	33.6%	1	University of California Berkeley	USA	183	9.9%
2	UK	353	19.1%	2	Max Planck Society	Germany	169	9.1%
3	China	351	19.0%	3	Chinese Academy of Sciences	China	167	9.0%
4	Germany	296	16.0%	4	University of Portsmouth	UK	129	7.0%
5	Italy	262	14.2%	5	Harvard University	USA	116	6.3%
6	Spain	260	14.1%	6	National Institute for Nuclear Physics	Italy	113	6.1%
7	France	204	11.0%	7	University of Chicago	USA	112	6.1%
8	Japan	147	8.0%	8	Pennsylvania State University	USA	92	5.0%
9	Canada	139	7.5%	9	California Institute of Technology	USA	90	4.9%
10	Brazil	122	6.6%	10	University of Tokyo	Japan	88	4.8%

2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN ASTRONOMY AND ASTROPHYSICS

There are two emerging research fronts in this area: “Studies of Comet 67P/ Churyumov-Gerasimenko by Rosetta” and “Theoretical and observational studies of star and galaxy formation”. We will give further analysis on the first one.

Table 46: Emerging research fronts in astronomy and astrophysics

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Studies of Comet 67P/Churyumov-Gerasimenko by Rosetta	15	237	2014.9
2	Theoretical and observational studies of star and galaxy formation	4	127	2014.5

2.2 KEY EMERGING RESEARCH FRONT – “STUDIES OF COMET 67P/ CHURYUMOV-GERASIMENKO BY ROSETTA”

The ESA's €1.4 billion ambitious Rosetta mission was designed to rendezvous with the comet 67P/ Churyumov-Gerasimenko, where it would study the nucleus of the comet and its environment. Launched in March 2004, Rosetta rendezvoused with Comet 67P in August 2014 after ten years and a flight of 6.4 billion kilometers. The lander, Philae, touched down on the comet's surface in November 2014. The Rosetta space mission, which put a spacecraft in orbit around a comet and landed a robotic probe on its surface for the first time, was voted the most important scientific breakthrough of 2014 by *Science*.

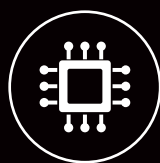
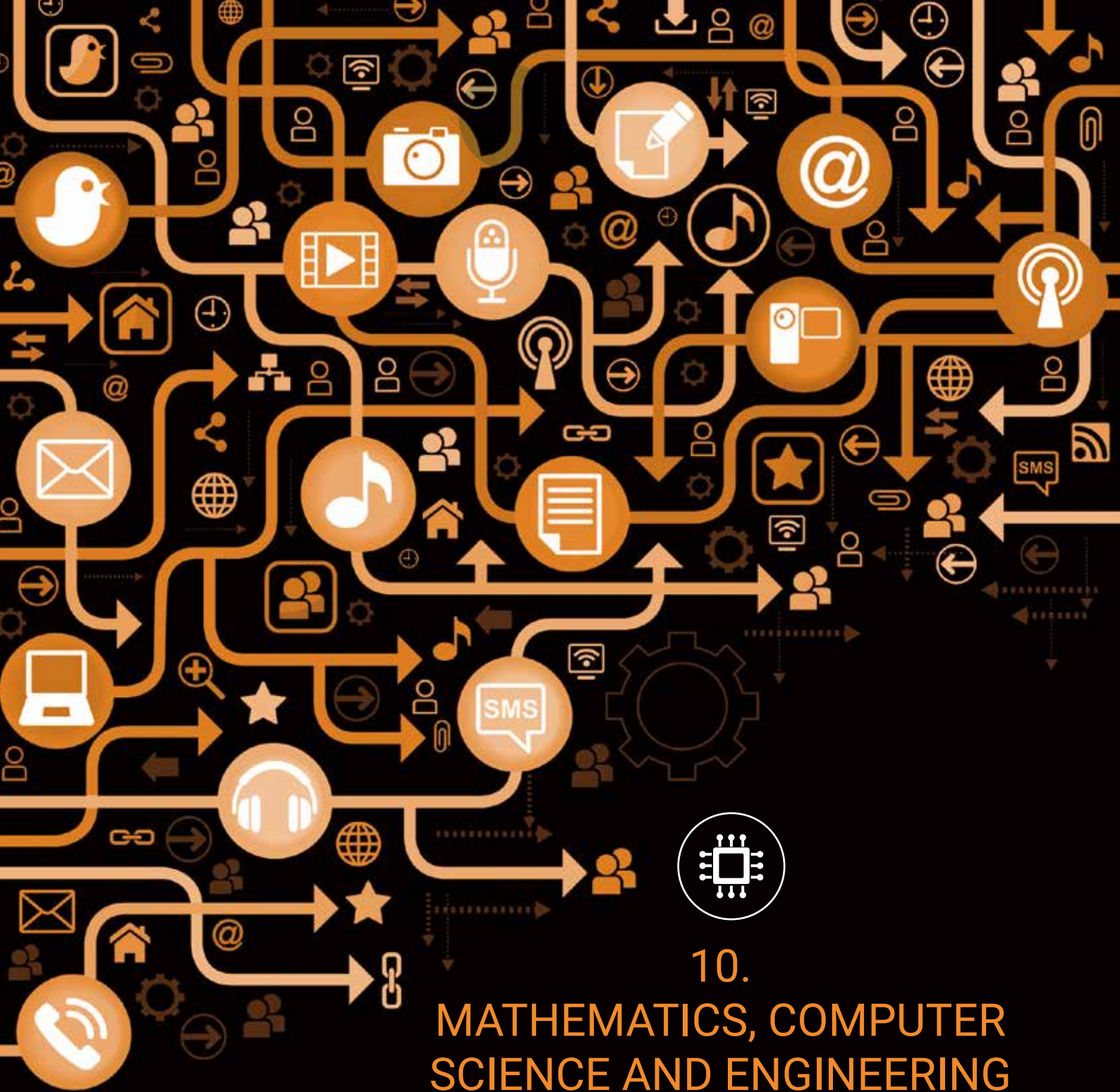
Comets are considered the primitive building blocks of the Solar System, and likely helped 'seed' the earth with water, and maybe even life. Rosetta was designed to follow the comet on its journey through the inner Solar System, measuring the increase in activity as the icy surface is warmed up by the Sun. The Philae lander, which was designed to probe the composition and structure of the comet nucleus material, completed its primary mission

after nearly 57 hours on the comet. Rosetta accompanied Comet 67P across the perihelion on August 13th, 2015. Recently, the ESA announced that Rosetta is set to complete its mission in a controlled descent to the surface of the comet on September 30th, 2016.

Ambitious missions bring great scientific returns. Fifteen core papers published during 2014 to 2015 in this emerging research front represent the most popular scientific discoveries of Rosetta. When analyzing the reprint organizations of these core papers, we found that most of organizations are either leading institutions (e.g. the ESA) or important partners of the Rosetta mission (e.g., the German Aerospace Center [DLR], the National Institute for Astrophysics in Italy, the Max Planck Society, the Southwest Research Institute in the USA, the University of Bern, etc.). This also indicates that leading or participating in space missions is vital for achieving original scientific breakthroughs.



Comets are considered the primitive building blocks of the Solar system, and likely helped 'seed' the earth with water, and maybe even life. The Rosetta space mission includes the orbit and the Philae lander. Rosetta accompanied Comet 67P across the perihelion observing and studying the changes of the comet along the whole journey.



10. MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING

1. HOT RESEARCH FRONT

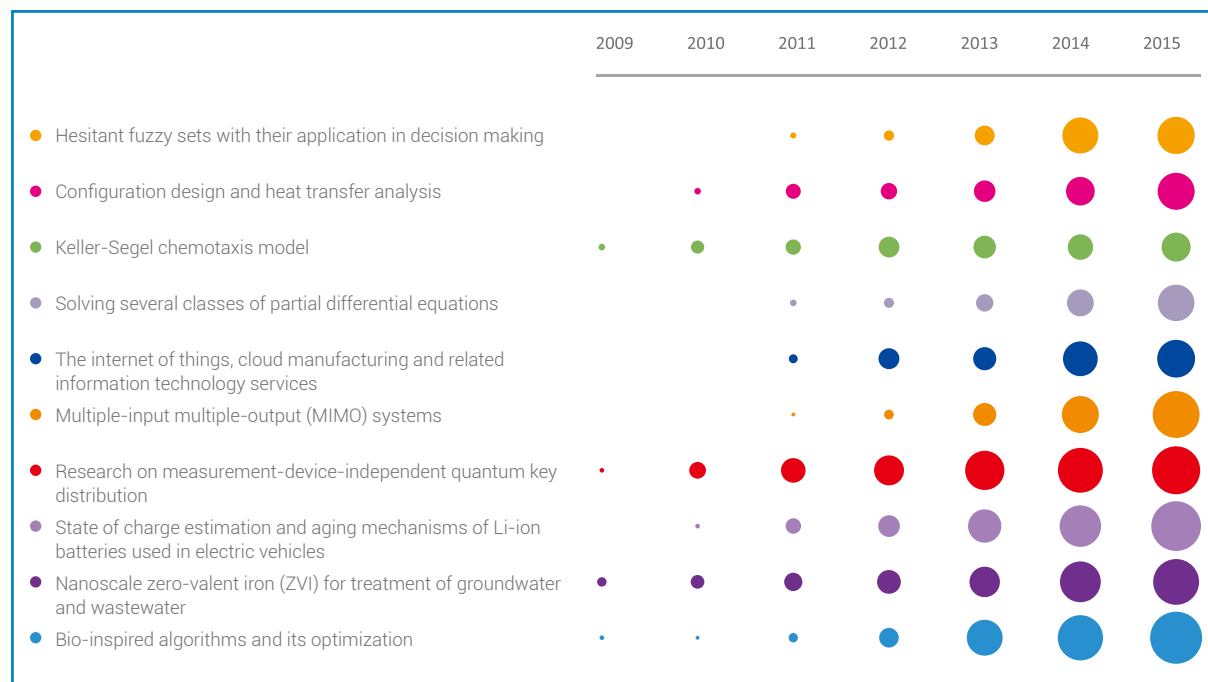
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING

The Top 10 research fronts in mathematics, computer science and engineering mainly focus on hesitant fuzzy sets, configuration design and heat transfer analysis, the Keller-Segel chemotaxis model, partial differential equations, cloud manufacturing, the internet of things, multiple-input multiple-output (MIMO) systems, measurement-device-independent quantum key distribution, Li-ion batteries and bio-inspired algorithms.

Table 47: Top 10 research fronts in mathematics, computer science and engineering

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Hesitant fuzzy sets with their application in decision making	42	2020	2013.3
2	Configuration design and heat transfer analysis	33	1047	2013.3
3	Keller-Segel chemotaxis model	39	1046	2013.3
4	Solving several classes of partial differential equations	24	989	2013.2
5	The internet of things, cloud manufacturing and related information technology services	38	1508	2013.1
6	Multiple-input multiple-output (MIMO) systems	19	1374	2013.1
7	Research on measurement-device-independent quantum key distribution	18	1882	2012.9
8	State of charge estimation and aging mechanisms of Li-ion batteries used in electric vehicles	41	1927	2012.6
9	Nanoscale zero-valent iron (ZVI) for treatment of groundwater and wastewater	19	1087	2012.6
10	Bio-inspired algorithms and its optimization	37	1839	2012.5

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



1.2 KEY HOT RESEARCH FRONT – “THE INTERNET OF THINGS, CLOUD MANUFACTURING AND RELATED INFORMATION TECHNOLOGY SERVICES”

The concept of the “internet of things” (IoT) originated from the radio frequency identification (RFID) systems proposed by the Massachusetts Institute of Technology (MIT) in 1999. In 2005, the international Telecommunication Union (ITU) defined the concept of the IoT in its annual report, that is, “by embedding short-range mobile transceivers into a wide array of additional gadgets and everyday items, new forms of collaboration and communication between people and people, people and things, and between things themselves are enabled. Therefore, real-time interaction is available anytime and everywhere.” The IoT is considered the most significant opportunity for transformation and development in the network information industry since the invention of computer, internet and mobile communication. In recent years, many countries have introduced IoT development plans and the layout of relevant technology and industry.

With the support of advanced technologies such as cloud computing and IoT, cloud manufacturing

breaks the bottleneck of advanced manufacturing and becomes a new manufacturing paradigm. It transforms manufacturing resources and manufacturing capabilities into manufacturing services, which can be managed and operated in an intelligent and unified way to enable the full sharing and circulation of manufacturing resources and capabilities. Cloud manufacturing can provide safe, reliable, high-quality and affordable manufacturing services on demand for the whole lifecycle of manufacturing.

Cloud manufacturing benefits from the development of manufacturing information technology. It realizes the application and extension of cloud computing in manufacturing industries and overcomes existing disadvantages. Therefore, since the concept was first proposed, it has attracted significant interest from scientists from all over the world.

The IoT is a remarkable revolution in information technology industry. As a bridge between the physical

Table 48: Top countries and institutions producing core papers in the research front “The internet of things, cloud manufacturing and related information technology services”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	29	76.3%	1	Old Dominion University	USA	23	60.5%
2	China	28	73.7%	2	Chinese Academy of Sciences	China	15	39.5%
3	UK	5	13.2%	3	Beihang University	China	6	15.8%
4	Sweden	3	7.9%	3	Shanghai Jiao Tong University	China	6	15.8%
5	Thailand	2	5.3%	5	University of Science and Technology of China	China	4	10.5%
6	New Zealand	1	2.6%	5	Indiana University–Purdue University Indianapolis	USA	4	10.5%
6	Poland	1	2.6%					
6	Canada	1	2.6%					

and virtual world in manufacturing industry, cloud manufacturing can hardly be achieved without the rapid development of new generation information service technologies. The key hot research front, “The internet of things, cloud manufacturing and related information technology services” focuses on recent development of the core technology of IoT and cloud manufacturing, as well as expanding the application scenarios for this technology. Lida Xu from Old Dominion University proposed a system architecture involving supply-chain management, automated assembly planning and service workflows. The concept of “Industrial Informatics” has drawn broad attention from the IoT and cloud-manufacturing communities. Research on snowmelt water resource management, flood forecasting, food safety, and health care based on IoT and cloud-manufacturing technologies are extending their range of applications.

Among the core papers in this key hot research front,

more than 70% come from researchers based in the USA and China (Table 48). A high degree of cooperation can also be observed between these two countries. The UK, Sweden, Thailand, New Zealand, Poland and Canada also contributed core papers. It is worth mentioning that Chinese scientists have very impressive performance in this research front. Thirty-six out of the 38 core papers are affiliated with Chinese reprint authors. Among them, Lida Xu has the greatest impact. Similarly, the top five institutions also from China or the USA. They are Old Dominion University, the Chinese Academy of Sciences, Beihang University, Shanghai Jiao Tong University, University of Science and Technology China and Indiana University–Purdue University Indianapolis.

In terms of the citing papers (Table 49), the top two countries are still China and the USA, confirming their prominence in this field. The UK, Taiwan, Sweden, and Spain rank 3rd to 6th. The top citing institutions are also mainly based in China and the USA.

Table 49: Top 10 countries/regions and institutions producing citing papers in the research front “The internet of things, cloud manufacturing and related information technology services”

Country Ranking	Country/Region	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	298	58.5%	1	Old Dominion University	USA	109	21.4%
2	USA	203	39.9%	2	Chinese Academy of Sciences	China	52	10.2%
3	UK	47	9.2%	3	Beihang University	China	45	8.8%
4	Taiwan	22	4.3%	4	Shanghai Jiao Tong University	China	43	8.4%
5	Sweden	19	3.7%	5	University of Science and Technology of China	China	26	5.1%
6	Spain	18	3.5%	6	Indiana University-Purdue University Indianapolis	USA	24	4.7%
7	Canada	16	3.1%	7	Tsinghua University	China	19	3.7%
8	India	13	2.6%	8	Wuhan University of Technology	China	18	3.5%
9	Australia	12	2.4%	9	Jilin University	China	16	3.1%
10	Japan	12	2.4%	10	Zhejiang University	China	15	2.9%

1.3 KEY HOT RESEARCH FRONT – “RESEARCH ON MEASUREMENT-DEVICE-INDEPENDENT QUANTUM KEY DISTRIBUTION”

Quantum key distribution (QKD) allows two remote parties to share an unconditional secure key based on the principle of quantum mechanics. However, the practical QKD system will be prone to quantum hacking due to device imperfections, and then the unconditional security of QKD is compromised. By exploiting these imperfections, especially those in detectors, researchers have demonstrated various quantum attacks including “time-shift attack,” “detector dead-time attack,” and “light blinding attack.” Consequently, solving the practical safety problems of the QKD system has become a focus of current research.

Eighteen core papers in this research front have been cited a total of 1,882 times (averaging 104 cites per paper) from 2009 to 2015. The most-cited paper, published by Valerio Scarani of the National University of Singapore and colleagues, reviews the security of quantum key distribution; the paper has now been cited more than 600 times. Another core

paper, “Measurement-device-independent quantum key distribution,” by Lo.Hoi Kwong from Canada and colleagues, has been cited 161 times and presents the idea of measurement-device-independent QKD (MDI-QKD). It is immune to all detector side-channel attacks, thus offering a clear avenue towards secure QKD realization and global application. The authors’ other three papers discuss the experimental demonstration of polarization encoding measurement-device-independent quantum key distribution, secure quantum key distribution, and measurement-device-independent quantum cryptography. In 2013, experimental measurement-device-independent quantum key distribution was realized respectively by Y. Liu and J. W. Pan from the University of Science and Technology of China and the W. Tittel group from Canada. Their achievement was selected as one of the top 11 advances in physics in 2013 by the American Physical Society’s *Physics* magazine. In 2014, Pan et al. extended

Table 50: Top countries and institutions producing the 18 core papers in the research front “Research on measurement-device-independent quantum key distribution”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	Canada	9	50.0%	1	University of Toronto	Canada	7	38.9%
2	Spain	4	22.2%	2	University of Vigo	Spain	4	22.2%
2	Switzerland	4	22.2%	3	NTT Corp	Japan	3	16.7%
2	UK	4	22.2%	3	Tsinghua University	China	3	16.7%
2	USA	4	22.2%	3	University of Science and Technology of China	China	3	16.7%
6	Germany	3	16.7%	3	University of York	UK	3	16.7%
6	Japan	3	16.7%	3	Massachusetts Institute of Technology (MIT)	USA	3	16.7%
6	China	3	16.7%	8	Chinese Academy of Sciences	China	2	11.1%
9	France	2	11.1%	8	University of Libre Brussels	Belgium	2	11.1%
9	Austria	2	11.1%	8	Norwegian University of Science and Technology	Norway	2	11.1%
9	Belgium	2	11.1%	8	University Graduate Center	Norway	2	11.1%
9	Norway	2	11.1%	8	National University of Singapore	Singapore	2	11.1%
9	Singapore	2	11.1%	8	University of Geneva	Switzerland	2	11.1%
				8	Max Planck Society	Germany	2	11.1%

the secure transmission distance of MDI-QKD to 200 km and achieved a secure key rate of three orders of magnitude higher by developing high speed independent laser interference technology and combining with the high efficiency, low noise superconducting nanowire single photon detector developed by Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, thus reaching a new world record. *Physical Review Letters* described the paper as “an important milestone in practical quantum key distribution” and “significant progress in both physics and technology” and selected the paper as an “editor’s suggestion.” Physicsworld.com, a website from the European Physical Society also reported their findings.

From the perspective of contributing countries and institutions (Table 50), Canada, Spain, Switzerland, the UK, the USA, Germany, Japan and China are the main countries producing core papers. Canada contributed nine of the total 18 core papers. Among

all the 45 participating institutions, the University of Toronto published seven core papers and ranks 1st. The University of Vigo in Spain ranks 2nd with four core papers. The University of Science and Technology of China contributed three core papers, written in collaboration with researches at Tsinghua University.

In terms of countries whose authors cited the core papers of this hot research front (Table 51), China contributed 294 citing papers, accounting for 27.8% of the total, which is the most among all the countries. The UK ranks 2nd with 162 citing papers and the USA ranks 3rd with 148 citing papers. In terms of citing institutions, three of the Top 10 institutions are in China, with University of Science and Technology of China accounting for the highest number of papers. Two of the Top 10 citing institutions are based in Canada. According to the above statistics, China has made significant progress in this research front.

Table 51: Top countries and institutions producing citing papers in the research front “Research on measurement-device-independent quantum key distribution”

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	China	294	27.8%	1	University of Science and Technology of China	China	73	6.9%
2	UK	162	15.3%	2	University of Waterloo	Canada	52	4.9%
3	USA	148	14.0%	3	University of Toronto	Canada	51	4.8%
4	Canada	133	12.6%	4	Max Planck Society	Germany	49	4.6%
5	Germany	114	10.8%	5	Chinese Academy of Sciences	China	35	3.3%
6	Japan	83	7.8%	6	Palacky University Olomouc	Czech Republic	34	3.2%
7	Spain	82	7.8%	7	National University of Singapore	Singapore	32	3.0%
8	Italy	74	7.0%	7	Massachusetts Institute of Technology (MIT)	USA	32	3.0%
9	Australia	59	5.6%	9	Tsinghua University	China	30	2.8%
10	Switzerland	56	5.3%	9	National Institute of Information and Communications Technology (NICT)	Japan	30	2.8%

2. EMERGING RESEARCH FRONT

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

There are three emerging research fronts in mathematics, computer science and engineering. They are “Optimization research on magnetic resonance

imaging of the brain toward clinical application,” “Energy management strategies of hybrid electric bus” and “Mitigation of urban heat island.”

Table 52: Emerging research fronts in mathematics, computer science and engineering

Rank	Emerging Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Optimization research on magnetic resonance imaging of the brain toward clinical application	13	130	2014.8
2	Energy management strategies of hybrid electric bus	7	143	2014.6
3	Mitigation of urban heat island	8	100	2014.6

2.2 KEY EMERGING RESEARCH FRONT – “ENERGY MANAGEMENT STRATEGIES OF HYBRID ELECTRIC BUS”

As the energy crisis and environmental pollution became the major challenges of the automotive industry and urban management, research on energy-saving and environment-friendly public transportation is very important to the sustainable development of countries and cities. The hybrid electric bus is one type of hybrid vehicle that combines a conventional internal combustion engine propulsion system with an electric propulsion system. It possesses the advantages of both the traditional and the electric bus. By optimizing the complementarities of different energy sources, the vehicle's dynamics, safety and comfort can be ensured, while the energy-saving performance can be improved, and the driving distance is unlimited. At the same time, the hybrid electric bus is affordable and suitable for industrialization, and is considered as the most promising alternative to a conventional bus. Therefore, the study of the key technologies of the hybrid electric bus has great practical significance.

Energy-management strategies of the hybrid electric bus are key technologies for these vehicles and are crucial to realizing the goals of fuel economy and environmental friendliness. Desired control objectives can only be achieved by fully understanding the working principles and characteristics of the different power sources, rationally exploiting the advantages of multiple sources of power and taking effective control strategies. The energy management of hybrid electric vehicle

involves the energy conversion of electrical, thermal, and mechanical energy. The control system is complex, and its control optimization objectives are diversified. Therefore, a large number of studies define and describe the problem of energy management for the hybrid electric bus from different perspectives.

There are seven core papers in this emerging research front, four of which were published by Hu XiaoSong from Chalmers University of Technology. His research focused on the energy-efficiency analysis of a series of plug-in hybrid electric buses with different energy management strategies and battery sizes; the comparison of electrochemical energy buffers applied to a hybrid bus; the optimal dimensioning and power management of a hybrid bus; and the longevity-conscious dimensioning and power management of the hybrid energy storage system in hybrid electric bus. Sun Chao from Beijing Institute of Technology contributed two core papers. His paper published in *IEEE Transactions on Control Systems Technology* in 2015 discussed the problem of dynamic traffic feedback data enabled energy management in hybrid electric vehicles. Another paper written by him during his visit to the University of California Berkeley focused on velocity predictors for predictive energy management in hybrid electric vehicles.

As the energy crisis and environmental pollution became the major challenges of the automotive industry and urban management, research on energy-saving and environment-friendly public transportation is very important to the sustainable development of countries and cities.





11. ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

1. HOT RESEARCH FRONT

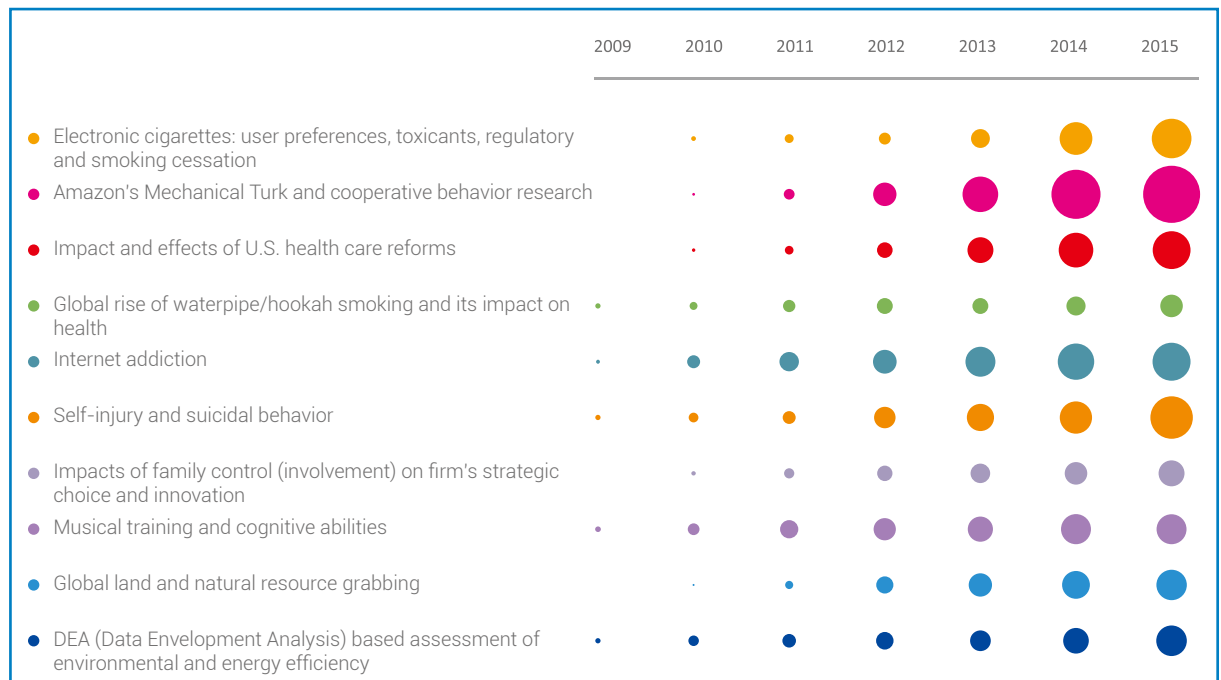
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

Among the Top 10 research fronts in economics, psychology and other social sciences, three fronts pertain to psychology, including "Internet addiction," "Self-injury and suicidal behavior," and "Musical training and cognitive abilities." The topic of "Internet addiction," which featured in *Research Fronts 2015*, is highlighted again this year. Studies on social issues such as "Related research on electronic cigarettes" and "Amazon's Mechanical Turk and cooperative behavior research" have continued to attract attention and have been selected among the Top 10 hot research fronts for two consecutive years, deepened by recent investigation of additional aspects – a trend evident in many of the hot fronts in this area that have recurred in recent years. Meanwhile, other new social issues emerge this year and enter the list of Top 10 hot research fronts, such as "Impact and effects of U.S. health care reforms" and "Global rise of waterpipe/hookah smoking and its impact on health." In addition, two research fronts are related to natural resources and the environment, including "Global land and natural resource grabbing" and "DEA (Data Envelopment Analysis)-based assessment of environmental and energy efficiency." In the area of economics and management, the research topic of family business has been selected for the third time as the Top 10 research fronts (2013, 2014 and 2016). Unlike in previous years, the research in 2016 specifically concentrates on "Impacts of family control (involvement) on the firm's strategic choice and innovation."

Table 53: Top 10 research fronts in economics, psychology and other social sciences

Rank	Hot Research Fronts	Core papers	Citation	Mean Year of Core Papers
1	Electronic cigarettes: user preferences, toxicants, regulatory and smoking cessation	50	3710	2012.8
2	Amazon's Mechanical Turk and cooperative behavior research	18	3019	2012.7
3	Impact and effects of U.S. health care reforms	23	1238	2012.7
4	Global rise of waterpipe/hookah smoking and its impact on health	23	1072	2012.7
5	Internet addiction	28	1834	2012.6
6	Self-injury and suicidal behavior	28	1625	2012.6
7	Impacts of family control (involvement) on firm's strategic choice and innovation	28	1360	2012.6
8	Musical training and cognitive abilities	19	1466	2012.5
9	Global land and natural resource grabbing	27	1350	2012.5
10	DEA (Data Envelopment Analysis) based assessment of environmental and energy efficiency	35	1545	2012.4

Figure 10: Citing papers of the Top 10 research fronts in economics, psychology and other social sciences



1.2 KEY HOT RESEARCH FRONT – “IMPACT AND EFFECTS OF U.S. HEALTH CARE REFORMS”

The Patient Protection and Affordable Care Act (PPACA), commonly called the Affordable Care Act (ACA) or Obamacare, is a US federal statute enacted by President Barack Obama on March 23rd, 2010. It is one of the most important pieces of legislation enacted by the Obama administration. The ACA is intended to provide medical insurance to US citizens who did not previously have health insurance. The ACA is the most significant regulatory overhaul of the US healthcare system in the past 45 years, which may bring profound impact to individuals, business and government. The ACA requires individual US states to expand their Medicaid program (called Medicaid expansions). However, the ACA has faced constant opposition and efforts to repeal it. In a poll released on March 26th, 2012, by *The New York Times* and CBS News, only 36% of those polled said they

support the law either somewhat or strongly and 47% of Americans disapprove of the president’s Affordable Care Act.

On July 11th, 2016, President Obama authored a paper in the leading medical journal – the *Journal of the American Medical Association*, to lay out the progress made by the ACA and future plans for health care. The ACA has succeeded in sharply increasing insurance coverage. Since the ACA became law, the number of uninsured individuals has declined from 49 million in 2010 to 29 million in 2015. (Because this article was published after the period of our data collection, it is not included in the core papers or citing papers of this research front.)

Table 54: Top countries and institutions producing the 23 core papers in the research front “Impact and effects of U.S. health care reforms”

Country Ranking	Country	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	USA	23	100%	1	Harvard University	USA	12	52.2%
				2	National Bureau of Economic Research	USA	6	26.1%
				3	Brigham & Womens Hospital	USA	4	17.4%
				4	Columbia University	USA	3	13.0%
				4	Massachusetts Institute of Technology (MIT)	USA	3	13.0%
				4	RAND Corporation	USA	3	13.0%
				4	Urban Institute	USA	3	13.0%

There are 23 core papers in this hot research front, focusing on the effects of US healthcare reform – a common concern in academia and other communities. These core papers, along with the citing papers, mainly discuss the possible impact of healthcare reform on emergency-department use, the effectiveness of Oregon medical insurance, as well as the progress and performance of Massachusetts' 2006 health reform initiative, which served as the prototype of the ACA.

Among the core papers, a paper published in 2010, elaborating the trends and characteristics of US emergency-room visits before Obama's health-reform measure (chiefly reflecting uninsured individuals seeking their only available medical care), has the highest number of citations, 184. Another two papers

published in 2012 and 2013, analyzing the effectiveness of the state of Oregon's system of medical insurance, also received very high citations, 141 and 125 respectively.

All the core papers come from institutions within the USA, and Harvard University occupies the dominant position, with 12 core papers, accounting for 52.2%. Meanwhile, Harvard University also ranks 1st in terms of contribution to the citing papers. The number of core papers featuring Harvard-affiliated authors is twice as much as the next-highest institution on the list, the National Bureau of Economic Research, while the number of Harvard's citing papers is more than twice that of University of California, San Francisco, which ranks 2nd.

Table 55: Top 10 countries and institutions producing citing papers in the research front "Impact and effects of U.S. health care reforms"

Country Ranking	Country	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Citing Paper	Proportion
1	USA	806	87.2%	1	Harvard University	USA	140	15.2%
2	Canada	35	3.8%	2	University of California San Francisco	USA	63	6.8%
3	UK	26	2.8%	3	University of Michigan	USA	53	5.7%
4	Australia	15	1.6%	4	Brigham & Womens Hosp	USA	51	5.5%
5	Netherlands	12	1.3%	5	University of Pennsylvania	USA	48	5.2%
6	Germany	11	1.2%	6	National Bureau of Economic Research	USA	38	4.1%
7	France	9	1.0%	7	George Washington University	USA	36	3.9%
8	China	8	0.9%	7	Yale University	USA	36	3.9%
9	Switzerland	8	0.9%	9	University of California Los Angeles	USA	31	3.4%
10	Japan	6	0.6%	10	Emory University	USA	30	3.2%

1.3 KEY HOT RESEARCH FRONT – “DEA (DATA ENVELOPMENT ANALYSIS) BASED ASSESSMENT OF ENVIRONMENTAL AND ENERGY EFFICIENCY”

With the development of industry and economy in modern history, natural resources were blindly extracted and exploited, pollutants were indiscriminately discharged, and as a consequence the great challenges of global warming, climate change and other environmental issues ultimately emerged. The balance between industrial pollution and economic growth has become an important policy issue. The concept of sustainable development has strengthened governments' environmental regulation. The evaluation of environmental and energy efficiency has become one of the world's major policy concerns, since effective evaluation not only aids understanding of regional environmental performance at a macro level, but also provides detailed information for the development and implementation of environmental management and energy consumption policies at a micro level.

Data envelopment analysis (DEA) is the most popular

approach in energy and environmental efficiency evaluation in recent years. All of the 35 core papers in this research front employed various DEA models as their assessment methods, among which the non-radial DEA models are more commonly used. In these non-radial DEA models, Metafrontier model, Malmquist index analysis, Slacks-based measurement models are used more frequently in environment and energy efficiency evaluation.

As seen in the national-level analysis (Table 56), Chinese researchers contributed to 20 of the 35 core papers, accounting for more than half (57.1%), followed by the USA (11), Japan (9), South Korea (6), Singapore (5), and Australia (2). Canada, Germany, Taiwan, UK and Portugal are also involved in this area.

Ten of the 20 core papers featuring China-based authors come from Nanjing University of Aeronautics

Table 56: Top countries/regions and institutions producing the 35 core papers in the research front “DEA (Data Envelopment Analysis) based assessment of environmental and energy efficiency”

Country Ranking	Country/Region	Core Paper	Proportion	Institution Ranking	Institution	Affiliated Country	Core Paper	Proportion
1	China	20	57.1%	1	Nanjing University of Aeronautics and Astronautics	China	10	25.7%
2	USA	11	31.4%	2	New Mexico Institute of Mining and Technology	USA	10	20.0%
3	Japan	9	25.7%	3	Central Research Institute of Electric Power Industry– (CRIEPI)	Japan	7	17.1%
4	South Korea	6	17.1%	3	Inha University	South Korea	6	17.1%
5	Singapore	5	14.3%	5	National University of Singapore	Singapore	5	14.3%
6	Australia	2	5.7%	6	Jiangxi University of Finance and Economics	China	4	11.4%
7	Canada	1	2.9%	7	Beijing Institute of Technology	China	3	8.6%
7	Germany	1	2.9%					
7	Taiwan	1	2.9%					
7	UK	1	2.9%					
7	Portugal	1	2.9%					

& Astronautics, which ranks 1st among the core-paper-producing institutions. Jiangxi University of Finance & Economics ranks 6th and Beijing Institute of Technology ranks 7th, with four and three core papers respectively. The USA has 11 core papers, 10 of which are from the New Mexico Institute of Mining and Technology (the corresponding author of the 10 papers is Toshiyuki Sueyoshi). Japan has nine core papers, seven of which are from the Central Research Institute of Electric Power Industry. South Korea contributes six core papers, all of which are from Inha University. Singapore accounts for five core papers, which are all contributed by National University of Singapore. The above three organizations rank from 3rd to 5th on the list of top-producing institutions in terms of core papers.

Analysis of the citing papers shows that China occupies first place by contributing 303 papers, accounting for 45% of the total. The USA and Taiwan are in 2nd and

3rd place with 99 and 74 citing papers respectively. In addition, Japan, Iran, UK, Spain, South Korea, Australia and Germany also perform well.

On the list of Top 10 institutions according to citing papers, seven are from China, including Xiamen University, Nanjing University of Aeronautics and Astronautics, Beijing Institute of Technology, Jiangxi University of Finance and Economics, the Chinese Academy of Sciences, Minjiang University, and the University of Science and Technology of China. Xiamen University occupies first place with 38 citing papers. Second is the New Mexico Institute of Mining and Technology in the USA. In addition, the Central Research Institute of Electric Power in Japan, the University of Tehran in Iran, Inha University in South Korea, the University of Valencia in Spain and Soochow University in Taiwan also make the list (Table 57).

Table 57: Top countries/regions and institutions producing citing papers in the research front "DEA (Data Envelopment Analysis) based assessment of environmental and energy efficiency"

Country Ranking	Country/Region	Citing Paper	Proportion	Institution Ranking	Institution	Affiliated Country/Region	Citing Paper	Proportion
1	China	303	45.0%	1	Xiamen University	China	38	5.6%
2	USA	99	14.7%	2	New Mexico Institute of Mining and Technology	USA	37	5.5%
3	Taiwan	74	11.0%	3	Nanjing University of Aeronautics and Astronautics	China	30	4.5%
4	Japan	46	6.8%	4	Central Research Institute of Electric Power Industry– (CRIEPI)	Japan	28	4.2%
5	Iran	39	5.8%	5	Beijing Institute of Technology	China	26	3.9%
6	UK	35	5.2%	6	Jiangxi University of Finance and Economics	China	22	3.3%
7	Spain	33	4.9%	7	Chinese Academy of Sciences	China	19	2.8%
8	South Korea	32	4.7%	8	Minjiang University	China	19	2.8%
9	Australia	31	4.6%	9	University of Tehran	Iran	19	2.8%
10	Germany	24	3.6%	10	University of Science and Technology of China	China	18	2.7%
				10	Inha University	South Korea	18	2.7%
				10	University of Valencia	Spain	18	2.7%
				10	Soochow University	Taiwan	18	2.7%



12. NATIONAL PERFORMANCE IN RESEARCH FRONTS

1. INTRODUCTION

In previous chapters, we have offered detailed interpretation and analysis of research fronts from 10 specialty areas. In this chapter, we will evaluate from a general perspective the performance of six countries – the USA, China, the UK, Germany, France and Japan – in these 180 research fronts. To understand the contributions and leading positions of these countries in the research fronts, we will analyze the nations' current participation as well as their potential development in these fields.

A research front, whether “hot” or “emerging,” usually represents a state-of-the-art theory or concept. Analysis of research fronts at a national level can provide insights about the countries' current and potential leading performance.

The core papers, which provide the foundations for research fronts, are all highly cited papers in ESI – reports that rank in the top 1 percent in terms of citations in the same ESI field and publication year. Core papers are usually innovative and play a notably leading role in their subject fields. Herein, we use the number of core papers with reprint authors' affiliations to identify the leading performance of a country.

Meanwhile, articles that cite the core papers can unveil how the technology, data, and theory in the core papers are applied and developed. (In this case, it is not necessary that the citing papers are themselves highly cited.) Therefore, citing papers are critical in tracking important scientific discoveries, advancing cutting-edge technologies, and potentially leading the future development of the specialty area. In this analysis, we use the number of citing papers, along with the reprint authors' national affiliations, to identify the potential leading performance of a country.

We define the coverage performance of a country as the ratio of the number of research fronts in which the country contributed core papers to the total number of research fronts in this research area. By comparing a country's contribution in the ten broad research areas, we can analyze the strength of a country and ascertain if its development is balanced across disciplines.

The leading performance and potential leading performance indicators were applied to compare the performance of countries in different research fronts. Specifically, the number of research fronts in which a country participates, and in which it ranks in first place or within the top three, is counted to determine the country's current contribution and potential development. Assessing the performance of the six countries reveals their strength in 10 research areas.

2. GENERAL PERFORMANCE OF SIX COUNTRIES

2.1 STRENGTH AND POTENTIAL DEVELOPMENT

The USA has reprint authors affiliated with core papers in 152 research fronts, which gives it a leading performance ratio of around 85%. In terms of the number of core papers listing US-based reprint authors, the USA has 145 research fronts (~80%) ranked in the top three. Meanwhile, the USA ranks 1st in 106 research fronts (~60%). From these perspectives, the USA is far ahead of the other five countries (Table 58, Figure 11 and Figure 12).

China has 68 (~40%) research fronts in which the reprint authors of core papers are from China, less than the UK's 90, and ranks 3rd. The same is true in terms of the numbers of top three research fronts in which reprint authors of core papers are from China. China has 58 (~33%), fewer than the UK's 68 (37.8%; Table 58, Figure 11). However, China has 30 research fronts in which the number of core papers with Chinese affiliations ranks 1st, a total far exceeding the UK's 14, the 11 claimed respectively by Germany and Japan, and France's 8

(Table 58, Figure 12).

In this analysis of the citing papers, all six countries have a current leading performance ratio of over 90% and even close to 100%, which indicates that these countries are closely tracking the research fronts and showing strength in each field's likely future development. There are 164 (>90%) research fronts in which the USA ranks among the top three in the number of citing papers. Meanwhile, the USA ranks 1st in 115 research fronts (~65%) based on the reprint authors' affiliation. By that same measure, China has 177 (98%) research fronts. There are 100 (~56%) research fronts in which China ranks in the top three. Meanwhile, China ranks 1st in 52 (~30%) research fronts in terms reprint-author affiliations in the citing papers. From the point of this view, China surpasses the UK to rank 2nd and shows a strong potential development capability (Table 59, Figure 11, and Figure 12).

Table 58 Leading performance of six countries in terms of reprint authors in core papers

	Contribution			First Place			Top three		
	Research Fronts	Proportion	Research Areas	Research Fronts	Proportion	Research Areas	Research Fronts	Proportion	Research Areas
USA	152	84.4%	10	106	58.9%	10	145	80.6%	10
China	68	37.8%	10	30	16.7%	8	59	32.8%	9
UK	90	50.0%	10	14	7.8%	5	68	37.8%	10
Germany	66	36.7%	10	11	6.1%	5	39	21.7%	9
France	57	31.7%	10	8	4.4%	5	26	14.4%	8
Japan	40	22.2%	10	11	6.1%	6	26	14.4%	7

Table 59 Leading performance of six countries in terms of reprint authors in citing papers

	Contribution			First Place			Top three		
	Research Fronts	Proportion	Research Areas	Research Fronts	Proportion	Research Areas	Research Fronts	Proportion	Research Areas
USA	177	98.3%	10	115	63.9%	10	164	91.1%	10
China	177	98.3%	10	52	28.9%	9	100	55.6%	10
UK	171	95.0%	10	2	1.1%	2	72	40.0%	10
Germany	171	95.0%	10	1	0.6%	1	55	30.6%	10
France	159	88.3%	10	1	0.6%	1	20	11.1%	7
Japan	163	90.6%	10	5	2.8%	4	19	10.6%	5

Figure 11 Percentage of top three research fronts of six countries in terms of leading performance and potential performance

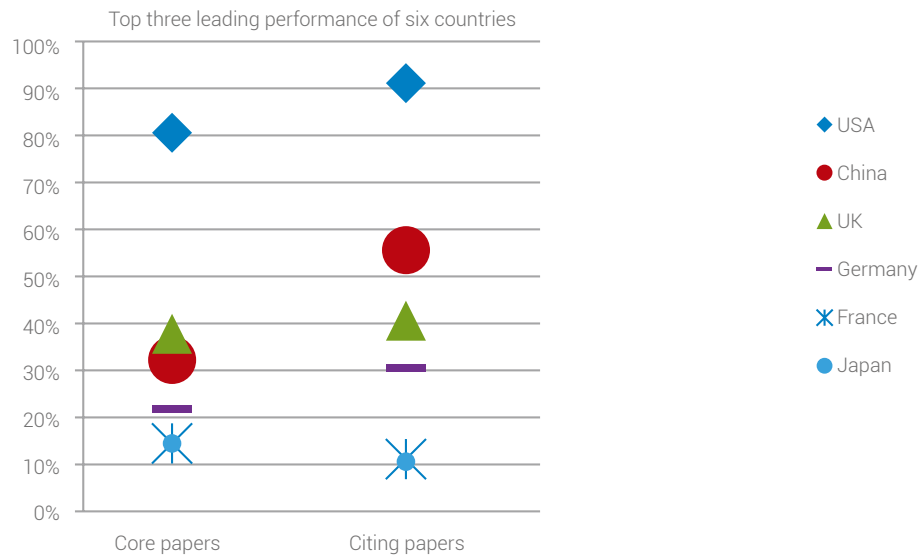
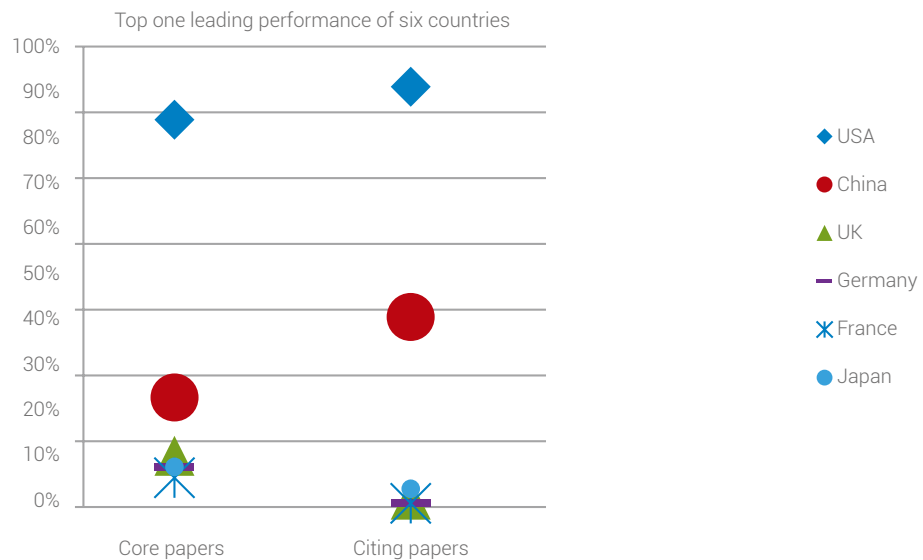


Figure 12 Percentage of first place research fronts of six countries in terms of leading performance and potential performance



Highlights and summaries

China has reprint author affiliation in around forty percent of the one hundred hot research fronts and 80 emerging research fronts this year, of which one third of the core potential papers rank top three and around seventeen percent ranks 1st. For citing papers reprint author affiliation, China follows all these hot research fronts and emerging research fronts. Besides, more than half of them gets into the top three and almost one third ranks 1st.

China is currently far behind USA and competing rigorously with UK in terms of leading performance. Meanwhile, for potential performance, China ranks 2nd fully beyond UK with strong developmental potential.

2.2 COVERAGE PERFORMANCE OF SIX COUNTRIES IN 10 RESEARCH AREAS

The strength of the above six countries can be revealed by comparing their contributions of core papers with reprint author affiliation in 10 research areas. The USA has a coverage ratio of over 80% in eight research areas, with the exception of chemistry and materials science (60%) and mathematics, computer science and engineering (70%).

China has three research areas with a coverage ratio over 50%, while the corresponding number of research areas for the UK, Germany and France is seven, four and three, respectively. Japan faces a large gap compared with the other five countries in this indicator. The highest coverage ratio of Japan is below 35% (Table 60, Figure 13, and Figure 14).

Although China has fewer research areas with coverage ratios over 50% compared with the UK, it shows high coverage ratios (over 60%) in three research areas: mathematics, computer science and engineering; chemistry and materials science; and agricultural, plant and animal sciences. However, the coverage ratio is below 40% in other research areas, with the lowest in astronomy and astrophysics (8.3%) and clinical medicine (12.9%).

The UK has seven research areas with coverage ratios over 50%, including economics, psychology and other

social sciences; physics; astronomy and astrophysics; geosciences; ecology and environmental sciences; clinical medicine; and agricultural, plant and animal sciences. Five of the above seven research areas have coverage ratios over 60%. In economics, psychology and other social sciences, more than 90% of the core papers are affiliated with UK reprint authors. Compared with China, the UK has more research areas with coverage ratios over 60%, and performs better in term of this indicator. It is clearly shown in the radar charts (Figure 13, Figure 14) that the UK has a more balanced coverage in the 10 research areas.

Germany has four research areas with coverage ratios over 50%, including agricultural, plant and animal sciences, geosciences, astronomy and astrophysics and physics. Three research areas have coverage ratio over 50%, including astronomy and astrophysics, geosciences, and physics. The coverage ratio of France in other research areas is below 40%. Japan has three research areas with coverage ratios between 30% and 35%, including physics, geosciences, and agricultural, plant and animal sciences. The highest coverage ratio of Japan comes from physics, which is 35%.

Figure 13 Percentage of leading performance contributions in 10 research areas of China, USA and UK

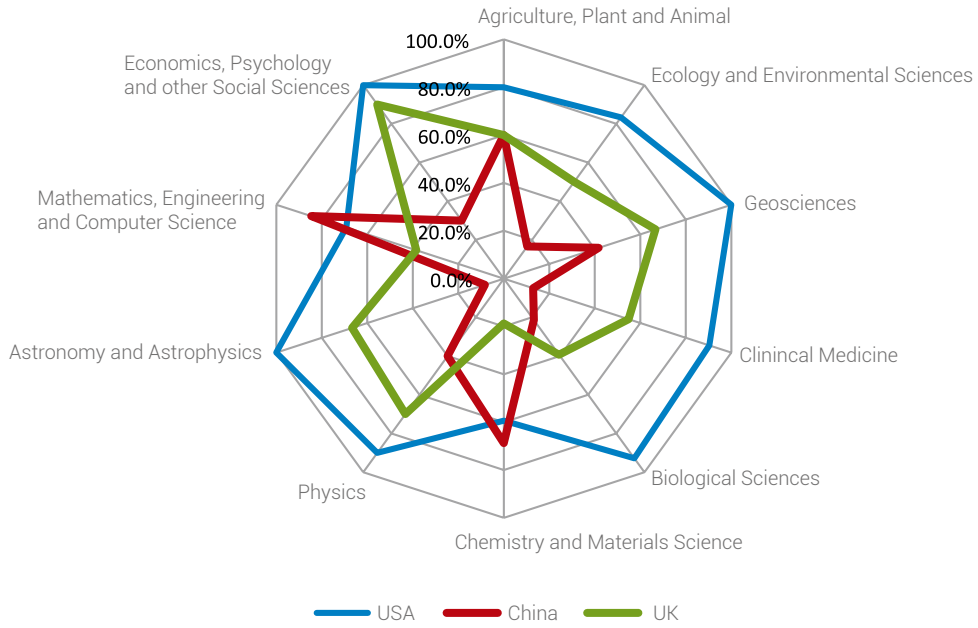


Figure 14 Percentage of leading performance contributions in 10 research areas of Germany, France and Japan

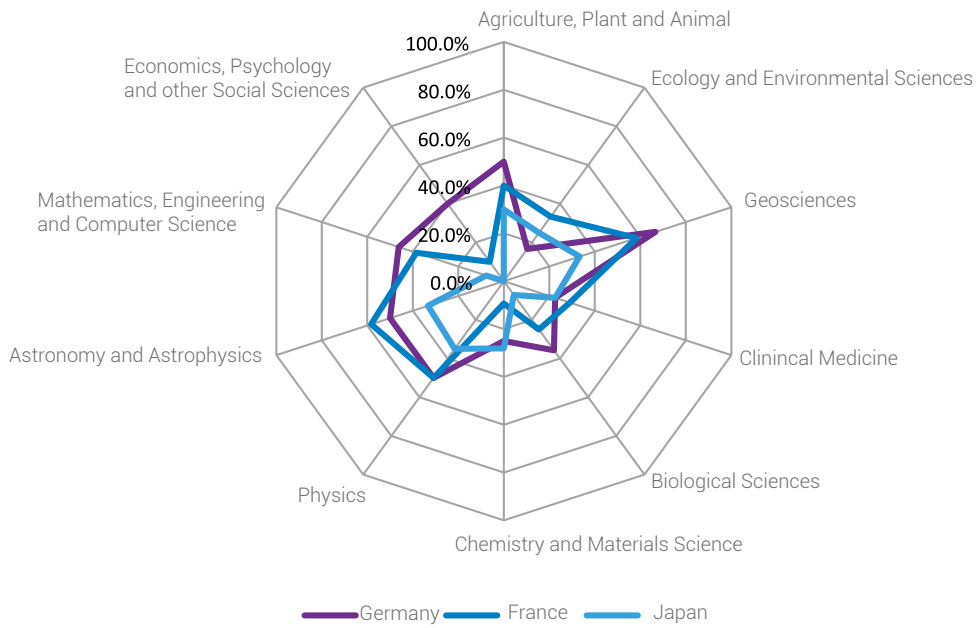


Table 60 Performance of six counties in terms of research fronts based on core-author affiliation in 10 research areas

No.	Research Area	Research Fronts	Research Fronts Contributed					
			USA	China	UK	Germany	France	Japan
1	Agriculture, Plant and Animal Sciences	10	8	6	6	5	4	3
2	Ecology and Environmental Sciences	12	10	2	6	2	4	3
3	Geosciences	12	12	5	8	8	7	4
4	Clinical Medicine	31	28	4	17	7	9	7
5	Biological Sciences	28	26	6	11	10	7	2
6	Chemistry and Material Sciences	32	19	22	6	8	3	9
7	Physics	20	18	8	14	10	10	7
8	Astronomy and Astrophysics	12	12	1	8	6	7	4
9	Mathematics, Computer science and Engineering	13	9	11	5	6	5	1
10	Economics, Psychology and other Social Sciences	10	10	3	9	4	1	0
Total		180	152	68	90	66	57	40

The USA ranks 1st in nine research areas in terms of reprint-author affiliations in the core reports, and the only exception is mathematics, computer science and engineering (Table 61).

China ranks 2nd based on first-place coverage in the research fronts. Eight research areas are presented in which China-based researchers are identified as the reprint author. The exceptions are geosciences and astronomy and astrophysics. In the eight research areas, China has the highest coverage in mathematics, computer science and engineering (53.8%), followed by chemistry and material sciences (37.5%) and agriculture, plant and animal sciences (20%).

The UK, Germany and France all cover five research areas in terms of the reprint's author's national affiliation. The research areas they have in common are clinical medicine, biological sciences, chemistry and material sciences and physics. The fifth research area for the UK is ecology and environmental sciences, while the corresponding field for Germany and France is astronomy and astrophysics.

Japan covers six research fronts, including agriculture, plant and animal sciences, ecology and environmental sciences, geosciences, clinical medicine, chemistry and material sciences, and physics.

Table 61 Performance of six counties in terms of research fronts with first place core papers, according to national affiliation of reprint authors, in 10 research areas

No.	Research Area	Research Fronts	Research Fronts Contributed					
			USA	China	UK	Germany	France	Japan
1	Agriculture, Plant and Animal Sciences	10	5	2				1
2	Ecology and Environmental Sciences	12	6	1	2			1
3	Geosciences	12	10					1
4	Clinical Medicine	31	23	2	5	1	3	3
5	Biological Sciences	28	20	3	2	1	1	
6	Chemistry and Material Sciences	32	12	12	4	4	1	3
7	Physics	20	11	2	1	4	2	2
8	Astronomy and Astrophysics	12	10			1	1	
9	Mathematics, Computer science and Engineering	13		7				
10	Economics, Psychology and other Social Sciences	10	9	1				
Total		180	106	30	14	11	8	11

Highlights and summaries

Compared to the other five countries, USA shows the most balanced coverage performance and the highest coverage rate in 10 research areas. In eight research areas, its coverage rate is more than 80%. USA ranks 1st in nine research areas with core paper reprint affiliation with the exception of mathematics, computer science and engineering.

According to Figure 13, UK shows similarity to USA in terms of the balanced coverage performance only with a half scale. In seven research areas, the coverage rate of UK is more than 50%.

Compared with UK, China holds less coverage rate and less balanced coverage performance in 10 research areas. In the research areas of mathematics, computer

science and engineering, chemistry and materials sciences, and agricultural, plant and animal sciences, China covered more than 60% while in astronomy and astrophysics and clinical medicine, the coverage rate is only 8.3% and 12.9%, respectively.

China sits beyond UK and only next to USA in terms of the No.1 coverage rate. China has core paper reprint author affiliation in eight research areas with the exception of geosciences and astronomy and astrophysics. The highest coverage rate is in the research area of mathematics, computer science and engineering with 53.8% followed by chemistry and materials sciences (37.5%) and agricultural, plant and animal sciences (20%).

3. PERFORMANCE OF SIX COUNTRIES IN EACH AREA

In previous sections, we have analyzed the overall performance of these six countries in 180 research fronts and their contributions in 10 research areas. In this section we will provide detailed analysis for these six countries in each area. Since the USA contributes

more than 60% of the research fronts in both "leading performance" and "potential leading performance," and the performances are balanced in 10 research areas, showing its comprehensive strength, the following analysis will focus on the other five countries.

3.1 AGRICULTURAL, PLANT AND ANIMAL SCIENCES

There are 10 hot research fronts in this area, and no emerging fronts. Regarding leading performance, the USA contributes the greatest number, followed by China and the UK. China scores slightly higher than the UK, as China has more research fronts ranked in the top three.

China far exceed the other four countries based on the fact that the USA ranks in the top three in eight fronts while and China earns the same distinction in seven research fronts – considerably more than the other four countries. Meanwhile, among these top three research fronts, the USA has six ranked 1st while China only has three.

In terms of potential leading performance, the USA and

Table 62 Performance of six countries in "agricultural, plant and animal sciences"

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	8	6	6	5	4	3	10	10	10	9	10	10
	Rank 1 st	5	2				1	6	3		1		
	Rank 2 nd -3 rd	1	4	3	1	1	1	2	4	2	1	2	

3.2 ECOLOGY AND ENVIRONMENTAL SCIENCES

There are 12 research fronts in this area. In terms of leading performance, besides the USA, the UK is the most outstanding country. Although China and Japan have fewer research fronts in which they rank in the top three, China ranks 1st in the research fronts "Heavy metal soil contamination" and Japan ranks 1st in "Environmental impact of Fukushima Dai-Ichi nuclear

accident" in both "leading performance" and "potential leading performance".

Compared with Japan, China is slightly better in this research area, as China has a higher number of research fronts in which it ranks 2nd or 3rd.

Table 63 Performance of six countries in "ecology and environmental sciences"

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	10	2	6	2	4	3	12	12	12	12	12	12
	Rank 1 st	6	1	2			1	9	1	1			1
	Rank 2 nd -3 rd	4	1	3	1	2		2	2	5	3	3	

3.3 GEOSCIENCES

There are 12 research fronts in this area. For contributions in leading performance, the ranking of the six countries is the USA, the UK, Germany, France, Japan and China. Japan performs better than China considering that, Japan ranks 1st in both leading performance and potential leading performance in the research front "Coseismic Slip of the 2011 Tohoku

Earthquake," while China ranks 2nd only in the research front "Climate system model."

China's contribution in terms of leading performance is far behind the other five countries. However, in potential leading performance, China is very close to the UK and Germany, ranking in the top three in six research fronts ranked in the top three and 1st in one.

Table 64 Performance of six countries in "geosciences"

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	12	5	8	8	7	4	12	11	12	11	11	11
	Rank 1 st	10					1	10	1				1
	Rank 2 nd -3 rd	2	1	8	5	3	1	2	5	6	6		

3.4 CLINICAL MEDICINE

There are 10 hot research fronts and 21 emerging research fronts in this area, in which, overall, the USA performs best. Additionally, the UK, Germany and France also play important roles. In terms of leading research fronts, the UK, Germany and France participate in 17, 7 and 9 while holding 14, 6, and 7 places in the top three leading research fronts respectively. China and Japan participate in far fewer leading research fronts than the USA, UK, Germany and France.

ranks 1st in 28 of the 31 research fronts and 2nd or 3rd in three other research fronts. The UK and Germany hold more 2nd and 3rd place research fronts. Although the numbers of 2nd or 3rd place research fronts are close among China, France and Japan, China ranks 1st in two research fronts: "Long non-coding RNA MATA T1 stimulates the proliferation and metastasis of cancer cells" and "Epidemiology, pathology and genetics study of bird flu virus," which demonstrates that China has great potential in this area.

In terms of potential leading research fronts, the USA

Table 65. Performance of six countries in "clinical medicine"

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	28	4	17	7	9	7	31	31	31	31	30	27
	Rank 1 st	23	2	5	1	3	3	28	2				
	Rank 2 nd -3 rd	5	1	9	5	4		3	4	18	13	4	3

3.5 BIOLOGICAL SCIENCES

There are 10 hot research fronts and 18 emerging research fronts in this area. Among the 28 research fronts, the USA contributed core papers (again, according to the national affiliation of reprint authors) in 26 research fronts and ranks 1st in 20 research fronts while ranking 2nd or 3rd in the six remaining research fronts. China contributed core papers as reprint authors in only six research fronts, ranking 1st in three fronts and 2nd to 3rd in other three. There are nine research fronts in

which the UK's number of core papers as reprint author ranks in the top three. But the UK ranks 1st in only two research fronts.

In terms of potential leading research fronts, China performs better than the UK. China holds 18 top three and five No.1 potential leading research fronts, while all the UK's potential leading research fronts are from 2nd to 3rd places.

Table 66. Performance of six countries in "biological sciences"

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	26	6	11	10	7	2	27	28	26	26	23	24
	Rank 1 st	20	3	2	1	1		21	5				
	Rank 2 nd -3 rd	6	3	7	3	2	2	6	13	12	9	3	2

3.6 CHEMISTRY AND MATERIALS SCIENCES

There are 10 hot research fronts and 22 emerging ones in this area. This is the only area in which China performs better than USA, both in terms of leading and potential leading research fronts.

compared to the USA's score of 19. Both China and the USA hold first place in 12 leading research fronts.

In respect to leading research fronts, China holds placements among the top three in 21 research fronts

China has evident advantage over the USA in potential leading research fronts. China participates in all 32 research fronts and ranks 1st in 25, while the USA only has six first place potential leading research fronts.

Table 67. Performance of six countries in "chemistry and materials sciences"

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	19	22	6	8	3	9	30	32	25	30	22	28
	Rank 1 st	12	12	4	4	1	3	6	25			1	1
	Rank 2 nd -3 rd	7	9	1	3		5	19	7	2	5	1	4

3.7 PHYSICS

This area features 10 hot and 10 emerging research fronts. In terms of leading research fronts, Germany captures first place in four fronts, many more than the UK, France, Japan and China. China holds placements among the top three in seven leading research fronts, approximately the same as the UK and Germany.

In respect to potential leading research fronts, China, the UK and Germany each have nine placements

among the top three. China ranks 1st in two hot research fronts: "Monolayer/multilayer black phosphorus's characteristics and application" and "Metasurface characteristics study and metasurface device design." The UK ranks 1st in an emerging research front, "Clustering and phase separation of self-propelled particles." And Germany can claim nine research fronts in which it ranks at 2nd or 3rd place.

Table 68. Performance of six countries in "physics"

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	18	8	14	10	10	7	20	19	20	20	19	20
	Rank 1 st	11	1	1	4	2	2	14	2	1			2
	Rank 2 nd -3 rd	4	6	8	3	1	3	5	7	8	9	2	3

3.8 ASTRONOMY AND ASTROPHYSICS

There are 12 research fronts in this area and, once again, the USA is the big winner. As for leading research fronts: Besides the USA, the UK, Germany and France perform well, participating respectively in eight, six and seven leading research fronts and holding top-three placements in six, five and four leading research fronts. Germany ranks 1st in the emerging research front "Rosseta's observation on 67P/Churyumov-Gerasimenko." China participates only in the hot

research front "Study of galaxy structure, composition and evolution based on the observation results of LAMOST, GCS and SDSS," and ranks 2nd.

In respect to potential leading research fronts, the USA ranks 1st in all 12 research fronts, and the UK has appearances among the top three in nine fronts. Germany, China and France, respectively, have five, four and four potential leading research fronts in which they rank 2nd or 3rd.

Table 69. Performance of six countries in "astronomy and astrophysics"

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	12	1	8	6	7	4	12	11	12	12	12	11
	Rank 1 st	10			1	1		12					
	Rank 2 nd -3 rd	1	1	6	4	3	2		4	9	5	4	

3.9 MATHEMATICS, COMPUTER SCIENCE AND ENGINEERING

There are 10 hot research fronts and three emerging research fronts in this area. China ranks 1st both in terms of leading and potential leading research fronts.

China holds seven first place leading and 12 first place potential leading research fronts.

Table 70. Performance of six countries in “mathematics, computer science and engineering”

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	9	11	5	6	5	1	13	13	13	10	10	11
	Rank 1 st	0	7					0	12				
	Rank 2 nd -3 rd	8	3	2	3	2	1	9	1	3	2		2

3.10 ECONOMICS, PSYCHOLOGY AND OTHER SOCIAL SCIENCES

There are 10 hot research fronts in this area. As for leading research fronts, the USA ranks No.1 in nine. The UK scores second to the USA and ranks 2nd or 3rd in seven leading research fronts. China contributes core papers as reprint authors in only three research fronts, but ranks 1st in the hot research front “Environmental benefits and energy efficiency evaluation of regional

industries”.

In terms of potential leading research fronts, China ranks among the top three in two research fronts, while the UK ranks 2nd or 3rd in six research fronts.

Table 71. Performance of six countries in “economics, psychology and other social sciences”

Number of fronts	Rank	Leading research fronts						Potential leading research fronts					
		USA	China	UK	Germany	France	Japan	USA	China	UK	Germany	France	Japan
10	Contribution	10	3	9	4	1		10	10	10	10	10	9
	Rank 1 st	9	1					9	1				
	Rank 2 nd -3 rd	1		7				1	1	6	1		

The background is a solid blue color. Overlaid on this are several white circles of varying sizes, connected by thin white lines. The circles are arranged in a way that suggests a network or a flow of information. One circle at the top center contains the word 'APPENDIX'. To its left, another circle contains the title 'RESEARCH FRONTS: IN SEARCH OF THE STRUCTURE OF SCIENCE'. Below the title, a smaller circle contains the author's name 'David Pendlebury'. The overall design is clean and modern, with a focus on geometric shapes and connectivity.

APPENDIX

RESEARCH FRONTS:
IN SEARCH OF THE
STRUCTURE OF
SCIENCE

David Pendlebury

When Eugene Garfield introduced the concept of a citation index for the sciences in 1955, he emphasized its several advantages over traditional subject indexing.¹ Since a citation index records the references in each article indexed, a search can proceed from a known work of interest to more recently published items that cited that work. Moreover, a search in a citation index, either forward in time or backward through cited references, is both highly efficient and productive because it relies upon the informed judgments of researchers themselves, reflected in the references appended to their papers, rather than the choices of indexing terms by cataloguers who are less familiar with the content of each publication than are the authors. Garfield called these authors “an army of indexers” and his invention “an association-of-ideas index”. He recognized citations as emblematic of specific topics, concepts, and methods: “the citation is a precise, unambiguous representation of a subject that requires no interpretation and is immune to changes in terminology.”² In addition, a citation index is inherently cross-disciplinary and breaks through limitations imposed by source coverage. The connections represented by citations are not confined to one field or several – they naturally roam throughout the entire landscape of research. That is a particular strength of a citation index for science since interdisciplinary territory is well recognized as fertile ground for discovery. An early supporter of Garfield’s idea, Nobel laureate Joshua Lederberg, saw this specific benefit of a citation index in his own field of genetics, which interacted with biochemistry, statistics, agriculture, and medicine. Although it took many years before the Science Citation Index (now the Web of Science) was fully accepted by librarians and the researcher community, the power of the idea and the utility of its implementation could not be denied. This year marks the 52th anniversary of the Science Citation Index, which first became commercially available in 1964.³

While the intended and primary use of the Science Citation Index was for information retrieval, Garfield knew almost from the start that his data could be exploited for the analysis of scientific research itself. First, he recognized that citation frequency was a method for

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

Garfield was not alone in his vision. During the same era, the physicist and historian of science, Derek J. de Solla Price, was exploring the characteristic features and structures of the scientific research enterprise. The Yale University professor used the measuring tools of science on scientific activity, and he demonstrated in two influential books, of 1961 and 1963, how science had grown exponentially since the late 17th century, both in terms of number of researchers and publications.^{6,7} There was hardly a statistic about the activity of scientific research that his restless mind was not eager to obtain, interrogate, and play with. Price and Garfield became acquainted at this time, and Price, the son of a tailor, was soon receiving data, as he said, “from the cutting-room floor of ISI’s computer room.”⁸ In 1965, Price published “Networks of scientific papers,” which used citation data to describe the nature of what he termed “the scientific research front.”⁹ Previously, he had used the term “research front” in a generic way, meaning the leading edge of research and including the most

knowledgeable scientists working at the coalface. But in this paper, and using the short-lived field of research on N-rays as his example, he described the research front more specifically in terms of its density of publications and time dynamics as revealed by a network of papers arrayed chronologically and their inter-citation patterns. Price observed that a research front builds upon recently published work and that it displays a tight network of relationships.

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

The year is 1972. Enter Henry Small, a young historian of science previously working at the American Institute of Physics in New York City who now joined the Institute for Scientific Information in Philadelphia hoping to make use of the Science Citation Index data and its wealth of title and key words. After his arrival, Small quickly changed allegiance from words to citations for the same reasons that had captivated and motivated Garfield and Price: their power and potential. In 1973, Small published a paper that was as groundbreaking in its own way as Garfield's 1955 paper introducing citation indexing for science. This paper, "Cocitation in the scientific literature: a new measure of relationship between two documents," introduced a new era in describing the specialty structure of science.¹¹ Small measured the similarity of two documents in terms of the number of times they were cited together, in other words their co-citation frequency. He illustrated his method of analysis with an example from recent papers in the literature of particle physics. Having found that such co-citation patterns indicated "the notion of subject similarity" and "the association or co-occurrence of ideas," he suggested that frequently cited papers, reflecting key concepts, methods, or experiments, could be used as a

starting point for a co-citation analysis as an objective way to reveal the social and intellectual, or the socio-cognitive, structure of a specialty area. Like Price's research fronts, consisting of a relatively small group of recent papers tightly knit together, so too Small found co-citation analysis pointed to the specialty as the natural organizational unit of research, rather than traditionally defined and larger fields. Small also saw the potential for co-citation analysis to make, by analogy, movies and not merely snapshots. "The pattern of linkages among key papers establishes a structure or map for the specialty which may then be observed to change through time," he stated. "Through the study of these changing structures, co-citation provides a tool for monitoring the development of scientific fields, and for assessing the degree of interrelationship among specialties."

It should be noted that the Russian information scientist Irena V. Marshakova-Shaikevich also introduced the idea of co-citation analysis in 1973.¹² Since neither Small nor Marshakova-Shaikevich knew of each other's work, this was an instance of simultaneous and independent discovery. The sociologist of science Robert K. Merton designated the phenomenon "multiple discovery" and demonstrated that it is more common in the history of science than most recognize.^{13,14} Both Small and Marshakova-Shaikevich contrasted co-citation with bibliographic coupling, which had been described by Myer Kessler in 1963.¹⁵ Bibliographic coupling measures subject similarity between documents based on the frequency of shared cited references: if two works often cite the same literature, there is a probability they are related in their subject content. Co-citation analysis inverts this idea: instead of the similarity relation being established by what the publications cited, co-citation brings publications together by what cites them. With bibliographic coupling, the similarity relationships are static because their cited references are fixed, whereas similarity between documents determined by co-citation can change as new citing papers are published. Small has noted that he preferred co-citation to bibliographic coupling because he "sought a measure that reflected scientists' active and changing perceptions."¹⁶

The next year, 1974, Small and Berver 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 SCIMAP, 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 living legends of information science.

REFERENCES

- [1] Eugene Garfield. Citation indexes for science: a new dimension in documentation through association of ideas. *Science*, 122 (3159): 108-111, 1955.
- [2] Eugene Garfield. *Citation Indexing: its Theory and Application in Science, Technology, and Humanities*. New York: John Wiley & Sons, 1979, 3.
- [3] *Genetics Citation Index*. Philadelphia: Institute for Scientific Information, 1963.
- [4] Eugene Garfield. Citation indexes in sociological and historical research. *American Documentation*, 14 (4): 289-291, 1963.
- [5] Eugene Garfield, Irving H. Sher, Richard J. Torpie. *The Use of Citation Data in Writing the History of Science*. Philadelphia: Institute For Scientific Information, 1964.
- [6] Derek J. de Solla Price. *Science Since Babylon*. New Haven: Yale University Press, 1961. [See also the enlarged edition of 1975]
- [7] Derek J. de Solla Price. *Little Science, Big Science*. New York: Columbia University Press, 1963. [See also the edition *Little Science, Big Science and Beyond*, 1986, including nine influential papers by Price in addition to the original book]
- [8] Derek J. de Solla Price. Foreword. in Eugene Garfield, *Essays of an Information Scientist, Volume 3, 1977-1978*, Philadelphia: Institute For Scientific Information, 1979, v-ix.
- [9] Derek J. de Solla Price. Networks of scientific papers: the pattern of bibliographic references indicates the nature of the scientific research front. *Science*, 149 (3683): 510-515, 1965.
- [10] *ibid.*
- [11] Henry Small. Co-citation in scientific literature: a new measure of the relationship between two documents. *Journal of the American Society for Information Science*, 24 (4): 265-269, 1973.
- [12] Irena V. Marshakova-Shaikovich. System of document connections based on references. *Nauchno Tekhnicheskaya, Informatsiya Seriya 2, SSR, [Scientific and Technical Information Serial of VINITI]*, 6: 3-8, 1973.
- [13] Robert K. Merton. Singletons and multiples in scientific discovery: a chapter in the sociology of science. *Proceedings of the American Philosophical Society*, 105 (5): 470-486, 1961.
- [14] Robert K. Merton. Resistance to the systematic study of multiple discoveries in science. *Archives Européennes de Sociologie*, 4 (2): 237-282, 1963.
- [15] Myer M. Kessler. Bibliographic coupling between scientific papers. *American Documentation*, 14 (1): 10-25, 1963.
- [16] Henry Small. Cogitations on co-citations. *Current Contents*, 10: 20, march 9, 1992.
- [17] Henry Small, Bavelas H. The structure of scientific literatures I: Identifying and graphing specialties. *Science Studies*, 4 (1): 17-40, 1974.
- [18] Bavelas H, Henry Small, Judith A. Stonehill, Sandra Dey. The structure of scientific literatures II: Toward a macro- and microstructure for science. *Science Studies*, 4 (4): 339-365, 1974.
- [19] *ibid.*
- [20] See note 8 above.
- [21] Eugene Garfield. Introducing the ISI Atlas of Science: Biochemistry and Molecular Biology, 1978/80. *Current Contents*, 42, 5-13,

- October 19, 1981 [reprinted in Eugene Garfield, *Essays of an Information Scientist*, Vol. 5, 1981-1982, Philadelphia: Institute for Scientific Information, 1983, 279-287]
- [22] ISI Atlas of Science: Biochemistry and Molecular Biology, 1978/80, Philadelphia: Institute for Scientific Information, 1981.
- [23] ISI Atlas of Science: Biotechnology and Molecular Genetics, 1981/82, Philadelphia: Institute for Scientific Information, 1984.
- [24] Eugene Garfield. Launching the ISI Atlas of Science: for the new year, a new generation of reviews. *Current Contents*, 1: 3-8, January 5, 1987. [reprinted in Eugene Garfield, *Essays of an Information Scientist*, vol. 10, 1987, Philadelphia: Institute for Scientific Information, 1988, 1-6]
- [25] Henry Small, ED Sweeney. Clustering the Science Citation Index using co-citations. I. A comparison of methods. *Scientometrics*, 7 (3-6): 391-409, 1985.
- [26] Henry Small, ED Sweeney, Edward Greenlee. Clustering the Science Citation Index using co-citations. II. Mapping science. *Scientometrics*, 8 (5-6): 321-340, 1985.
- [27] Henry Small, Eugene Garfield. The geography of science: disciplinary and national mappings. *Journal of Information Science*, 11 (4): 147-159, 1985.
- [28] Eugene Garfield, Alexander I. Pudovkin, Vladimir S. Istomin. Why do we need algorithmic historiography?. *Journal of the American Society for Information Science and Technology*, 54(5): 400-412, 2003.
- [29] Eugene Garfield. Historiographic mapping of knowledge domains literature. *Journal of Information Science*, 30(2):119-145, 2004.
- [30] Henry Small. The synthesis of specialty narratives from co-citation clusters. *Journal of the American Society for Information Science*, 37 (3): 97-110, 1986.
- [31] Henry Small. Macro-level changes in the structure of cocitation clusters: 1983-1989. *Scientometrics*, 26 (1): 5-20, 1993.
- [32] Henry Small. A passage through science: crossing disciplinary boundaries. *Library Trends*, 48 (1): 72-108, 1999.
- [33] Henry Small. Charting pathways through science: exploring Garfield's vision of a unified index to science. In Blaise Cronin and Helen Barsky Atkins, editors, *The Web of Knowledge: A Festschrift in Honor of Eugene Garfield*, Medford, NJ: American Society for Information Science, 2000, 449-473.
- [34] Edward O. Wilson. *Consilience: The Unity of Knowledge*, New York: Alfred A. Knopf, 1998.
- [35] Henry Small. A Sci-MAP case study: building a map of AIDS Research. *Scientometrics*, 30 (1): 229-241, 1994.
- [36] Henry Small. Update on science mapping: creating large document spaces. *Scientometrics*, 38 (2): 275-293, 1997.
- [37] Henry Small. Visualizing science by citation mapping. *Journal of the American Society for Information Science*, 50 (9):799-813, 1999.
- [38] George S. Davidson, Bruce Hendrickson, David K. Johnson, Charles E. Meyers, Brian N. Wylie. Knowledge mining with Vxinsight®: discovery through interaction. *Journal of Intelligent Information Systems*, 11 (3): 259-285, 1998.
- [39] Kevin W. Boyack, Brian N. Wylie, George S. Davidson. Domain visualization using Vxinsight for science and technology Management. *Journal of the American Society for Information Science and Technology*, 53 (9): 764-774, 2002.
- [40] Katy Börner. *Atlas of Science: Visualizing What We Know*, Cambridge, MA: MIT Press, 2010.

STEERING COMMITTEE

Director	Chunli BAI
Associate Director	Jinghai LI
Committee Member	Zhihong XU, Lu YU, Guojie LI, Yongfang LI, Fu GAO, Hongguang JIN, Yunqi LIU, Jinmin LI, Jiaofeng PAN, Xiangyang HUANG, Xiaolin ZHANG, Li GUO, Qing LIU

WORKING COMMITTEE

General Plan Team (methodology, data analysis and drafting)

Clarivate Analytics	David PENDLEBURY, Weiping YUE
Institute of Strategic Information of Institutes of Science and Development, Chinese Academy of Sciences	Fuhai LENG, Qiuju ZHOU

Research Front Interpretation Team (analysis and interpretation of research front and hot research front)

Agriculture, plant and animal sciences	Jianxia YUAN, Ying XING
Ecology and environmental sciences	Qiuju ZHOU, Fan YANG, Haiming WANG, Weiwei FAN
Clinical medicine	Zanmei LI, Junlian LI Xinying AN, Meimei XU
Biological Sciences	Yanping YANG, Yu DONG, Qun ZHOU, Peijuan CHI
Chemistry and materials science	Wenyue BIAN
Physics	Longguang HUANG
Astronomy and astrophysics	Lin HAN, Haiming WANG, Shijie Guo
Mathematics, computer science and engineering	Xiapping LIU (Mathematics), Zexia LI (Computer science), Di ZHANG (Engineering), Haiming WANG (Engineering)
Economics, psychology and other social sciences	Ruimin PEI
National performance	Fuhai LENG, Qiuju ZHOU

Data Support Team

Clarivate Analytics	
Institute of Strategic Information of Institutes of Science and Development, Chinese Academy of Sciences	Xiaomei WANG, Guopeng LI

Interpretation Team

Jianxia YUAN, Xing YING, Qiuju ZHOU, Fan YANG, Haiming WANG, Weiwei FAN, Zanmei LI, Junlian LI, Xinying AN, Meimei XU, Qun ZHOU, Wenyue BIAN, Longguang HUANG, Lin HAN, Ruimin PEI, Yanping YANG, Peijuan CHI, Shijie GUO, Di ZHANG, Wei HE, Lin WANG, Wei WANG, Weiping YUE, Zihui ZHANG, Christopher M. King

About Institutes of Science and Development, Chinese Academy of Sciences

In November 2015, the CAS was identified in the National High-end Think Tanks Building Pilot Program as one of the first 10 high-caliber think-tank organizations directly under the CPC Central Committee, the State Council and the Central Military Commission of the CPC. It clarifies that priority should be given to the establishment of Institutes of Science and Development, Chinese Academy of Sciences (CASISD). CASISD was founded in January 2016. The orientation of CASISD is a research and support organization supporting the Academic Divisions of CAS (CASAD) to play its role as China's highest advisory body in science and technology. It is an important carrier and a comprehensive integration platform for the CAS to build a high-impact national S&T think tank, and an innovation center bringing together elite research forces from both inside and outside the CAS and across the world.

The missions of CASISD are to offer scientific and policy evidence to the government for its macroscopic decision-making through:

- Finding out trends and directions of S&T development in light of scientific rules and conducting research into major issues concerning socioeconomic progress and national security from the point of view of S&T impact by focusing on such areas as S&T development strategy, S&T and innovation policy, ecological civilization and sustainable development strategy, forecasting and foresight analysis, strategic information.
- Capitalizing the CAS advantage in integrating research institutions, academic divisions and universities, pooling together elite research talent both at home and abroad, and building an international strategy and policy research network featuring opening and cooperation.

About The National Science Library, Chinese Academy Of Sciences

The National Science Library, Chinese Academy of Sciences (NSLC) is the largest research library in China. NSLC reserves information resources in natural sciences and high-tech fields for the researchers and students of Chinese Academy of Sciences and researchers around the country. It also provides services in information analysis, research information management, digital library development, scientific publishing (with its 17 academic and professional journals), and promotion of sciences.

NSLC is a member in the International Federation of Library Associations and Institutes (IFLA). It also is a member of Electronic Information for Libraries (EIFL) and Confederation of Open Access Repositories (COAR).

About Clarivate Analytics

Clarivate™ Analytics accelerates the pace of innovation by providing trusted insights and analytics to customers around the world, formerly the Intellectual Property and Science business of Thomson Reuters, enabling them to discover, protect and commercialize new ideas, faster. We've been assisting our customers for over 60 years. Now as an independent company with over 4,000 employees, operating in more than 100 countries around the world, we remain expert, objective and agile. For more information, please visit us at Clarivate.com.

Institutes of Science and Development, Chinese Academy of Sciences

ADD: No.15 ZhongGuanCunBeiYiTiao Alley, Haidian District, Beijing P. R. China
Postal Code: 100190
Website: <http://www.casisd.cn/>

The National Science Library, Chinese Academy of Sciences

ADD: No.33 North Fourth Ring Road, ZhongGuanCun, Beijing P. R. China
Postal Code: 100190
Website: <http://www.las.ac.cn/>

Clarivate Analytics

ADD: Unit 610, North Tower Raycom Info Tech Park Building C, No. 2, Kexueyuan South Road, Haidian Dist., Beijing P. R. China
Postal Code: 100190
Website: <http://ip-science.thomsonreuters.com.cn/>



中国科学院科技战略咨询研究院
Institutes of Science and Development, Chinese Academy of Sciences



**中国科学院
文献情报中心**
NATIONAL SCIENCE LIBRARY
CHINESE ACADEMY OF SCIENCES

**Clarivate
Analytics**

Formerly the IP & Science
business of Thomson Reuters