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1. BACKGROUND

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

To that end, Clarivate 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).
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.

   \[
   \text{CPT} = \frac{C}{P \cdot T} = \frac{C}{P \cdot T}
   \]

   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 papers 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.
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

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

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

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

<table>
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</table>
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>
<thead>
<tr>
<th>Country Ranking</th>
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<th>Institution Ranking</th>
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</table>
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"

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<td></td>
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</table>
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>
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<th>Rank</th>
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<th>Citation</th>
<th>Mean Year of Core Papers</th>
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<td>Ecosystem services</td>
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<td>4639</td>
<td>2012</td>
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<td>4</td>
<td>The ecology and impact of chytridiomycosis: infectious diseases of amphibians</td>
<td>23</td>
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<td>Biodiversity loss and its impact on ecosystem functions and ecosystem services</td>
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<td>Heavy metal contamination of soil and sediment</td>
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Figure 2  Citing papers of the Top 10 research fronts in ecology and environmental sciences

Table 6: 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 problem today.

<table>
<thead>
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<th>Country Ranking</th>
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<th>Proportion</th>
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</table>
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”

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<td>43</td>
<td>5.6%</td>
<td>8</td>
<td>Universidade Federal Rural de Pernambuco</td>
<td>Brazil</td>
<td>15</td>
<td>1.9%</td>
</tr>
<tr>
<td>9</td>
<td>Netherlands</td>
<td>35</td>
<td>4.5%</td>
<td>8</td>
<td>Sea Education Association (SEA)</td>
<td>USA</td>
<td>15</td>
<td>1.9%</td>
</tr>
<tr>
<td>10</td>
<td>Spain</td>
<td>34</td>
<td>4.4%</td>
<td>8</td>
<td>University of Hawaii</td>
<td>USA</td>
<td>15</td>
<td>1.9%</td>
</tr>
<tr>
<td>11</td>
<td>China</td>
<td>32</td>
<td>4.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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”

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

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>USA</td>
<td>531</td>
<td>39.5%</td>
<td>1</td>
<td>University of Minnesota Duluth</td>
<td>USA</td>
<td>67</td>
<td>5.0%</td>
</tr>
<tr>
<td>2</td>
<td>Germany</td>
<td>257</td>
<td>19.1%</td>
<td>2</td>
<td>Chinese Academy of Sciences</td>
<td>China</td>
<td>53</td>
<td>3.9%</td>
</tr>
<tr>
<td>3</td>
<td>UK</td>
<td>240</td>
<td>17.8%</td>
<td>3</td>
<td>Institut National de la Recherche Agronomique (INRA)</td>
<td>France</td>
<td>52</td>
<td>3.9%</td>
</tr>
<tr>
<td>4</td>
<td>Australia</td>
<td>182</td>
<td>13.5%</td>
<td>3</td>
<td>Wageningen University and Research Centre</td>
<td>Netherlands</td>
<td>52</td>
<td>3.9%</td>
</tr>
<tr>
<td>5</td>
<td>France</td>
<td>159</td>
<td>11.8%</td>
<td>5</td>
<td>University of Zurich</td>
<td>Switzerland</td>
<td>44</td>
<td>3.3%</td>
</tr>
<tr>
<td>6</td>
<td>Canada</td>
<td>138</td>
<td>10.3%</td>
<td>6</td>
<td>University of Western Sydney</td>
<td>Australia</td>
<td>43</td>
<td>3.2%</td>
</tr>
<tr>
<td>7</td>
<td>Switzerland</td>
<td>127</td>
<td>9.4%</td>
<td>6</td>
<td>Centre National de la Recherche Scientifique (CNRS)</td>
<td>France</td>
<td>43</td>
<td>3.2%</td>
</tr>
<tr>
<td>8</td>
<td>Spain</td>
<td>123</td>
<td>9.1%</td>
<td>8</td>
<td>University of Gottingen</td>
<td>Germany</td>
<td>42</td>
<td>3.1%</td>
</tr>
<tr>
<td>9</td>
<td>Netherlands</td>
<td>115</td>
<td>8.5%</td>
<td>9</td>
<td>German Centre for Integrative Biodiversity Research (iDiv)</td>
<td>Germany</td>
<td>41</td>
<td>3.0%</td>
</tr>
<tr>
<td>10</td>
<td>China</td>
<td>102</td>
<td>7.6%</td>
<td>9</td>
<td>Helmholtz-Centre for Environmental Research - UFZ</td>
<td>Germany</td>
<td>41</td>
<td>3.0%</td>
</tr>
</tbody>
</table>
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 chaotropicity, kosmotropicity: their uses, abuses and biological implications.”

Table 11: Emerging research fronts in ecology and environmental sciences

<table>
<thead>
<tr>
<th>Rank</th>
<th>Emerging Research Fronts</th>
<th>Core papers</th>
<th>Citation</th>
<th>Mean Year of Core Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Effects of systemic insecticides (neonicotinoids and fipronil) on non-target organisms and environment</td>
<td>7</td>
<td>108</td>
<td>2015</td>
</tr>
<tr>
<td>2</td>
<td>Water structure and chaotropicity, kosmotropicity: their uses, abuses and biological implications</td>
<td>9</td>
<td>124</td>
<td>2014.8</td>
</tr>
</tbody>
</table>

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.
1. HOT RESEARCH FRONT
1.1 TRENDS IN THE TOP 10 RESEARCH FRONTS IN GEO SCIENCES

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

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

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

<table>
<thead>
<tr>
<th>Year</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Links between Arctic amplification and mid-latitude weather</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
<tr>
<td>Soil-carbon cycle response to climate variability</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
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<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
<tr>
<td>Global warming hiatus</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
<tr>
<td>Oxygenation of Earth’s early ocean and the associated biological evolution</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
<tr>
<td>Climate system model</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
<tr>
<td>Glacier mass change in High Asia</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
<tr>
<td>Next Generation Attenuation (NGA) ground motion prediction model</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
<tr>
<td>Coseismic Slip of the 2011 Tohoku Earthquake</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
<tr>
<td>Carbon cycle of inland waters and the ocean</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
<tr>
<td>Climate change during last deglaciation</td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
<td><img src="chart" alt="Citations" /></td>
</tr>
</tbody>
</table>
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”

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

<table>
<thead>
<tr>
<th>Country</th>
<th>Citing Paper</th>
<th>Proportion</th>
<th>Institution</th>
<th>Affiliated Country</th>
<th>Citing Paper</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>1408</td>
<td>52.3%</td>
<td>National Oceanic and Atmospheric Administration (NOAA)</td>
<td>USA</td>
<td>260</td>
<td>9.7%</td>
</tr>
<tr>
<td>UK</td>
<td>521</td>
<td>19.4%</td>
<td>National Aeronautics and Space Administration (NASA)</td>
<td>USA</td>
<td>242</td>
<td>9.0%</td>
</tr>
<tr>
<td>Germany</td>
<td>413</td>
<td>15.3%</td>
<td>National Center for Atmospheric Research (NCAR)</td>
<td>USA</td>
<td>217</td>
<td>8.1%</td>
</tr>
<tr>
<td>France</td>
<td>285</td>
<td>10.6%</td>
<td>University of Colorado Boulder</td>
<td>USA</td>
<td>145</td>
<td>5.4%</td>
</tr>
<tr>
<td>China</td>
<td>280</td>
<td>10.4%</td>
<td>Chinese Academy of Sciences</td>
<td>China</td>
<td>144</td>
<td>5.3%</td>
</tr>
<tr>
<td>Australia</td>
<td>256</td>
<td>9.5%</td>
<td>Met Office</td>
<td>UK</td>
<td>143</td>
<td>5.3%</td>
</tr>
<tr>
<td>Canada</td>
<td>197</td>
<td>7.3%</td>
<td>California Institute of Technology</td>
<td>USA</td>
<td>135</td>
<td>5.0%</td>
</tr>
<tr>
<td>Japan</td>
<td>181</td>
<td>6.7%</td>
<td>University of Reading</td>
<td>UK</td>
<td>111</td>
<td>4.1%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>166</td>
<td>6.2%</td>
<td>Max Planck Society</td>
<td>Germany</td>
<td>105</td>
<td>3.9%</td>
</tr>
<tr>
<td>Spain</td>
<td>133</td>
<td>4.9%</td>
<td>Swiss Federal Institute of Technology in Zurich</td>
<td>Switzerland</td>
<td>104</td>
<td>3.9%</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Country</th>
<th>Core Paper</th>
<th>Proportion</th>
<th>Institution</th>
<th>Affiliated Country</th>
<th>Core Paper</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>11</td>
<td>84.6%</td>
<td>Uppsala University</td>
<td>Sweden</td>
<td>5</td>
<td>38.5%</td>
</tr>
<tr>
<td>Sweden</td>
<td>5</td>
<td>38.5%</td>
<td>Yale University</td>
<td>USA</td>
<td>4</td>
<td>30.8%</td>
</tr>
<tr>
<td>Brazil</td>
<td>5</td>
<td>38.5%</td>
<td>University of Washington Seattle</td>
<td>USA</td>
<td>3</td>
<td>23.1%</td>
</tr>
<tr>
<td>France</td>
<td>4</td>
<td>30.8%</td>
<td>University of Brussels</td>
<td>Belgium</td>
<td>3</td>
<td>23.1%</td>
</tr>
<tr>
<td>Belgium</td>
<td>4</td>
<td>30.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>3</td>
<td>23.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>3</td>
<td>23.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>3</td>
<td>23.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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.
2. EMERGING RESEARCH FRONT

2.1 OVERVIEW OF EMERGING RESEARCH FRONTS IN GEO SCIENCES

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

<table>
<thead>
<tr>
<th>Rank</th>
<th>Emerging Research Fronts</th>
<th>Core papers</th>
<th>Citation</th>
<th>Mean Year of Core Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fault Zone of the 2012 Haida Gwaii earthquake</td>
<td>8</td>
<td>100</td>
<td>2014.8</td>
</tr>
<tr>
<td>2</td>
<td>Elemental composition of the North Atlantic Ocean and Southern Ocean</td>
<td>11</td>
<td>203</td>
<td>2014.5</td>
</tr>
</tbody>
</table>

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.
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.”


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

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

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

<table>
<thead>
<tr>
<th>Country Rank</th>
<th>Country</th>
<th>Core Paper</th>
<th>Proportion</th>
<th>Institution Rank</th>
<th>Institution</th>
<th>Affiliated Country</th>
<th>Core Paper</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>USA</td>
<td>35</td>
<td>92.1%</td>
<td>1</td>
<td>Gilead Sciences</td>
<td>USA</td>
<td>17</td>
<td>44.7%</td>
</tr>
<tr>
<td>2</td>
<td>France</td>
<td>13</td>
<td>34.2%</td>
<td>1</td>
<td>University of Texas Health Science Center San Antonio</td>
<td>USA</td>
<td>17</td>
<td>44.7%</td>
</tr>
<tr>
<td>3</td>
<td>Germany</td>
<td>11</td>
<td>28.9%</td>
<td>3</td>
<td>Cornell University</td>
<td>USA</td>
<td>11</td>
<td>28.9%</td>
</tr>
<tr>
<td>3</td>
<td>Spain</td>
<td>11</td>
<td>28.9%</td>
<td>4</td>
<td>Goethe University Frankfurt</td>
<td>Germany</td>
<td>10</td>
<td>26.3%</td>
</tr>
<tr>
<td>5</td>
<td>Belgium</td>
<td>10</td>
<td>26.3%</td>
<td>4</td>
<td>Virginia Mason Medical Center</td>
<td>USA</td>
<td>10</td>
<td>26.3%</td>
</tr>
<tr>
<td>5</td>
<td>UK</td>
<td>10</td>
<td>26.3%</td>
<td>6</td>
<td>AbbVie Co.</td>
<td>USA</td>
<td>8</td>
<td>21.1%</td>
</tr>
<tr>
<td>7</td>
<td>Canada</td>
<td>9</td>
<td>23.7%</td>
<td>6</td>
<td>Johns Hopkins University</td>
<td>USA</td>
<td>8</td>
<td>21.1%</td>
</tr>
<tr>
<td>7</td>
<td>Italy</td>
<td>9</td>
<td>23.7%</td>
<td>8</td>
<td>University of Florida</td>
<td>USA</td>
<td>7</td>
<td>18.4%</td>
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<tr>
<td>9</td>
<td>Australia</td>
<td>8</td>
<td>21.1%</td>
<td>8</td>
<td>University of Pennsylvania</td>
<td>USA</td>
<td>7</td>
<td>18.4%</td>
</tr>
<tr>
<td>10</td>
<td>New Zealand</td>
<td>6</td>
<td>15.8%</td>
<td>10</td>
<td>University of North Carolina Chapel Hill</td>
<td>USA</td>
<td>6</td>
<td>15.8%</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Country</th>
<th>Citing Paper Proportion</th>
<th>Institution</th>
<th>Affiliated Country</th>
<th>Citing Paper Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 USA</td>
<td>48.4%</td>
<td>Gilead Sciences</td>
<td>USA</td>
<td>4.9%</td>
</tr>
<tr>
<td>2 France</td>
<td>12.4%</td>
<td>Johns Hopkins University</td>
<td>USA</td>
<td>4.1%</td>
</tr>
<tr>
<td>3 Germany</td>
<td>10.2%</td>
<td>Harvard University</td>
<td>USA</td>
<td>3.8%</td>
</tr>
<tr>
<td>4 UK</td>
<td>9.2%</td>
<td>University of Paris Diderot - Paris VII</td>
<td>France</td>
<td>3.4%</td>
</tr>
<tr>
<td>5 Italy</td>
<td>8.6%</td>
<td>University of Texas Health Science Center San Antonio</td>
<td>USA</td>
<td>3.4%</td>
</tr>
<tr>
<td>6 Japan</td>
<td>8.0%</td>
<td>Goethe University Frankfurt Hospital</td>
<td>Germany</td>
<td>3.2%</td>
</tr>
<tr>
<td>7 Canada</td>
<td>6.7%</td>
<td>University of Pennsylvania</td>
<td>USA</td>
<td>3.2%</td>
</tr>
<tr>
<td>8 Spain</td>
<td>6.7%</td>
<td>Hannover Medical School</td>
<td>Germany</td>
<td>2.9%</td>
</tr>
<tr>
<td>9 Australia</td>
<td>4.2%</td>
<td>Cornell University</td>
<td>USA</td>
<td>2.9%</td>
</tr>
<tr>
<td>10 Belgium</td>
<td>3.8%</td>
<td>Institut National de la Sante et de la Recherche Medicale (Inserm)</td>
<td>France</td>
<td>2.6%</td>
</tr>
</tbody>
</table>
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”

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

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

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

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

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

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

- Isolation, characterization and transmission of Middle East Respiratory Syndrome coronavirus
- Biological function of melatonin in humans and plants
- Femtosecond x-ray nanocrystallography of biological macromolecules
- The molecular mechanism for origin, development and differentiation of macrophage
- The association analysis of genes related to Alzheimer’s disease
- RNA secondary structure and N-6-methyladenosine (m(6)A) modification
- Broadly neutralizing antibodies for HIV vaccine design
- The molecular mechanism of mitochondrial autophagy mediated by PINK1/Parkin
- Differentiation, function, and metabolism of T cells
- Frontotemporal dementia and amyotrophic lateral sclerosis caused by C9orf72 hexanucleotide repeat expansion
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 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.

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

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

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

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

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

<table>
<thead>
<tr>
<th>Rank</th>
<th>Emerging Research Fronts</th>
<th>Core papers</th>
<th>Citation</th>
<th>Mean Year of Core Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Genome-wide identification of CRISPR RNA-guided nucleases (RGNs) off-target effects</td>
<td>4</td>
<td>152</td>
<td>2015</td>
</tr>
<tr>
<td>2</td>
<td>Botanical extracts and nanoparticles for mosquito control</td>
<td>12</td>
<td>132</td>
<td>2015</td>
</tr>
<tr>
<td>3</td>
<td>Genome-wide association studies of obesity</td>
<td>3</td>
<td>119</td>
<td>2015</td>
</tr>
<tr>
<td>4</td>
<td>Activation of mechanistic target of rapamycin complex 1 (mTORC1)</td>
<td>3</td>
<td>106</td>
<td>2015</td>
</tr>
<tr>
<td>5</td>
<td>Nanopore sequencing</td>
<td>9</td>
<td>156</td>
<td>2014.8</td>
</tr>
<tr>
<td>6</td>
<td>Dendrimer-based nanovectors for tumor-targeted drug and gene delivery</td>
<td>4</td>
<td>112</td>
<td>2014.8</td>
</tr>
<tr>
<td>7</td>
<td>Prediction for structure and function of proteins using pseudo amino acid composition (PseAAC)</td>
<td>9</td>
<td>236</td>
<td>2014.7</td>
</tr>
<tr>
<td>8</td>
<td>Genetic diagnosis using the human phenotype ontology</td>
<td>6</td>
<td>152</td>
<td>2014.7</td>
</tr>
<tr>
<td>9</td>
<td>Type-2 innate lymphoid cells and regulation of beige fat biogenesis</td>
<td>5</td>
<td>197</td>
<td>2014.6</td>
</tr>
<tr>
<td>10</td>
<td>Nanotechnological carriers for cancer chemotherapy</td>
<td>5</td>
<td>109</td>
<td>2014.6</td>
</tr>
<tr>
<td>11</td>
<td>Genome-scale transcriptional activation by CRISPR-Cas9</td>
<td>2</td>
<td>168</td>
<td>2014.5</td>
</tr>
<tr>
<td>12</td>
<td>The interplay of autophagy and apoptosis</td>
<td>2</td>
<td>154</td>
<td>2014.5</td>
</tr>
<tr>
<td>13</td>
<td>Principles of chromatin looping and evolution of chromosomal domain architecture</td>
<td>2</td>
<td>142</td>
<td>2014.5</td>
</tr>
<tr>
<td>14</td>
<td>Actin assembly and network homeostasis</td>
<td>4</td>
<td>129</td>
<td>2014.5</td>
</tr>
<tr>
<td>15</td>
<td>Fluorogenic probes for live-cell imaging of the cytoskeleton</td>
<td>4</td>
<td>126</td>
<td>2014.5</td>
</tr>
<tr>
<td>16</td>
<td>Characterization of highly pathogenic avian influenza viruses (H5N8 and H5N6)</td>
<td>6</td>
<td>108</td>
<td>2014.5</td>
</tr>
<tr>
<td>17</td>
<td>The impact of genetic structure and diet on the gut microbiota</td>
<td>2</td>
<td>103</td>
<td>2014.5</td>
</tr>
<tr>
<td>18</td>
<td>Regeneration and gene expression of cochlear hair cell</td>
<td>4</td>
<td>102</td>
<td>2014.5</td>
</tr>
</tbody>
</table>
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.

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

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

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-rending 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”

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

<table>
<thead>
<tr>
<th>Country/Region</th>
<th>Citing Paper Proportion</th>
<th>Institution</th>
<th>Affiliated Country/Region</th>
<th>Citing Paper</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country Ranking</td>
<td>Institution Ranking</td>
<td>Institution</td>
<td>Affiliated Country/Region</td>
<td>Citing Paper</td>
<td>Proportion</td>
</tr>
<tr>
<td>1 China</td>
<td>1</td>
<td>Chinese Academy of Sciences</td>
<td>China</td>
<td>366</td>
<td>13.8%</td>
</tr>
<tr>
<td>2 South Korea</td>
<td>2</td>
<td>Pukyong National University</td>
<td>South Korea</td>
<td>134</td>
<td>5.0%</td>
</tr>
<tr>
<td>3 USA</td>
<td>3</td>
<td>China University of Geosciences</td>
<td>China</td>
<td>115</td>
<td>4.3%</td>
</tr>
<tr>
<td>4 Japan</td>
<td>4</td>
<td>Sun Yat-sen University</td>
<td>China</td>
<td>100</td>
<td>3.8%</td>
</tr>
<tr>
<td>5 India</td>
<td>5</td>
<td>Lanzhou University</td>
<td>China</td>
<td>88</td>
<td>3.3%</td>
</tr>
<tr>
<td>6 Taiwan</td>
<td>6</td>
<td>Jilin University</td>
<td>China</td>
<td>56</td>
<td>2.1%</td>
</tr>
<tr>
<td>7 Germany</td>
<td>7</td>
<td>South China University of Technology</td>
<td>China</td>
<td>55</td>
<td>2.1%</td>
</tr>
<tr>
<td>8 Netherlands</td>
<td>7</td>
<td>Suzhou University</td>
<td>China</td>
<td>55</td>
<td>2.1%</td>
</tr>
<tr>
<td>9 Russia</td>
<td>9</td>
<td>National Taiwan University</td>
<td>Taiwan</td>
<td>54</td>
<td>2.0%</td>
</tr>
<tr>
<td>10 France</td>
<td>10</td>
<td>University of Science and Technology Beijing</td>
<td>China</td>
<td>52</td>
<td>2.0%</td>
</tr>
</tbody>
</table>
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”

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>455</td>
<td>41.7%</td>
<td>1</td>
<td>Chinese Academy of Sciences</td>
<td>China</td>
<td>92</td>
<td>8.4%</td>
</tr>
<tr>
<td>2</td>
<td>USA</td>
<td>249</td>
<td>22.8%</td>
<td>2</td>
<td>Kyoto University</td>
<td>Japan</td>
<td>46</td>
<td>4.2%</td>
</tr>
<tr>
<td>3</td>
<td>South Korea</td>
<td>121</td>
<td>11.1%</td>
<td>3</td>
<td>Central South University</td>
<td>China</td>
<td>40</td>
<td>3.7%</td>
</tr>
<tr>
<td>4</td>
<td>Japan</td>
<td>96</td>
<td>8.8%</td>
<td>4</td>
<td>Korea Advanced Institute of Science and Technology (KAIST)</td>
<td>South Korea</td>
<td>39</td>
<td>3.6%</td>
</tr>
<tr>
<td>5</td>
<td>Australia</td>
<td>75</td>
<td>6.9%</td>
<td>5</td>
<td>University of Wollongong</td>
<td>Australia</td>
<td>33</td>
<td>3.0%</td>
</tr>
<tr>
<td>6</td>
<td>Germany</td>
<td>66</td>
<td>6.0%</td>
<td>5</td>
<td>Wuhan University</td>
<td>China</td>
<td>33</td>
<td>3.0%</td>
</tr>
<tr>
<td>7</td>
<td>Spain</td>
<td>57</td>
<td>5.2%</td>
<td>5</td>
<td>University of Texas at Austin</td>
<td>USA</td>
<td>33</td>
<td>3.0%</td>
</tr>
<tr>
<td>8</td>
<td>Singapore</td>
<td>45</td>
<td>4.1%</td>
<td>8</td>
<td>University of Science and Technology of China</td>
<td>China</td>
<td>30</td>
<td>2.7%</td>
</tr>
<tr>
<td>9</td>
<td>France</td>
<td>32</td>
<td>2.9%</td>
<td>9</td>
<td>University of Maryland College Park</td>
<td>USA</td>
<td>27</td>
<td>2.5%</td>
</tr>
<tr>
<td>10</td>
<td>India</td>
<td>28</td>
<td>2.6%</td>
<td>10</td>
<td>Nankai University</td>
<td>China</td>
<td>26</td>
<td>2.4%</td>
</tr>
</tbody>
</table>
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 MnO₂, 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>
<thead>
<tr>
<th>Rank</th>
<th>Emerging Research Fronts</th>
<th>Core papers</th>
<th>Citation</th>
<th>Mean Year of Core Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Organolead trihalide perovskite single crystals with long carrier diffusion lengths</td>
<td>2</td>
<td>225</td>
<td>2015</td>
</tr>
<tr>
<td>2</td>
<td>Methylammonium lead iodide perovskite degradation by water</td>
<td>7</td>
<td>160</td>
<td>2015</td>
</tr>
<tr>
<td>3</td>
<td>Lead halide perovskites luminescent nanomaterials</td>
<td>7</td>
<td>121</td>
<td>2015</td>
</tr>
<tr>
<td>4</td>
<td>Fluorescent carbon quantum dots</td>
<td>3</td>
<td>101</td>
<td>2015</td>
</tr>
<tr>
<td>5</td>
<td>Core-shell composites with electromagnetic absorption performance</td>
<td>12</td>
<td>200</td>
<td>2014.8</td>
</tr>
<tr>
<td>6</td>
<td>Ortho-quinone methides as reactive intermediates in asymmetric catalysis</td>
<td>8</td>
<td>166</td>
<td>2014.8</td>
</tr>
<tr>
<td>7</td>
<td>Organolead trihalide perovskite photodetectors</td>
<td>6</td>
<td>123</td>
<td>2014.8</td>
</tr>
<tr>
<td>8</td>
<td>Nickel-catalyzed activation of aryl ethers via C-O bond cleavage</td>
<td>6</td>
<td>112</td>
<td>2014.8</td>
</tr>
<tr>
<td>9</td>
<td>Asymmetric catalysis activated by visible light</td>
<td>5</td>
<td>111</td>
<td>2014.8</td>
</tr>
<tr>
<td>10</td>
<td>Lanthanide metal-organic frameworks for luminescence thermometry</td>
<td>6</td>
<td>160</td>
<td>2014.7</td>
</tr>
<tr>
<td>11</td>
<td>The mechanism of Li$_2$O$_2$ formation in non-aqueous lithium-oxygen batteries</td>
<td>3</td>
<td>117</td>
<td>2014.7</td>
</tr>
<tr>
<td>12</td>
<td>High efficiency single-junction polymer solar cells</td>
<td>5</td>
<td>662</td>
<td>2014.6</td>
</tr>
<tr>
<td>13</td>
<td>The origin of high-performance in perovskite solar cells</td>
<td>12</td>
<td>641</td>
<td>2014.6</td>
</tr>
<tr>
<td>14</td>
<td>Two-dimensional transition metal dichalcogenide nanomaterials</td>
<td>5</td>
<td>286</td>
<td>2014.6</td>
</tr>
<tr>
<td>15</td>
<td>MnO$_2$-based nanostructures for high-performance supercapacitors</td>
<td>9</td>
<td>131</td>
<td>2014.6</td>
</tr>
<tr>
<td>16</td>
<td>Sodium-ion batteries</td>
<td>2</td>
<td>198</td>
<td>2014.5</td>
</tr>
<tr>
<td>17</td>
<td>Pillararene-based supramolecular polymers</td>
<td>4</td>
<td>135</td>
<td>2014.5</td>
</tr>
<tr>
<td>18</td>
<td>Transition metal-catalyzed direct (hetero) arylation reactions of heteroarenes</td>
<td>2</td>
<td>122</td>
<td>2014.5</td>
</tr>
<tr>
<td>19</td>
<td>Porphyrins for dye-sensitized solar cells</td>
<td>2</td>
<td>112</td>
<td>2014.5</td>
</tr>
<tr>
<td>20</td>
<td>The effects of nanoparticles on cell biology</td>
<td>4</td>
<td>106</td>
<td>2014.5</td>
</tr>
<tr>
<td>21</td>
<td>Rhodium(III)-catalyzed C-H activation of arenes</td>
<td>4</td>
<td>106</td>
<td>2014.5</td>
</tr>
<tr>
<td>22</td>
<td>High-performance lithium-sulfur batteries</td>
<td>4</td>
<td>102</td>
<td>2014.5</td>
</tr>
</tbody>
</table>
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, ABX₃, where A= CH₃NH₃, B=Pb, and X=Cl, Br or I. The most common perovskite is CH₃NH₃PbI₃. The first peer-reviewed journal publication of a perovskite-sensitized solar cell came in 2009, written by Tsutomu Miyasaka from Toin University of Yokohama, where the CH₃NH₃PbI₃ 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 CH₃NH₃PbI₃ quantum dots on nanocrystalline TiO₂ 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 II 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 cm² 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.
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

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

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

- Galactic center gamma-ray excess
- Property and application of monolayer/few-layer black phosphorus
- Property and experimental realization of Weyl semimetal
- Pseudogap state of $\text{YBa}_2\text{Cu}_3\text{O}_{6+\delta}$ superconductors
- Dynamic evolution and gravitational waves detection of binary system
- Study of Standard Model based on Higgs coupling
- Collective motion of self-propelled particles
- Nonlinear massive gravity
- Property of metasurfaces and design of metasurface devices
- Research on neutrino oscillations with recent results of the mixing angle $\theta_{13}$
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”

<table>
<thead>
<tr>
<th>Country</th>
<th>Core Paper</th>
<th>Proportion</th>
<th>Institution</th>
<th>Affiliated Country</th>
<th>Core Paper</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>USA</td>
<td>33</td>
<td>67.3%</td>
<td>Fermi National Accelerator Laboratory (Fermilab)</td>
<td>USA</td>
<td>14</td>
</tr>
<tr>
<td>France</td>
<td>5</td>
<td>10.2%</td>
<td>2</td>
<td>University of Chicago</td>
<td>USA</td>
<td>11</td>
</tr>
<tr>
<td>Netherlands</td>
<td>5</td>
<td>10.2%</td>
<td>3</td>
<td>University of Amsterdm</td>
<td>Netherlands</td>
<td>5</td>
</tr>
<tr>
<td>India</td>
<td>4</td>
<td>8.2%</td>
<td>3</td>
<td>University of California Irvine</td>
<td>USA</td>
<td>5</td>
</tr>
<tr>
<td>China</td>
<td>4</td>
<td>8.2%</td>
<td>5</td>
<td>SLAC National Accelerator Laboratory</td>
<td>USA</td>
<td>4</td>
</tr>
<tr>
<td>Australia</td>
<td>3</td>
<td>6.1%</td>
<td>5</td>
<td>University of California Santa Cruz</td>
<td>USA</td>
<td>4</td>
</tr>
<tr>
<td>Italy</td>
<td>3</td>
<td>6.1%</td>
<td>7</td>
<td>Chinese Academy of Sciences</td>
<td>China</td>
<td>3</td>
</tr>
<tr>
<td>UK</td>
<td>3</td>
<td>6.1%</td>
<td>7</td>
<td>Durham University</td>
<td>UK</td>
<td>3</td>
</tr>
<tr>
<td>Switzerland</td>
<td>2</td>
<td>4.1%</td>
<td>7</td>
<td>Istituto Nazionale di Fisica Nucleare</td>
<td>Italy</td>
<td>3</td>
</tr>
<tr>
<td>New Zealand</td>
<td>2</td>
<td>4.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>2</td>
<td>4.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>2</td>
<td>4.1%</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
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 nanoelectronic 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 37: Top countries and institutions producing citing papers in the research front “Galactic center gamma-ray excess”

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

### 1.3 KEY HOT RESEARCH FRONT – “PROPERTY AND APPLICATION OF MONOLAYER/FEW-LAYER BLACK PHOSPHORUS”
### Table 38: Top countries and institutions producing core papers in the research front “Property and application of monolayer/few-layer black phosphorus”

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

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

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

<table>
<thead>
<tr>
<th>Rank</th>
<th>Emerging Research Fronts</th>
<th>Core papers</th>
<th>Citation</th>
<th>Mean Year of Core Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Advanced LIGO and related tools and simulations</td>
<td>4</td>
<td>129</td>
<td>2015</td>
</tr>
<tr>
<td>2</td>
<td>Torsional Newton-Cartan geometry</td>
<td>10</td>
<td>132</td>
<td>2014.9</td>
</tr>
<tr>
<td>3</td>
<td>Property of periodically driven quantum systems</td>
<td>7</td>
<td>120</td>
<td>2014.9</td>
</tr>
<tr>
<td>4</td>
<td>Valleytronics of MoS$_2$ and WSe$_2$</td>
<td>5</td>
<td>363</td>
<td>2014.6</td>
</tr>
<tr>
<td>5</td>
<td>Integrability of the AdS(5)xS(5) superstring</td>
<td>10</td>
<td>210</td>
<td>2014.6</td>
</tr>
<tr>
<td>6</td>
<td>Study of inflationary models based on the 2013 Planck data</td>
<td>8</td>
<td>178</td>
<td>2014.6</td>
</tr>
<tr>
<td>7</td>
<td>Nematicity of FeSe superconductors</td>
<td>8</td>
<td>171</td>
<td>2014.6</td>
</tr>
<tr>
<td>8</td>
<td>New soft graviton theorem</td>
<td>14</td>
<td>297</td>
<td>2014.5</td>
</tr>
<tr>
<td>9</td>
<td>Experimental realization of fractional Chern insulators</td>
<td>2</td>
<td>202</td>
<td>2014.5</td>
</tr>
<tr>
<td>10</td>
<td>Spin-orbit coupling ultracold atomic systems</td>
<td>2</td>
<td>119</td>
<td>2014.5</td>
</tr>
</tbody>
</table>

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

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

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

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 ($\Lambda$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>
<thead>
<tr>
<th>Country Ranking</th>
<th>Country</th>
<th>Core Paper</th>
<th>Proportion</th>
<th>Institution Ranking</th>
<th>Institution</th>
<th>Affiliated Country</th>
<th>Core Paper</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>USA</td>
<td>40</td>
<td>95.2%</td>
<td>1</td>
<td>University of California Berkeley</td>
<td>USA</td>
<td>38</td>
<td>90.5%</td>
</tr>
<tr>
<td>2</td>
<td>Canada</td>
<td>38</td>
<td>90.5%</td>
<td>2</td>
<td>Max Planck Society</td>
<td>Germany</td>
<td>37</td>
<td>88.1%</td>
</tr>
<tr>
<td>3</td>
<td>Germany</td>
<td>37</td>
<td>88.1%</td>
<td>3</td>
<td>California Institute of Technology</td>
<td>USA</td>
<td>34</td>
<td>81.0%</td>
</tr>
<tr>
<td>4</td>
<td>UK</td>
<td>36</td>
<td>85.7%</td>
<td>3</td>
<td>University of Illinois Urbana-Champaign</td>
<td>USA</td>
<td>34</td>
<td>81.0%</td>
</tr>
<tr>
<td>5</td>
<td>France</td>
<td>32</td>
<td>76.2%</td>
<td>5</td>
<td>McGill University</td>
<td>Canada</td>
<td>33</td>
<td>78.6%</td>
</tr>
<tr>
<td>6</td>
<td>Italy</td>
<td>31</td>
<td>73.8%</td>
<td>5</td>
<td>University of California Davis</td>
<td>USA</td>
<td>33</td>
<td>78.6%</td>
</tr>
<tr>
<td>7</td>
<td>Netherlands</td>
<td>30</td>
<td>71.4%</td>
<td>7</td>
<td>Cardiff University</td>
<td>UK</td>
<td>32</td>
<td>76.2%</td>
</tr>
<tr>
<td>7</td>
<td>South Africa</td>
<td>30</td>
<td>71.4%</td>
<td>7</td>
<td>University of Toronto</td>
<td>Canada</td>
<td>32</td>
<td>76.2%</td>
</tr>
<tr>
<td>9</td>
<td>Spain</td>
<td>29</td>
<td>69.0%</td>
<td>9</td>
<td>Princeton University</td>
<td>USA</td>
<td>31</td>
<td>73.8%</td>
</tr>
<tr>
<td>9</td>
<td>Norway</td>
<td>29</td>
<td>69.0%</td>
<td>9</td>
<td>University of British Columbia</td>
<td>Canada</td>
<td>31</td>
<td>73.8%</td>
</tr>
<tr>
<td>9</td>
<td>Poland</td>
<td>29</td>
<td>69.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Country</th>
<th>Citing Paper</th>
<th>Proportion</th>
<th>Institution</th>
<th>Affiliated Country</th>
<th>Citing Paper</th>
<th>Proportion</th>
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<tr>
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<td>University of Paris Diderot - Paris VII</td>
<td>France</td>
<td>183</td>
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<td>Canada</td>
<td>178</td>
<td>9.3%</td>
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</table>
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>
<thead>
<tr>
<th>Country Ranking</th>
<th>Country</th>
<th>Core Paper</th>
<th>Proportion</th>
<th>Institution Ranking</th>
<th>Institution</th>
<th>Affiliated Country</th>
<th>Core Paper</th>
<th>Proportion</th>
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<td>Australia</td>
<td>4</td>
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<td>2</td>
<td>New York University</td>
<td>USA</td>
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</table>
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”

<table>
<thead>
<tr>
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<td>92</td>
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<tr>
<td>9</td>
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<td>10</td>
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<td>10</td>
<td>University of Tokyo</td>
<td>Japan</td>
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<td>4.8%</td>
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</table>
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

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

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.
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>
<thead>
<tr>
<th>Rank</th>
<th>Hot Research Fronts</th>
<th>Core papers</th>
<th>Citation</th>
<th>Mean Year of Core Papers</th>
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<tr>
<td>1</td>
<td>Hesitant fuzzy sets with their application in decision making</td>
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<td>2020</td>
<td>2013.3</td>
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<tr>
<td>2</td>
<td>Configuration design and heat transfer analysis</td>
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<td>Keller-Segel chemotaxis model</td>
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<td>1046</td>
<td>2013.3</td>
</tr>
<tr>
<td>4</td>
<td>Solving several classes of partial differential equations</td>
<td>24</td>
<td>989</td>
<td>2013.2</td>
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<tr>
<td>5</td>
<td>The internet of things, cloud manufacturing and related information technology services</td>
<td>38</td>
<td>1508</td>
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<tr>
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<td>Multiple-input multiple-output (MIMO) systems</td>
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<td>18</td>
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<td>8</td>
<td>State of charge estimation and aging mechanisms of Li-ion batteries used in electric vehicles</td>
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<td>1927</td>
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<td>9</td>
<td>Nanoscale zero-valent iron (ZVI) for treatment of groundwater and wastewater</td>
<td>19</td>
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<td>Bio-inspired algorithms and its optimization</td>
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<td>1839</td>
<td>2012.5</td>
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Figure 9: Citing papers of the Top 10 research fronts in mathematics, computer science and engineering

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<tr>
<td>Hesitant fuzzy sets with their application in decision making</td>
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<td>Configuration design and heat transfer analysis</td>
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<td>Keller-Segel chemotaxis model</td>
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<td>Solving several classes of partial differential equations</td>
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<tr>
<td>The internet of things, cloud manufacturing and related information technology services</td>
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<tr>
<td>Multiple-input multiple-output (MIMO) systems</td>
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<tr>
<td>Research on measurement-device-independent quantum key distribution</td>
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<tr>
<td>State of charge estimation and aging mechanisms of Li-ion batteries used in electric vehicles</td>
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<td>Nanoscale zero-valent iron (ZVI) for treatment of groundwater and wastewater</td>
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<tr>
<td>Bio-inspired algorithms and its optimization</td>
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<td>•</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Country Ranking</th>
<th>Country</th>
<th>Core Paper</th>
<th>Proportion</th>
<th>Institution Ranking</th>
<th>Institution</th>
<th>Affiliated Country</th>
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</table>
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>
<thead>
<tr>
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<td>Shanghai Jiao Tong University</td>
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<tr>
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</tr>
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<td>Japan</td>
<td>12</td>
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<td>Zhejiang University</td>
<td>China</td>
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</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Country Ranking</th>
<th>Country</th>
<th>Core Paper</th>
<th>Proportion</th>
<th>Institution Ranking</th>
<th>Institution</th>
<th>Affiliated Country</th>
<th>Core Paper</th>
<th>Proportion</th>
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<td>4</td>
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<td>University of York</td>
<td>UK</td>
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<tr>
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<td>Singapore</td>
<td>2</td>
<td>11.1%</td>
<td>8</td>
<td>Max Planck Society</td>
<td>Germany</td>
<td>2</td>
<td>11.1%</td>
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</tbody>
</table>
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 researchers 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"

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<tr>
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<td>Germany</td>
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<td>6</td>
<td>Palacky University Olomouc</td>
<td>Czech Republic</td>
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<td>National University of Singapore</td>
<td>Singapore</td>
<td>32</td>
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<td>30</td>
<td>2.8%</td>
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<td>9</td>
<td>National Institute of Information and Communications Technology (NICT)</td>
<td>Japan</td>
<td>30</td>
<td>2.8%</td>
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</table>
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

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

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

As the energy crisis and environmental pollution become 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

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

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”

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<th>Proportion</th>
<th>Institution Ranking</th>
<th>Institution</th>
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<td>National Bureau of Economic Research</td>
<td>USA</td>
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<td>USA</td>
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<td>Columbia University</td>
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<td>13.0%</td>
<td>4</td>
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</tbody>
</table>
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”

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

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

<table>
<thead>
<tr>
<th>Contribution</th>
<th>First Place</th>
<th>Top three</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Research Fronts Proportion Research Areas</td>
<td>Research Fronts Proportion Research Areas</td>
</tr>
<tr>
<td>USA</td>
<td>152 84.4% 10</td>
<td>106 58.9% 10</td>
</tr>
<tr>
<td>China</td>
<td>68 37.8% 10</td>
<td>30 16.7% 8</td>
</tr>
<tr>
<td>UK</td>
<td>90 50.0% 10</td>
<td>14 7.8% 5</td>
</tr>
<tr>
<td>Germany</td>
<td>66 36.7% 10</td>
<td>11 6.1% 5</td>
</tr>
<tr>
<td>France</td>
<td>57 31.7% 10</td>
<td>8 4.4% 5</td>
</tr>
<tr>
<td>Japan</td>
<td>40 22.2% 10</td>
<td>11 6.1% 6</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Contribution</th>
<th>First Place</th>
<th>Top three</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Research Fronts Proportion Research Areas</td>
<td>Research Fronts Proportion Research Areas</td>
</tr>
<tr>
<td>USA</td>
<td>177 98.3% 10</td>
<td>115 63.9% 10</td>
</tr>
<tr>
<td>China</td>
<td>177 98.3% 10</td>
<td>52 28.9% 9</td>
</tr>
<tr>
<td>UK</td>
<td>171 95.0% 10</td>
<td>2 1.1% 2</td>
</tr>
<tr>
<td>Germany</td>
<td>171 95.0% 10</td>
<td>1 0.6% 1</td>
</tr>
<tr>
<td>France</td>
<td>159 88.3% 10</td>
<td>1 0.6% 1</td>
</tr>
<tr>
<td>Japan</td>
<td>163 90.6% 10</td>
<td>5 2.8% 4</td>
</tr>
</tbody>
</table>
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
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

<table>
<thead>
<tr>
<th>No.</th>
<th>Research Area</th>
<th>Research Fronts</th>
<th>Research Fronts Contributed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>USA</td>
</tr>
<tr>
<td>1</td>
<td>Agriculture, Plant and Animal Sciences</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Ecology and Environmental Sciences</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Geosciences</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Clinical Medicine</td>
<td>31</td>
<td>23</td>
</tr>
<tr>
<td>5</td>
<td>Biological Sciences</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>Chemistry and Material Sciences</td>
<td>32</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>Physics</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>Astronomy and Astrophysics</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>Mathematics, Computer science and Engineering</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>Economics, Psychology and other Social Sciences</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>180</td>
<td>106</td>
</tr>
</tbody>
</table>

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.

In terms of potential leading performance, the USA and 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.

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

<table>
<thead>
<tr>
<th>Number of fronts</th>
<th>Rank</th>
<th>Leading research fronts</th>
<th>Potential leading research fronts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>USA</td>
<td>China</td>
</tr>
<tr>
<td>10</td>
<td>Contribution</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Rank 1st</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Rank 2nd-3rd</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

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”

<table>
<thead>
<tr>
<th>Number of fronts</th>
<th>Rank</th>
<th>Leading research fronts</th>
<th>Potential leading research fronts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>USA</td>
<td>China</td>
</tr>
<tr>
<td>10</td>
<td>Contribution</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Rank 1st</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
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<td>Rank 2nd-3rd</td>
<td>4</td>
<td>1</td>
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</tbody>
</table>
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”

<table>
<thead>
<tr>
<th>Number of fronts</th>
<th>Rank</th>
<th>Leading research fronts</th>
<th>Potential leading research fronts</th>
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<td></td>
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<td>Rank 2nd-3rd</td>
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<td>1</td>
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</table>

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.

In terms of potential leading research fronts, the USA 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.

Table 65. Performance of six countries in “clinical medicine”

<table>
<thead>
<tr>
<th>Number of fronts</th>
<th>Rank</th>
<th>Leading research fronts</th>
<th>Potential leading research fronts</th>
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</tr>
</tbody>
</table>

86 Research Fronts 2016 | National Performance in Research Fronts
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"

<table>
<thead>
<tr>
<th>Number of fronts</th>
<th>Rank</th>
<th>Leading research fronts</th>
<th>Potential leading research fronts</th>
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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.

In respect to leading research fronts, China holds placements among the top three in 21 research fronts compared to the USA’s score of 19. Both China and the USA hold first place in 12 leading 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"

<table>
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<tr>
<th>Number of fronts</th>
<th>Rank</th>
<th>Leading research fronts</th>
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</table>
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”

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<th>Number of fronts</th>
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<th>Leading research fronts</th>
<th>Potential leading research fronts</th>
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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”

<table>
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<th>Number of fronts</th>
<th>Rank</th>
<th>Leading research fronts</th>
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</table>
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”

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<thead>
<tr>
<th>Number of fronts</th>
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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”

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<thead>
<tr>
<th>Number of fronts</th>
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<th>Leading research fronts</th>
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When Eugene Garfield introduced the concept of a citation index for the sciences in 1955, he emphasized its several advantages over traditional subject indexing. 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.” 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 52nd anniversary of the Science Citation Index, which first became commercially available in 1964.

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. 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. 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. 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.” In 1965, Price published “Networks of scientific papers,” which used citation data to describe the nature of what he termed “the scientific research front.” 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.”

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 literature: a new measure of relationship between two documents, or individual papers by the place they occupied within the map, and by their degree of strategic centralness within a given strip.”

It should be noted that the Russian information scientist Irena V. Marshakova-Shaikevich also introduced the idea of co-citation analysis in 1973. 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. Both Small and Marshakova-Shaikevich contrasted co-citation with bibliographic coupling, which had been described by Myer Kessler in 1963. 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.”

The next year, 1974, Small and Belver C. Griffith of Drexel University in Philadelphia published a pair of landmark articles that laid the foundations for defining specialties using co-citation analysis and mapping them according
to their similarity.\textsuperscript{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,\textsuperscript{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.”\textsuperscript{20} Garfield remarked that “the work by Small and Griffith was the last theoretical rivet needed to get our flying machine off the ground.”\textsuperscript{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.\textsuperscript{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—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. 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. 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. 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. 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. 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.

In this, he shared the perspective of E. O. Wilson, expressed in the 1998 book Consilience: The Unity of Knowledge. Early in the 1990s, Small developed SCI-MAP, a PC based system for interactively mapping the literature. 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. 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. 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


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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).

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