Empirical Research on International S&T Cooperation Promoting the Progress of Academic Frontiers from the View of Case Analysis

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Abstract--**Disciplines that best reflects the current academic trends, best represents the latest research progress, and can solve the most critical scientific issues and challenges in the S&T development is academic frontiers. So, whether does international S&T cooperation promote the development of Chinese academic frontiers? Or what effects does international S&T cooperation have on Chinese basic research fields? The present paper analyzes the degree and mode of international S&T cooperation employing the emphasis papers belongs to "Top 10 News of Basic Research of China" (later renamed "Top 10 Science Advances of China") from the perspective of disciplines from 2005 to 2014. The major findings of this study confirm that the synergistic effects of international S&T cooperation are conducive to enhance the forefront of research questions, broaden the research ideas and improve the research capacity of researchers. In addition, there are obvious positive role in promoting the development of Chinese vulnerable discipline and traditional preponderant discipline.**

I. INTRODUCTION

Disciplines that best reflects the current academic trends and represents the latest research progress as well as can solve the most critical scientific issues and challenges in the S&T development is academic frontiers. The standard of research in academic frontiers reflects the country's competitive ability of discipline and S&T innovation capacity to a large extent. It is stressed in the "National Program for Medium- to Long-term Scientific and Technological Development (2006-2020) "that the competition of comprehensive national power has been moved to basic research. As a fast developing country, China should be more emphasized on the importance of basic research which serves national goals and how to solve critical problems and bottlenecks through basic research in the future. In recent years, it makes a significant progress in basic research areas along with the combination of national strategic goal and encouragement of free exploring. And the standard of some disciplines has caught up with and surpassed the world's advanced level. For example, we made a groundbreaking scientific achievements in space physics areas by coordinating "The Earth Double Star" implemented by China with " Cluster" implemented by the European Space Agency (ESA) and establishing the "six-point detection " to universe. Also we obtained scientific data which supports not only multi-level space but also multiple spatial and temporal scales [1].

The globalism and complexity of modern science raised inevitable requirement of international cooperation to develop scientific research and engineering. It is a popular topic that Chinese scientific researchers cooperate with those in other countries [2-4]. For instance, Chinese scholars, Zheng et al. [5] examined the international scientific and technological collaboration development of China from the perspective of paper and patent analysis. Wang et al. [6] investigated China's international scientific collaboration from three levels of collaborating countries, institutions and individuals. There also have many researches that compared China with Japan [7] or India [8-9] on international collaboration performance. What's more, China's collaboration with the US [10-11], Europe [12] and Canada [13] has been elaborated. The year before last, a study of international scientific collaboration between Australia and China based on a combination of bibliometric analysis and interviews lead Niu [14] to conclude that augmenting the information base with qualitative data helps toward a more comprehensive understanding of science, technology and innovation collaboration. Even so, studies examining the international collaboration with the methods of qualitative analysis and quantitative analysis are not yet fully developed.

Thus, whether international S&T cooperation promote the development of Chinese academic frontiers especially the basic research fields? Or what effects does international S&T cooperation have on Chinese basic research fields specifically? We solved the above questions by empirical analysis and answered them both in qualitative way and the quantitative one.

II. DATA AND METHOD

To attract a lot of publicity for the progress of key basic research [15], the selecting activity of "10 News of Basic Research of China" was official started in 2005. And in 2010 it was renamed "Top 10 Science Advances of China" which is hereinafter referred to as "Top 10 Science Advances". The selecting activity of "Top 10 Science Advances" emphasizes the journalism, originality and social influence of basic research [16]. As the basic research in "Top 10 Science Advances" selected over the years has strong timeliness and originality in the frontier of all kinds of disciplines. It can be taken as canonical case to analyze the progress of academic frontiers very well.

Academic papers are the main form of basic research work. "Top 10 Science Advances" as the significant progress of academic frontiers in China emerges a number of original research results of which many major findings are published in Science and Nature two top journals in the world. And it proves the quality and value of the research production. By

analyze the authors of these articles we can get the degree of corporation as all the scientists deeply involved in research work are onymous. National information of the authors can be analyzed for international cooperation of papers as well as reveal the existence of international cooperation in the research process. This kind of cooperation is different from both generic international exchange activities such as exchange of visitors, exchange of lectures, convening or participating in international conference, going abroad to study and training etc. and simple importing technology and equipment. It carries out cooperative research substantially, achieves significant results and publishes high-level academic papers at last under the joint signature of all authors' names who are from different countries. So the international cooperation relations found in "Top 10 Science Advances" is most substantial and important. Based on the major academic papers in "Top 10 Science Advances" the present paper reveals the mode and effect of international cooperation using bibliometric analysis which is more objective than other methods like questionnaire survey and field survey. It can identify substantive international cooperation relations and has high feasibility and operability.

According to the introduction of "Top 10 Science Advances" from 2005 to 2014, we firstly identify all the academic papers containing remarkable research results in "Top 10 Science Advances" one by one. Then we analyze the international cooperation, co-authors, collaborative nations and collaborative scale by downloading these papers from WOS and importing them to VP. During this process, both bibliometric analysis and social network analysis methods are used. At last the present paper makes analysis and summary comprehensively combined with "Top 10 Science Advances".

III. RESULTS AND DISCUSSION

A. Overall trend

There has been selected 102 items altogether in "Top 10 Science Advances" from 2005 to 2014 of which there are 11 items each in 2005 and 2007 as the last two items are the same rank (see Table 1). According to the introduction of "Top 10 Science Advances" from 2005 to 2014, we totally identify 125 academic papers containing remarkable research results. Some research progresses such as aerospace science and technology, earth science and big science engineering have no academic papers. For example, "the success of Shenzhou VI manned spaceflight", "the forth scientific investigation of Mount Qomolangma has acquired a great achievement" and "the first THz radiation based on free electron laser emits". All the major academic papers are classified into two categories the nationality of the co-authors, one is international cooperation and the other is non-international cooperation. We conclude the international cooperation of "Top 10 Science Advances" by the international cooperation of major papers. And if the scientific progress has no paper, we identify it with artificial estimate.

Of all the progresses of "Top 10 Science Advances" from 2005 to 2014, there are a certain proportion of major progresses accomplished by international cooperation each year. There are 5 items by international cooperation in six consecutive years from 2005 to 2010, especially in 2013, China has 8 major breakthrough achieved through international cooperation. Results show that China's international S&T cooperation in basic research are developing deeper and further.

During last 10 years from 2005 to 2014, China has received significant achievement in international cooperation of basic research. Of all the 125 papers, there are 72 papers accomplished by international cooperation, most of which are distributed in frontier areas such as Life Science and Earth Science. Furthermore, the first authors of all 66 papers are Chinese. In 2010, the number of major academic papers published reaches a maximum 21. Considering the proportion of cooperative papers in "Top 10 Science Advances", we can draw the conclusion that the percent in each year fluctuates around 60% and it is higher than 70% in year 2005, 2006 and 2010.

TAB 1 OVERVIEW OF INTERNATIONAL S&T COOPERATION OF TOP 10 SCIENCE ADVANCES (2005-2014)

Year	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*
Total Items	11	10	11	10	10	10	10	10	10	10
International Cooperation Items	6	7	6	5	5	7	3	4	8	6
Share (%)	54.6	70.0	54.6	50.0	50.0	70.0	30.0	40.0	80.0	60.0
Number of Papers	9	9	11	12	12	21	10	15	15	11
Number of Cooperative Papers	7	7	7	5	5	15	4	5	10	7
Share (%)	77.8	77.8	63.6	41.7	41.7	71.4	40.0	33.3	66.7	63.6

B. Key partners

27 countries have taken part in the Chinese basic research from 2005 to 2014. The frequency of collaboration is 121 which are calculated by integer value. That is we calculate the frequency of associated nations separately if there are several nations in one cooperative paper [17]. UNDP which is short of the United Nations Development Programs use Human Development Index (HDI [18]) to evaluate the level of social and economic development of each collaborative country in "Human Development Report 1990". According to the "Human Development Report 2013", China belongs to high human development countries. The important Cooperating Countries of "Top 10 Science Advances" from 2005 to 2014 are classified to three types: very high human development countries, high human development countries and medium human development countries. Among them, there are 19 very high human development countries whose frequency of collaboration is 108, sharing 89.26%, 5 high human development countries whose frequency of collaboration is 11, sharing 9.09% and only 2 medium human development countries (India & Pakistan) whose frequency of collaboration is 2, sharing 1.65%. The results show that the cooperation between China and very human development countries are most frequently.

TAB 2 OVERVIEW OF COOPERATIVE COUNTRIES OF TOP 10 SCIENCE ADVANCES (2005-2014)

Year	*Number of Cooperating Countries*	*Cooperating Countries*
2005	4	USA、Germany、UK、Brazil
2006	5	USA、Germany、Canada、France、Japan
2007	4	USA、Germany、UK、Austria
2008	6	USA、Germany、Canada、Japan、Russia、Singapore
2009	9	USA、Germany、UK、Canada、France、Russia、Switzerland、Denmark、Mexico
2010	14	USA、Germany、UK、Canada、France、Russia、Singapore、Republic of Korea、Brazil、Netherlands、Poland、India、Czech Republic、Croatia
2011	2	USA、Japan
2012	8	USA、Germany、UK、Canada、France、Australia、Austria、Kingdom of Saudi Arabia
2013	18	USA、Germany、UK、Canada、Japan、Russia、Switzerland、Denmark、Netherlands、Australia、Republic of Korea、Mexico、Kingdom of Saudi Arabia、Italy、Spain、Sweden、Turkey、Pakistan
2014	2	USA、Japan

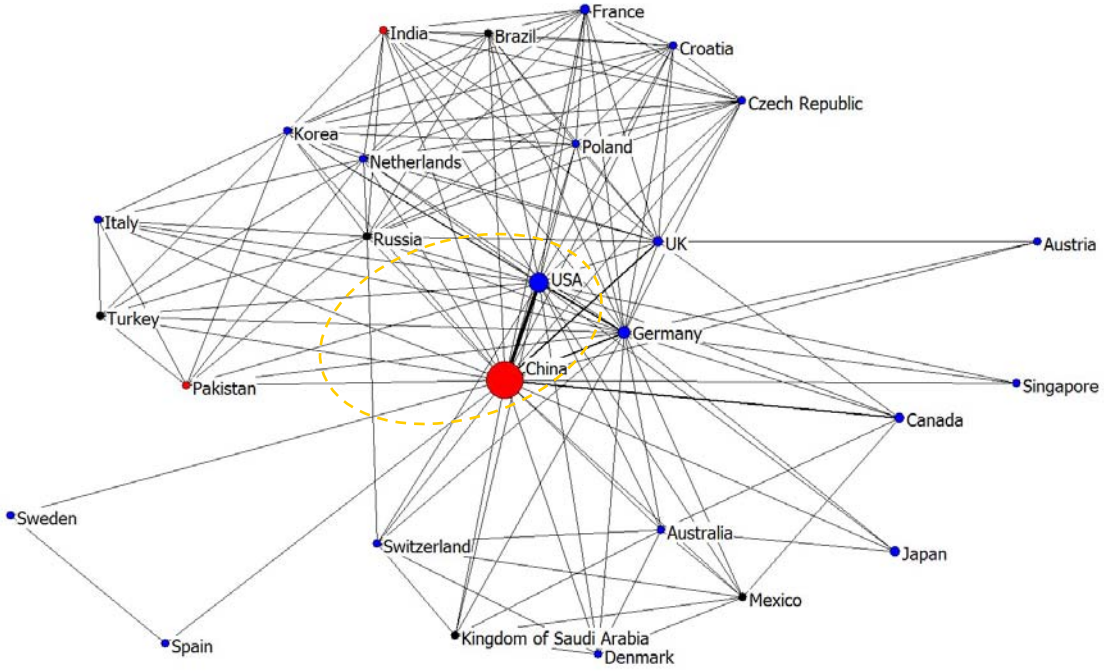

Fig. 1 The co-authorship network pf all the Cooperating Countries

NOTE: On this map, different colors have different meanings. Blue, black and red nodes represent very high human development countries, high human development countries and medium human development countries respectively. The size of the nodes is determined by the number of publications. The strength of the ties between nodes represents the quantity of collaboration.

Of all the Cooperating Countries, USA, Germany and UK have got the most research breakthroughs with China and the number of research paper is 53, 17, and 10 respectively. For example, "Old-Growth Forests Can Accumulate Carbon in Soils (2006)", "The role of Tet3 DNA dioxygenase in epigenetic reprogramming by oocytes (2011)" and "Eastward expansion of the Tibetan Plateau by crustal flow and strain partitioning across faults (2014)" by Sino-U.S. collaboration; "Solar Wind Origin in Coronal Funnels (2005)" and "Discovery of dissolved inorganic carbon in the global water cycle as an important carbon sink (2007)" by Sino-German Cooperation; "Amorphous Metallic Plastic (2005)" and "Genetic Viability and Population History of the Giant Panda, Putting an End to the "Evolutionary Dead End (2007)" by Sino-UK Cooperation and so on. USA, Germany and UK are all Powerful Nations of Science and Technology in the world. China can solve complex scientific problems and make major scientific breakthroughs more easily by cooperating with the powerful nations and using their scientific and technological resources.

C. Collaboration patterns

According to the number of cooperating countries, the cooperative patterns are divided into three types: bilateral cooperation, trilateral cooperation and multilateral cooperation. Over the last 10 years, the number of significant research programs occupies 47.37% by bilateral cooperation and 31.58% by trilateral cooperation and 21.05% by multilateral cooperation respectively. Considering the cooperative type of major academic papers, we find that there are 41 papers by bilateral cooperation sharing 56.94% and 20 papers by trilateral cooperation sharing 27.78% and 11 papers by multilateral cooperation sharing 15.28%. Table 3 shows us the quantitative distribution of cooperative countries of "Top 10 Science Advances" from 2005 to 2014. And we can see that the quantity of cooperative countries ranging from 1 to 3 is the most reaching 88.24%, while 4 reaching 6.86% and others (5, 7, 8, 9, 13) totally reaching 4.9%. The international cooperation in frontier areas in China is dominated by bilateral cooperation. But some major research projects such as big science engineering need more countries to participate.

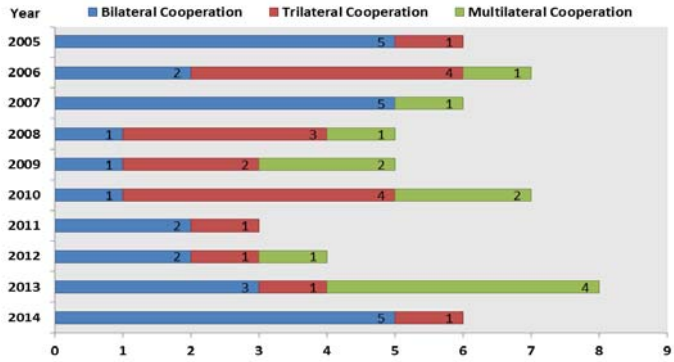

Fig. 2 The cooperative patterns distributions of Top 10 Science Advances (2005-2014)

For example, the "Observation of an Antimatter Hypernucleus" selected in 2010 involves 13 partner countries. It is the participation of J. H. Chen and Y. G. Ma of CAS Shanghai Applied Physics and Research Institute in International Coil Track Detector Coordinate Group with foreign scientists that makes the program.

D. A case analysis

Daya Bay Reactor Neutrino Experiment is the biggest international cooperative project in Chinese basic research, as well as the biggest cooperative project by Sino-U.S. collaboration. Scientists from Russia, Czech Republic, Hong Kong and Taiwan also participate in the experiment led by China and USA.

As early as 2003, Chinese physicists in High Energy Physics have attached great importance to the important trends of international particle physics research. And they proposed to measure a nonzero value for the neutrino mixing angle θ13 using Daya Bay Reactor Neutrino Experiment and worked out a complete and integrated experiment plan [19-20]. Chinese physicists in High Energy Physics bring the geographical advantage of Daya Bay nuclear power plant and ingenious design ideas into full play and stand out from the 8 experimental programs around the world winning the international peer support. Even US Department of Energy swung around to participate in Daya Bay Reactor Neutrino Experiment while giving up its two experimental programs. Thus it sets up an international group called Daya Bay Reactor Neutrino Experiment comprising over 20 institutions both in domestic and foreign and more than 100 physicists. As the scientific research constantly goes deeper, the international cooperation research team goes bigger including nearly 40 R&D institutions from 6 countries and regions about 250 scientists.

As a "take the initiative and multinational participation" international project, Daya Bay Reactor Neutrino Experiment produces a synergistic effect to the forefront of research issues, openness of research ideas and scientific research ability of researchers. The following are three good examples.

- For the scientific research, experiments on research of neutron detecting technique, control of radioactive background and data acquisition and analysis are low-energy and high-precision. China crosses the exploratory stage rapidly to station to the international forefront with a minimum of input thanks to the international cooperation. Also China has gain a place in frontier and increased its influence to international science and technology.
- For the personnel training, the international cooperation helps us to train a group of outstanding research personnel mastering vanguard nuclear rays-detected technology.
- For the project management, advanced and mature modern management methods used in big international projects have greatly promoted management mechanism and management philosophy of Chinese scientific research to be brought in line with international practice.

All in all, it is of great significance to improve basic research to a new level by working with world-class research institutions and high strength exchange and cooperation.

E. Synergistic effects

International S&T cooperation has been one of the characteristics of modern science. In fact, the Synergy of Collaboration is to create value in scientific research cooperation though global partnering [21]. It is documented that international scientific collaboration not only plays an indispensable role in improving research efficiency and deepening scientific research findings but also is an important channel to raise the level of scientific research and explore innovation research [22-23]. By analyzing the significant breakthroughs and latest developments in basic research over the last 10 years, we find that the synergy of international cooperation mainly embodies in the following four aspects:

1) International cooperation promotes the development of Chinese frontier areas such as space science and information technology which is characterized by independent innovation.

In the search for the origins of the universe, many research programs can support the above conclusion. For example, the Beijing Spectrometer(BES) International Group of Institute of High Energy Physics gave an observation of a resonance X(1835) and a Charged Charmoniumlike Structure on Beijing Electron Positron Collider (BEPC) in 2006 and 2013 respectively; Scientists from China, USA and Germany found a potential evidence for dark matter annihilation in 2008; researchers both in Shanghai Institute of Applied Physics and STAR Group gave the first observation of an Antimatter Hyper nucleus in; in the international cooperative project of Daya Bay Reactor Neutrino Experiments, scientists found new neutrino oscillation mode in 2012. And the research group lead by Professor Jian-Wei Pan from University of Science and Technology of China carried out a series of research work in the field of quantum communications. In 2006 and 2007 the 1 international cooperation results in a row wins "Top 10 Science Advances". Based on this, Chinese scientific researchers have begun to explore independently. In 2010, the joint research group by University of Science and Technology of China and Tsinghua University developed a number of key technologies and took a giant step forward towards application. The research group of University of Science and Technology of China scored a series of important achievements in extendible quantum information processing using High Luminosity and Purity Quantum Entanglement Source Technologies developed on their own in 2012. What's more, another research group and their American collaborators reported the experimental observation of the quantum anomalous Hall Effect in a magnetic topological insulator in 2013; and the Solution-processed, high-performance light-emitting diodes based on quantum dots were successfully prepared by the researchers at Zhejiang University in 2014. All these get extensive solicitude and highly valued of international academic, which reflects that China is becoming stronger in international competition in the field of quantum communications.

2) International cooperation encourages the close integration of frontier study and the needs of the country.

To the global warming issue, for instance, Chinese and foreign scientists made breakthrough successively through cooperation on carbon balance. In 2006, Chinese and American scientists from South China Botanical Garden of Chinese Academy of Sciences and U.S. Geological Survey (USGS) Center for Earth Resources Observation and Science made a breakthrough in Theory of non-equilibrium framework of ecosystem ecology. Scientists from Institute of geochemistry of Chinese Academy of Sciences, School of geographical sciences of Southwestern University and University of Bremen in Germany present a new research direction in carbon cycle research in 2007. In 2009, the group of College of Urban and Environmental Science of Peking University collaborated with British and France researchers to bring the carbon balance of terrestrial ecosystems in China out into the open in 2009. And it laid a solid foundation to understand space-time pattern and driving mechanism of Chinese terrestrial ecosystem carbon source/sink. Another hot issue, global food security, is not only a country's internal problems, but a global problem. Chinese and foreign scientists made great importance on food security. Take example for 2014, Chinese researchers not only studied the strigolactone signaling in rice under joint efforts with others, but also proposed and verified a planting pattern producing more grain with lower environmental costs independently. The application of these conclusions will play crucial roles for increasing productivity and adaptability of rice globally.

3) International cooperation makes Chinese traditional subjects develop constantly and steadily.

Of all the countries doing the research on paleontology, China has a unique geographical advantage and academic resources. In 2009, a progress of the study on the origin of Aves avifauna was selected in "Top 10 Science Advances". Xing Xu from Institute of Vertebrate Paleontology and Paleoanthropology of Chinese Academy of Sciences cooperated with researchers from USA, Canada and Mexico and achieved a breakthrough. After that, professor Xu bore into this subject with other Chinese scholars so as to make a series of major progresses about the long-term argued problems such as avian finger homologies, the time of Aves avifauna origination, the time of theropods differentiation, origin of plumage and the the evolution of Aves avifauna. The progress of early modern human fossils by Sino-U.S. collaboration was selected in "Top 10 Science Advances" in 2010. In 2012 the collaborative result illustrating the mass extinction patterns and their causes in Permian-Triassic interval was selected in "Top 10 Science Advances". The

cooperative nations are USA, Canada, Australia, Germany, UK and Austria. That shows China has formed a complete research system in geologists emerging a collective of researchers who keep the international dialogue and numerous related fields have been synchronized with the international.

4) International cooperation promotes the development of weak subjects while emerging mass breakthroughs.

In recent years, it develops rapidly in medicine science which belongs to weak area. There were 2 cooperative progresses being selected in "Top 10 Science Advances" in 2008：the diploid genome sequence of an Asian individual by Beijing Genomics Institute at Shenzhen and many other organizations from USA and Canada; the Crystal structure of the polymerase PAC–PB1N complex from an avian influenza H5N1 virus by Institute of Biophysics of Chinese Academy of Sciences, Joint Laboratory on Biophysics of Nankai University and Tsinghua University and Cooperation Group of USA and Singapore. In 2009, there were 3 medical achievements selected in "Top 10 Science Advances" of which 1 is by international cooperation and the other 2 are by Chinese scientific researchers independently. While there were 3 medical achievements selected in "Top 10 Science Advances" in 2010 and all of them were achieved by international cooperation. The situation of medical achievements in 2012 is different which there are 4 progresses and only 1 of them by international cooperation and other 3 by Chinese scientific researchers independently. In 2013, the experimental studies of new avian influenza H7N9 virus have obtained fast development, and achieved a series of significant experimental progress by Chinese scientific researchers. As was the case for 2012, there were 4 medical achievements selected in "2014 Top 10 Science Advances" of which 3 are by international cooperation and only 1 is by Chinese scientific researchers independently. The result shows that China has a group of breakthroughs in medicine area on the basis of international cooperation and the accumulation by herself.

IV. CONCLUSION

The "Top 10 Science Advances" plays an active role in promoting in strengthening the popularization of scientific spirit, scientific knowledge and scientific method and society's attention to basic research work in China. Choosing the"Top 10 Science Advances" from 2005 to 2014 as typical examples, the present paper finds that international cooperation promotes the development of Chinese basic research by analyzing the degree, mode and partners of international cooperation. And China has made breakthrough in basic research area and published high-qualified papers in world-class journals. International cooperation is the major character and inexorable trend of modern science research playing an irreplaceable role in combination superiority, improving the efficiency of research, deepening the research results and advancing the progress in frontiers. Considering the specific programs over the years, we find that international S&T cooperation makes Chinese traditional subjects develop constantly and steadily, promotes the development of weak subjects and encourages the close integration of frontier study and the needs of the country while emerging mass breakthroughs. International S&T cooperation has a guiding function for enhancing comprehensive national strength and innovative strength and fostering emerging industries of strategic importance. And it services the needs of the country in research topics related with national sustainable development and S&T benefiting people's livelihood such as Energies and Resources, Health and Medicine, Environment and Ecology etc.

Inevitably, there are some limitations in the research depth and breadth of this paper. For the research depth, we can introduce some indicators measuring the cooperative degree in the process of completing the papers. And for the research breadth, we can analyze both "Top 10 Science Advances of China" and "Top 10 Science Advances in the World" in the paper. Then it will reflect the role of international cooperation in Chinese basic research more completely and accurately.

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