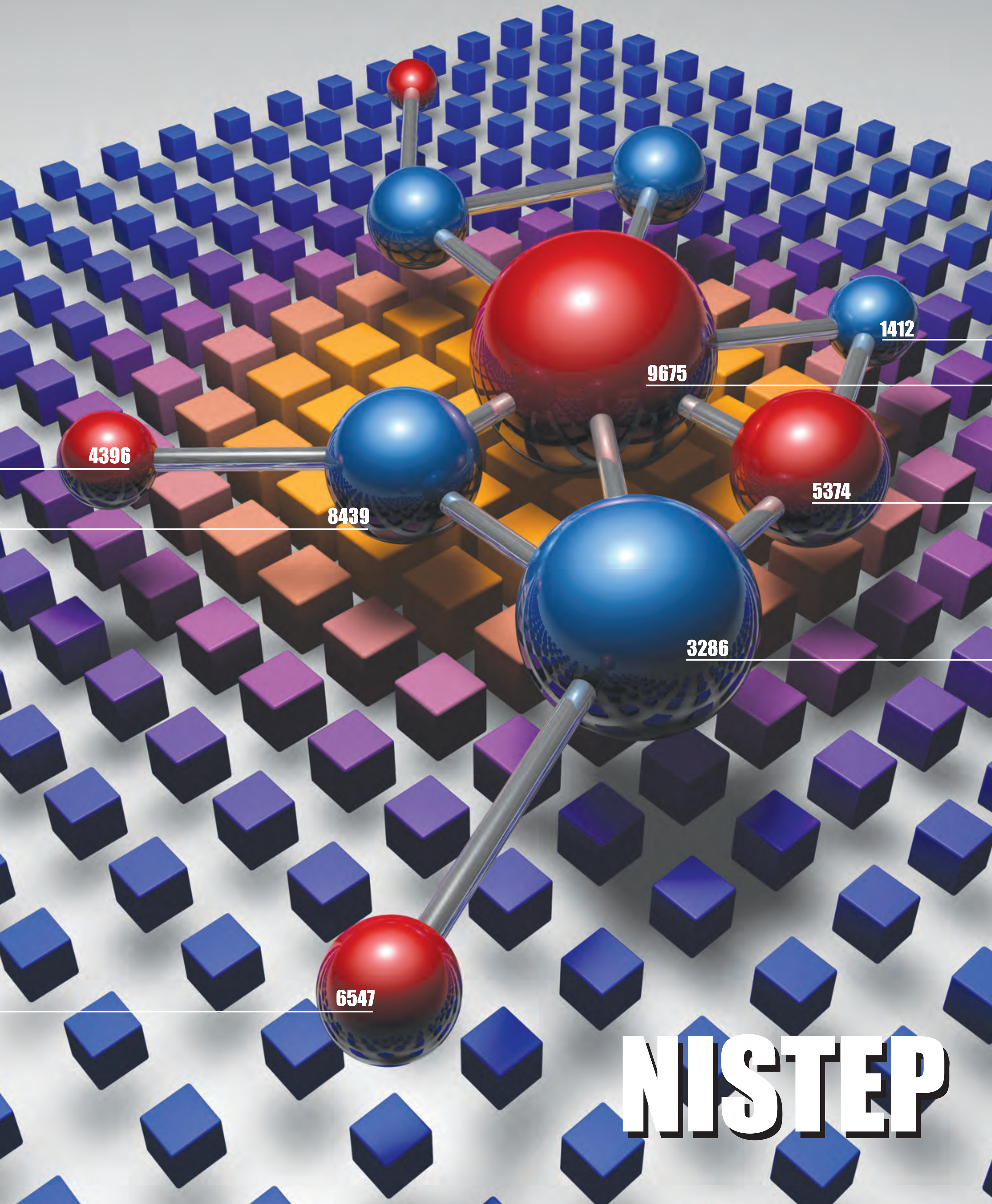
Science Map 2006

Study on Hot Research Areas (2001-2006) by bibliometric method



NISTEP

Science Map 2006

- Study on Hot Research Areas (2001-2006) by bibliometric method -

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Science Map 2006 Highlights

1. What is the Science Map?

There is a long history of attempts to describe the structure and development of science and technology from a bibliometric perspective. The dramatic development of information processing technology and enhancement of databases of scientific papers and patents in recent years have brought innovation to research in this field. The mapping of knowledge is a growing area of research, and a variety of studies are being conducted, mainly in the USA and Europe. The targets of mapping are diverse. They include analysis of relationships between fields of science through examination of journal citations and analysis of co-authorships by country, organization, and researcher.

The National Institute of Science and Technology Policy's Science Map project aims to periodically observe dynamic change in natural science.[1] The unit of the mapping is research areas.

Analysis of scientific research using Science Map is carried out through 1) structuring of research areas through the clustering of research papers, 2) visualization of research areas by mapping, and 3) content analysis of hot research areas.

Science Map 2006 used the top 1 percent highly-cited research papers (approximately 50,000) during each year in each of 22 fields (including Clinical medicine, Plant and Animal Science, Chemistry, Physics, etc.) among research papers published during the six years 2001 through 2006. These highly-cited research papers were clustered in two stages (research papers → research fronts → research areas) by using "co-citation." Six hundred eighty-seven research areas were obtained. Of these, detailed content analysis was performed on 124 hot research areas above a certain size.

These highlights summarize the results of the following analyses using the Science Map.

- The snapshot of the current status of scientific research
- Changes in scientific research, a comparison of Science Map 2004 and Science Map 2006
- Observation of inter-/multi-disciplinary research on the Science Map
- The breadth and intensity of research activities in Japan, the USA, and China

How to read the Science Map

In the main part of this report, three Science Maps (the Individual Research Area Map, the Academic Disciplines Relation Map, and the Research Area Correlation Map) are used to visualize and analyze scientific research. In this summary, only analysis using the Research Area Correlation Map is described, so the Research Area Correlation Map will be referred to as "the Science Map."

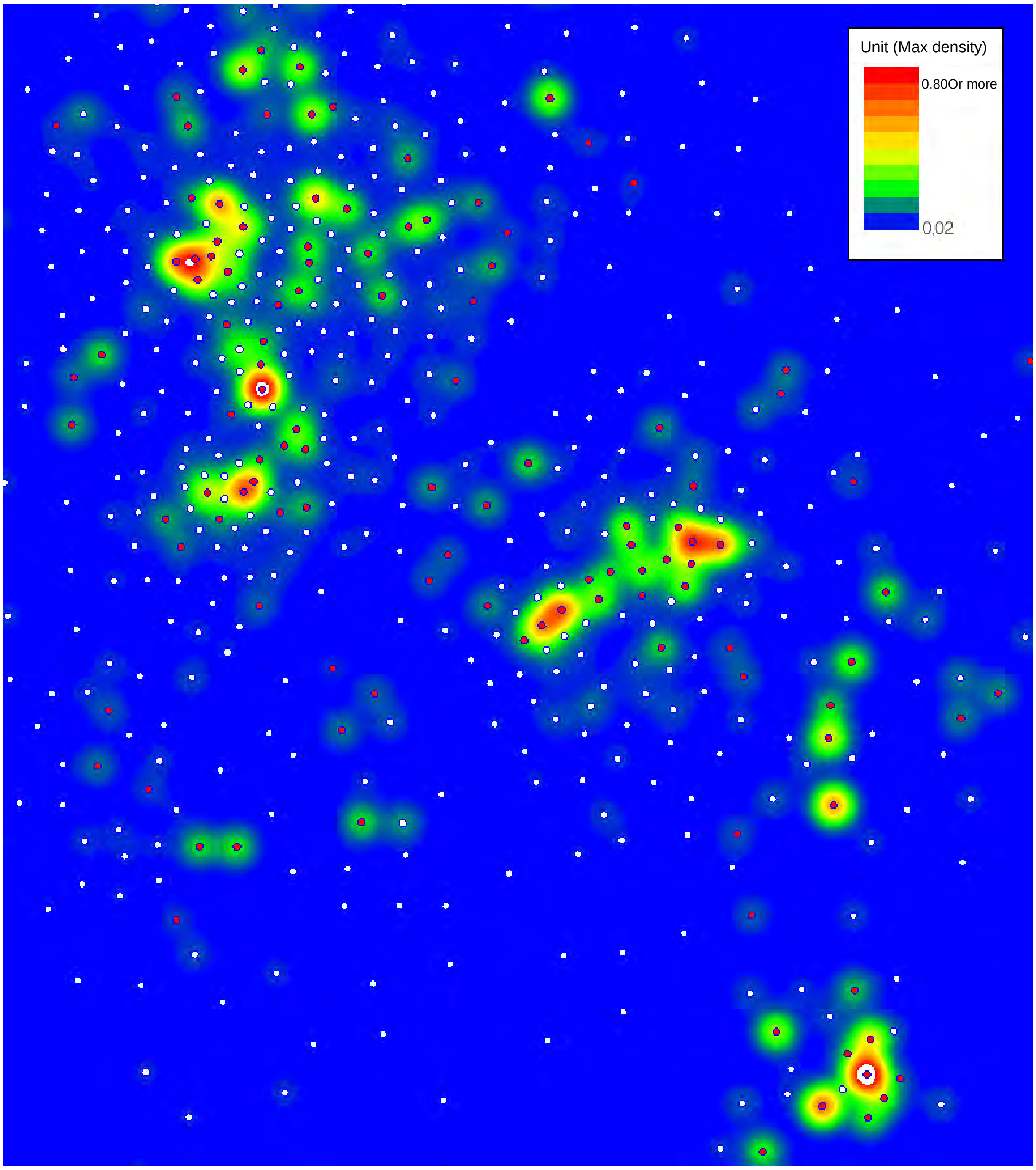
Figure 1 and Figure 2 depict the Science Map. The unit of visualization is research areas. Research areas with a high degree of co-citation are located near one another.

In the Science Map 2006, all 687 research areas obtained by clustering research papers were mapped. By showing the positions of 124 hot research areas for which content analysis was performed, the roles of the hot research areas within scientific research as a whole become evident. In Figure 1, the white dots represent the positions of research areas, and the red dots the positions of hot research areas. The Science Map can be regarded as a two-dimensional aerial map showing the accumulations of core papers and the formation of mountains of science on the land. The hot research areas are mountains that exceed a certain elevation.

Because showing all 687 research areas on the Science Map makes it overly complex, hot research areas alone are shown in these Highlights. (See Figure 2.)

[1] This is the third report. The first report is NISTEP REPORT No. 95, Study on Rapidly-developing Research Area (May 2005); the second report is NISTEP REPORT No. 100, Science Map 2004 (March 2007).

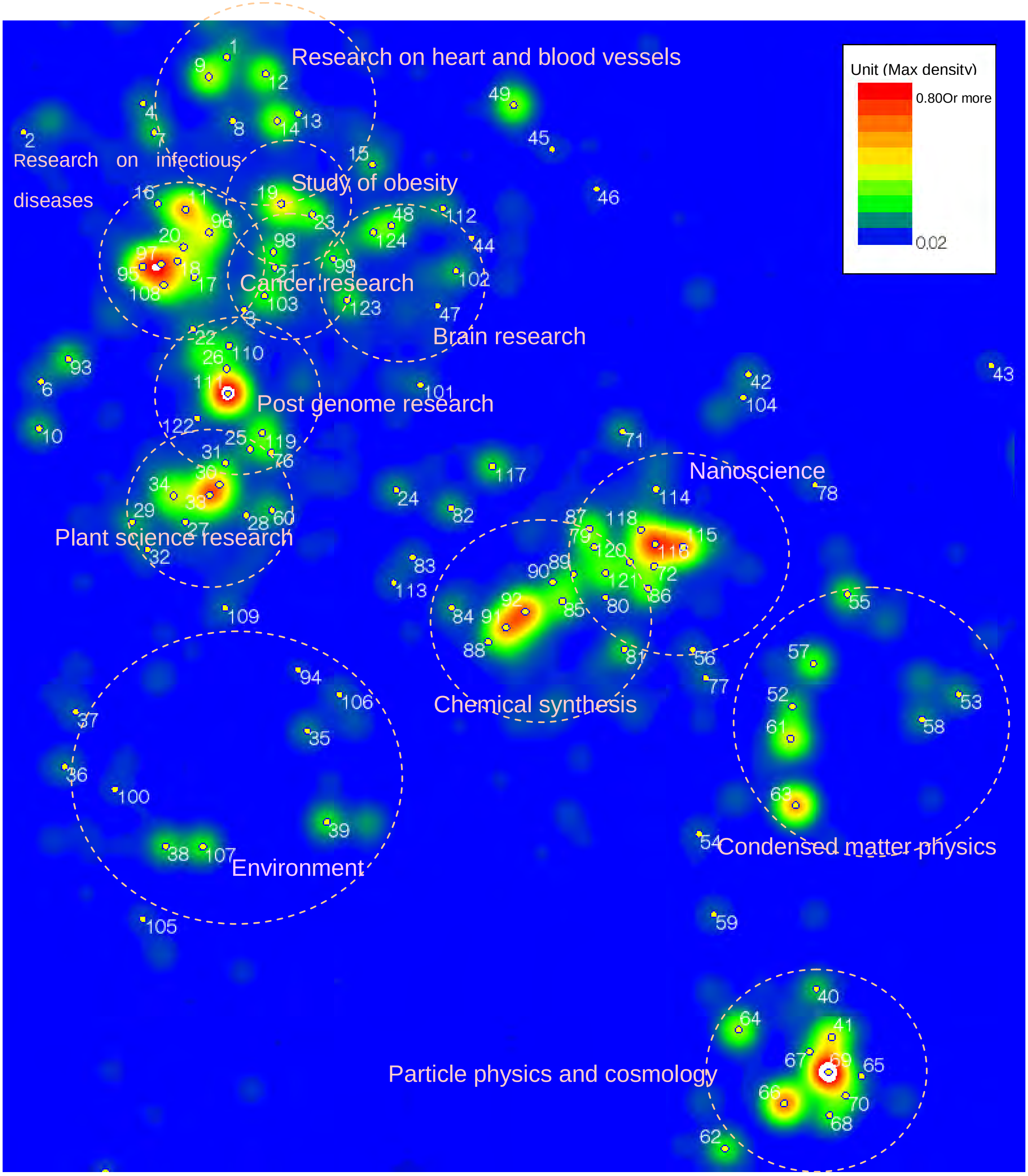
Figure 1: Science Map 2006 (showing the positions of all research areas)



Note 1: Because a gravitational model was used to create this map, up-down and left-right have no meaning; relative position carries meaning. In these Highlights, life science happens to be positioned at the upper left and particle physics/cosmological research at the lower right.
Note 2: White dots indicate the positions of research areas, and red dots the positions of hot research areas. Some research areas with few co-citations with other areas are so far from the center of the map that they are not included above.
Note 3: This map was created through a four-step process. 1) Determine the location of each research area according to the strength of co-citation relationships with the other research areas. 2) Express the position of each research area with a dot, and establish hypothetical spreads for research areas. 3) Divide that map into a grid with squares of a given area, calculating core-paper density (number of core papers divided by mesh area) for each square of the grid. 4) Based on these values, assign colors.

Data: Tabulated from Thomson Reuters' "Essential Science Indicators" by the National Institute of Science and Technology Policy

Figure 2: Science Map 2006 (showing the positions only of hot research areas)



Note 1: The yellow circles indicate the center locations of hot research areas. The numbers next to the yellow circles are the hot research areas' ID numbers. Gradations in the map correspond to the density of core papers. Warm colors represent greater concentrations of core papers, with colors becoming cooler as the density of core papers decreases. The standard for colors in the Science Map is "Observational cosmology and an elementary model for it (ID 69)," which has the highest density of core papers. Places with a maximum density of about 0.8 are red; higher densities are represented as white.
Note 2: Some research areas with few co-citations with other areas are so far from the center of the map that they are not included above.
Data: Tabulated from Thomson Reuters' "Essential Science Indicators" by the National Institute of Science and Technology Policy

2. The snapshot of the current status of scientific research

(1) Relationships among research areas

Scientific research develops through mutual relationships. The Science Map shows that research areas can be divided into several groups, and that these groups of research areas are interrelated.

The research areas at the lower right of the Science Map are related to particle physics/cosmology. The group of research areas related to condensed matter physics spreads out above them. There are two groups of research areas at the center of the Science Map. The group of research areas related to nanoscience is at the center-right, and the group of research areas related to chemical synthesis at the center left. To the left and below chemical synthesis is the group of research areas related to environmental research. Unlike the group of research areas related to chemical synthesis that concentrate close together, this group is spread out on the map.

Groups of research areas related to life science are at the upper left of the Science Map. The lowest of these groups and the closest to the group of chemical synthesis is plant science research. Above it spreads post-genomics, with linkage to research on infectious diseases/immunology, cancer research, study of obesity, and brain research. Above them is the group of research areas related to research on heart and blood vessels.

(2) What does core-paper density indicate?

Looking at the Science Map, both particle physics/cosmology and life science have high core-paper density. The characteristics of each group, however, are different. Particle physics/cosmology has a limited relationship to other groups of research areas, so its position is unlikely to change significantly, and its core papers are likely to remain concentrated. In life science, on the other hand, the evolution of science has brought about links among research areas that developed separately, creating new research areas. This makes it likely that the locations of core papers will shift on the map.

The Science Map shown in Figure 2 can be regarded as depicting a two-dimensional aerial map with accumulations of core papers forming mountains of science on the land. On the Science Map, grids with red gradation are those with high core-paper density. Core-paper density is high in research areas and groups of research areas in which many highly-cited research papers are published and frequently co-cited. This is characteristic of all parts of the map with high densities.

The processes, by which regions with high core-paper density form, however, are not uniform. Figure 3 shows the orthographic projection of the Science Map 2006 on vertical and horizontal axes. Orthographic projection on the vertical axis is the vertical projection, and orthographic projection on the horizontal axis is the horizontal projection.

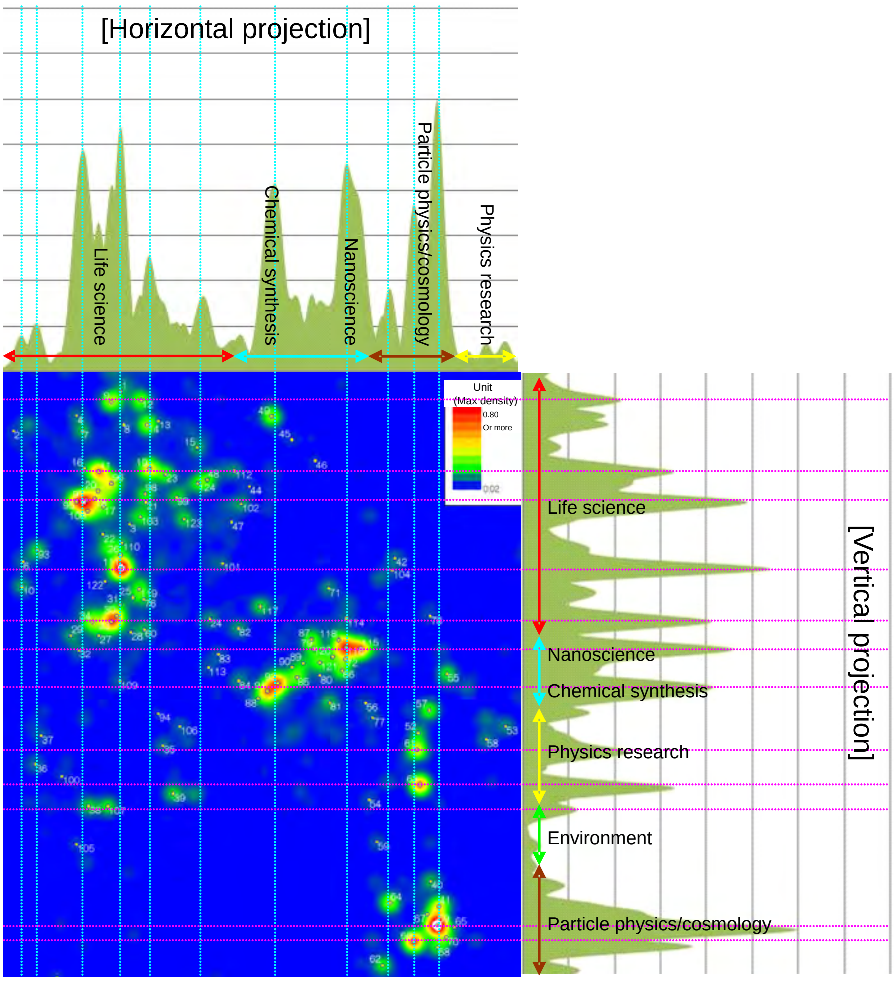
Looking at the breadth of research areas in these vertical and horizontal projections, the group of research areas related to life science has the broadest breadth. The breadths of other groups vary somewhat in their vertical and horizontal projections. The particle physics/cosmology group of research areas is separate from other research areas and has a narrow skirt.

The isolated location of the particle physics/cosmology group on the map is attributable to a limited knowledge transfer between this group and other groups. Particle physics/cosmology has ultimate goals such as the unification of force fields and understanding of the origin of the universe, and experimental and theoretical research are co-evolved over time in deep entanglement. There is thus a tendency towards co-citation among specific research papers and research areas, resulting in a relatively narrow distribution for the group of research areas on the map. Because co-citation with research areas other than particle physics/cosmology is limited, even in time series, the peaks of particle physics/cosmology will probably change little, and core papers will remain concentrated.

The situation is different for the group of research areas related to life science. The subjects of life science research are diverse (plants, animals, fungi, etc.), as are its approaches (i.e., the molecular, cell, organ, and individual level). Thus, widely diverse themes can be set and joined in complex combinations to advance understanding of nature. This makes it possible for research areas fuse, separate, move, nucleate, and disappear on the map. There is therefore no need for the core papers to concentrate in a single region the way those of particle physics/cosmology do.

Furthermore, citation of life science related research papers begins sooner after publication than with other fields. In other words, the process of research area formation is more volatile. A snapshot of a given time such as the Science Map should therefore enable one to view research areas in various phases of development. In fact, on the Science map that plots 687 research areas (Figure 1), the majority of research areas are observed in the life science related region.

Figure 3: Science Map 2006 in horizontal and vertical projection



Note 1: Orthographic projection on the vertical axis is the vertical projection, and orthographic projection on the horizontal axis is the horizontal projection.
Note 2: The height of the mountains indicates core-paper density. The higher the mountain, the greater the concentration of core papers.
Data: Tabulated from Thomson Reuters' "Essential Science Indicators" by the National Institute of Science and Technology Policy

3. Changes in scientific research, a comparison of Science Map 2004 and Science Map 2006

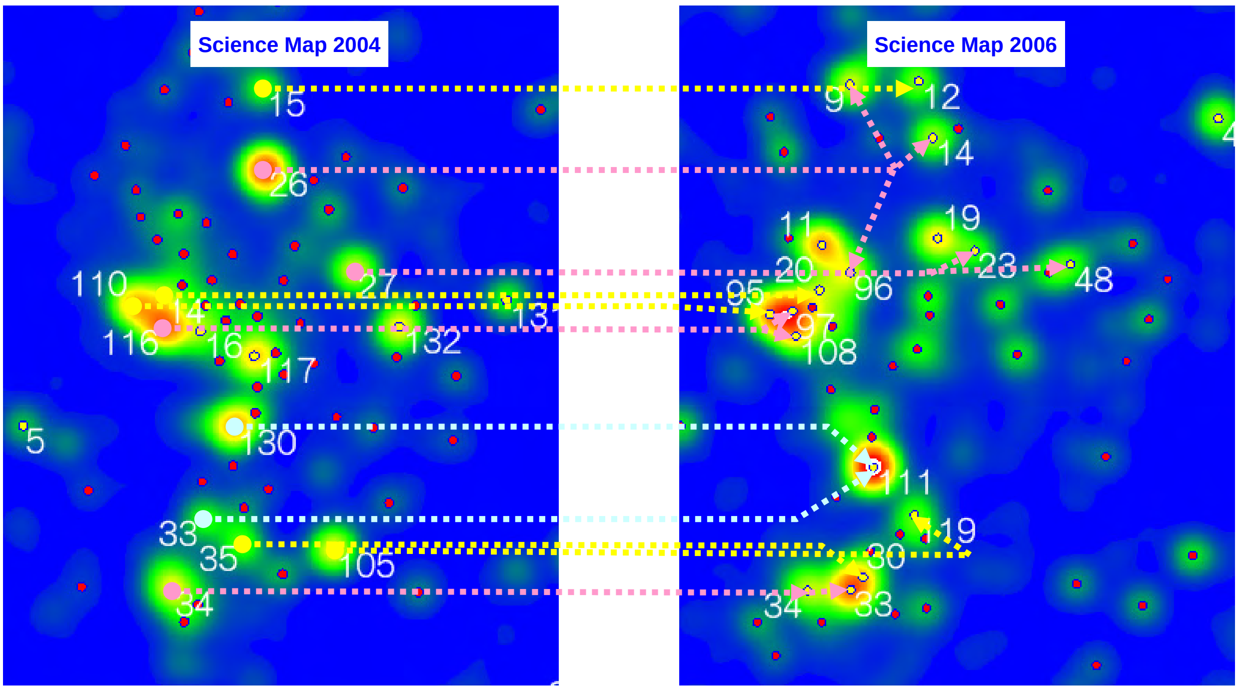
Comparison of Science Map 2004 (covering the years 1999–2004) and Science Map 2006 (2001–2006) and interviews with experts confirmed steady, ongoing change over two years. The important points were as follows.

(1) Life science

In life science related research areas, post-genomics is about to bridge 1) plant science research that focuses mainly on studying plants and fungi and 2) heart and blood vessels research, brain research, study of obesity, cancer research, and research on infectious diseases/immunology that focus mainly on studying animals and fungi.

Two factors contribute to this phenomenon. First, there is the trend in life science research to attempt to understand broader and more complex regulatory mechanisms of life phenomena. Research on life phenomena in animals and plants, long focused on elucidating the regulatory mechanisms for transcription from DNA to RNA. Beginning in 2000, however, much research on RNAi and other regulatory mechanisms at the RNA level, regulatory mechanisms after protein translation, and *in vivo* protein localization regulation has also been published. On the Science Map, this trend can be observed in the fusion of "Research on epigenetic transcriptional regulation (2004, ID 130)" and "Analysis of mechanism of regulation of plant growth (2004, ID 33)" to form "Multi-hierarchical regulatory mechanism of life phenomena (2006, ID 111)" (movement indicated by the blue arrow in Figure 4).

Figure 4: Changes in life science related research



Note: Yellow arrows indicate hot research areas in which concentrations of core papers continued without division. Red arrows indicate hot research areas in which concentrations of core papers divided into multiple groups. Blue arrows indicate hot research areas that fused on the Science Map 2006. This indicates a correspondence relationship in which there were at least 80 core papers, with at least 20 overlapping between different hot research areas. Hot research areas with at least 80 core papers are depicted as yellow dots, while the locations of those with less than 80 core papers are indicated with red dots.
Data: Tabulated from Thomson Reuters' "Essential Science Indicators" by the National Institute of Science and Technology Policy

Second, the position of protein research changed. In the Science Map 2004, "Research on proteome (2004, ID 105)" had a somewhat isolated position between chemical synthesis and life science. In the Science Map 2006, however, its successor research area, "Isotope labeling/quantitative mass spectrometry/protein analysis (2006, ID 119)," moved to the center of the post-genomics group of research areas. This kind of research has a very strong "chemistry" element to it, which can be taken as a scientific trend. In mass spectrographic analysis of proteins, Koichi Tanaka of Shimadzu Corp. developed a "desorption ionization" method for mass spectrographic analysis of macromolecules, which earned him a Nobel Prize in chemistry. As genome sequencing using model organisms advances, comprehensive research on proteins is drawing attention. Mass spectrography is being aggressively incorporated into life science related research and has taken root as a post-genomics method.

<Plant science research>

Links between post-genomics and plant science research have grown stronger, changing the characters of some research areas and dividing others. "Stress response in plants (2004, ID 34)" in the Science Map 2004 divided into "Environmental stress response/metabolic profiling/cellular structure and phospholipid metabolism in plant (2006, ID 33)" and "Plant defense against infection/plant immunity" in the Science Map 2006. In the 2000s, research on gene identification, intergenetic networks, transcriptome analysis, and metabolome in model plants has grown active. More detailed research has progressed, and various research communities have formed. Experts indicated that henceforth the relationship between such research and environmental and food-related issues will likely become important. As in the Science Map 2004, Japan is making a strong effort in plant science. China's presence in the field, however, is growing, so that trend bears watching.

<Clinical medicine>

Clinical medicine is one of the more rapidly changing fields in science. Since the Science Map 2004, research areas directly related to or linked to clinical medicine have continued at a larger size or grown so large that they have split. In the Science Map 2006, it was found that many research areas expected to grow further in the future were scattered around the group of research areas relate to life science. The seeds for the next hot research areas have already been planted.

(2) Chemical synthesis and nanoscience

In life science and nanoscience, as research at the molecular level progresses, the territory of "chemistry" is broadening. Nanoscience is steadily developing. As can be seen in the Science Map, the volume of research linking chemical synthesis and nanoscience is increasing.

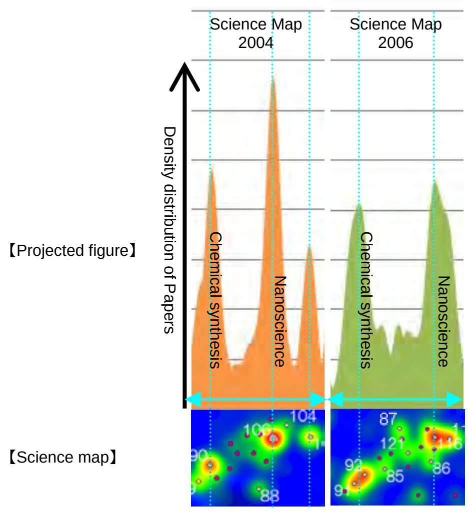
<Chemical synthesis>

Research on asymmetric synthesis using organic catalysts showed a rapid increase. Understanding nature at the level of chemical structural formulas is fundamental to chemistry. With life science and nanoscience research at the molecular level progressing, the territory covered by chemistry is expanding. On the Science Map, chemistry is located between life science and physics, reflecting this situation.

<Nanoscience>

Nanoscience is steadily progressing. In the Science Map 2004, "Development of nanostructure and its application to molecular devices (2004, ID 106)" is observed as a single research area. It has since expanded to three independent research areas, "Study on supramolecular nanodevice by molecular machine and single-molecule conductor (2006, ID 86)," "DNA-nanomaterial and nanodevice (2006, ID 87)," and "Study on synthesis and optical application of metal and metal oxide nanoparticle/nanostructure (2006, ID116)." As can be seen in the Science Map (See Figure 5), the volume of research linking chemical synthesis and nanoscience is increasing.

Figure 5: Increase in research areas between chemical synthesis and nanoscience



Data: Tabulated by the National Institute of Science and Technology Policy based on Thomson Reuters' "Essential Science Indicators"

(3) Condensed matter physics and particle physics/cosmology

In condensed matter physics, quantum computing and superconductivity were extracted as hot research areas. Launch of the European Organization for Nuclear Research's (CERN) Large Hadron Collider (LHC) will be a large step for particle physics/cosmology. Discoveries of new phenomena and verification and testing of theories will take place.

<Condensed matter physics>

Condensed matter physics includes hot research areas related to quantum computing and superconductivity. Comparing the Science Map 2004 with the Science Map 2006, the number of research papers in "Ferromagnetic semiconductor spintronics (2006, ID 55)" and "Electrical control of spin in semiconductors/quantum computer using solid state components (2006, ID 57)" increased. Experts suggested that while the location of condensed matter physics in between chemical synthesis and particle physics/cosmology on the map will probably not change, the hot research areas are likely to change with the times.

<Particle physics/cosmology>

Comparing the Science Map 2004 with the Science Map 2006, the hot research areas from 2004 generally continued, although some merged. This is because particle physics/cosmology has ultimate goals such as the unification of force fields and understanding of the origin of the universe, and research continues to evolve in those directions. Relationships between particle physics/cosmology and other groups of research areas were not expected to change significantly, and indeed observation of changes in the Science Map over time found no change in the group's position on the map, even though research content changed.

Particle physics/cosmology is a field that progresses as experimentation and theory mutually stimulate one another. Theory has led the way, but with the launch of the European Organization for Nuclear Research's (CERN) Large Hadron Collider (LHC), discoveries of new phenomena and verification and testing of theories will take place.

4. Observation of inter-/multi-disciplinary research on the Science Map

It was found that the mapping is helpful to distinguish multidisciplinary research, e.g., environmental research, from interdisciplinary research, e.g., nanoscience.

Figure 6 shows the field distribution of core papers in the Science Map, and plots inter-/multi-disciplinary hot research areas by analysis of field category.

The differences in the distribution of hot research areas in nanoscience and environment were distinctive. In the map, the group of research areas related to nanoscience stakes out a clear domain between chemical synthesis and physics, but the group of research areas related to environment spreads out spatially. This indicates that mapping is helpful to distinguish multidisciplinary research from interdisciplinary research.

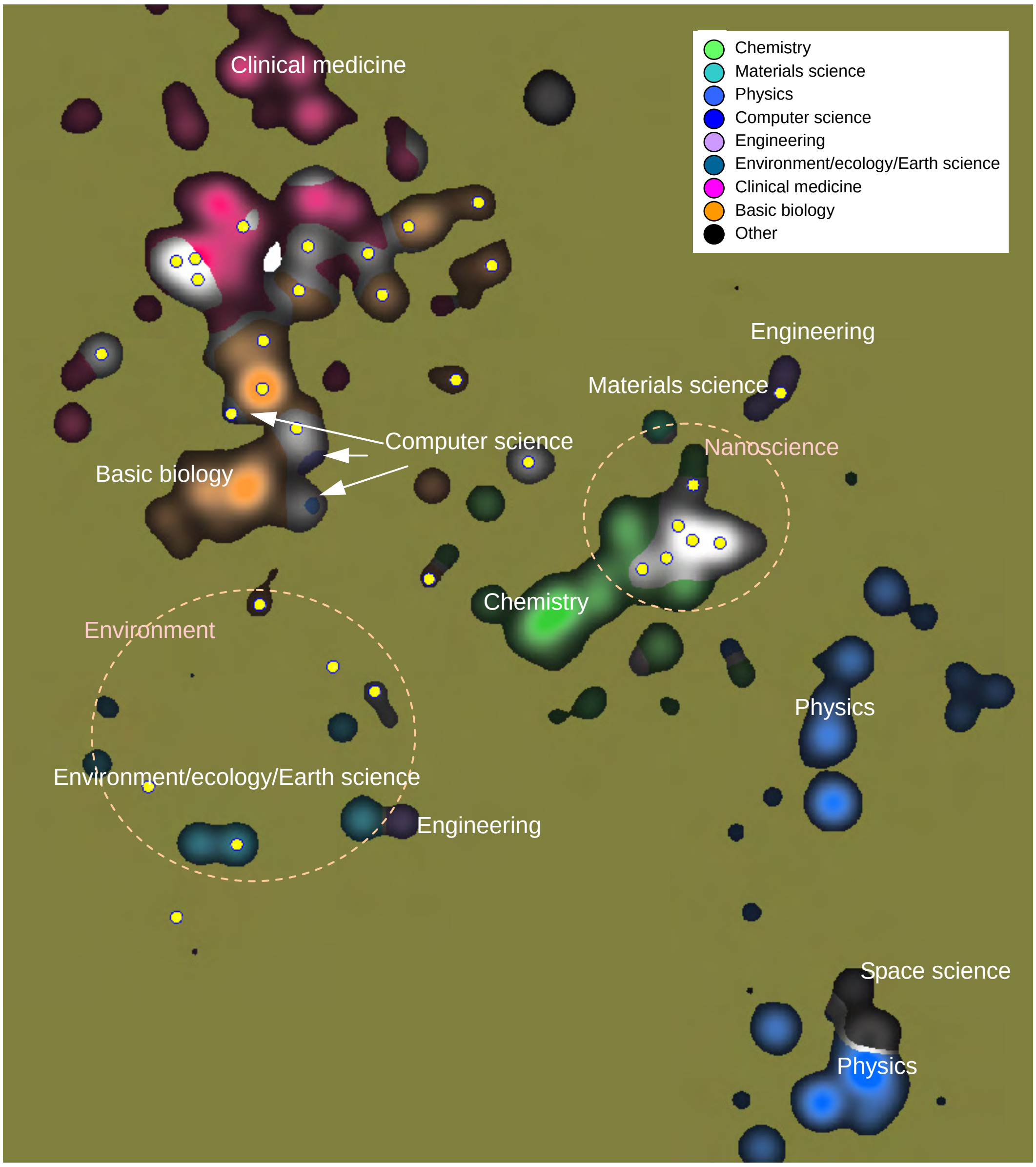
Interdisciplinary research that relies on shared knowledge is generated when separate fields such as physics and chemistry interact. Nanoscience typifies this phenomenon. In interdisciplinary research that relies on shared knowledge, the important thing is that research development stages (research methods and research targets) should be the same in multiple fields. If development stages differ, generation of interdisciplinary research is extremely unlikely. For example, interdisciplinary research in nanoscience was realized during the early 1990s because both chemistry and physics were targeting nanoscale phenomena and matter, the former at the molecular level and the latter at the bulk level. The accumulation of knowledge is a precondition that sets the stage for interdisciplinary research that relies on shared knowledge. Observation of such research can therefore be expected in the Science Map where existing research interacts. In fact, nanoscience appears on the Science Map where differing fields such as physics and chemistry intersect.

In multidisciplinary research, various disciplines address scientific and social challenges independently rather than in collaboration. Thus it shares goals of research. Environmental research typifies this phenomenon. For example, in environmental research, study of biodiversity requires approaches from plant and animal science, while research on the environmental impacts of chemicals requires approaches from chemistry. These research areas stand on the foundation of knowledge in existing fields, and goal-oriented approaches are common. This means that in the Science Map, environmental research is likely to come from the vicinity of existing fields. In fact, the environment group of research areas appears on the Science Map with ongoing links to existing fields, and a broad spread with sometimes weak ties to environmental research.

It thus becomes clear that interdisciplinary research that relies on shared knowledge (nanoscience) and multidisciplinary research that relies on shared goals (environment) are observed in differing forms in the Science Map.

The points to bear in mind differ when promoting interdisciplinary type research or multidisciplinary type research. To promote interdisciplinary research that relies on shared knowledge, an arena for interdisciplinary research must be constructed when the research development stages (research methods and targets) of multiple fields match. On the other hand, to promote multidisciplinary research that relies on shared goals, clear goals must be set, and an arena for researchers who have the knowledge to meet those goals to gather must be constructed.

Figure 6: Locations of inter-/multi-disciplinary research areas in the Science Map



Note: Locations where at least 60 percent of core papers in a given field are distributed have that field's color. Locations where less than 60 percent of a given field's core papers are distributed are considered inter-/multi-disciplinary and not given a field color.
Data: Tabulated from Thomson Reuters' "Essential Science Indicators" by the National Institute of Science and Technology Policy

5. The breadth and intensity of research activities in Japan, the USA, and China

Adding information such as the ratios of each country's research papers to the Science Map enables visualization of activity in the countries. In the Science Map 2006, it became clear that the breadth and intensity of China's scientific research are expanding.

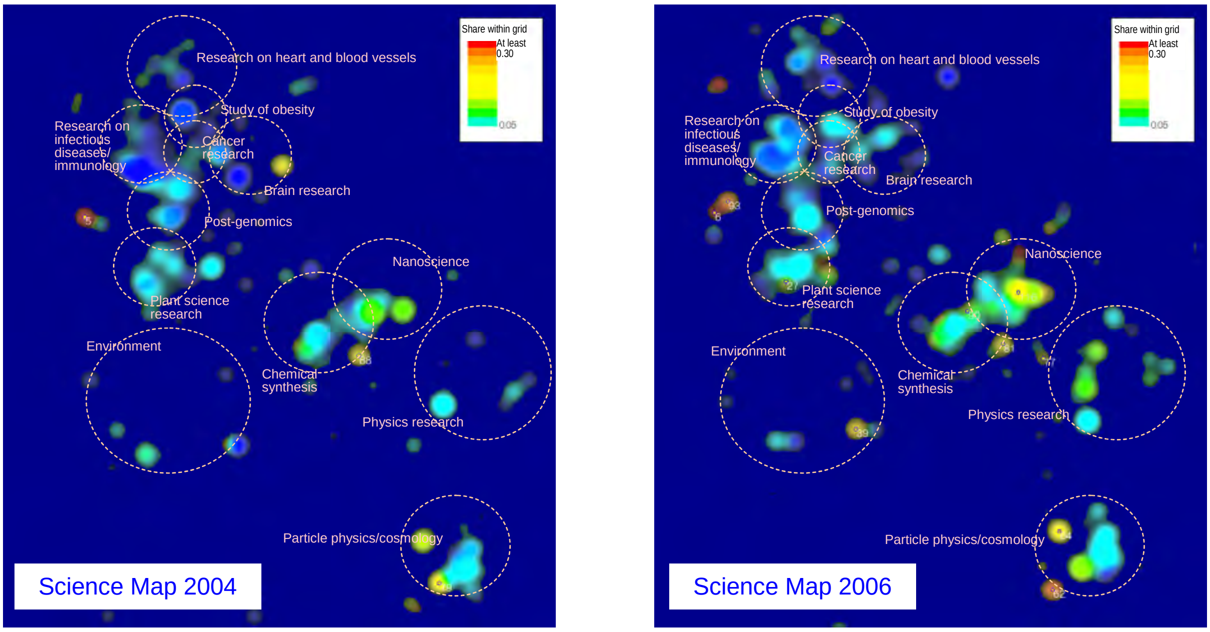
Japan's average share of research papers in the 124 hot research areas derived for the Science Map 2006 is 9.6%, an increase from the Science Map 2004 (9.1%). Furthermore, the percentage of the 124 hot research areas for which Japan has a 0-percent share decreased. Within the 124 hot research areas, Japan's presence is relatively large in hot research areas in physics, chemistry, and plant and animal science.

The hot research area where Japan's share of core papers is highest is "Construction of artificial photosynthesis model mimicking antenna system and charge separation system (ID 80)," with an 80-percent share. Japan's next highest shares are in "High-temperature superconductivity spectroscopy/new electron phase (ID 58)," "Innate immunity (ID 108)," "Brane cosmology from the perspective of duality of anti de sitter space and conformal field theory (ID 65)," and "Ghrelin/function and pathophysiological significance (ID 15)."

Looking at other countries, even though many nations around the world are increasing their production of research papers, the USA remains an important source of knowledge for science as a whole. The USA's activities as illustrated in the Science Map show lower shares of research papers in the chemical synthesis and nanoscience groups of research areas than in life science.

In the Science Map 2004, China's scientific research was limited to nanoscience. Over the following two years, China increased both the breadth and intensity of its activities. (See Figure 7.) China increased its share of research papers in nanoscience, with an increase in the neighboring area of physics as well. Furthermore, in the Science Map 2006, China's share of research papers in plant science research also increased. The breadth of scientific research in China has thus extended to life science.

Figure 7: China's share of research papers as shown in Science Map 2004 and Science Map 2006



Note: Research paper shares of at least 5 percent are shown in light blue, and shares of at least 30 percent in red. Research paper shares were calculated by whole number count.
Data: Tabulated from Thomson Reuters' "Essential Science Indicators" by the National Institute of Science and Technology Policy

6. Future developments

Use of the Science Map has established methodology for observation of dynamic change in natural science, analysis of the forms of inter-/multi-disciplinary research areas, and analysis of the status of scientific activity in various countries. The following are four possible developments for the future developments.

<Periodic observation of science>

Comparison of the Science Map 2004 and the Science Map 2006 and interviews with experts confirmed that scientific research gradually changes over a two-year period. Even as the Science Map 2006 was being created, science continued its development with accomplishments such as the production of iPS cells. By carrying out periodic observation of science and taking panoramic snapshots of science over time with the Science Map, we can describe dynamic change in natural science, such as the way one scientific innovation influences other research areas.

Furthermore, considering the application of the Science Map to science and technology policy, finding emerging research areas that will develop in the future is an important theme. This research experimented with attempting to find research areas likely to develop in the future. Beginning with the next Science Map, trends in these research areas will be tracked. This should deepen knowledge of methods for using science mapping to find emerging research areas.

<Linkage of the Science Map with other data>

Adding statistical data to the Science Map, such as the ratios of research papers from various countries, is effective. The Science Map 2006 clearly showed that China is expanding the breadth and intensity of its scientific research activity. In addition to the ratios of research papers for various countries, linkage to the distribution of research funding or the distribution of universities and government research institutions, for example, is possible. Analysis of the relationship between the development of scientific research and such information over time could obtain data on the influence of research funding on the development of scientific research or the role of universities and government research institutions in the generation of knowledge. Moreover, detailed investigation of co-authorship within research areas could clarify dependence on interaction among researchers and organizations in the process of forming scientific knowledge.

<Linkage of science and technology>

Considered from the perspective of science and technology, the breadth of observation using the Science Map is limited to science, in terms of results published in research papers. In order to take a broader view of science and technology, it is necessary to create technology maps as well, using data such as patents. Using the research papers cited in patent documents, Science Maps and technology maps could be linked. The knowledge transfer from science to technology and from technology to science and field dependence could be observed.

<The Science Map as an arena for discussion>

During interviews, we were struck by the usefulness of the Science map as a basis for discussion. In most interviews with experts, they express their opinions based on their own backgrounds. With shared data such as the Science Map, researchers from different fields can engage in more meaningful discussion of the development of scientific research. By sharing the same "arena," researchers can mutually adjust their sense of distance, facilitating discussion among researchers or among researchers and policy makers. In the future, we will incorporate this idea of the Science Map as an arena for discussion.

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