NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA

2022 ANNUAL REPORT

Editorial Committee

In 2022, under the guidance of Xi Jinping Thought on Socialism with Chinese Characteristics for a New Era, focusing on paving the way for a successful 20th National Congress of the Chinese Communist Party and implementing its guiding principles, the National Natural Science Foundation of China (NSFC) thoroughly implemented the important statements of President Xi Jinping on scientific and technological innovation, especially on basic research, comprehensively implemented the decisions and arrangements of the CPC Central Committee and the State Council. Working in collaboration with the research community and host institutions, NSFC continued deepening the systematic reform on science funding with an emphasis on the improvement of the National Natural Science Funding, and successfully completed annual funding work, providing strong support for the high-quality development of basic research.

NSFC strengthened the systematic planning of basic research funding to encourage free exploration and original innovation. We developed annual funding plan in a scientific manner and deepened the reform on the section-based restructuring of funding portfolio, so as to enhance the coordinated efforts to target the global science frontiers, serve the main economic battlefield, fulfill the significant needs of the country and benefit people's lives and health. In 2022, NSFC received 306.9 thousand proposals from 2405 host institutions, and approved 51.6 thousand awards with a funding amount of 32.699 billion yuan. We continued carrying out the Original Exploratory Program, and explored application and review mechanisms that are conducive to this program type, so as to encourage researchers to think freely and conduct high-risk and high-reward research. We approved 125 awards of Original Exploratory Program, with an investment of 285 million yuan. To fulfill national major needs, we planned for funding research on critical scientific problems in advance, by formulating *Guidelines for Basic Research on Carbon Peaking and Carbon Neutrality*, and funding two Major Research Plans, i.e. "Interpretable, general-purpose approaches to the next generation of AI" and "Scientific basis and control mechanism of efficient flight in multi-physics field". We funded 81 projects by the Special Fund for Research on National Major Research Instruments to support original research and development of research instruments and core components. *The 14th Five-Year Plan of National Natural Science Foundation of China* was also published, illustrating the priority areas and key tasks of NSFC.

NSFC improved talent funding system and consolidated the capabilities of cultivating basic research talents. We strengthened the support for young talents, with 22,262 awards for Young Scientists Fund, 630 awards for Excellent Young Scientists Fund, and 415 awards for National Science Fund for Distinguished Young Scholars, an increase of 100 awards from last year. A total of 3521 awards of Fund for Less Developed Regions were approved to foster talents in these regions. The Excellent Young Scientists Fund (Overseas) and the Excellent Young Scientists Fund (Hong Kong and Macao) continued to thrive. Young Scientists Fund was open to host institutions in Hong Kong and Macao Special Administrative Regions.

The major tasks of NSFC's comprehensive reform made major progress. NSFC steadily advanced the implementation of the funding categories based on the four attributes of scientific problems, with over 85% of the applications going through category-specific review, which further improved the overall quality of research content. We further expanded the pilot reform of evaluation mechanism featuring "Respons ibility+Credibility+Contribution (RCC)" to over 60% of the disciplines, which increased the quality of peer review. We optimized the disciplinary layout and adopted a dynamic adjustment of codes based onthe new application code system. The logic, inclusiveness and guiding effect of the application code system has been significantly enhanced. We strengthened the capabilities of refining scientific problems, optimized the program planning mechanism, and published *Cases of Refining Scientific Problems* for the reference of researchers. Pilot performance evaluation was conducted for Departments of Chemical Sciences, Life Sciences and Information Sciences by professional, third-party evaluators, which aimed to summarize reform experience and identify the future directions of improving funding performance.

NSFC continued strengthening international (regional) collaborations to foster new global prospects on opening-up and cooperation. Through extensive strategic dialogues with international science funding agencies, we actively participated in global science policy discussions. We strengthened collaborations with overseas science funders and international organizations to support substantive joint research and academic exchanges, with a total number of 577 grants awarded. Under the Research Fund for International Scientists, 259 grants were awarded. Pilot Group Program for Research Fund for International Senior Scientists was implemented, under which 13 grants were awarded. We also launched the Sustainable Development International Cooperation (SDIC) Program, with 16 partner agencies and international organizations joining the first round of call for proposals. We also started the preparation for a Department of International Science Funding and steadily advanced the pilot work for the building of a global science fund.

NSFC actively attracted diversified investment to increase the impact of the reform of Programs of Joint Funds. We made the utmost of Programs of Joint Funds as a platform to attract researchers' attention to the key scientific questions behind major needs and encourage them to work together in seek of solutions. In 2022, Joint Fund for Regional Innovation and Development had three new partners, i.e. Shanghai Municipality, and Yunnan and Guizhou provinces. Joint Fund for Corporate Innovation and Development welcomed four corporate partners, namely, China National Petroleum Corporation, Genertec, Yalong Hydro and China Coal. A new Joint Fund was established with China Geological Survey. Since the reform of the Joint Funds in 2018, a total of 13.397 billion yuan has been raised from joint funders. In 2022, the investment of joint funders accounted for 8% of the public funding that NSFC received from the Central Government.

NSFC continued to optimize administrative management to boost researchers' vigor of innovation. We enacted the *Notice of Special Actions to Ease the Burden on Young Researchers* with relevant government ministries and stakeholders, to ensure young researchers focus on scientific research instead of being distracted by administrative matters. We simplified the requirements on application materials, adopted online approach to collect the information of project participants, and continued advancing the reform of"one form, multiple use", and simplified the authorship and funding acknowledgement requirements on the publications of NSFC-funded projects. Contract-based system was adopted in some talent programs, and has benefited over 23 thousand researchers by ensuring more convenient and better use of research fund.

NSFC strengthened the work on research integrity, and actively promoted a favorable atmosphere for basic research. We implemented the *National Natural Science Foundation Scientific Integrity Promotion Implementation Plan*, and made coordinated efforts to push forward research integrity-related work that includes education, motivation, regulation, supervision, and discipline. A special scheme to stop and control acts of influencing peer reviewers to commit dishonesty through personal connections was formulated. We reinforced the on-site supervision of panel reviews and standardized the supervision of review process, handled research misconduct investigation carefully, and inspected funding management on a regular basis. We also worked with other members of the Research Integrity Joint Meeting on joint punishment, to improve regular collaborations regarding information sharing and misconduct handling.

NSFC solidly carried out the commitment of serving the scientific community and upholding integrity through the systematic implementation of requirements on anti-corruption. We thoroughly implemented the guiding principles of the 20th National Congress of CPC, and used it as a guidance to the daily operation of NSFC. We frequently organized Party history studies, implemented the eight-point decision on improving Party discipline of the CPC Central Committee, and systematically carried out the work of rigorous self-governance, upholding integrity and anti-corruption. NSFC consciously accepted the supervision by the representative office of the CPC Commission of Discipline Inspection and National Supervisory Commission to the Ministry of Science and Technology, and seriously implement the supervisory recommendations. We also developed a regular auditing mechanism together with National Audit Office to ensure prompt rectification.

In 2023, under the guidance of Xi Jinping's Thought on Socialism with Chinese Characteristics for a New Era, NSFC will deepen the understanding of the decisive significance of the establishment of Comrade Xi Jinping's core position on the Party Central Committee and in the Party as a whole and the guiding role of Xi Jinping Thought on Socialism with Chinese Characteristics for a New Era; strengthen our consciousness of the need to maintain political integrity, think in big-picture terms, follow the leadership core, and keep in alignment with the central Party leadership; stay confident in the path, theory, system, and culture of socialism with Chinese characteristics; uphold Comrade Xi Jinping's core position on the Party Central Committee and in the Party as a whole and uphold the Party Central Committee's authority and its centralized, unified leadership; thoroughly implement the guiding principles of the 20th National Congress of CPC and the Central Economic Working Conference, as well as President Xi's important speeches and remarks. We will adhere to the principle of targeting the global science frontiers, serving the main economic battlefield, fulfilling the significant needs of the country and benefiting people's lives and health,simultaneously push forward both use-inspired and curiosity-driven researches, formulate funding plan for researches advancing science frontiers and solving theoretical questions drawn from applied research as a whole, and focus on the shift of scientific paradigm and the refining of scientific problems. We will emphasize originality, adhere to the principle of innovation, strengthen investigation and research, continue to promote reform, consolidate the foundation of scientific and technological self-reliance, promote education development, scientific and technological innovation, and talent cultivation, provide strong support to the high-quality development of basic research in China, the building of an S&T power, and the great rejuvenation of the Chinese nation through a Chinese path to modernization.

Prof. Dr. Li Jinghai
President of NSFC

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PART 1

Overview

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I. Review of the achievements of NSFC's systematic reform

In 2018, NSFC launched its systematic reform on all fronts. Since then, we have been adhering to the guidance of Xi Jinping Thought on Socialism with Chinese Characteristics for a New Era, thoroughly implemented the guiding principles of President Xi's important speeches on scientific and technological innovation, especially on basic research, firmly grasped the strategic positioning of "basic research is the bedrock of the whole scientific system and the key to all technological issues", resolutely implemented the requirement that "science and technology is the field that needs continuous reform the most", and made great efforts to build the National Natural Science Fund into a science funding system that features advanced concepts, standardized systems, and fairness and efficiency.

(i) Key Measures

1. NSFC reformed the funding strategies by advancing three major tasks of identifying funding categories, improving evaluation mechanism, and optimizing the layout of disciplines. Firstly, we identified four funding categories to improve the quality of proposals. The pilot reform launched in 2019 experimented different application requirements and review criteria based on the four attributes of scientific problems, i.e. high-creative research, research on the frontier of science in unique ways, use-inspired basic research, and transdisciplinary and convergent research. In 2022 the category-specific application and review has been applied to over 85% of the total applications. We selected and published 111 typical cases of research in the four categories to help scientific community better understand the four attributes of scientific problems, and raise the awareness of researchers to find the right scientific problems. The quality of topic selection in proposals has been improved significantly. Secondly, we improved review mechanism to promote responsible peer review. The pilot reform was launched in 2020 to promote review mechanism featuring "Responsibility+Credibility+Contribution (RCC)". In 2022, the review mechanism has been applied to 61% of all the disciplines. The sense of responsibility of the reviewers as well as the quality of peer review have been greatly improved. Thirdly, we optimized the layout of disciplines to lay a solid foundation for scientific development. We simplified the application code system and reduced the total number of codes from 3,542 to 1,390. Such adjustment was considered scientific, inclusive and trend-leading, and conducive to transdisciplinarity and convergence.

2. NSFC reformed the funding mechanisms by fully implementing a series of important measures. Firstly, we explored new mechanisms to foster major original innovation. The Original Exploratory Program was well underway. A series of new mechanisms were installed including pre-application and rebuttal process to give highly innovative ideas timely support. A total of 329 awards were funded from 2020 to 2022. Secondly,we improved funding mechanism to support scientific talents. The talent funding portfolio was upgraded to build a complete funding system for the fostering of basic research talents. In 2022, the number of awards for National Science Fund for Distinguished Young Scholars rose to 415 from 200 in 2018, that for Excellent Young Scientists Fund from 400 to 630. There is also an increase of nearly 26% in the number of awards for Young Scientists Fund. We also optimized the funding mechanisms of Science Fund for Creative Research Groups and Basic Science Center Program, and launched Excellent Young Scientists Fund (Hong Kong and Macao) and Excellent Young Scientists (Overseas). Thirdly,we diversified fund sourcing mechanism. Program of Joint Funds was reformed to enhance coordinated efforts in innovation by encouraging industries, provincial governments and other ministries to increase investment in basic research. The ratio of investment with industries, provincial governments and ministries are 1:4, 1:3 and 1:2 respectively. Fourthly, we optimized the funding and project management mechanisms. Measures of "decentralizing approval authorities,improving management and service" were thoroughly implemented. "Contract mode" was adopted first in the funding management of National Science Fund for Distinguished Young Scholars, and later expanded to other talent programs. PIs and their host institutions are authorized to review and approve

the budget adjustment. Such effort ensures researchers more flexibility and better motivates them to focus on innovative research. No hard copies of application were required for any program in 2022. Application requirements were further simplified with clearer criteria for compliance check. The representative works evaluation mechanism was adopted to further ease the burden on researchers and host institutions. Lastly, we further strengthened international research collaborations. The planning for Department of International Science Funding is underway, to steadily advance the goal of building NSFC into a global funding organization for scientific research. Research Fund for International Young Scientists was upgraded to three tiers inlcuding Research Fund for International Young Scientists, Research Fund for International Excellent Young Scientists and Research Fund for International Senior Scientists, and thus accumulated experience for establishing and operating Global Funding for Scientific Research.

3. NSFC reformed the layout of organizational structure by integrating the 9 existing scientific departments into four sections. In accordance with the requirements of "targeting the global science frontiers, serving the main economic battlefield, fulfilling the significant needs of the country and benefiting people's lives and health" and the principles of "following the inherent logic of knowledge system, promoting knowledge translation and highlighting convergence and integration", the 9 existing scientific departments were integrated into four sections, i.e. basic sciences, technical sciences, life and health sciences, and convergence sciences. We further explored consultation and decision-making processes and developed the mechanisms for program designing, review, and funding that are tailored to the features of different sections. By doing so, program management became more creative, and disciplinary barriers were removed to facilitate transdisciplinary convergence, and better guide researchers from different fields to tackle comprehensive and complex problems together.

(ii) Major Achievements

Since the 19th CPC National Congress, NSFC has been adhering to our mission, pushing forward systematic reform, and improving funding system, and has played a unique role in strengthening basic research from the following aspects.

1. As the major funding source for basic research, the National Natural Science Fund has steadily supported the sustainable and coordinated development of all the basic science disciplines, which has laid a solid foundation for disciplinary development. NSFC's investment accounts for 20% of China's basic research expenditure. The funding scope covers all the academic disciplines except arts and humanities and social sciences. Since 2018, NSFC has received approximately 1.35 million proposals, and awarded 240 thousand grants, with a total funding amount of 146.4 billion yuan, which plays a fundamental role in supporting the overall development of natural science and engineering in China.

2. As a talent fostering fund, the National Natural Science Fund has developed a funding portfolio that covers all the career stages of researchers, which strengthens the talent base for accelerating the construction of China into a world important talent center and innovation highland. Since 2018, about 553 thousand researchers, 42 thousand postdoctoral fellows, and 707 thousand graduate students have led or participated in NSFC-funded projects. As an incubation fund for outstanding talents, the National Science Fund for Distinguished Young Scholars has become a significant brand for fostering high-level S&T talents, and played an irreplaceable role in cultivating young researchers and advancing S&T innovation. Among all the Academicians of Chinese Academy of Sciences under the age of 60, about 87% of them were grantees of this fund.

3. As the source of scientific breakthroughs, the National Natural Science Fund has provided initial support for scientific research expanding science frontiers and serving national needs. We have funded research projects that generated a number of cutting-edge achievements such as iron-based superconducting materials, quantum anomalous Hall effect, and multi-photon entanglement, and provided strong support for the basic science aspect of major national projects such as the Beidou satellite

positioning system, aerospace technology research and development, and the construction of the Qinghai-Tibet and Sichuan-Tibet railways. Since 2018, all the National Natural Sciences Award-winning achievements were once supported by NSFC. Since the outbreak of SARS in 2003, NSFC has continuously funded research on corona virus with 353 awards and an investment of 297 million yuan. At the outbreak of COVID-19 at the end of 2019, we allocated 124 million yuan as emergency fund to support critical research, and provided essential S&T and personnel support for rapid response to the pandemic.

4. As a facilitator of collaborative innovation, NSFC has been actively encouraging enterprises, industries, ministries and local governments to support basic research. There have been 26 provincial governments, 12 SOEs and 8 ministries establishing Joint Funds with NSFC. Till now, we have attracted external investment of 13.397 billion yuan. In 2022, the budget for Programs of Joint Funds accounted for 8% of NSFC's total budget, which significantly enhanced the capacity for original innovation.

5. As an important platform for international scientific cooperation, NSFC has constantly maintained open channel for international cooperation. We have established partnerships with 101 funding agencies and international organizations in 54 countries and regions. We also launched the Sustainable Development International Cooperation program which aimed to address common challenges to the UN SDGs. In 2022, 16 international partner agencies joined the first round of call for proposals.

II. Overview of Budget & Outlays and Funding

(I) Overview of Budget and Outlays

In 2022, the fiscal budget of NSFC was 33,010.4848 million yuan, of which the budget for project funding was 32,496.5918 million yuan. In 2022, NSFC completed the appropriation of project funds with a total amount of 31,856.4710 million yuan, of which the direct cost was 26,881.1776 million yuan, and the indirect cost was 4,975.2934 million yuan. The fiscal budget statistics of NSFC in 2022 are shown in Table 1-2-1.

Table 1-2-1 2022 NSFC Fiscal Budget and Outlays (unit: 10,000 yuan)

	Program Type	Fiscal Budget	Fiscal Outlays
1	General Program	1,342,058.18	1,339,556.06
2	Key Program	252,588.00	251,847.53
3	Major Program	72,423.00	72,098.60
4	Major Research Plan	115,571.00	105,481.62
5	International (Regional) Joint Research Program	89,748.00	88,992.50
6	Young Scientists Fund	505,984.00	505,948.00
7	Excellent Young Scientists Fund	120,536.00	119,652.04
8	National Science Fund for Distinguished Young Scholars	140,003.00	135,677.00
9	Science Fund for Creative Research Groups	48,498.00	48,389.35
10	Fund for Less Developed Regions	138,153.00	137,774.43
11	Programs for Joint Funds	75,140.00	74,659.66
12	Special Fund for Research on National Major Research Instrument	113,414.00	113,271.27
13	Basic Science Center Program	92,718.00	90,930.20
14	Fund for Special Purpose	94,215.00	68,224.68
15	Tianyuan Fund for Mathematics	6,840.00	3,850.00
16	Research Fund for International Scientists	24,500.00	19,766.86
17	International (Regional) Personnel Exchange Program	17,000.00	9,265.32
18	Joint Research Fund for Overseas Chinese Scholars and Scholars in Hong Kong and Macao	270.00	262.00
Total		3,249,659.18	3,185,647.10

(II) Overview of Funding

In 2022, NSFC invested a total of 38909.1569 million yuan to fund various types of projects, of which: the direct cost was 32,699.2135 million yuan, and the indirect costs of 1200 host institutions were 6,209.9434 million yuan. The project funding statistics of NSFC in 2022 are shown in Table 1-2-2.

Table 1-2-2 2022 NSFC Project Funding Statistics (unit: 10,000 yuan)

	Program Type	Number of Projects	Funding Amount		
			Direct Cost	Indirect Cost	Total
1	General Program	20,472	1087,845.00	324,861.48	1,412,706.48
2	Key Program	761	205,282.00	60,098.88	265,380.88
3	Major Program	55	80,126.92	23,020.56	103,147.48
4	Major Research Plan	320	80,258.70	20,887.34	101,146.04
5	International (Regional) Joint Research Program	329	59,783.50	17,398.65	77,177.15
6	Young Scientists Fund	22,262	-	-	662,800.00
7	Excellent Young Scientists Fund	655	-	-	131,000.00
8	National Science Fund for Distinguished Young Scholars	415	-	-	162,880.00
9	Science Fund for Creative Research Groups	43	42,400.00	8,600.00	51,000.00
10	Fund for Less Developed Regions	3,521	115,080.00	34,833.04	149,913.04
11	Programs for Joint Funds	1,075	287,167.00	56,436.72	343,603.72
12	Special Fund for Research on National Major Research Instrument	81	105,325.60	22,713.64	128,039.24
13	Basic Science Center Program	19	111,000.00	23,842.95	134,842.95
14	Fund for Special Purpose	970	101,420.72	21,881.79	123,302.51
15	Tianyuan Fund for Mathematics	95	6,000.00	0	6,000.00
16	Research Fund for International Scientists	272	22,149.61	6,424.29	28,573.90
17	International (Regional) Personnel Exchange Program	248	9,402.30	0	9,402.30
Total		51,593	3,269,921.35	620,994.34	3,890,915.69

* Contract model has been adopted for Young Scientists Fund, Excellent Young Scientists Fund and National Science Fund for Distinguished Young Scholars; hence direct and indirect costs no long apply.

III. Overview of Concluded Projects

In 2022, 42,669 NSFC-funded projects were concluded. Among the numerous achievements coming out of the concluded projects, 551 national awards and 4,946 provincial and ministerial awards were received including 157 National Natural Science Awards, 282 National Science and Technology Progress Awards, and 112 National Technology Invention Awards. 1,545 international invention patents and 50,337 domestic invention patents were obtained.

The statistics of research achievements coming out of the concluded projects supported by NSFC in 2022 are shown in Table 1-3-1.

Table 1-3-1 Research Achievements Coming Out of the Concluded Projects Supported by NSFC in 2021

Research Achievements		Program Type														
		General Program	Key Program	Major Program	Major Research Plan	Young Scientists Fund	Fund for Less Developed Regions	Excellent Young Scientists Fund	National Science Fund for Distinguished Young Scholars	Science Fund for Creative Research Groups	Joint Research Fund for Overseas Chinese Scholars and Scholars in Hong Kong and Macao	Programs for Joint Funds	Special Fund for Research on National Major Research Instrument	Basic Science Center Program	Fund for Special Purpose	International (Regional) Cooperation &Exchange Program
No. of Concluded Projects		17,670	611	122	538	17,651	3,003	399	197	47	23	784	96	3	45	848
Publications	Keynote Speeches at International Academic Conferences	4,134	1,205	392	305	760	89	310	556	352	12	336	130	116	40	620
	Keynote Speeches at Domestic Academic Conferences	7,165	1,452	425	507	1,344	346	421	596	526	21	541	177	65	80	451
	Journal Papers	237,237	27,832	9,312	9,716	110,481	28,814	7,120	7,751	8,202	400	17,441	3,315	1,459	1,082	10,464
	Conference Papers	21,576	3,288	824	804	9,579	1,832	634	733	257	66	2,694	336	34	70	1,058
	SCI-indexed research articles	166,856	20,217	7,520	7,341	76,029	13,462	5,817	6,147	5,994	224	12,438	2,319	934	552	7,946
	EI-indexed research articles	18,505	2,480	725	446	9,477	2,302	545	651	329	22	2,576	233	1	53	723
	Monographs	2,505	297	124	62	1,321	473	93	110	139	3	189	21	1	21	143
Patents	International	746	132	7	29	251	40	41	40	55	5	106	37	0	1	52
	Domestic	23,074	2,736	873	784	11,700	2,927	854	1,244	1,619	46	2,676	766	20	47	895
Awards	National level	246	70	17	19	52	3	21	23	27	1	34	5	7	0	26
	Provincial/ Ministerial level	2,519	297	85	70	959	263	110	104	80	6	280	30	0	5	124
Talents Trained	Postdoctors Fellow	2,010	508	237	173	836	48	130	236	144	16	200	77	22	29	228
	PhD students	20,354	3,638	1,214	1,226	4,281	673	634	1,076	1,397	83	1,593	453	88	142	1,491
	Masterstudents	47,966	4,749	1,340	1,470	13,677	6,956	1,124	1,012	1,366	61	4,212	745	23	216	1,661

Note:

1. Data source: Concluding Reports submitted by PIs

2. International (Regional) Cooperation & Exchange Program includes International (Regional) Joint Research Program, Research Fund for International Scientists, and International (Regional) Personnel Exchange Program.

3. Statistics of Tianyuan Fund for Mathematics are included in Fund for Special Purpose

PART 2

The Funding statistics and selective introduction of projects supported by NSFC in 2022

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NSFC

1. Application and Funding Statistics

1.1 General Program

The General Program aims at supporting researchers to select topics independently within the funding scope of NSFC, carry out innovative scientific research, and promote the balanced, coordinated and sustainable development of various disciplines.

In 2022, a total of 116,561 applications were received for the General Program. Based on the attributes of the scientific questions, these applications were divided into four categories, including ground-breaking applications(Category I), frontier-extending applications(category II), bottleneck-breaking applications(category III), and crossing-disciplines applications(category IV). 4.68% of the total applications were under category I, 44.27% under category II, 45.63% under category III, and 5.43% under category IV.

Statistics on applications and funding for the General Program in 2022 are shown in Table 2-1-1 and 2-1-2. The age distribution of project PIs is shown in Figure 2-1-1, and the composition of project teams is shown in Figure 2-1-2.

Table 2-1-1 Application and Funding Statistics of the General Program in 2022 (by Scientific Department)

(Unit: 10,000 *yuan*)

Scientific Department	Applications	Grants	Direct Costs	Average Funding per Project①	Success rate② (%)
Mathematical and Physical Sciences	8,566	1,927	101,120.00	52.48	22.50
Chemical Sciences	9,428	2,035	109,870.00	53.99	21.58
Life Sciences	16,701	3,189	172,230.00	54.01	19.09
Earth Sciences	9,826	2140	116,580.00	54.48	21.78
Engineering and Materials Sciences	21,213	3,486	188,265.00	54.01	16.43
Information Sciences	12,024	2,182	117,890.00	54.03	18.15
Management Sciences	4,827	828	37,250.00	44.99	17.15
Health Sciences	33,976	4,685	244,640.00	52.22	13.79
Total or average	116,561	20,472	1,087,845.00	53.14	17.56

Note: ①Average funding intensity=funding amount/number of approved funding projects (the same below).
②Funding rate=number of approved funding projects/number of received applications (the same below).

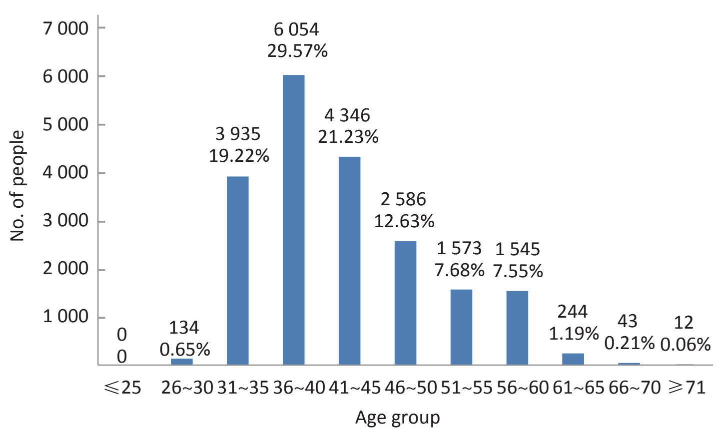


Figure 2-1-1 Age Distribution of Principal Investigators of General Program Projects in 2022

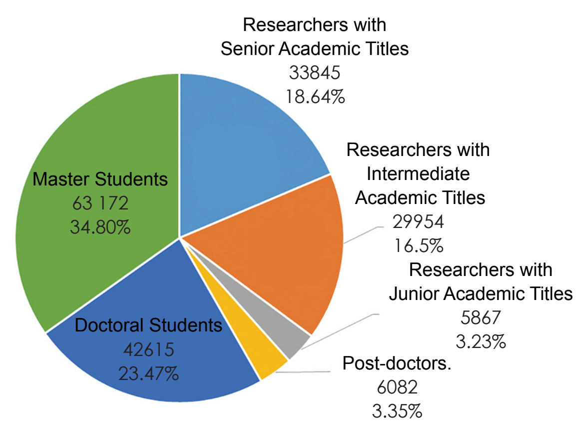


Figure 2-1-2 Project Team Composition of General Program Projects funded in 2022

Table 2-1-2 Statistics of General Program Projects by Region in 2022

(Unit: 10,000 *yuan*)

No.	Region	Grants	Direct Costs	No.	Region	Grants	Direct Costs
1	Beijing	3,517	187,155.00	17	Heilongjiang	467	24,856.00
2	Jiangsu	2,104	111,885.00	18	Jiangxi	95	5,018.04
3	Guangdong	1,999	105,648.00	19	Yunan	132	7,067.00
4	Shanghai	2,192	115,682.00	20	Jilin	306	16,347.00
5	Hubei	1,328	70,649.00	21	Gansu	196	10,535.00
6	Zhejiang	1,089	57,675.00	22	Guangxi	67	3,577.00
7	Shaanxi	1,074	57,272.00	23	Guizhou	54	2,916.96
8	Shandong	928	49,574.00	24	Shanxi	185	9,876.00
9	Sichuan	780	41,662.00	25	Hebei	164	8,780.00
10	Hunan	701	37,153.00	26	Xinjiang	29	1,560.00
11	Liaoning	615	32,733.00	27	Hainan	37	1,979.00
12	Tianjin	607	32,197.50	28	Inner Mongolia	18	1,004.00
13	Anhui	519	27,678.00	29	Ningxia	11	590.00
14	Henan	344	18,312.50	30	Qinghai	2	110.00
15	Chongqing	438	23,293.00	31	Tibet	2	102.00
16	Fujian	472	24,958.00		Total	20,472	1,087,845.00

1.2 Key Program

The Key Program aims at supporting researchers to carry out in-depth and systematic innovation research on research directions with good basis or the new growing points of disciplines, promoting scientific development, and making breakthroughs in several important fields or scientific frontiers.

In 2022, a total of 4,337 applications were received for the Key Program. Based on the four categories of the scientific problems, 4.73% of the total applications were under category I,43.65% under category II, 47.06% under category III, and 4.57% under category IV.

Statistics on applications and funding for the Key Program in 2022 are shown in Table 2-1-3. The age of project PIs is shown in Figure 2-1-3, and the composition of research teams is shown in Figure 2-1-4.

Table 2-1-3 Application and Funding Statistics of the Key Program in 2022 (by Scientific Department)

(Unit:10,000 yuan)

Scientific Departments	Applications	Grants	Direct Costs	Average funding per project	Success Rate (%)
Mathematical and Physical Sciences	475	91	25,480.00	280.00	19.16
Chemical Sciences	357	68	19,040.00	280.00	19.05
Life Sciences	675	110	29,660.00	269.64	16.30
Earth Sciences	664	112	30,450.00	271.88	16.87
Engineering and Materials Sciences	819	118	31,742.00	269.00	14.41

(continued)

Scientific Departments	Applications	Grants	Direct Costs	Average funding per project	Success Rate (%)
Information Sciences	385	106	30,210.00	285.00	27.53
Management Sciences	121	29	5,510.00	190.00	23.97
Health Sciences	841	127	33,190.00	261.34	15.10
Total or average	4,337	761	205,282.00	269.75	17.55

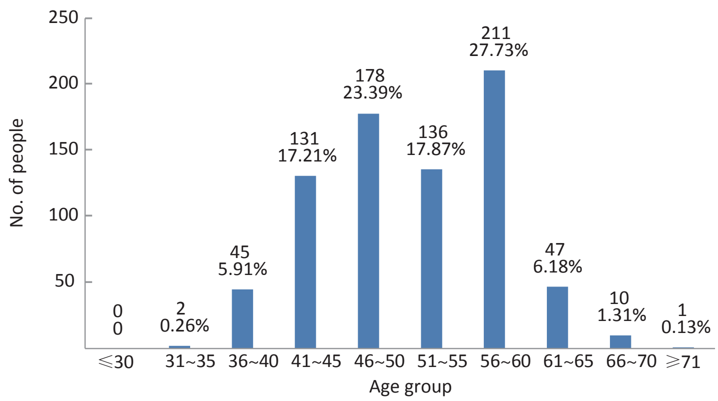


Figure 2-1-3　Age Distribution of Principal Investigators of Key Program Projects in 2022

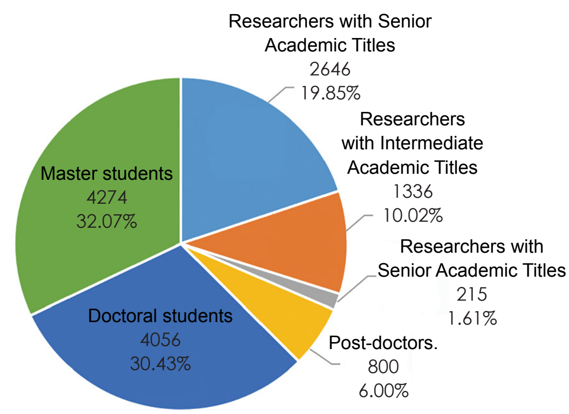


Figure 2-1-4　Project Team Composition of Key Program Projects funded in 2022

1.3　Major Program

The Major Program projects focus on major scientific issues in the forefront of science and the major needs of national economic, social, technological development and national security. It supports multidisciplinary research and comprehensive research through far-sighted investment and plays a supporting and leading role in enhancing China's original innovation ability of basic research.

In 2022, 147 applications were received and 55 grants were approved, with a total direct costs of 801,269,200 yuan.

Statistics on applications and funding of the Major Program in 2022 are shown in Table 2-1-4.

Table 2-1-4　Application and Funding Statistics of the Major Program in 2022 (by Scientific Department)

(Unit: 10,000 yuan)

Scientific Department	Applications	Grants	Direct Costs	Average Funding per Project
Mathematical and Physical Sciences	12	5	7,426.00	1,485.20
Chemical Sciences	12	6	8,877.60	1,479.60
Life Sciences	13	6	8,996.20	1,499.37
Earth Sciences	14	6	8,885.60	1,480.93
Engineering and Materials Sciences	14	9	13,383.70	1,487.08
Information Sciences	17	7	9,872.26	1,410.32
Management Sciences	14	4	4,793.33	1,198.33

(continued)

Scientific Department	Applications	Grants	Direct Costs	Average Funding per Project
Health Sciences	26	5	7,495.00	1,499.00
Interdisciplinary Sciences	25	7	10,397.23	1,485.32
Total or average	147	55	80,126.92	1,456.85

1.4 Major Research Plan

Major Research Plan projects focus on national major strategic needs and major scientific frontiers, strengthens top-level design, identifies scientific goals, and gathers strong teams and research resources to form a cluster of projects with relatively unified goals or directions. It intends to enhance the intersection and integration of disciplines, cultivates innovative talents and teams, strengthens the original innovation ability of China's basic research, and provides scientific support for national socio-economic development and national security.

Statistics on applications and funding of the Major Research Plan in 2022 are shown in Table 2-1-5.

Table 2-1-5 Applications and Funding Statistics of the Major Research Plan in 2022

(Unit: 10,000 yuan)

No.	Title of Project	Applications	Grants	Direct Costs
1	Toxicological and health effects of atmospheric fine particulate matter	1	1	31.90
2	Catalysis science of carbon-based energy conversion and utilization	1	1	124.90
3	Big Data-driven management and decision-making research	1	1	111.70
4	Runoff change and adaptive utilization in the source region of Southwest China's rivers	1	1	413.20
5	Research on basic theory and key technology of inclusive robots	37	4	1,500.00
6	Mechanism of organ aging and organ degenerative changes	10	5	2,500.00
7	Physics and applications of novel light field regulation	14	7	4,700.00
8	Mechanisms by which hydrospheric microorganisms drive the cycling of Earth's elements	9	7	6,650.00
9	Formation, evolution and action mechanism of turbulent structure	73	12	2,400.00
10	Dynamic modification and chemical intervention of biological macromolecules	51	9	5,400.00
11	Study on organelle interaction network and its function	22	8	7,000.00
12	Tethys geodynamic system	5	4	1,946.00
13	The precise construction of multiple layers of chiral matter	19	8	4,850.00
14	Multi - sphere interaction in the Western Pacific Earth system	5	4	2,400.00
15	Molecular functional visualization of tumor progression and diagnosis and treatment	316	14	3,000.00
16	High temperature materials for aeroengines/Fundamentals of Advanced Manufacturing and Fault diagnosis science	3	1	500.00
17	Cluster structure, function and multistage evolution	202	26	3,850.00

(continued)

No.	Title of Project	Applications	Grants	Direct Costs
18	Metallogenic dynamics of strategic key metals in supernormal enrichment	14	6	2,300.00
19	Basic research of high-performance materials for functional element ordering	349	19	3,000.00
20	Basic research of new devices in post-Moore era	51	13	1,933.00
21	Construction and manipulation of the second-generation quantum system	50	25	4,500.00
22	Scientific basis of electromagnetic energy equipment in extreme conditions	76	19	3,955.00
23	Basic theory and key technologies of future industrial Internet	91	17	3,560.00
24	Information decoding and orderly regulation of tissue and organ regeneration and repair	357	26	3,200.00
25	Panoramic dynamic mechanism and intervention strategy of coronavirus-host immune interaction	126	23	2,697.00
26	Explicable and universally applicable next generation of AI methodologies	266	32	4,094.00
27	Scientific basis and regulation mechanism of high-efficiency flight in multiple physical fields	124	27	3,642.00
Total		2,274	320	80,258.70

1.5 International (Regional) Cooperative Research Program

The International (Regional) Cooperative Research Program funds researchers to follow the international science frontiers, effectively use international scientific and technological resources, conduct international collaborative research following the principle of equal cooperation, mutual benefit and results sharing, thus improving the scientific research and international competitiveness of China. International (regional) cooperative research projects include key international (regional) cooperative research projects and MoU-based cooperative research projects.

The key international (regional) cooperative research projects fund researchers to work on priority areas of the National Natural Science Fund, the research areas that China urgently needs to develop, the international large-scale scientific research projects or programs that Chinese scientists initiate or participate in, and large international (regional) collaborative research based on large international scientific facilities.

The MoU-based cooperative research projects aim to expand bilateral and multilateral scientific cooperation, make use of the platforms and opportunities provided by international scientific and technological organizations in international scientific research, support Chinese scientists to initiate, plan and participate in regional or global research projects with important scientific significance, and actively advance cooperation with countries and regions along the “Belt and Road” area and on common challenges to sustainable development. Cooperation and exchanges with scientists from Hong Kong, Macao and Taiwan are also encouraged.

Statistics on applications and funding of the international (regional) cooperative research program in 2022 are shown in Table 2-1-6 and 2-1-7.

Table 2-1-6 Application and Funding Statistics of Key International (Regional) Cooperative Research Projects in 2022

(unit: 10,000 yuan)

Scientific Department	Applications	Grants	Direct Costs	Average Funding per Project
Mathematical and Physical Sciences	15	5	1,250.00	250
Chemical Sciences	18	5	1,290.00	258
Life Sciences	68	13	3,000.00	231
Earth Sciences	67	10	2,400.00	240
Engineering and Materials Sciences	72	11	2,750.00	250
Information Sciences	55	12	3,000.00	250
Management Sciences	17	2	506.00	253
Health Sciences	124	21	5,250.00	250
Total or average	436	79	19,446.00	246

Table 2-1-7 Application and Funding Statistics of MoU-based Cooperative Research Projects in 2022

(unit: 10,000 yuan)

Scientific Department	Applications	Grants	Direct Costs	Average Funding per Project
Mathematical and Physical Sciences	246	31	4,065.00	131.13
Chemical Sciences	229	19	2,709.00	142.58
Life Sciences	374	51	8,639.00	169.39
Earth Sciences	330	36	5,762.00	160.06
Engineering and Materials Sciences	582	45	6,864.00	152.53
Information Sciences	230	23	3,447.00	149.87
Management Sciences	158	13	2,445.00	188.08
Health Sciences	218	24	4,652.00	193.83
Interdisciplinary Sciences	77	8	1,754.50	219.31
Total or average	2,444	250	40,337.50	161.35

1.6 Young Scientists Fund

The Young Scientists Fund (YSF) supports young researchers to conduct basic research on independently selected topics within the funding scope of the National Natural Science Fund. It puts special focus on training young talents to carry out research and innovation work independently and develop innovative ideas, and cultivating new generations of talents for basic research. In 2022, the YSF was open to researchers from host institutions in the Hong Kong SAR and Macao SAR on a pilot basis. The funding mechanism and review metrics remain unchanged.

In 2022, 129,193 applications were received and 22,262 grants were approved, with a total funding amount of 6 628,000,000 yuan.

The application and funding statistics of YSF in 2022 are shown in Table 2-1-8 and Table 2-1-9. Statistics of academic titles of project PIs are shown in Figure 2-1-5, and statistics of academic degrees of projects PIs are shown in Figure 2-1-6.

Table 2-1-8 Application and Funding Statistics of the Young Scientists Fund in 2022 (by Scientific Department)

(Unit: 10,000 *yuan*)

Scientific Department	Applications	Grants	Funding Amount	Success Rate (%)
Mathematical and Physical Sciences	8,623	2,224	66,100.00	25.79
Chemical Sciences	10,739	2,042	60,490.00	19.01
Life Sciences	17,538	3,000	89,170.00	17.11
Earth Sciences	9,902	2,145	63,770.00	21.66
Engineering and Materials Sciences	21,985	3,822	113,880.00	17.38
Information Sciences	10,976	2,634	78,370.00	24.00
Management Sciences	6,972	1,075	32,140.00	15.42
Health Sciences	42,458	5,320	158,880.00	12.53
Total or average	129,193	22,262	662,800.00	17.23

Note:there were 63,115 applications from male applicants, of which 13,084 were funded; and 66,078 were from female applicants, of which 9,178 were funded.

Table 2-1-9 Statistics of Projects Funded by Young Scientists Fund by Region in 2022

(Unit: 10,000 *yuan*)

No.	Region	Application	Awards	Funding Amount	Success rate%
1	Beijing	14,341	3,361	98,710.00	23.44
2	Jiangsu	12,679	2,384	71,230.00	18.80
3	Guangdong	12,474	2,365	70,090.00	18.96
4	Shanghai	10,842	1,972	58,390.00	18.19
5	Zhejiang	8,226	1,406	42,010.00	17.09
6	Hubei	6,391	1,206	36,030.00	18.87
7	Shandong	8,355	1,205	36,050.00	14.42
8	Shaanxi	6,208	1,118	33,510.00	18.01
9	Sichuan	5,658	900	26,970.00	15.91
10	Hunan	4,262	777	23,240.00	18.23
11	Anhui	3,978	672	20,060.00	16.89
12	Henan	5,977	668	20,040.00	11.18
13	Tianjin	3,136	561	16,780.00	17.89
14	Liaoning	3,512	557	16,670.00	15.86
15	Chongqing	3,163	490	14,630.00	15.49
16	Fujian	2,536	387	11,510.00	15.26
17	Heilongjiang	1,972	373	11,180.00	18.91
18	Jilin	2,047	313	9,360.00	15.29
19	Shanxi	2,321	276	8,280.00	11.89
20	Hebei	2,115	232	6,960.00	10.97
21	Gansu	1,167	191	5,700.00	16.37

(continued)

No.	Region	Application	Awards	Funding Amount	Success rate%
22	Jiangxi	1,757	181	5,430.00	10.30
23	Yunnan	1,126	148	4,430.00	13.14
24	Guangxi	1,475	125	3,740.00	8.47
25	Guizhou	1,053	88	2,640.00	8.36
26	Hainan	673	88	2,620.00	13.08
27	Hongkong	173	70	2,100.00	40.46
28	Xinjiang	588	50	1,500.00	8.50
29	Inner Mongolia	518	50	1,500.00	9.65
30	Ningxia	280	31	930.00	11.07
31	Qinghai	164	10	300.00	6.10
32	Macao	21	7	210.00	33.33
33	Tibet	5	0	0	0
Total/average		129,193	22,262	662,800.00	17.23

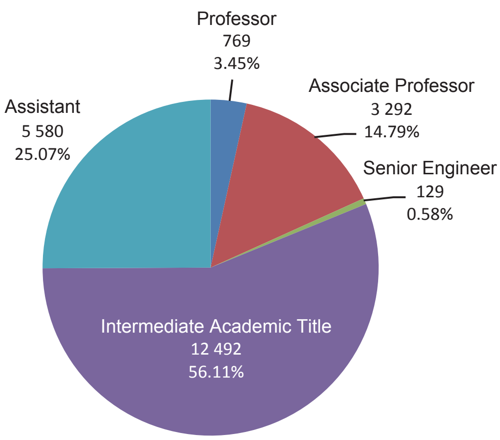


Figure 2-1-5 Academic Titles of Project PIs Funded by Young Scientists Fund in 2022

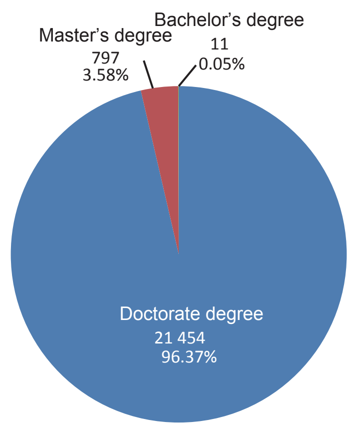


Figure 2-1-6 Academic degrees of PIs Supported by Young Scientists Fund in 2022

1.7 The Fund for Less Developed Regions

The Fund for Less Developed Regions supports researchers from host institutions in specific regions to carry out innovative scientific research within the scope of the National Natural Science Fund, cultivates and supports local scientific and technical talents, and pools together outstanding talents, so as to facilitate the development of the regional innovation system as well as its economy and society.

Statistics of application and funding of the Fund for Less Developed Regions in 2022 are shown in Table 2-1-10. Figure 2-1-7 shows the age distribution of project PIs, and Figure 2-1-8 shows the composition of project teams.

Table 2-1-10 Application and Funding Statisticsof the Fund for Less Developed Regions by Regions in 2022

(Unit: 10,000 *yuan*)

No.	Region		Applications	Grants	Direct costs	Success rate (%)
1	Jiangxi		4,631	769	25,075.00	16.61
2	Yunnan		3,534	509	16,585.00	14.40
3	Guangxi		3,633	496	16,232.00	13.65
4	Guizhou		3,346	488	16,025.00	14.58
5	Xinjiang		2,155	295	9,678.00	13.69
6	Gansu		1,908	243	7,972.00	12.74
7	Inner Mongolia		1,702	229	7,444.00	13.45
8	Hainan		1,121	192	6,294.00	17.13
9	Ningxia		979	125	4,081.00	12.77
10	Qinghai		400	59	1,931.00	14.75
11	Shaanxi	Yan'an	183	30	977.00	16.39
		Yulin	145	15	491.00	10.34
12	Jilin	Yanbian	191	23	752.00	12.04
13	Tibet		131	124	709.00	17.74
14	Hunan	Xiangxi	84	12	386.00	14.29
15	Hubei	Enshi	99	12	382.00	12.12
16	Sichuan	Liangshan	55	1	33.00	1.82
		Ganzi	1	0	0	0
		Aba	9	1	33.00	11.11
Total or average			24,300	3,521	115,080.00	14.49

Note: there were 15,234 applications from male applicants, of which 2,313 were funded; and 9,066 were from female applicants, of which 1,208 were funded.

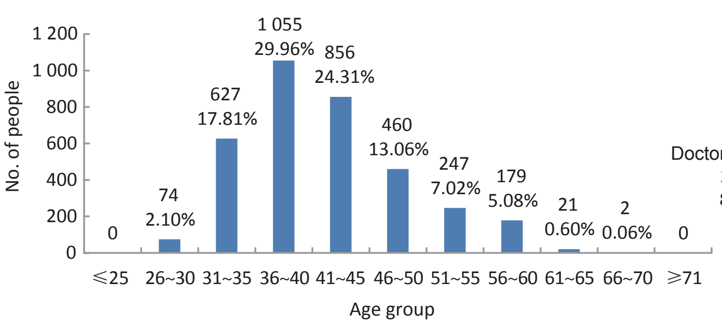


Figure 2-1-7 Age Distribution of Principal Investigators of Projects Funded by the Fund for Less Developed Regions in 2022

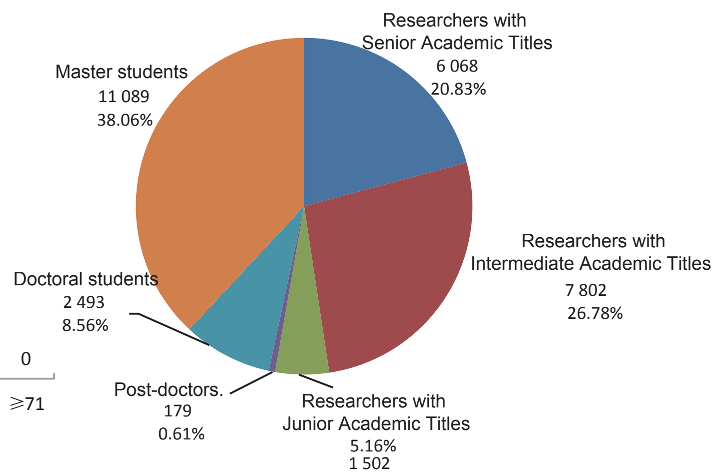


Figure 2-1-8 Research Team Composition of Projects Supported by the Fund for Less Developed Regions in 2022

1.8 Excellent Young Scientists Fund

The Excellent Young Scientists Fund supports young scholars who have achieved good results in basic research to independently conduct innovative research, promotes the rapid growth of young science and technology talents, and cultivates a group of outstanding researchers who have the potential to become leading scientists of the world.

To support the scientific and technological innovation of the Hong Kong Special Administrative Region and the Macao Special Administrative Region, to encourage high-quality scientific and technological talents from Hong Kong and Macao to participate in scientific programs supported by the central government, and to contribute to the building of China into a strong science power, NSFC continued to open the EYSF to researchers of Hong Kong and Macao in 2022.

In 2022, Excellent Young Scientists Fund received 7,099 applications. After peer review, 655 projects were approved with a funding amount of 2 million yuan per project on a contract-based appropriation model. The total funding amounted to 1.31 billion yuan.

Statistics of application and funding of Excellent Young Scientists Fund in 2022 are shown in Tables 2-1-11 and 2-1-12.

Table 2-1-11 Application and Funding Statistics of the Excellent Young Scientists Fund in 2022 (by Scientific Department)

(Unit: 10,000 *yuan*)

Scientific Department	Applications	Grants	Funding amount
Mathematical and Physical Sciences	804	71	14,200.00
Chemical Sciences	854	86	17,200.00
Life Sciences	921	86	17,200.00
Earth Sciences	772	59	11,800.00
Engineering and Materials Sciences	1,320	110	22,000.00
Information Sciences	955	90	18,000.00
Management Sciences	216	22	4,400.00
Health Sciences	830	76	15,200.00
Interdisciplinary Sciences	274	30	6,000.00
Total or average	6,946	630	126,000.00

Note: There were 5351 applications from male applicants, of which 467 were funded; and 1595 were from female applicants, of which 163 were funded.

Table 2-1-12 Application and Funding Statistics of the Excellent Young Scientists Fund for Hong Kong and Macao SARs in 2022 (by Scientific Department)

(Unit: 10,000 *yuan*)

Scientific Department	Applications	Grants	Funding amount
Mathematical and Physical Sciences	27	5	1,000.00
Chemical Sciences	14	2	400.00
Life Sciences	17	4	800.00
Earth Sciences	8	2	400.00
Engineering and Materials Sciences	26	4	800.00

(continued)

Scientific Department	Applications	Grants	Funding amount
Information Sciences	24	4	800.00
Management Sciences	13	1	200.00
Health Sciences	24	3	600.00
Total or average	153	25	5,000.00

Note: There were 127 applications from male applicants, of which 19 were funded; and 26 were from female applicants, of which 6 were funded.

1.9 National Science Fund for Distinguished Young Scholars

The National Science Fund for Distinguished Young Scholars supports young scholars who have achieved outstanding results in basic research to independently conduct innovative research, promotes the growth of young scientific and technological talents, supports overseas talents to work in China, and cultivates a group of leading scientists in the world.

In 2022, the National Science Fund for Distinguished Young Scholars received 4,612 applications. After peer review, 415 applicants were funded with an average funding of 4 million yuan per project (2.8 million yuan per project for the Departments of Mathematical and Physical Sciences and Management Sciences) on a contract-based appropriation model. The total funding reached 1.6288 billion yuan.

The application and funding statistics of the National Science Fund for Distinguished Young Scholars in 2022 are shown in Table 2-1-13.

Table 2-1-13 Application and Funding Statistics of the National Science Fund for Distinguished Young Scholars in 2022

(Unit: 10,000 yuan)

Scientific Department	Applications	Grants	Funding Amount
Mathematical and Physical Sciences	561	50	18,440.00
Chemical Sciences	610	55	22,000.00
Life Sciences	557	50	20,000.00
Earth Sciences	468	42	16,800.00
Engineering and Materials Sciences	831	75	30,000.00
Information Sciences	581	52	20,800.00
Management Sciences	139	13	3,640.00
Health Sciences	547	50	20,000.00
Interdisciplinary Sciences	318	28	11,200.00
Total or average	4,612	415	162,880.00

Note: There were 4,057 applications from male applicants, of which 359 were funded; and 555 were from female applicants, of which 56 were funded.

1.10 Science Fund for Creative Research Groups

The Science Fund for Creative Research Groups supports outstanding young and middle-aged scientists as academic leaders and research backbones, working together on an important research direction to conduct innovative research, cultivating and building a research community that has a leading role in the forefront of global science.

In 2022, a total of 333 applications were received for the Fund. After peer review, 43 groups were funded with a total direct funding of 10 million yuan per project (8 million yuan per project for the Departments of Mathematical and Physical Sciences and Management Sciences). The total direct funding reached 424 million yuan and the indirect funding was 2 million yuan per project.

Statistics of application and funding of the Science Fund for Creative Research Groups in 2022 are shown in Table 2-1-14.

Table 2-1-14 Application and Funding Statistics of the Science Fund for Creative Research Groups in 2022

(Unit: 10,000 yuan)

Scientific Department	Applications	Grants	Direct costs
Mathematical and Physical Sciences	36	5	4,800.00
Chemical Sciences	36	5	5,000.00
Life Sciences	31	5	5,000.00
Earth Sciences	44	5	5,000.00
Engineering and Materials Sciences	54	6	6,000.00
Information Sciences	48	5	5,000.00
Management Sciences	9	2	1,600.00
Health Sciences	37	5	5,000.00
Interdisciplinary Sciences	38	5	5,000.00
Total	333	43	42,400.00

1.11 Joint Funds

New progress was achieved in expanding the funding sources of the National Natural Science Fund. In 2022, the Joint Funds received 2.5145 billion yuan from the external participating partners, and the NSFC invested a matching fund of 798.5 million yuan. The total fund reached 3.313 billion yuan. Efforts were also made to explore policies and measures of receiving funds from social sectors and personal donations.

The 2022 application and funding statistics of Joint Funds are shown in Table 2-1-15.

Table 2-1-15 Application and Funding Statistics of Joint Funds in 2022

(unit: 10,000 yuan)

No.	Joint Fund	Applications	Grants	Direct costs
1	Joint Fund for Regional Innovation and Development	2,585	629	167,653.00
2	Joint Fund for Corporate Innovation and Development	676	161	50,370.00
3	NSAF Joint Fund	199	43	7,220.00
4	Joint Fund of Civil Aviation Research	83	18	3,780.00
5	"Qisun Ye" Science Fund	386	90	23,311.00
6	Joint Meteorological Fund	64	14	3,704.00
7	NSFC-CR Joint Fund for Basic Research	61	17	4,099.00
8	Geological Science Joint Fund	150	30	7,408.00

(continued)

No.	Joint Fund	Applications	Grants	Direct costs
9	Joint Fund of Yellow River Water Science Research	132	22	6,317.00
10	Seismological Science Joint Fund	41	9	2,520.00
11	Nuclear Technology Innovation Joint Fund	85	21	5,871.00
12	NSFC-Yunnan Joint Fund	278	21	4,914.00
	Total	4,740	1,075	287,167.00

1.12 The Special Fund for Development of National Major Research Instruments and Facilities

The Special Fund for Development of National Major Research Instruments and Facilities focuses on science frontier and national needs and supports the development of original scientific research instruments and core components that play an important role in promoting scientific development, exploring natural laws and opening up new research areas, thus enhancing the country's original innovation ability.

In 2022, the Special Fund for Development of National Major Research Instruments and Facilities received 642 applications from individual researchers. After peer review, 76 applications were funded with a total direct funding of 629.5572 million yuan and and average direct costs of 8.2836 million yuan per project. Another 51 applications were recommended by Ministries or institutions and 5 of them were funded after peer review, with a total funding of 423.6988 million yuan and an average direct costs of 84.7398 million yuan per project.

Application and funding statistics of the Special Fund for Development of National Major Research Instruments and Facilities applied by individual researchers in 2022 are shown in Table 2-1-16.

Table 2-1-16 Application and funding statistics of the Special Fund for Development of National Major Research Instruments and Facilities applied by individual researchers in 2022 (by Scientific Department)

(unit: 10,000 yuan)

Scientific Department	Applications	Grants	Direct costs	Average Funding per Project
Mathematical and Physical Sciences	102	10	8,294.26	829.43
Chemical Sciences	72	12	10,057.29	838.11
Life Sciences	27	2	1,592.00	796.00
Earth Sciences	74	6	4,703.71	783.95
Engineering and Materials Sciences	117	15	12,406.33	827.09
Information Sciences	177	23	19,062.34	828.80
Health Sciences	73	8	6,839.79	854.97
Total or average	642	76	62,955.72	828.36

1.13 Basic Science Center

The Basic Science Center program aims to integrate domestic research resources, target at the forefront of global science and make far-sighted investment. It relies on leading scientists, unites outstanding scientific and technological talents, promotes the deep integration of disciplines, provides long-term and steady support to researchers.It is dedicated to nurturing breakthroughs at the frontiers of science, producing a number of internationally leading original achievements, focusing on the most cutting-edge research, and form a number of academic highland with important international influences.

In 2022 the Basic Science Center program received 71 applications. After peer review, 16 projects were approved with a total direct cost of 940 million yuan.

In 2022, 3 Basic Science Center projects funded in 2016 received a second term of funding with a total direct costs of 170 million yuan.

The application and funding statistics of Basic Science Center program in 2022 are shown in Table 2-1-17.

Table 2-1-17 Application and Funding Statistics of Basic Science Center Program in 2022 (by Scientific Department)

(unit: 10,000 yuan)

Scientific Department	Applications	Grants	Direct costs
Mathematical and Physical Sciences	8	2	11,000.00
Chemical Sciences	6	2	12,000.00
Life Sciences	5	2	12,000.00
Earth Sciences	5	1	6,000.00
Engineering and Materials Sciences	15	2	12,000.00
Information Sciences	4	2	12,000.00
Management Sciences	6	1	5,000.00
Health Sciences	7	2	12,000.00
Interdisciplinary Sciences	15	2	12,000.00
Total	71	16	94,000.00

1.14 Fund for Special Purpose

The Fund for Special Purpose supports innovative research that needs fast track funding, and scientific and technological activities related to the development of the National Natural Science Fund. Special-purpose projects include research projects, scientific and technological activities projects, original exploration projects and special projects for scientific management. Research projects are to fund research on timely implementation of the national strategies related to economy, society, science and technology, or research on key scientific issues related to major emergencies, and research with strong innovation and development potentials and involving frontier scientific issues that need to be funded in time.

The S&T Activities projects are to fund strategic and policy studies, academic exchange, science communication, platform construction and other activities related to the development of the National Natural Science Fund.

Original exploration projects aim to encourage researchers to put forward original ideas, carry out exploratory and high-risk original basic research work, such as new theory, new method, and new pattern, with the purpose of making group-breaking discoveries, solving scientific challenges, driving research direction or expanding the research boundaries, thus laying a solid foundation for the high-quality development of the basic research in China.

The funding statistics of the Fund for Special Purpose in 2022 are shown in Table 2-1-18.

Table 2-1-18 Applications and Funding Statistics of the Fund for Special Purpose in 2022

(unit: 10,000 yuan)

No.	Types		Grants	Direct costs
1	Research Projects	General Research Projects of Scientific Departments	369	53,016.00
		Emergency Projects of Department of Management Sciences	43	903.00
		Theoretical Physics Research Projects	87	5,338.00
2	Scientific and Technological Activities	General Scientific and Technological Activities of Scientific Departments	237	3,373.72
		Theoretical Physics Scientific Activity Projects	15	662.00
		Shared Voyage Scientific Investigation Projects	15	6,000.00
		Projects Entrusted by NSFC Bureaus and Offices	74	3,486.00
		Special Funds for Poverty Alleviation	5	150.00
3	Original Exploration Research Projects	Original Exploration Research Projects Based on Guidelines	49	14,401.00
		Original Exploration Research Projects Based on Nomination	60	10,456.00
		Extended Original Exploration Research Projects	16	3,635.00
Total			970	101,420.72

1.15 Tianyuan Fund for Mathematics

Tianyuan Fund for Mathematics is set up to harness the collective wisdom of mathematicians, explore funding mechanism that meets the characteristics and development laws of mathematics, and promote the building of China into a mathematical power. The Tianyuan Fund for Mathematics supports researchers to conduct scientific research, nurture young talents, promote academic exchanges, optimize the research environment, and disseminate mathematics culture,in line with the characteristics and needs of mathematics disciplines, thereby improving mathematical research in China.

In 2022, the Tianyuan Fund for Mathematics received 330 applications, and 95 projects were funded with a total direct funding of 60 million yuan, and the average funding of direct costs was 631,600 yuan per project.

1.16 Research Fund for International Scientists

Research Fund for International Scientists supports foreign researchers who come to China to carry out research work on their interested topics within the scope of the National Natural Science Fund. It aims to promote the long-term and stable academic cooperation and exchange between foreign and Chinese scholars. The Research Fund for International Scientists includes three categories: The Research Fund for International Young Scientists (RFIS-I), The Research Fund for International Excellent Young Scientists (RFIS-II), and The Research Fund for International Senior Scientists (RFIS-III).

The statistics of application and funding of Research Fund for International Scientists in 2022 are shown in Table 2-1-19.

Table 2-1-19 Application and Funding Statisticsof the Research Fund for International Scientistsin 2022 (by Scientific Department)

(unit: 10,000 yuan)

Scientific Department	RFIS-I			RFIS-II			RFIS-III			Pilot GroupProgram of the RFIS-III			Total		
	Applica-tions	Grants	Direct costs	Applica-tions	Grants	Direct costs	Applica-tions	Grants	Direct costs	Applica-tions	Grants	Direct costs	Applica-tions	Grants	Direct costs
Mathematical and Physical Sciences	92	24	671.00	71	10	714.00	60	8	1,252.00	13	2	740.00	236	44	3,377.00
Chemical Sciences	113	18	516.00	58	7	520.00	41	5	800.00	29	2	740.00	241	32	2,576.00
Life Sciences	215	42	1,330.00	76	9	635.61	94	12	1,920.00	24	1	370.00	409	64	4,255.61
Earth Sciences	69	16	480.00	31	3	187.00	33	5	800.00	6	1	370.00	139	25	1,837.00
Engineering and Materials Sciences	181	29	819.00	71	9	640.00	56	7	1,120.00	16	2	740.00	324	47	3,319.00
Information Sciences	85	9	275.00	37	3	240.00	50	6	960.00	13	1	370.00	185	19	1,845.00
Management Sciences	112	6	169.00	29	3	170.00	28	3	388.00	9	1	367.00	178	13	1,094.00
Health Sciences	43	3	80.00	27	4	316.00	70	9	1,440.00	24	1	370.00	164	17	2,206.00
Interdisciplinary Sciences	56	3	100.00	23	1	80.00	35	5	720.00	15	2	740.00	129	11	1,640.00
Total	966	150	4,440.00	423	49	3,502.61	467	60	9,400.00	149	13	4,807.00	2,005	272	22,149.61

1.17 International (Regional) Exchange Program

The International (Regional) Exchange Program encourages participants of NSFC-funded projects to carry out extensive international (regional) cooperation and exchange activities during the implementation of the project under the framework of the MoU agreements between NSFC and international funding partners, improve research and innovation, talent training, and disciplinary development of on-going projects. Such projects can be divided into exchange projects based on mutual visits and academic workshop projects. The international (regional) exchange program helps researchers to deepen the understanding of international academic frontiers, develop cooperative relationship with domestic and foreign partners, and laying a good foundation for more extensive and substantial international collaboration. It also helps to increase the publicity of research results funded by NSFC and enhance the international impact of scientific research in China.

The statistics of application and funding of international (regional) exchange programs in 2022 are shown in Table 2-1-20.

Table 2-1-20 Application and Funding Statistics of International (Regional) Exchange Program in 2022

(unit: 10,000 yuan)

No.	Type	Applications	Grants	Direct costs	Average Funding per Project
1	Visits and mobilities	1,280	214	8,999.20	42.05
2	Participation at Overseas Conferences/workshops	33	14	96.70	6.90
3	Organization of International Conferences/workshops in China	82	20	306.40	15.32

2. Selected Introduction of Projects supported by the Major Research Plan of the National Natural Science Foundation of China

The Scientific Basis of Critical Metals Metallurgy

The major research plan project of *Scientific Basis of Critical Metals Metallurgy*was approved in 2022, with a direct funding of 200 million yuan for 8 years.

The supply of critical metals, especially whose support the development of clean energy and electronic information industries, has raised considerable concern. In recent years, the demand of critical metals increased sharply and how to fill the huge supply gap has become the focus of competition among major countries. This project, to guarantee the security of basic raw materials and meet national strategic demand, aims to establish a metallurgical system for ultra-normal enrichment and ultra-pure preparation of critical metals, which are highly demanded in the fields of clean energy and electronic information (Fig. 2-2-1). The project also has the objectives of breaking through the traditional reaction of bulk metal metallurgy characterized by high temperature, high pressure, high concentration, and strong agitation and form a metallurgical reaction characterized by high selectivity; revealing the primary principles and methods of ultra-enrichment and ultra-pure preparation of critical metals, and promoting the revolution of metallurgical processes intensification, meanwhile targeting on high-purity metals (alloys); forming the initial innovation capability of critical metals metallurgy.

This project intends to address the following three critical scientific issues:

(1) The rare and scattered distribution and ultra-normal enrichment mechanism of critical metal elements. The project intends to reveal the rare/scattered distribution and chemical affinity of critical metal elements, the mineralogy principle of enrichment and enrichment kinetics, and the mechanisms of critical metals' poly-molten salts separation and their ultra-normal enrichment.

(2) Deep separation of critical metals and their kinetics.The project aims to analyze the kinetic process of similar elements separation, develop a deep separation system with high selectivity based on weak interaction, and achieve the selective reduction and separation of key metals based on the reactivity-selectivity principle, molecular recognition mechanism and Nernst equation in electrochemical system.

(3) Impurity migration behavior and process control of critical metal metallurgy. This project intends to reveal the phase transition process of ultra-normal enrichment and separation of similar critical metals, as well as the structure heredity law. Concurrently, it serves to clarify the mechanism of impurity element removal and the ultra-purification process. It will also develop methods of structure control concerning critical metals' basic raw materials and processing.

The overall scientific goal of this project is to establish a metallurgical theory and system for high-purity critical metals. The expected results are: at the theoretical level, to form the basic theory of critical metal metallurgy; at the level of process breakthroughs and key technology prototypes, to promote the upgrading of critical metal metallurgical processes and industries; at the level of resource development and metal production, to boost the production of critical metals and strategic resources development; solve the problems of ultra-normal enrichment, separation and utilization of complex resources. This project also dedicates to establishing preparation processes for ultra-pure critical metals production, applied in new energy and electronics, realizing independent production and supply of ultra-pure critical metal materials and promoting the supply chain security of basic raw materials.

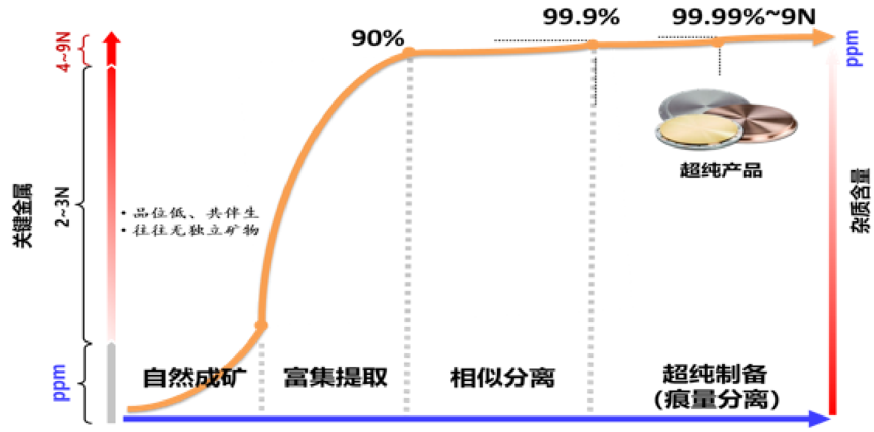


Fig.2-2-1 Metallurgical process and characteristics of critical metals

Cutting-edge Technology and Fundamental Science of Integrated Chips

The major research plan project *Cutting-edge Technology and Fundamental Science of Integrated Chips* was approved in 2022, with a direct funding of 200 million yuan for 8 years.

Integrated chips consist of a set of pre-fabricated chiplets with specific functions, integrated into systems according to applications by advanced semiconductor fabrication technologies. Different from transistor scaling, it is another path for boosting integrated circuit performance. Facing the increasingly urgent demand for high-performance chips in China's digital economy industry and the restrictions imposed by the United States on China's integrated circuit industry, this project proposes a new paradigm for developing high-performance chips with domestic technology based Integrated Chips rather than simply relying on process scaling down. Through three steps of "function decomposition", "combination design" and "physical integration", Integrated Chips with larger scale, number and variety of chiplets can be realized (Fig.2-2-2). This project will focus on the mathematic/physical basis and design methodology of Integrated Chips to address the problems brought by the substantial improvement of chiplet integration in hope of nurturing breakthroughsof China's chip industry.

This project aims to resolve the following three critical scientific problems:

(1) Chiplets' mathematical description and combinatorial optimization theory.It aims to explore new mathematical means to model the decomposition and combination process of chiplets, with a mathematical description of basic chiplet components building complex functions,establish chiplet-level optimal decomposition theory of high-performance chip system, and build high-performance, high-reusability chiplet library with mathematical abstractions.

(2) Large-scale parallel architecture of chiplet and design automation technology.It aims to explore the scalable architecture of multi-chiplet interconnection, break structural constraints of control for core-level parallelism, develop cross-layer electronic design automation (EDA) technology for 2.5D/3D integrated chips, avoiding the problem of chip design complexity increasing exponentially with scale.

(3) Chiplet granularity coupling mechanism and interface theory. It aims to clarify the complicated interface of electrical, thermal and mechanical cross-field coupling mechanisms, establish an efficient computing technology that can accurately predict the electromagnetic field, heat conduction and stress warpage of chiplets, andbreak through the 3D integration process of multiple masks, high-power thermal management technology and fault tolerance design.

The overall scientific object of this project is to address national urgent demand for integrated circuits and high-performance chips, propose a novel development path for Integrated Chips, develop mathematical theory, multiphysics theory and simulation methods for chiplet integration, multi-chiplet parallel architecture, design automation of Integrated Chips and so on. It aims to achieve a series of original achievements, promote the deep convergence of disciplines and industries' collaborative innovation, form a new paradigm of high-performance chip design based on domestic technology, and provide critical theories, methodologies, technologies and talent pipelinefor China's future integrated circuit industry.

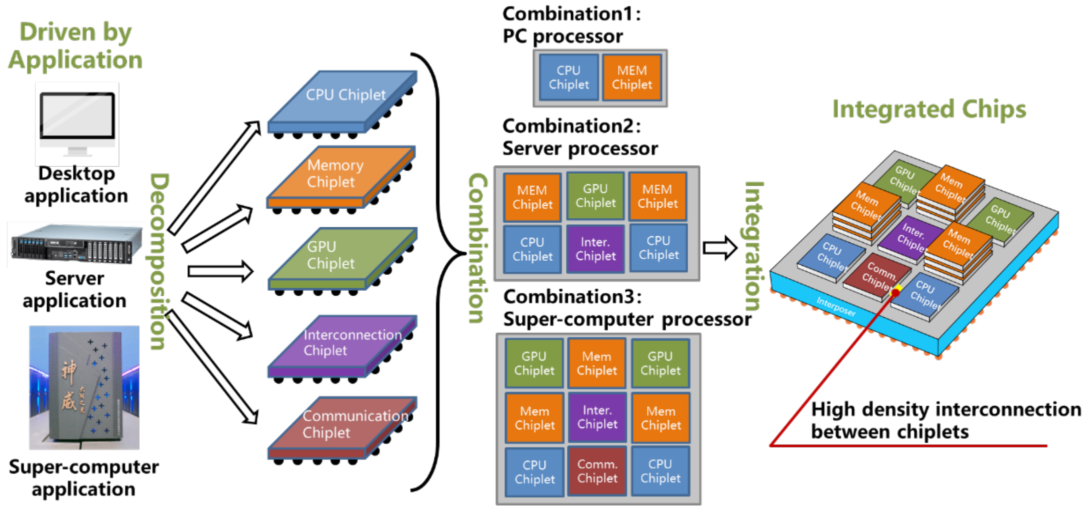


Fig.2-2-2 "Decomposition", "Combination" and "Integration" for integrated chips: taking processor chips as an example.

CN-Battery Project: Beyond Traditional Battery Systems

The major research plan project *CN(China)-Battery Project: Beyond Traditional Battery Systems* was approved in 2022, with a direct funding of 200 million yuan for 8 years.

Batteries (chemical power source) are devices for energy storage and conversion between chemical and electrical energies, mainly including primary batteries, secondary batteries (or rechargeable batteries), and fuel cells. Being a critical part of the modern energy system, batteries have been widely used in consumer electronics, electric vehicles, electrochemical energy-storage devices, unmanned aerial vehicles, and scientific facilities for aerospace, deep sea, and deep earth. This project is oriented to the "carbon peaking and carbon neutrality" strategy and the major needs of national security, and addresses the great challenges in battery resources, energy density, fast charging, safety, and environmental adaptability. This project is expected to go beyond the traditional battery systems (Fig. 2-2-3) to make breakthroughs on both low-cost high-safety energy-storage batteries and the long-life power batteries with wide working temperature range. The goals are to achieve emerging batteries with an energy density greater than 1000 Wh/kg, cycling life more than 10,000 times, and a working temperature ranging from −80°C to 80°C. These significant achievements will provide strong innovative supports to China's TWh-scale energy storage, electric transportation with ultra-long mileage, and power equipment under extreme conditions.

This project focuses on the following three key scientific issues:

(1) Unveiling the rules of ion, electron and molecule transport under coupled multi-fields, which includes extending and revising the traditional thermodynamics and kinetics in working battery systems, proposing new theories that are applicable for complex battery systems and taking into account the dynamic and complex interfaces coupled with multiple fields (including electricity, stress, thermal fields, etc.).

(2) Clarifying the rules of cross-scale and multi-structure energy-mass transfer and conversion, which includes illustrating the cooperative reaction mechanisms and structure-property relationship of active sites under multi-phase and complex micro-environments, building macro-, meso- and microscopic multi-structure evolution mechanisms on the failure of battery systems, and analyzing the carbon footprint across the life cycle of batteries and constructing related models of carbon sinks.

(3) Clarifying the interfacial mechanism and regulation strategies, which includes synthesizing advanced materials for batteries beyond traditional systems, understanding the surface and interfacial mechanisms inside the batteries, accelerating the ion and electron transport for multi-electron reactions, and uncovering the interactions, reaction processes, and kinetic laws between electrolyte and interface/surface of electrodes.

The overall scientific goal of this project is to go beyond the theoretical limitations of traditional battery systems, and better serve the major national needs in the field of electrochemical energy storage and electric transportation. Specifically, this project seeks to make breakthroughs in the following aspects:

(1) Theorizing the complex interphase referring to porous electrodes, dynamic processes, and concentrated electrolyte, which replaces the current simple models based on flat electrodes, static interactions, and dilute electrolytes;

(2) Putting forward a metal deposition-dissolution mechanism to replace the ion insertion-extraction mechanism of current power batteries;

(3) Proposing non-resource-limited sodium-based organic batteriesas substitutes for present electrochemical energy storage devices such as Li-ion batteries and redox flow cells;

(4) Establishing a new paradigm based on large-scale scientific facilities, big-data-driven approaches, and carbon footprints across the lifecycle of batteries to replace the current ex-situ characterizations and trial-and-error learning.

By innovations in theories, mechanisms, materials, and paradigms through cross-disciplinary integration of chemistry, energy, materials, physics, mathematics, engineering, life science and etc., the project seeks to establish a comprehensive innovation chain from resource extraction and material preparation to system design, battery management, and recycling utilization. This project aims to achieve major breakthroughs in forward-looking fundamental researches and encourage researchers to explore cutting-edge scientific discoveries that no one has achieved, contribute to the national goal of carbon peak and carbon neutralization and scientific and technological self-reliance of China.

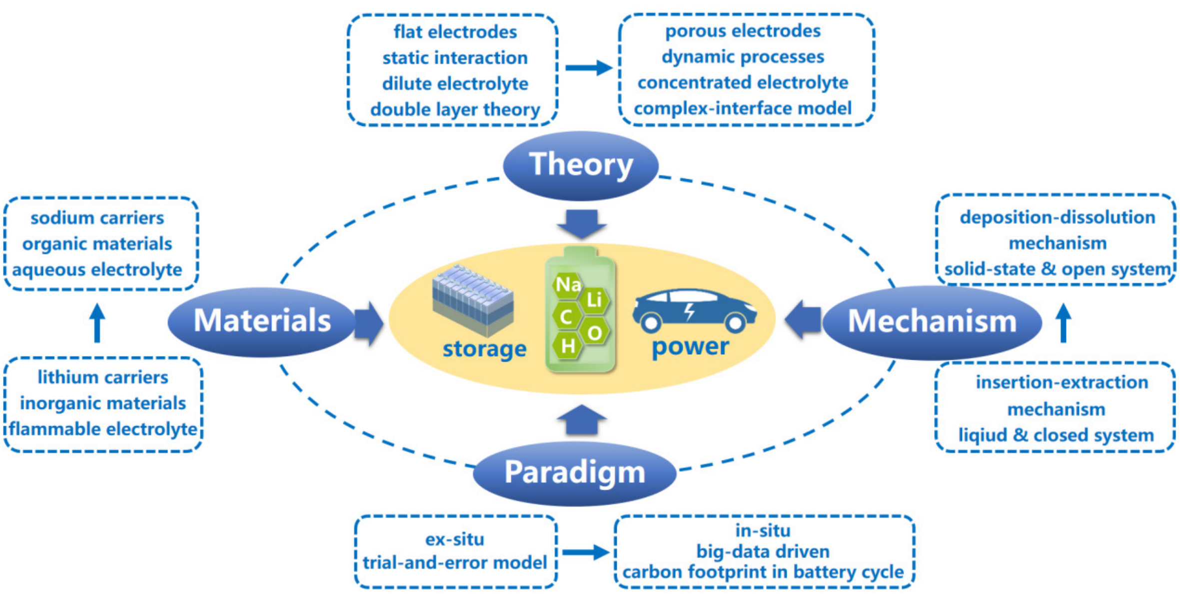


Fig.2-2-3 Research roadmap of the CN-Battery Project

The Immunity Deciphering Project

The major research plan project *the Immunity Deciphering Project* was approved in 2022, with a direct funding of 200 million yuan for 8 years.

Immunity is the sum of body's forces of immune system to ensure normal function, protect the body from pathogenic invasion and maintain homeostasis. As a crucial part of immunity, the T/B lymphocytes can number in the trillions. One basis of this T/B lymphocyte diversity is the highly variable combinations of the four bases of ATGC in a specific region of the genes encoding the receptors (TCR/BCR). These combinations also record major physiological and pathological events in life courses. Existing biotechnology is capable of collecting information and digitally present immune diversity. The project aims to decipher the connotation of the immune diversity codes of severe diseases and their different stages, such as tumors, and thus to provide new approaches for the diagnosis and treatment of diseases. Since immune perception can sense the earliest signal of disease, capturing immune signal of severe diseases may provide much earlier warning than the currently-used clinical detection methods such as magnetic resonance and CT, which could provide a theoretical innovation for the technology improvement of clinical diagnosis and treatment.

This project aims to address the following four key scientific problems:

1. The quantification and evaluation of immunity.By sequencing immune signature data and analyzing and modeling individual immune signatures from millions of molecules using artificial intelligence and other digital modeling methods, the project seeks to evaluate and visualize immunity and health status at the individual level. How to identify the essential principles of the immune signature molecular changes, and how to construct accurate and effective immune profiling technologies through digital modeling methods such as artificial intelligence, are key issues to be resolved.

2.The recognition of ectopic immune signals in the very early stage of disease. Most severe diseases are asymptomatic at early stages, making the diagnosis difficult by traditional techniques. The immune system can response to the pathological signals in the early stage of diseases, therefore it is possible to detect and analyze the immune response signals of early diseases by accurately describing and analyzing individual immunity characteristics. This may determine the early immune response signals of diseases and provide technical supports for early warning of severe diseases.

3.The mechanism by which immune characteristics determine the occurrence and progression of diseases. Immunity is closely related to the occurrence and progression of severe diseases such as tumors, autoimmune diseases, and infections. By deep learning and other advanced methods, the project seeks to depict the characteristics of individual immunity and explore the effects of diversities of immune molecules on the occurrence and progression of severe diseases. It may reveal the underlying principles of diseases by interpreting the internal relationship between individual immune diversity and the occurrence and progression of severe diseases, and thus to reveal the underlying principles of disease occurrence and progression.

4. The depiction of the age and health status of individuals by deciphering immunity.

The speed of aging is different for individuals, and the chronological age cannot accurately reflect the biological age. The aging of immune system is a key attributor to the aging of the body, and the aging process is also accompanied with process of immunity degeneration. Therefore, by developing technologies for in-depth analysis and digital presentation of immunity, it is possible to detect an individual's "immune age" and the aging process accurately.

The overall scientific goals of this project are as follows: (1) to establish immune big data with high quality and standardization consisting of immune signature data, clinical data, and other relevant information of both healthy individuals and patients with multiple diseases. (2) On the basis of big data of immunity, to establish a characteristic profile of immunity through mathematics and artificial intelligence, and interpret the correlation between immunity characteristic profile and severe diseases. (3) to establish immunity-based and disease-predicting technology, immunity visualization technology and immune age detecting technology, etc. (4) to establish new paradigms for disease prediction, prognosis assessment, precision medicine and health management by immunity profiles (Fig. 2-2-4).

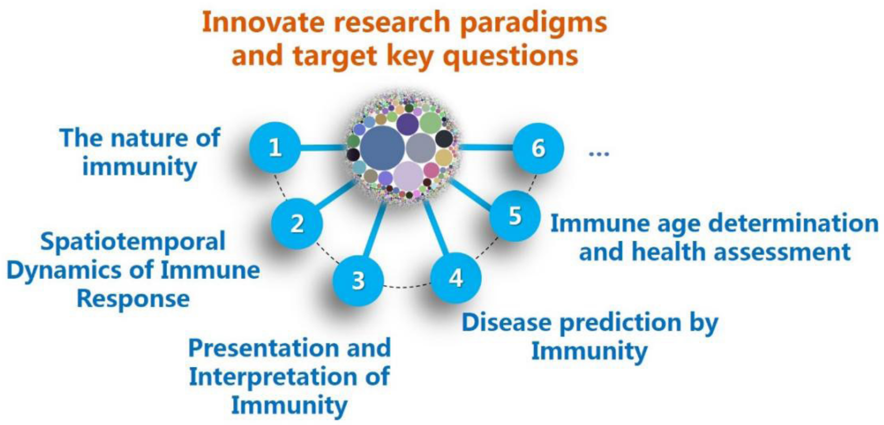


Fig. 2-2-4 Schematic diagram of the Immunity Deciphering Project

PART 3

Funding Achievement Tour

NSFC

The Mathematical Theory and Scientific Applications of Machine Learning

Under the support of the National Natural Science Foundation of China (Major Research Plan Project 91130005, 91530322), Prof.Weinan E of Peking University and his team has made major advances in the mathematical theory and scientific applications of machine learning.

Around 2015 and 2016, E first recognized that deep neural networks may provide a general tool for approximating functions in high dimension. This motivated E to initiate a fundamental research program in three directions. Firstly, the mathematical theory of neural network-based machine learning, the main purpose of which is to develop the approximation theory and study the generalization error of neural network-based machine learning models. Secondly, efficient algorithms for high dimensional problems in scientific computing. In 2016, E and Jiequn Han developed a deep learning-based algorithm for high dimensional stochastic control problems. This is the first algorithm of such kind for high dimensional problems in scientific computing. In 2017, E and collaborators proposed the first deep learning-based algorithm for solving high dimensional partial differential equations. Thirdly, E was the earliest to propose the idea of "AI for Science" and has led a program to systematically explore the application of deep learning in chemistry, material science, biology, and fluid mechanics.

E is a pioneer on developing deep learning-based algorithms in multi-scale modeling. He and his collaborators have made fundamental breakthroughs in several areas including the quantum many-electron problem, density functional theory, molecular dynamics, kinetic theory and continuum mechanics. The DeePMD model developed by E and collaborators is now widely used by researchers in chemistry, physics, material science and biology. For the quantum many-body problem, E and his collaborators developed the first deep learning-based algorithm for the quantum many-electron problem, DeePWF. In density functional theory, E and collaborators developed the first general deep learning-based model DeePKS. In fact, for almost all the commonly used physical models, E and collaborators have led the effort on developing deep learning-based algorithms and models.

E is awarded the 2023 Maxwell Prize by the International Council of Industrial and Applied Mathematics "for his seminal contributions to applied mathematics and in particular on analysis and application of machine learning algorithms, multi-scale modeling, the modeling of rare events and stochastic partial differential equations". E is a plenary speaker at the 2022 International Congress of Mathematicians. E is also the opening keynote speaker at the 2022 International Conference on Machine Learning.

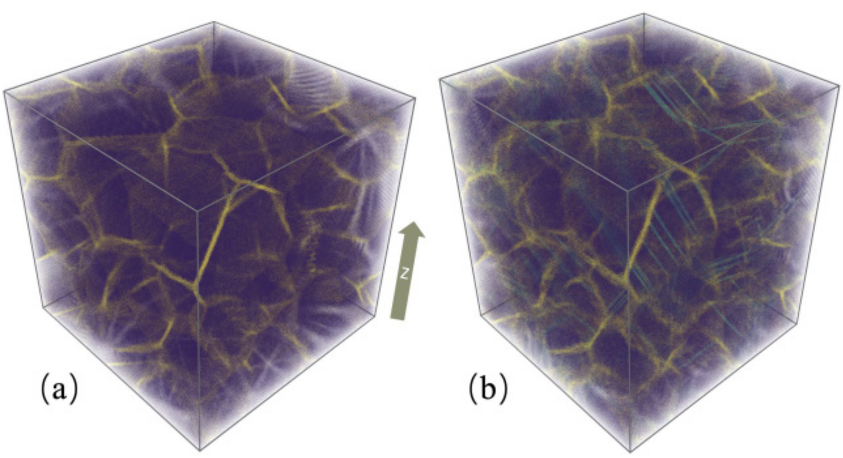


Fig 3-1-1 10,401,218-atom DeePMD simulation of nanocrystalline copper consisting of 64 randomly oriented crystals. Left: without stress; Right: 10% tensile deformation along the z axis. Grain boundaries and stacking faults can be clearly seen.

Manipulation for the Interfacial Instability Induced by a Shock Wave

Under the support of the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars 11625211, Major Research Plan 91952205), Prof. Xisheng Luo and Dr. Yu Liang from the University of Science and Technology of China revealed that the instability of a shocked gas layer presents a notable difference from the classical Richtmyer-Meshkov (RM) instability. The coupling between the multiple interfaces of a gas layer and the reverberating waves reflected inside the layer are highlighted. The study is the first to propose to control the interfacial instability by manipulating the interface-coupling and the reverberating waves inside a shocked fluid layer. They have published four papers in the *Journal of Fluid Mechanics*. Prof. Luo was invited to present a talk (50 minutes) at *the International Colloquium on Shock Waves* in December 2021.

When an interface separating two fluids is accelerated by a shock wave, the perturbation on the interface grows, and the turbulent mixing might finally be induced. This complex interface instability phenomenon is called RM instability. On the one hand, RM instability involves major scientific problems such as shock dynamics and turbulent mixing. On the other hand, it plays a vital role in many applications, including Inertial Confinement Fusion (ICF), scramjet, and astrophysics. Notably, a typical ICF capsule contains an outer-ablator-layer, a middle-push-layer, and an inner-fuel-layer. The turbulent mixing of these multiple layers induced by RM instability is considered to lead to the failure of fusion reaction in ICF. Therefore, understanding the hydrodynamic instabilities of shocked multiple interfaces is substantial.

The shock tube experiment can provide accurate information on the RM unstable flow. Since RM instability is extremely sensitive to initial conditions, generating a gas interface with controllable initial conditions becomes a critical technical obstacle. The researchers adopted the constrained soap film technique to create gas interfaces with controllable initial conditions. They experimentally investigated the shock-induced dual-layer, single-layer, and single-interface evolutions in a shock tube (Fig. 3-1-2). Based on the linear stability analysis and the gas dynamics theory, the interface-coupling effect and the reverberating waves effect on the interfacial instability are quantified, respectively. According to international scholar comments, "The conclusion that a heavy/light dual-layer has the potential to suppress the hydrodynamic instabilities in ICF is interesting and will stimulate further research and discussion on this topic."

Further, the researchers formed a gas layer with arbitrary gas combinations with controllable initial perturbations and thicknesses. They carried out a series of shock-induced gas layer evolution experiments with various gas combinations (Fig. 3-1-3). The results indicate that the interfacial instability can be effectively controlled by carefully choosing the gas layer thickness and the gases inside and outside the layer, thus providing valuable suggestions for the ICF capsule designs. For example, the rarefaction waves strongly destabilize the upstream interface of a heavy gas layer; therefore, the heavy gas layer is unsuitable for the ICF capsule designs. However, due to the stabilizing effect of the interface-coupling, the light/medium/heavy gas layer is ideal for the ICF capsule designs. International scholar comments, "The experimental schlieren pictures and schematics convey the complexity of wave dynamics. Experimental results are supported and verified by complex mathematical models."

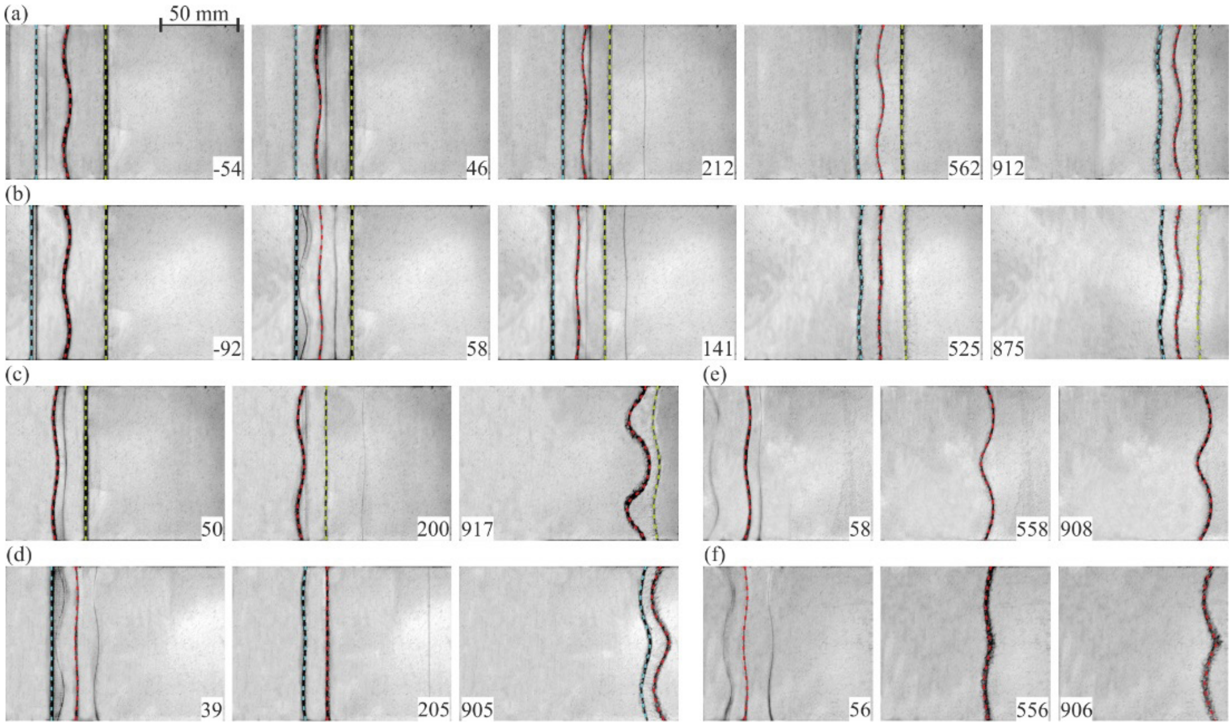


Fig 3-1-2 Schlieren images of the shock-induced gas layer evolution: (a)-(b) dual-layer, (c)-(d) single-layer, (e)-(f) single-interface. Numbers indicate time with a unit of μs.

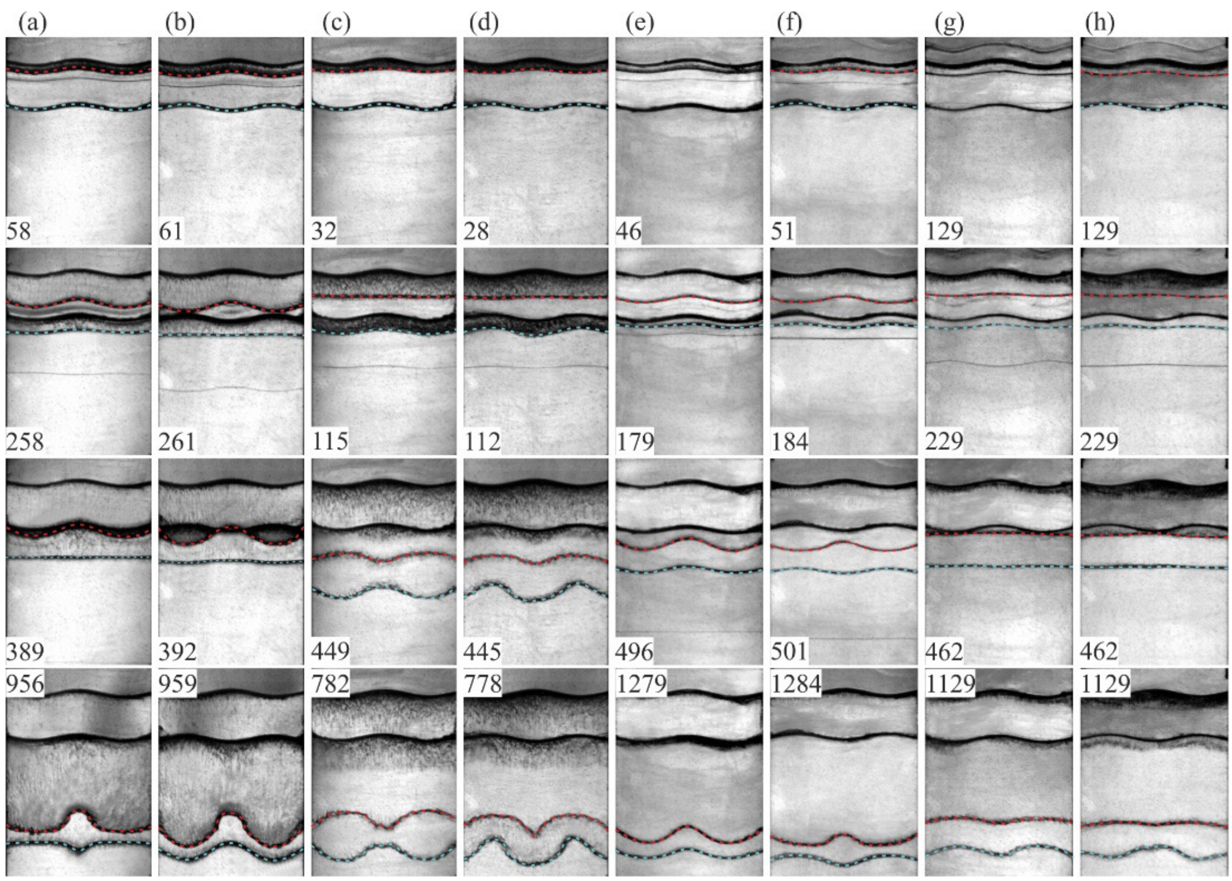


Fig 3-1-3 Schlieren images of the shock-induced single-layer evolution: (a)-(b) heavy gas layer, (c)-(d) light gas layer, (e)-(f) light/medium/heavy gas layer, (g)-(h) heavy/medium/light gas layer.

Precise Measurement of the Polarized Radiation in the Radio Universe using FAST

Supported by the National Natural Science Foundation of China (Basic Science Center Program 11988101, Special Fund 12041304, National Science Fund for Distinguished Young Scientists11725313), research teams from National Astronomical Observatories of the Chinese Academy of Sciences (NAOC), Peking University, and other collaborating institutes, have achieved precise characterization of radio Universe's polarization, using the Five-hundred-meter Aperture Spherical radio Telescope (FAST).

Prof. Li Di from NAOC proposed the world's first pulsar-HI simultaneous survey mode, which multiplies the survey efficiency of FAST. Based on this novel concept, "The Commensal Radio Astronomy FAST Survey (CRAFTS)" has become one of the key projects approved by the FAST Science Committee. CRAFTS discovered the world's first persistently active repeating Fast Radio Burst (FRB), namely FRB20190520B, which possesses the largest environmental density among all known FRBs (Fig. 3-1-4), representing a significant advance in multi-band characterization of FRBs (Fig. 3-1-5). This work was published in *Nature* on June 2022. Prof. Lee Kejia and the key program team obtained the largest FRB polarization sample based on FAST observations of FRB20201124A that suggest a changing magnetic environment local the source. This work was published in *Nature* on September 2022. Based on these significant data sets, Dr. Feng Yi, a PhD candidate in NAOC (now a staff scientist in Zhejiang Laboratory), proposed a unified mechanism to depict

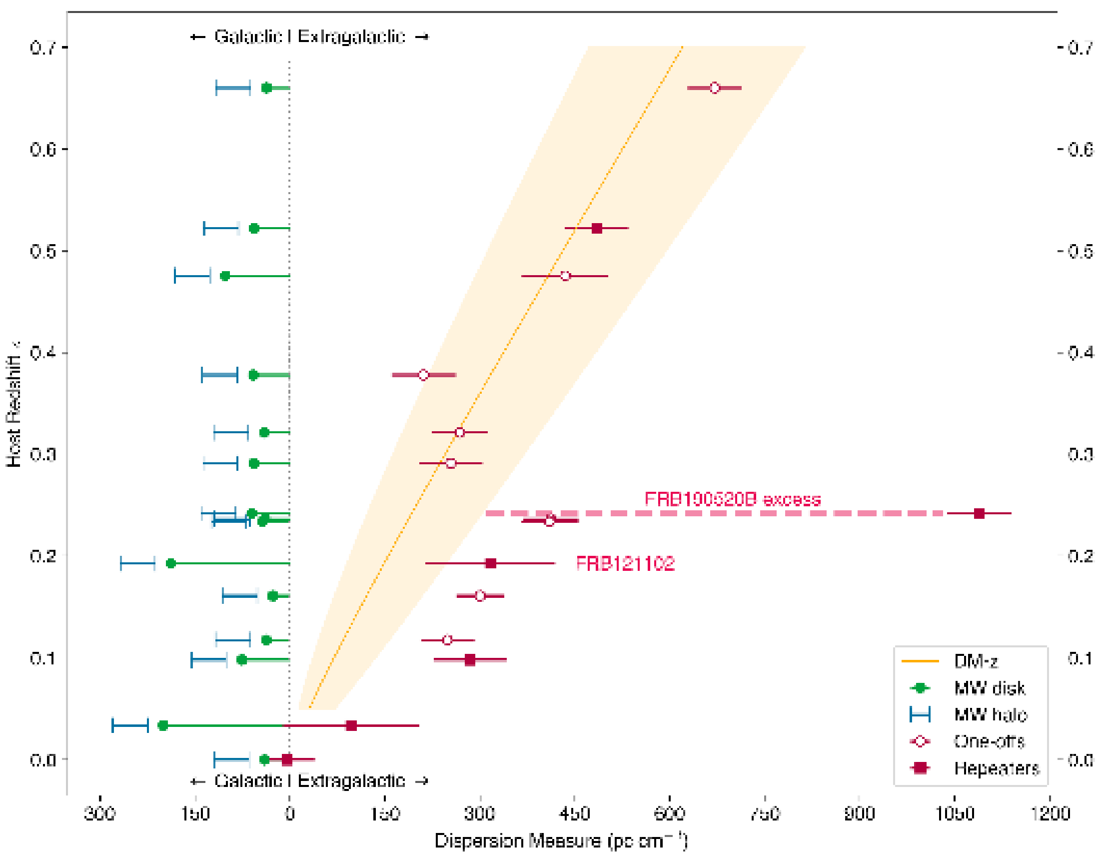


Fig 3-1-4 Dispersion measure (electron density) versus redshift for localized FRBs (also known as the "Macquart relation". The environmental electron density of FRB20190520B far exceeds all other FRBs and thus deviates severely from the Macquart relation.

the frequency evolution of FRBs' polarization, which is a critical step in understanding the core physical process of FRBs. This work was published in *Science* on March 2022.

This series of significant works attest to FAST's advantage in polarization characterization, which was further utilized to measure the interstellar magnetic field. Prof. Li Di named HI Narrow Self-Absorption (HINSA, a tracer of cold atomic hydrogen) and led the team to achieve the first successful HINSA Zeeman detection with FAST. Published as an *Nature* cover article in January 2022, this result lays the foundation for solving the classical "magnetic flux" problem in the field of star formation and was hailed by independent experts as "extremely important" (invited perspective on *Nature*) and "revolutionary" (news report on *Science*).

Fig 3-1-5 Artist impression of the multiband observation of FRB20190520B. The Chinese thundering god represents the mysterious source of FRB20190520B, who gives out real pulse profiles as detected by FAST. The telescopes utilized in this paper are located in China, the islands of Hawaii, and the continental United States.

A Universal Quantitative Relationship for High-temperature Superconductors Unveiled by Materials Genome Technique

The microscopic mechanism of high-temperature (high-T_c) superconductivity is one of the most challenging problems in condensed-matter physics. When superconductivity is suppressed, the normal state of high-T_c superconductors usually exhibit strange-metal behaviors, e.g. the linear-in-temperature (T-linear) dependence of resistivity (from high temperatures to the zero-temperature limit). It has been recognized a decade ago that there is a close link between superconductivity and the strange metallicity, and the community yearns for scaling laws. However, owing to complex structural and electronic properties high-T_c superconductors, it is a great challenge to accumulate enough reliable data for a quantitative expression by traditional synthesis and characterization methods. Therefore, advanced techniques are highly desired to achieve single-parameter tuning and meanwhile with high efficiency and precision. Supported by the National Natural Science Foundation of China (Special Fund on Research for National Major Research Instruments 11927808, Basic Science Center Program 11888101, Key Program 11834016), a research team led by Prof. Kui Jin and Prof. Jianping Hu at the Institute of Physics, Chinese Academy of Sciences and their collaborators have made important progress in quantifying the paradigm between high-

T_c superconductivity and strange metallicity employing the materials genome experimentation technique. The main innovative results are as follows: 1) A combinatorial film fabrication technique was developed to achieve a fine control of the chemical composition on 1 cm^2 $SrTiO_3$ substrate. With this technique, the research team synthesized single-crystal $La_{2-x}Ce_xCuO_4$ combinatorial films with Ce content varying continuously from 0.10 to 0.19 (Fig. 3-1-6A). 2) With multiscale structural and transport characterizations (Fig. 3-1-6B), the doping resolution was improved by two orders of magnitude (from 10^{-2} to 10^{-4}), and consequently, a quantitative relationship between the coefficient of the *T*-linear resistivity A_1 and T_c was established, namely $A_{10.5} \propto T_c$ (Fig. 3-1-6C).

The above research entitled "Scaling of the Strange-metal Scattering in Unconventional Superconductors" was published in *Nature* on Feb 16, 2022. This work is a prototype of interdisciplinary approach between the materials genome initiative and the high-T_c superconductivity research. Experts highlighted this "tour de force" technique and the results as "the key empirical laws that can be tested against existing or subsequent microscopic models". The research team successively employed an ionic-liquid gating technique to continuously tune charge carrier density, and unveiled the validity of $A_{10.5} \propto T_c$ in an FeSe superconductor, strongly suggesting that the unconventional superconductivity and the strange metallicity are likely driven by the same microscopic mechanism. Meanwhile, they have successfully applied the advanced film technique on fabrication of FeSe-FeTe system and established the phase diagram in details (published in *Science Bulletin* in 2022).

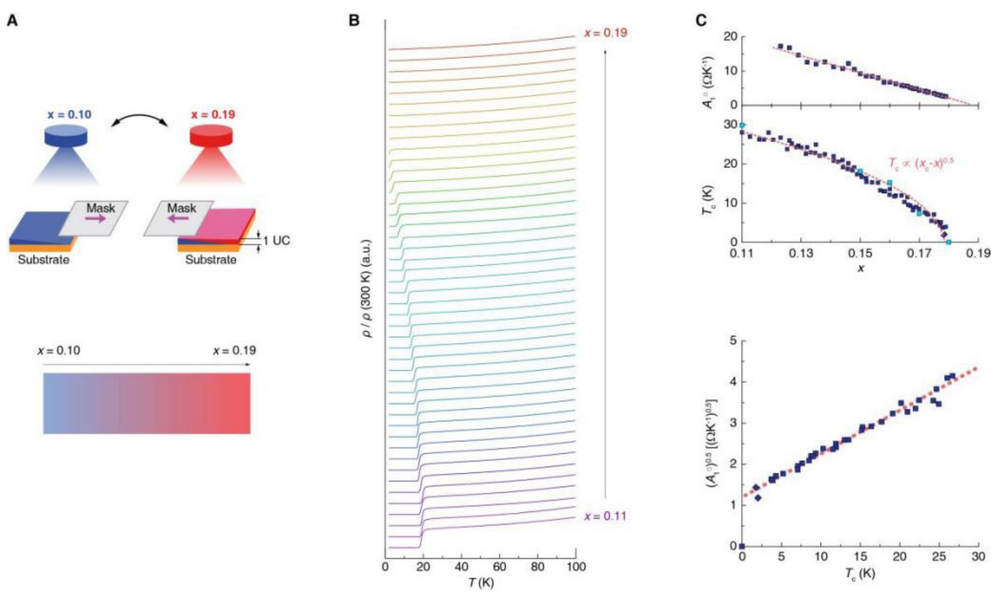


Fig 3-1-6 A common quantitative relationship between high-T_c superconductivity and strange metallicity
A. Schematics for the $La_{2-x}Ce_xCuO_4$ combinatorial film fabrication. B. Temperature dependence of resistivity for different chemical compositions. C. The quantitative relationships among transition temperature (T_c), coefficient of *T*-linear resistivity (A_1) and chemical doping (x)

Chiral Emission from Resonant Metasurface

Ultracompact circularly polarized light sources are crucial for classical and quantum optical information processing and have been intensively explored in the past decade. Conventional approaches utilizing chiral materials or chiral cavity typically produce low coherent light emissions with large divergence angles and low degree of circular polarizations (DOP). The chiral microlasers, however, are restricted to a particular power range and their DOPs plummet dramatically below threshold. Recently, supported by the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars 12025402, 62125501, Key Program 11934012), a team led by Prof. Qinghai Song at Harbin Institute of Technology collaborated with Prof. Yuri Kivshar from Australia National University has made important breakthrough in the chiral light emission. By employing the physics of bound states in the continuum (BICs), both the chiral spontaneous emission and chiral lasing with large DOP, high directionality, and high-quality factor have been achieved from the same resonant metasurface. The main innovations are as follows:

(1)The evolution of polarization singularity in momentum space as a function of structural symmetry has been theoretically revealed (Figure 3-1-7A-C). By simultaneously controlling the in-plane asymmetry and the out-of-plane asymmetry of meta-atoms, the position of half-integer topological charge polarization singularity in momentum space can be precisely manipulated for the first time, enabling the chiral quasi-BICs with maximum intrinsic chirality.

(2)A slanted reactive ion etching (RIE) process has been developed for TiO_2 nanostructures. The slant angle of TiO_2 nanopillar can be precisely adjusted in an angle range from 0° to 45°, with a tiny deviation below ±0.5°. Based on the high precision RIE process, a metasurface with ell-defined in-plane and out-of-plane asymmetry was fabricated (Figure 3-1-7D). As a result, chiral quasi BICs with circular dichroism of 0.925±0.03 and quality factor > 1000 was experimentally achieved.

(3)The mechanism for full control of light emission has been proposed and experimentally confirmed. By combing the chiral quasi-BIC and the band structure of photonic crystals, it is shown that the density of states of two circularly polarized states can be enhanced and suppressed, respectively. Consequently, both chiral spontaneous emission (Figure 3-1-7E) and chiral laser (Figure 3-1-7F) are achieved in experiment. The corresponding DOP and divergence angle are ~0.98. and 1.06°, breaking the conventional limitations of circularly polarized light sources.

On Sep 9th 2022, the above research progress was published online in *Science*, entitled with "Chiral Emission from Resonant Metasurface". This work demonstrates for the first time a chiral quasi-BIC in experiment, providing a new strategy for manipulating the spectrum, far-field modes, and angular momentum of light in a large range from photoluminescence to lasing. This approach may improve the design of current compact chiral light sources and boost their applications in photonic and quantum systems.

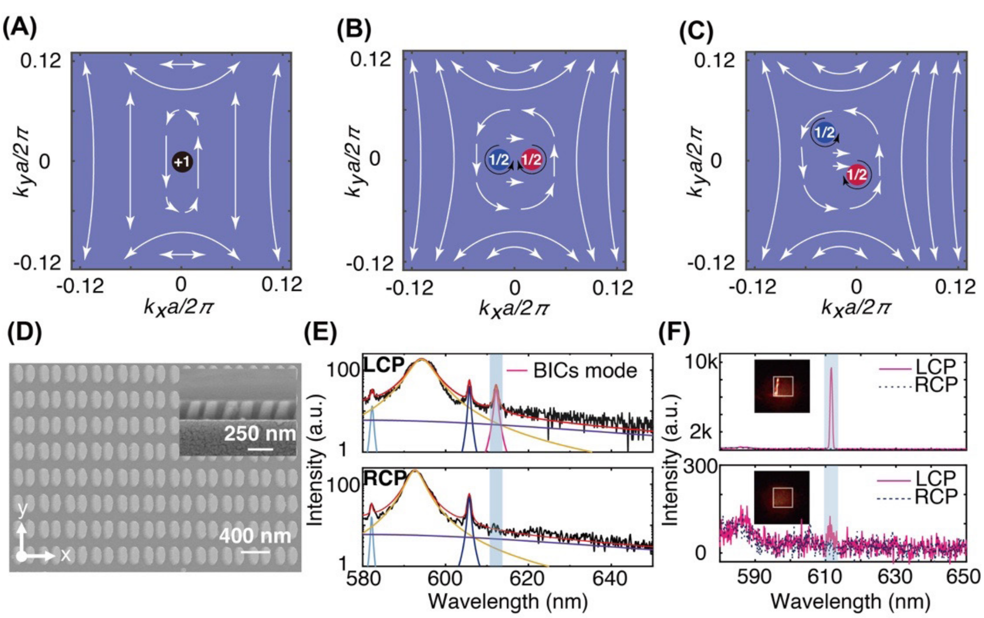


Fig 3-1-7 BICs polarization singularity evolution in momentum space and chiral emission generation

China Jinping Underground Laboratory Opens a New Era of Nuclear Astrophysics Studies

In 2014, Australian astronomers observed an oldest star (SMSS0313-6708) in the universe, which was born about hundred-million years after the Big Bang, and it was composed of a nebula formed by the supernova explosion of the first generation of stars. Lithium, carbon, magnesium and calcium have been observed, but the origin of calcium has been a mystery. According to the stellar models, these calcium elements may come from the break-out reaction of the hot carbon nitrogen oxygen (CNO) cycle, but there are few experimental data to support the hypothesis. Therefore, it is difficult to explain the observed data by the current stellar evolution models. Due to the interference of cosmic-ray background in the above-ground laboratory, scientists have been unable to directly measure these break-out reactions of extremely small cross sections. China Jinping Underground Laboratory (CJPL) is the deepest operational underground laboratory for particle and nuclear physics experiments in the world, with a vertical rock overburden of 2400 meters. CJPL offers a great reduction in the cosmic-ray fluxes by six orders of magnitude, compared to those at the Earth's surface.

Under the support of the National Natural Science Foundation of China (National Science Fund of Distinguished Young Scholars 11825504 and Major Researh Plan 11490560), professor He Jianjun's team from Beijing Normal University, under the Jinping Underground Nuclear Astrophysics experiment (JUNA) collaboration, directly detected the CNO break-out reaction of fluorine-19 proton radiative capture in low energy region of astrophysics interest, and achieved the following major innovative achievements:

(1) The break-out reaction was successfully pushed to the Gamow window of the first generation stars, and a new resonance was found at 225 keV (Figure 3-1-8). At the temperature of 100 million Kelvin(K), the discovery of this new resonance makes the targeted reaction rate about 7 times higher than the previously NACRE's recommended one, and reduces the error from several orders of magnitude to about 50%.

(2) The stellar model calculation shows that the probability of this reaction breaking out of the CNO cycle is about 7 times higher than previously expected, revealing the mystery of the origin of the calcium

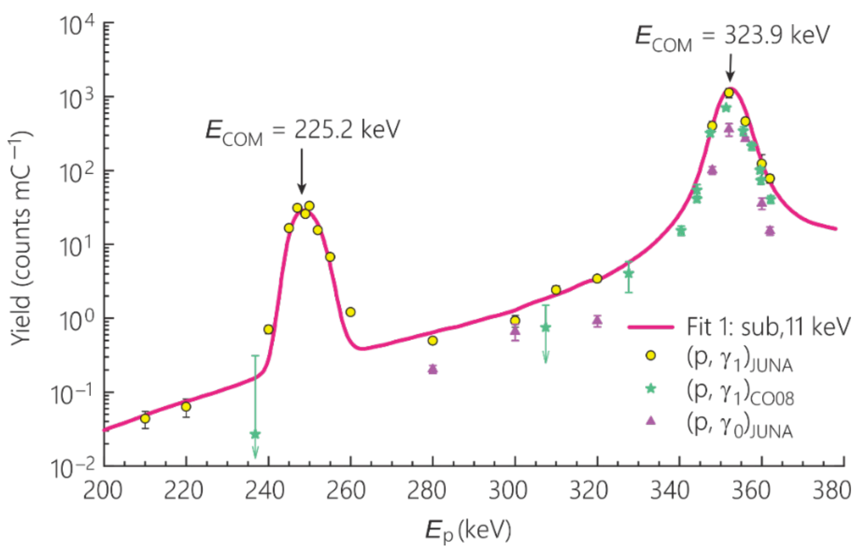


Fig. 3-1-8 Yield curve of fluorine-19 proton radiative capture reaction. The new resonance found is located at 225.2 keV. The label of JUNA represents the JUNA data.

element observed in the extremely metal poor star (SMSS0313-6708), which strongly supports the faint supernova model of the first generation stars. This work provides reliable nuclear-physics input for studying the future observation targets of the James Webb Space Telescope (JWST).

The above research results were published in *Nature* on October 27, 2022, under the title of "Measurement of $^{19}F(p, \gamma)^{20}Ne$ Reaction Suggestions CNO Break Out in First Stars", and were commented positively in the News & Views section of *Nature*. The reviewer of *Nature* believes that "this is a great experimental success, which provides a new way for future nuclear astrophysics research". John Mather, the winner of the 2006 Nobel Prize in Physics and the chief scientist of JWST, sent a letter of congratulations, saying, "Congratulations on your new measurements. I think they are quite important". As one of the first achievements of the JUNA experimental facility, the successful implementation of the $^{19}F(p, \gamma)^{20}Ne$ experimental campaign proves that JUNA has fully possessed the capability to conduct deep underground nuclear astrophysics studies.

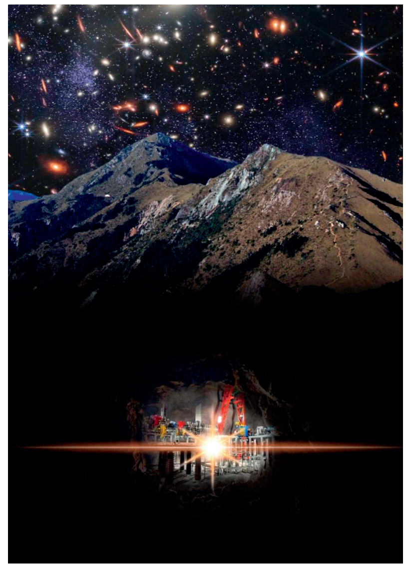


Fig. 3-1-9 Explore the mystery of the universe in the world's deepest lab (an Art picture)

The Deracemization via Photo-Induced Isomerization of Enamine

Chirality is an essential structural feature in nature's matters ranging from small molecule to macroscopic physical world. Chiral molecules formulate the material basis for the colorful living world characteristic of homochirality and hence also become indispensable across biology, medicine, materials, information and other disciplines. Therefore, the precise construction of chiral molecules has always been the forefront of synthetic chemistry. The most ideal method of chiral molecular construction is to directly convert the racemate into corresponding optically pure compound, obtaining the target chiral molecule with 100% yield. This process is called as deracemization (Fig. 3-1-10A). However, this ideal pathway is endergonic, which is thermodynamically disfavored and is also against the kinetic principle of microscopic reversibility. How to break the thermodynamic and kinetic barriers and develop efficient deracemization strategy is a challenging problem in asymmetric synthesis.

Supported by the National Natural Science Foundation of China (Major Research Plan 91956000, Key Program 22031006, International (Regional) Cooperation and Exchanges Program 21861132003), the team of Prof. Luo Sanzhong, Center of Basic Molecular Science, Department of Chemistry, Tsinghua University, has developed a new method for chiral molecule synthesis based on their previously studies of asymmetric enamine protonation process. They merged primary amine catalysis with visible light photocatalysis and realized deracemization of α-aryl aldehydes with excellent enantioselectivity (Fig. 3-1-10B). Photochemical equilibrium could be achieved within 1 hour to accomplish efficient deracemization under rather mild conditions. The reaction can be applied to aldehydes bearing either electron withdrawing group, electron donating group, alkyl group, polar functional group, natural product fragment or heterocyclic moiety, showing broad scopes. The developed protocol could be easily scaled up and successfully applied in the synthesis of chiral nonsteroidal anti-inflammatory drugs. The team clarified the mechanism of deracemization based on systematic experimental investigation and theoretical calculation. The deracemization was driven by a distinctive photoinduced E/Z isomerization of enamine intermediate (Fig. 3-1-10C). The research results were published in *Science* on February 25, 2022, entitled "deracemization through photochemical E/Z isomerization of enamine". This research paves a new way in the construction of chiral molecules.

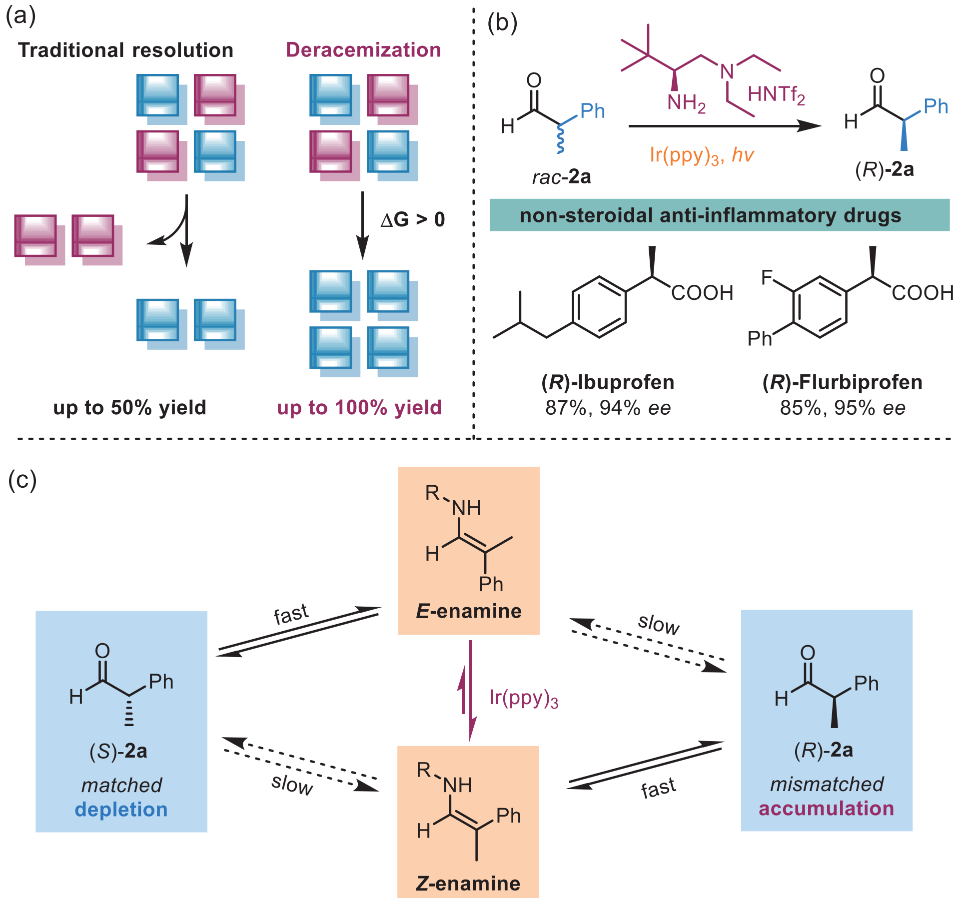


Figure3-1-10 (a) diagram of deracemization; (b) deracemization reaction catalyzed chiral primary amine; (c) proposed mechanism

Imaging the Holistic Evolution of Charge Transfer in a Single Photocatalyst Particle

Supported by the National Natural Science Foundation of China (Basic Science Center program 22088102), Prof. Can Li and Fengtao Fan's group in Dalian Institute of Chemical Physics, Chinese Academy of Sciences, reports an advance in the tracking of holistic evolution of charge transfer in a single photocatalyst particle, and complex charge transfer mechanisms were revealed. The team published their results in *Nature*, entitled"Spatiotemporal Imaging of Charge Transfer in Photocatalyst Particles".

Photocatalysts can utilize sunlight to produce hydrogen from water splitting and to produce solar fuels through CO_2 reduction. Photoinduced charges transfer and transport in photocatalysts, and from bulk to surface reaction sites is the key to determining the photocatalytic efficiency. However, it is challenging to understand the mechanisms which span a wide spatiotemporal range from sub-nanometers to micrometers and from femtoseconds to seconds. By combining three different methods, time-resolved photoemission microscopy (femto- to nanoseconds), transient surface photovoltage spectroscopy (nano- to microseconds), and surface photovoltage microscopy (microseconds to seconds), the entire mechanism of electron and hole to surface reaction centers in a single photocatalyst particle was thoroughly studied.

By precisely tuning the types of defect structures that form on the different facets, the researchers produced particles that preferentially accumulate negatively charged electrons and positively charged holes on {001} and {111} facets, respectively, under excitation. An ultrafast electron transfer process from the {111} to {001} facets was observed within sub-picosecond, while this ultrafast transport behavior cannot be explained by the conventional drift-diffusion model. Through a set of exquisite experiments and high-accuracy DFT calculations, they ascribed the ultrafast charge transfer to the quasi-ballistic transport regime, in which the carriers propagated at extremely high speeds, as the carriers traveled the length of the particle prior to scattering. Further, they performed a transient photovoltage analysis and found that signals shifted from negative to positive as the timescale progressed from nano- to microseconds, indicating the appearance of holes on {111}, which was induced by defect structures.

The ability to spatiotemporally track charge transfer enables advancing experimental techniques for understanding the complex mechanisms in energy conversion devices, will extend the understanding of the fundamental microscopic mechanisms underlying photocatalytic function, and holds great promise for solving the bottlenecks in photocatalytic processes in the future.

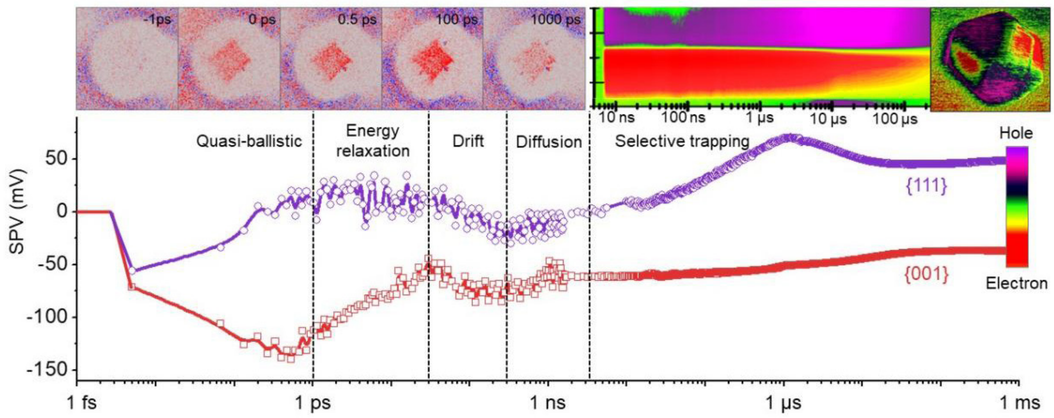


Figure 3-1-11 Schematic shows the spatiotemporal tracking of charge transfer in a photocatalytic particle, through a combination of different methods

In Vivo Imaging Analysisof Inflammation-Associated mRNA

Accurate measurement of inflammatory processes is of great importance for the early diagnosis, treatment and prognosis assessment of diseases such as stroke, cardiomyopathy and cancer. Traditional clinical diagnostic methods such as blood tests and tissue biopsies are limited to single-timepoint tests, thus preventing their use for in situ real-time monitoring of the inflammatory process. Studies have shown that mRNA is a key regulator of inflammation and plays an important role in the initiation, spread and termination of inflammation. Therefore, accurate detection and imaging of relevant mRNA targets are expected to achieve early diagnosis and real-time monitoring of inflammation. In recent years, thanks to the rapid development of RNA detection technology, many signal amplification methods have been developed for the high-sensitive detection of low-abundance RNA and even imaging analysis in cells. However, these signal amplification techniques generally lack cell selectivity and spatial resolution, leading to non-specific signal amplification in healthy tissues, which limits their applications in imaging analysis in vivo.

To this end, this project focuses on the following key scientific question: how to construct triggered signal amplification technologies based on DNA self-assembly to solve the challenge of traditional methods that possess no cell-specificity in RNA imaging. On the basis of previous works on spatiotemporally-controlled molecular imaging, the project will explore and develop inflammatory microenvironment responsive signal amplification technologies, allowing for in situ imaging of inflammation-related RNA in vivo with high sensitivity and spatial resolution, which is of great significance for the accurate diagnosis and treatment of inflammation-related diseases.

Recently, with the support of the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars 22125402, Young Scientists Fund program 22004023), the research group of Li Lele in the National Center for Nanoscience and Technology has made progress in the invivo imaging of inflammation-related mRNA. The work has been published in *Nature Biomedical Engineering* with the title "Spatially resolved in vivo imaging of inflammation-associated mRNA via enzymatic fluorescence amplification in a molecular beacon". The team developed an enzymatic signal amplification method that uses an enzyme specifically distributed in inflammatory cells to trigger signal amplification reactions to achieve spatially-selective amplification of mRNA detection signal in inflammatory cells, which enables early diagnosis and real-time monitoring of the inflammation process (Figure3-1-12). By introducing apurinic/apyrimidinic sites into the loop of traditional molecular beacons, the systems could bind to target mRNA and then are specifically cleaved by human apurinic/apyrimidinic endonuclease 1 on translocation from the nucleus into the cytoplasm specifically in inflammatory cells, leading to the release of the target RNA to react for the next cycles of cleavage. Therefore, the approach enables the fluorescence signal to be amplified in the inflammatory cells over in normal cells, resulting in substantially improved sensitivity and signal-to-background ratios for mRNA imaging in vivo. Furthermore, the method was utilized to achieve in situ detection and early diagnosis of acute inflammation and drug-induced acute liver injury.

This strategy provides a new method for in vivo detection and imaging of inflammation-related mRNA with high sensitivity, which is expected to be applied for the early diagnosis of inflammation-related diseases and the real-time monitoring and evaluation of their treatment process.

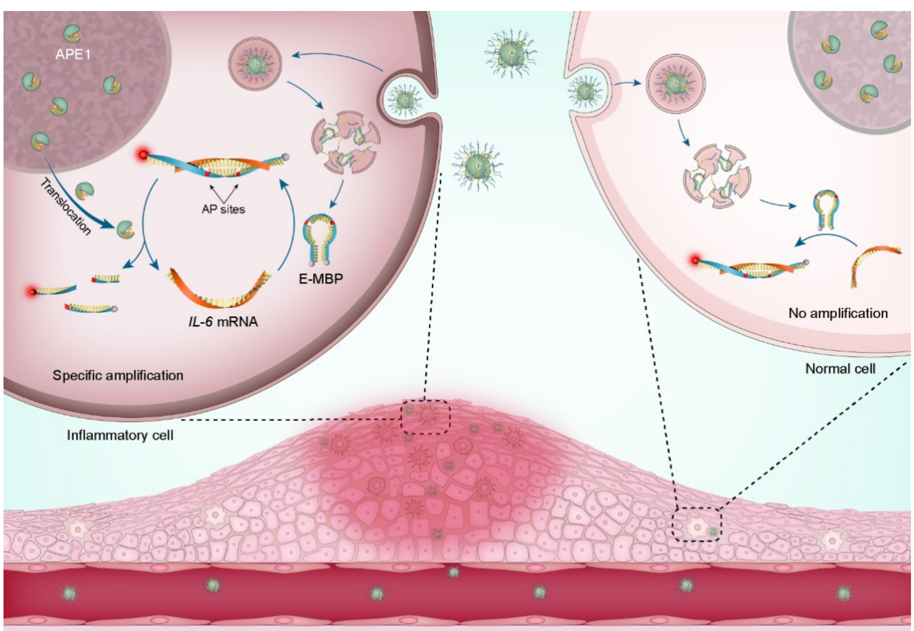


Figure 3-1-12 Enzyme-triggered signal-amplification for spatially resolved imaging of inflammation-associated mRNA in vivo

Novel 2D Single Crystal Carbon Material

Carbon is one of the most diverse elements in the periodic table. It can form chemical bonds in a variety of hybridization form to obtain a unique ϖ electron conjugation system, thus showing excellent mechanical, thermal, optical and electrical properties. These properties of carbon materials are closely related to their topological structures. Therefore, it is of great significance to create new carbon allotropes, specifically those with band gaps. The preparation of a brand-new carbon material has been a frontier research topic in the field of materials science. Each discovery of new carbon materials, such as fullerenes, carbon nanotubes, graphene and graphyne, has always triggered a research upsurge. However, due to the lack of effective and reliable synthesis methods, the large-scale preparation of new carbon materials remains a great challenge.

Supported by the National Natural Science Foundation of China (General Program 22175184, Young Scientist Fund 22105207), Dr. Zheng Jian's group from the Institute of Chemistry, Chinese Academy of Sciences developed a facile synthesis strategy for preparing new carbon materials (Figure 3-1-13). They successfully prepared a single-layer polymerized C_{60} single crystal, and identified its crystal structure. By adjusting the ratio of magnesium to C_{60}, two closely aligned magnesium intercalated polymer single crystals, quasi hexagonal and quasi tetragonal phase, were obtained at atmospheric pressure. An organic cation slicing strategy was then employed to exfoliate the intercalated quasi hexagonal C_{60} single crystals into monolayer with tetrabutylammonium salicylate as an exfoliation reagent. The results of single crystal X-ray diffraction and scanning tunneling electron microscopy certify that adjacent C_{60} is connected by carbon-carbon bridged single bond and [2+2] cycloaddition bridged bond in one layer of qHP C_{60}, forming a new two-dimensional topological structure. This research creates a new member to the family of carbon materials. The method of constructing two-dimensional topological structure using zero-dimensional clusters provides a new prospect for exploring new carbon materials.

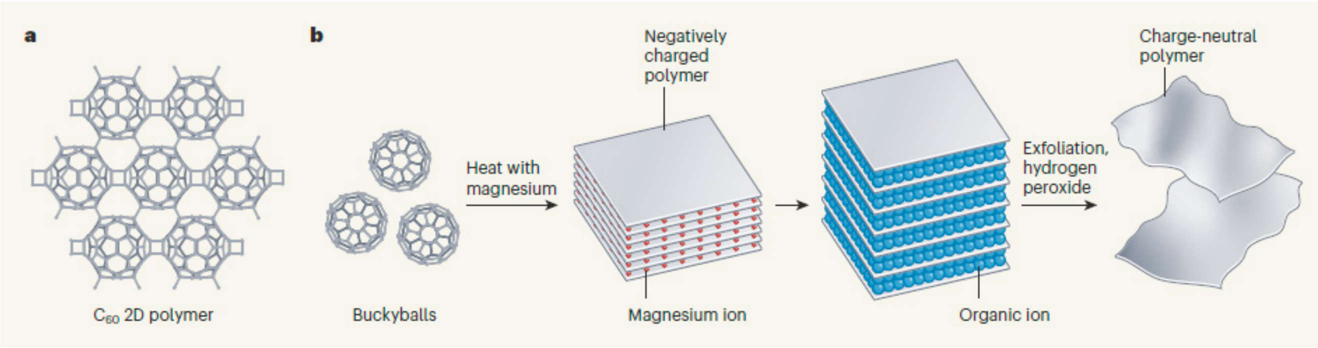


Figure 3-1-13 Synthetic route of monolayer qHP C_{60}.

The monolayer qHP C_{60}has been shown to be a semiconductor with a band gap of about 1.6 eV and has promising applications in 2D electronic and optoelectronic devices. Due to the asymmetric structure, the monolayer qHP C_{60}has remarkable in-plane anisotropy, and is expected to be applied in the fields of nonlinear optics and functional electronic devices. Moreover, the unique conjugated system, lattice and porous skeleton structure all endow this new carbon material potentially suitable for applications in superconductivity, quantum computing, spin transport, energy storage and catalysis.(Nature, 2022, 606, 507-510)

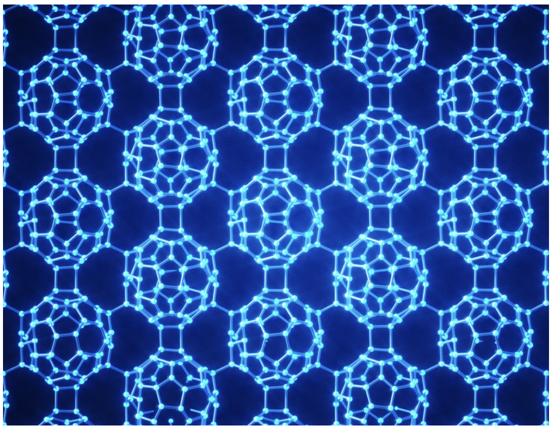


Figure 3-1-14 Schematic of crystal structure of monolayer qHP C_{60}

Synthesis of a Mirror-image T7 RNA Polymerase and Mirror-image T7 Transcription

Both natural nucleic acids and protein, which constitute life, have the characteristics of single chirality. Natural-chirality nucleic acids are exclusively composed of D-ribose, while almost all natural-chirality proteins are composed of L-amino acids. The key to building mirror-image biology systems is to create a mirror-image version of the central dogma that includes mirror-image genetic replication, transcription, reverse transcription, and translation to produce mirror-image proteins. A critical step towards this goal requires the preparation of high-quality mirror-image 122-nt 5S, 1.5-kb 16S, and 2.9-kb23S ribosomal RNAs (rRNAs)that make up the structural and catalytic core and about two-thirds of the molecular mass of the mirror-image ribosome. Nevertheless, the maximum length of mirror-image RNAs obtained by existing techniques was 120 nt, insufficient for producing long mirror-image RNAs.

Supported by the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars 21925702 and Special Fund 32050178), Professor Ting Zhu and his team applied split-protein design strategy to facilitate the synthesis of a 100-kDa mirror-image T7 RNA polymerase. They divided the 883-aa polymerase into three split-protein fragments, including a 363-aa N fragment, a 238-aaM fragment, and a 282-aa C fragment. After synthesis, ligation, purificationand lyophilization, the N, M, and C fragments were co-folded *in vitro* into a functionally intact 100-kDa mirror-image T7 RNA polymerase, which is the largest chemically synthesized mirror-image protein reported to date. Zhu's team used the synthetic T7 RNA polymerase to transcribe mirror-image5S, 16S and 23SrRNAs,as well as a mirror-image riboswitch and a mirror-image ribozyme, among which the 2.9-kb23SrRNA is the longest mirror-image RNA reported to date. Additionally, they found that mirror-image RNAs exhibited longer half-lives compared with natural-chirality RNAs. This work, entitled "Mirror-image T7 transcription of chirally inverted ribosomal and functional RNAs", was published in *Science* on October 28, 2022.

The total chemical synthesis of large mirror-image proteins and assembly and transcription of kilobase-long mirror-image genes addressed the issue of preparing large mirror-image biomolecules, paving the way for the realization of a mirror-image translation system and mirror-image central dogma, as well as the exploration of their applications. The realization of mirror-image T7 transcription may enable a variety of potential applications in diagnostics and therapeutics, information storage, computation, imaging, and basic RNA research.

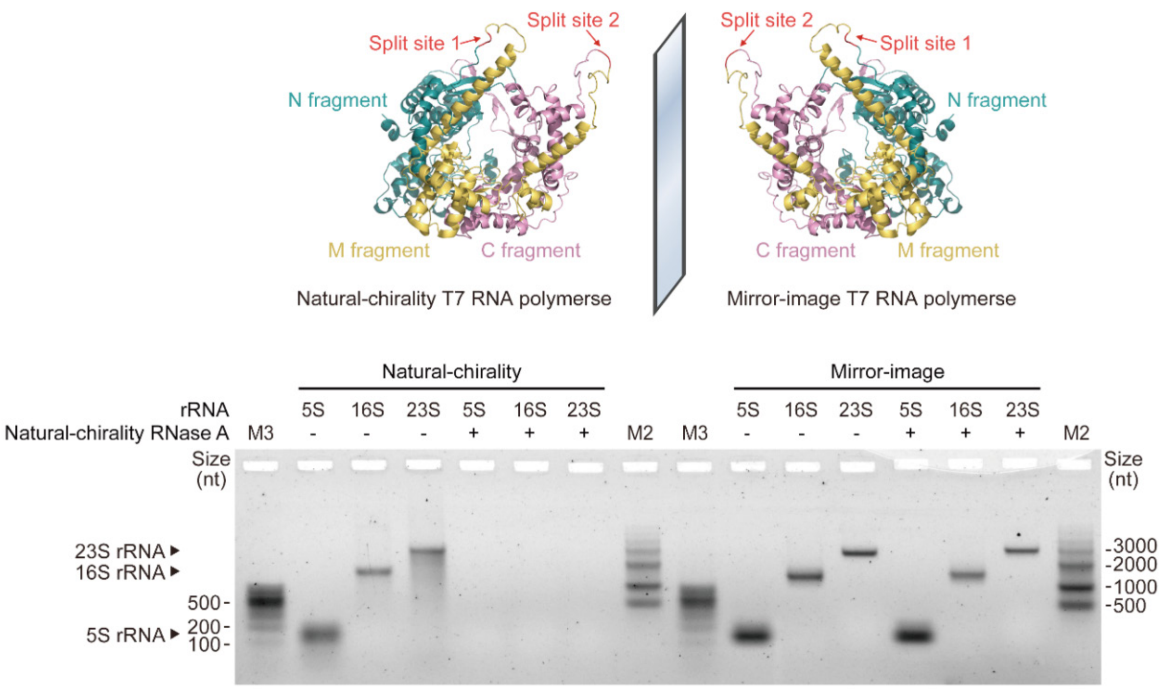


Figure 3-1-15 Mirror-image T7 RNA polymerase and gel electrophoresis of mirror-image ribosomal RNAs

Research on Adsorption Separation of Xylene Isomers

Para-xylene (PX) and other xylene isomers are important organic chemicals, which are widely used for manufacturing commodities including plasticizer and polyester fiber. The highly similar structure and nearly-the-same boiling point (the difference of boiling point between PX and MX is less than 1 °C) make it an energy-intensive process to separate xylene isomers through distillation with the theoretical plate number over 150. Efficient separation of xylene isomers is recognized as one of the seven chemical separations to change the world. The dominant industrial method for large-scale separation of xylene isomers is based on the simulated moving bed (SMB) using FAU-type zeolites with low separation selectivity (<5). The SMB requires as many as 24 adsorption columns connected in series and is favorably run at relatively high temperatures of 180 °C to ensure a sufficient microporous diffusion rate. Therefore, developing adsorbents with higher PX selectivity and sufficient mass-transfer rate is highly desired for adsorptive separation of xylene isomers.

Supported by the National Natural Science Foundation (Excellent Young Scientist Fund 21722609, General Program 21878260 and Special Fund 22141001), the team led by academician Ren Qilong and professor Bao Zongbi at Zhejiang University have developed anultra-high PX selective coordination polymer (Mn-dhbq)to purify the three xylene isomers. They used H_2dhbq (2,5-Dihydroxy-1,4-benzoquinone) as organic linker to coordinate withMn^{2+} ions to fabricate a strip-like 1D straight chain. The adjacent chains linked by multiple hydrogen bonds between water molecules lead to the H-bonded stacked 3D structure, which generates substantial open metal sites after dehydration. In particular, para-xylene with optimal C-C distance between two methyl groups fits well into the cavities, thus showcases stronger hydrogen bonding and dipole–dipole interactions with the manganese coordination polymer. At 393 K, only PX can enter the space between chains and is strongly adsorbed, while OX can enter at temperatures below 333 K and MX in the temperature range of 333-393 K (Figure 3-1-16). Discrimination of xylene isomers can be realized by such unique temperature-dependent separation mechanism, and the PX/OX selectivity for the ternary liquid mixture is as high as 84.6. Moreover, Mn-dhbq strikes a good balance between high adsorption capacity and high mass-transfer rate and also shows excellent thermal stability, representing one of the most promising materials for industrial xylene separation.

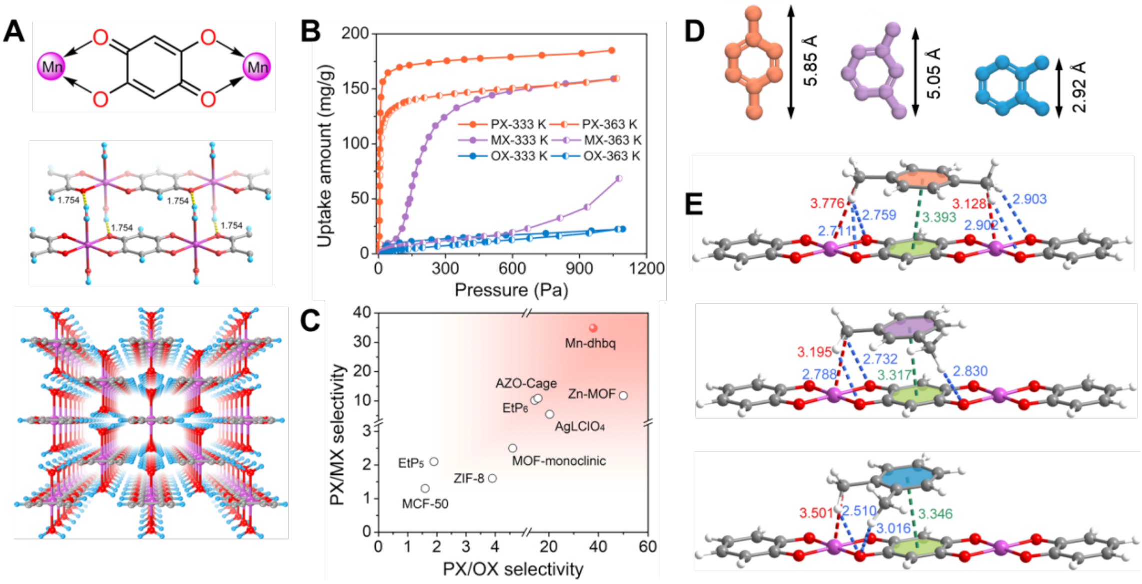


Figure 3-1-16 (A) The structure of the stacked coordination polymer termed as Mn-dhbq; (B) Single-component vapor adsorption isotherms of xylene isomers on Mn-dhbq at 333 and 363 K; (C) Comparison of separation selectivities for binary vapor-phasemixtures of PX/OX and PX/MX between Mn-dhbq and the other outperforming adsorbents; (D) The structure and length between the two methyl groups for xylene isomers; (E) The adsorption binding sites between the xylene molecules and the 1D chain of the Mn-dhbq framework.

The research article titled "Discrimination of xylene isomers in a stacked coordination polymer" was published in *Science* in July 2022. This work addresses the key scientific issue of simultaneously enhancing shape recognition capabilities and mass transfer in confined space within adsorbent materials. The work has attracted widespread attention internationally and has been featured on science news sites such as Chemistry World and Phys.org.

The Mechanism of Local Hyperthermia Therapy Inducing White Fat Browning and Treating Obesity

Obesity is a major risk factor for metabolic diseases including diabetes, hyperlipidemia, NAFLD, which poses a serious threat to human health. Beige fat, a newly discovered adipose tissue featuring high functional flexibility, exhibits the characteristics of white fat at rest, but can be induced to function like brown fat under cold or β-adrenergic stimulation and promotes heat production and energy consumption as well as improves systemic glucose and lipid metabolism, which endows its great potential for intervention of obesity and metabolic diseases. Although cold stimulation or β-adrenergic receptor agonists can effectively activate beige fat, these methods have limited application in human due to various health concerns and potential side effects. Thus, scientists are striving to pursue novel and safe targets/strategies for beige fat activation to treat obesity.

With the support of the National Natural Science Foundation of China (Excellent Young Scientists Fund

32022034), Prof. Xinran Ma from East China Normal University reported that in addition to cold stimulation, local hyperthermia therapy on beige fat effectively treats obesity and improves metabolic disorders by enhancing thermogenesis and energy consumption, and further analyzes the regulatory mechanism. This work was published in *Cell* entitled "Local hyperthermia therapy induces browning of white fat and treats obesity", and has been selected as Featured Article and Cover Story for its significance in the metabolic field (Figure 3-1-17).

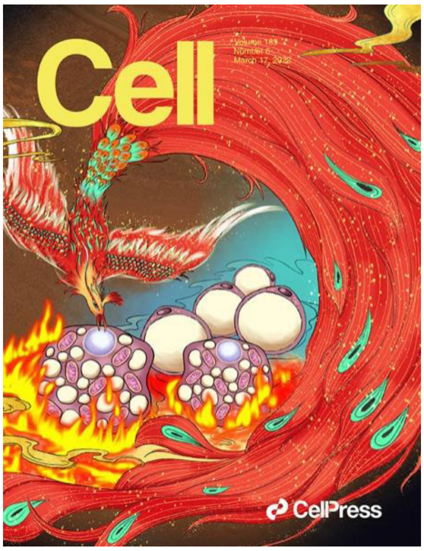


Figure 3-1-17 *Cell* cover image

Researchers used polyethylene glycol (PEG) cross-linked polydopamine nanoparticles to achieve local hyperthermia therapy in mice beige fat (LHT, 41±0.5℃) via NIR illumination. Applying thermosensitive fluorescent dyes and infrared thermography found that local hyperthermia could promote the thermogenesis of beige adipocytes in vitro, as well as activate adipose tissue thermogenesis in mice and humans. More importantly, researchers made the innovative discovery that, beige fat sense local hyperthermia and induce thermogenesis via HSF1, which effectively ameliorates metabolic disorders including obesity, insulin resistance and hepatic steatosis without obvious side effects. Furthermore, via ChIP-sequencing, researchers comprehensively analyzed the direct target genes of HSF1 on a whole genome scale in beige adipocytes, which provided a full picture for the HSF1 regulatory network in adipose tissues and newly identified the HSF1-A2b1 transcriptional axis in beige fat activation. Lastly, researchers revealed the association of HSF1 SNP with human metabolic traits in over 10,000 population (Figure 3-1-18).

This innovative finding that beige fat can sense local mild heat effects and activate heat production through HSF1 which can safely and effectively improve metabolic disorders such as obesity and insulin resistance, establishes an important research foundation for subsequent clinical drug development and precision therapy.

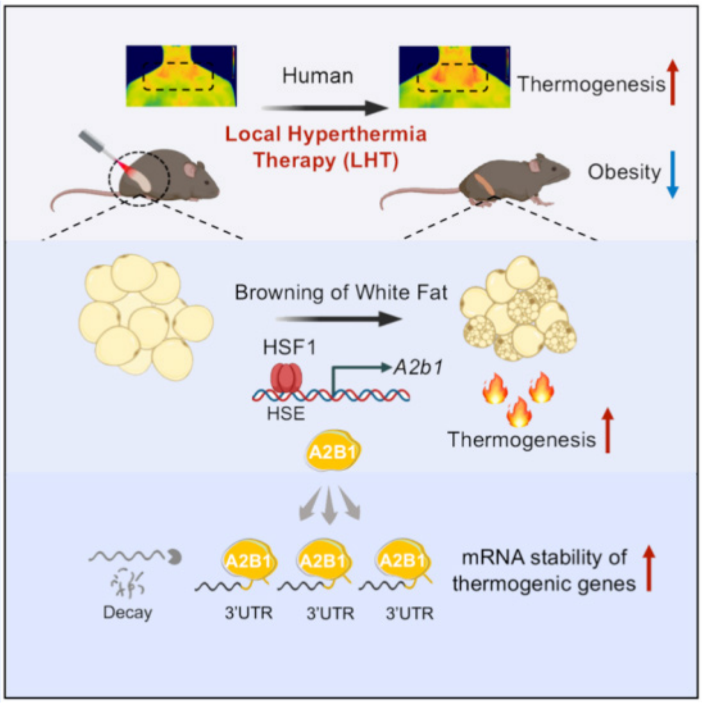


Figure 3-1-18 Schematic diagram of local hyperthermia therapy induces white fat browning and treats obesity via HSF1-A2b1 axis

Convergent Selection of a WD40 Protein that Enhances Grain Yield in Maize and Rice

The major cereals, such as maize and rice, domesticated independently ~10,000 years ago, represent a primary source of human calories. During the independent process of cereal evolution, many trait shifts appear to have been under convergent selection to meet the specific needs of humans. Given the close phylogenetic relationships among cereals, a key question is whether convergent phenotypic selection in distinct lineages was driven by conserved molecular changes. Identification of convergently selected genes across cereals could help to clarify the evolution of crop species and to accelerate breeding programs.

Supported by the National Natural Science Foundation of China (Major Research Plan 91935302, 91435205, Science Fund for Creative Research Groups 31421005, and International (Regional) Cooperation and Exchange Program 31961133002), the groups of Xiaohong Yang and Jiansheng Li from China Agricultural University and Jianbing Yan from Huazhong Agricultural University developed an introgression line, MT-6, with six kernel rows from the wild ancestor of maize, and identified a selected gene, *KRN2* (*kernel row number*2), that differs between domesticated maize and its wild ancestor, teosinte. This gene underlies a major quantitative trait locus for kernel row number in maize. Selection in the noncoding upstream regions resulted in a reduction of *KRN2* expression and an increased grain number through an increase in kernel rows. The rice ortholog, *OsKRN2*, also underwent selection and negatively regulates grain number via control of secondary panicle branches. These orthologs encode WD40 proteins and function synergistically with a gene of unknown function, DUF1644, which suggests that a conserved protein interaction controls grain number in maize and rice. Field tests show that knockout of *KRN2* in maize or *OsKRN2* in rice increased grain yield by ~10% and ~8%, respectively, with no apparent trade-off in other agronomic traits. This suggests potential applications of *KRN2* and its orthologs for crop improvement. Furthermore, they identified a set of 490 orthologous genes that underwent convergent selection during maize and rice evolution on a genome-wide scale, including *KRN2*/*OsKRN2*. These findings show that common phenotypic shifts during maize and rice evolution acting on conserved genes are driven at least in part by convergent selection, which in maize and rice likely occurred both during and after domestication (Figure 3-1-19).

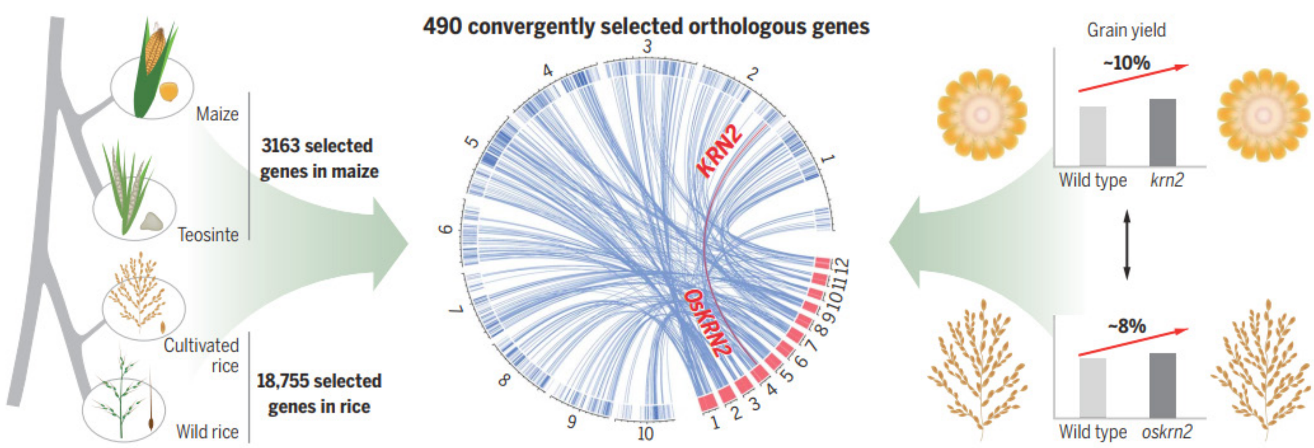


Figure 3-1-19 Shared selected orthologous genes in maize and rice for convergent phenotypic shifts during domestication and improvement. By comparing 3,163 selected genes in maize and 18,755 selected genes in rice, 490 orthologous gene pairs were identified, including *KRN2* and its rice ortholog *OsKRN2*, as having been convergently selected. Knockout of *KRN2* in maize or *OsKRN2* in rice increased grain yield by increasing kernel rows and secondary panicle branches, respectively.

This research was published in *Science* on March 25, 2022, and has been highly praised by international and domestic peers. The findings have provided gene resources for crop breeding, enriched the genetic theory of crop domestication, and provided an important theoretical basis forknowledge-driven *de novo* domestication or re-domestication to create new crops.

Deciphering the Causative Mutation and Unrevalling its Mechanism of Host Genome Affecting Porcine Gut Microbiota Composition

Gut microbiota is closely related to host metabolism and immunity, and significantly affects many economically important traits in pigs, such as growth, feed efficiency and disease resistance. Different individuals show significantly different gut microbiota compositions, which are affected by multiple factors including environments, diets, health status and host genetic variations. To what extent and how host genetic variations affect its own gut microbiota composition is an international research focus as well as a difficult hot topic.

With the support of the National Natural Science Foundation of China (Major Program 31790410), the group of Prof. Huang Lusheng from Jiangxi Agriculture University used more than 1500 experimental pigs from the sixth (F6) and seventh generations (F7) of a specifically designed mosaic population constructed with four worldwide commercial pig breeds and four Chinese indigenous pig breeds, and fed with the same formula diets under the standard management as experimental materials. A total of 5110 gut microbial samples were collected at three growth stages and in five different gut locations at age of 240 days to systematically investigate gut microbiota composition and the effect of host genes on gut microbiota composition in healthy pigs.

The extensive heterogeneity of gut microbiota composition at different ages and in different gut locations at the same age were observed and confirmed in two pig populations of the F6 and F7 generations (Figure 3-1-20). The group confirmed the significant influences of host genetic background on the gut microbiota composition in three aspects: 1. In the same litter of whole-sib pigs living in the same

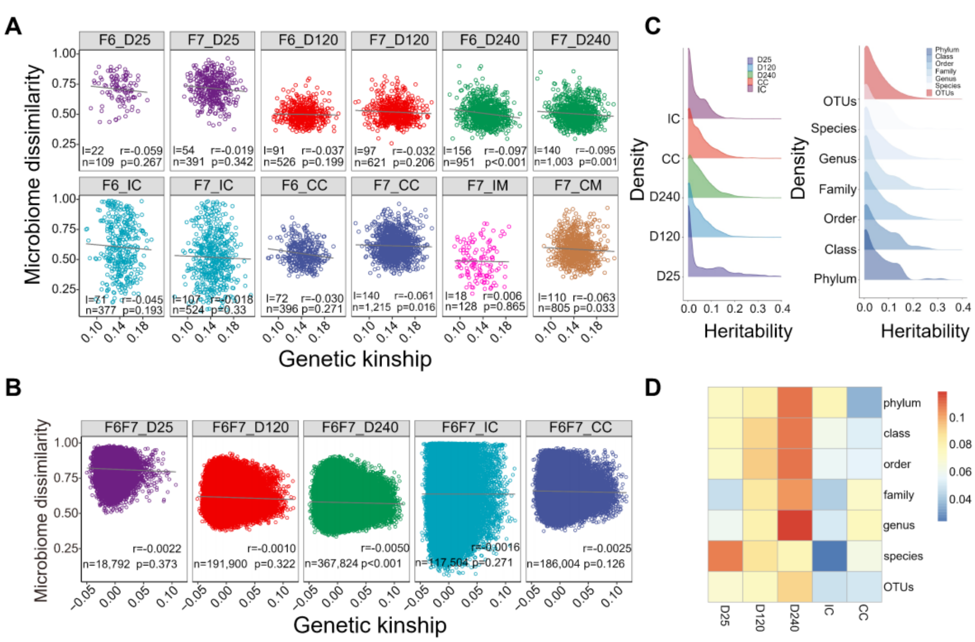


Figure 3-1-20 The effect of host genetics on the gut microbial compositions of pigs

environment, it was found that pigs with more genetic kinship showed higher gut microbiota composition similarity. 2. Among the 1050 and 955 heritable bacterial taxa identified in F6 and F7 generations 450 heritable bacterial taxa were repeated cross the two generations. 3. Genome-wide association analysis was performed on 8490 bacterial taxa, and a total of 1527 host genomic variants significantly affecting 846 bacterial taxa were detected. By systematically genetic survey, we identified a 2.3-kb ancient deletion mutation in ABO blood group that directly caused the difference in the abundance of bacterial taxa belonging to Erysipelotrichaceae in the gut of domestic pigs. The 2.3-kb deletion in *ABO* gene leads to the inactivity of *N*-acetyl-galactosaminyl-transferase encoded by the A allele, therefore, cannot add *N*-acetyl-d-galactosamine to glycan substrates of the heavily glycosylated mucins. This significantly reduced the concentration of intestinal *N*-acetyl-d-galactosamine in individuals of OO genotype, which affects the growth of bacterial taxa relying on *N*-acetyl-d-galactosamine as the carbon source.

To our knowledge, this is the first causative mutation in the host genome, which was identified to affect the gut microbial composition in agricultural animals in the world. This finding provides an important reference for the development of potential technology to genetically improve pig feed efficiency and growth rate of pigs by regulating gut microbiota, and also provide potentials for cultivating pig breeds with excellent performance of grain saving and fast growing. The research results were published in *Nature*, which is also the first original article published by Nature in the field of animal husbandry in China to date (Figure 3-1-21).

Figure 3-1-21 The cover of Nature magazine in which the paper was published

Mixed Forest Plantations Outyield Monocultures

Supported by the National Natural Science Foundation of China (Basic Science Center Program 31988102 and Excellent Young Scientist Program 32122053), an international research team, led by Prof. Jingyun Fang from the Institute of Ecology, College of Urban and Environmental Sciences, Peking University,spent five years to compile a global dataset of matched monocultures and mixedplantations (Global MixTress),which contains 243 tree species and >5900 samples at 255 sites. They examined the effects of species mixing on three growth variables(tree height, diameter at breast heightor DBH, and aboveground biomass), demonstrated substantial benefits of multi-species plantations, and revealed the mechanisms underlying the effects of species mixing. The major findings are as follows:

(1) The averaged tree height,DBH, and aboveground biomass were 5.5%, 6.8%, and 25.5% higher, respectively, in mixedplantations compared with monocultures. These positive effects were mainly the result of interspecific complementarities,which were stronger in mixed plantations with more species (Figure 3-1-22).

(2) The effects of species mixing were modulated by functional trait composition. Specifically, mixed stands containing both broad and needle-leaved species had larger mixing effects than mixed stands containingonly broad-leaved or only needle-leaved species, and mixed stands containing both deciduous and evergreen specieshad larger mixing effectsthan mixed standscontaining only deciduous or only evergreenspecies. But mixed stands containing both nitrogen-fixingand non–nitrogen-fixing species

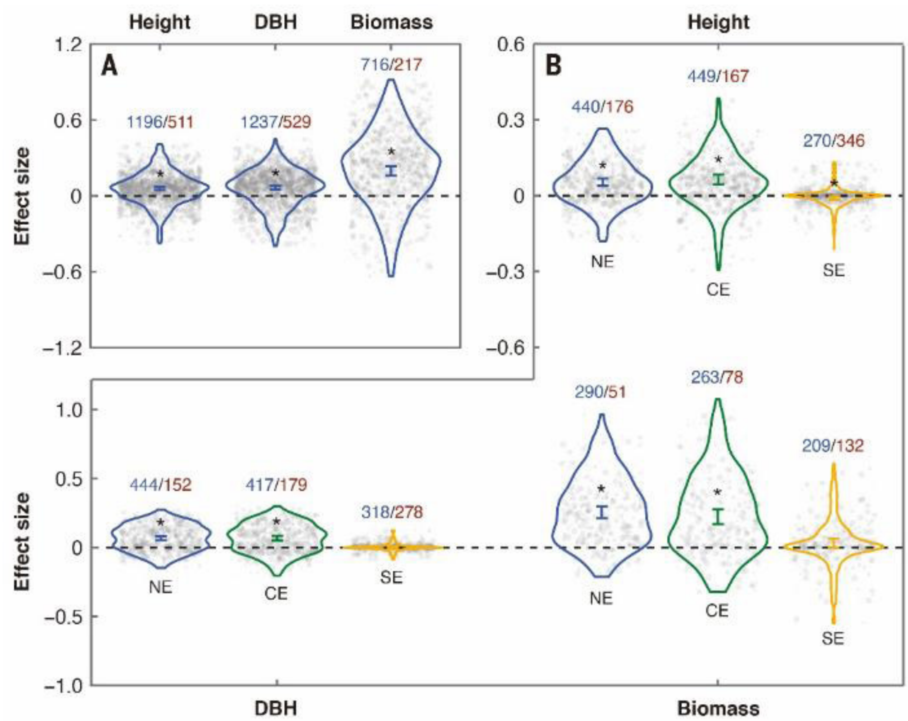


Figure 3-1-22 Effect sizes of species mixing on height, DBH, and aboveground biomass

performedsimilarly to mixed stands containingonly nitrogen-fixing or only non–nitrogenfixingspecies.

(3) The effects of species mixing exhibited unimodal patterns along gradients of stand age and planting density, peaking at ~25 years and 2500-4100 stems ha^{-1}. The mixing effects also changed with climatic conditions, which were stronger in warmer areas.

Using the compiled dataset of matched monocultures and mixed plantations, this study overcomes several limitations of traditional field surveys and experiments and offers a systematical assessment of the effects of species mixing and their underlying mechanisms. As a result, the findings resolve a long-standing puzzle in forestry and have useful implications for forest management and afforestation and reforestation practices. This research was published as "Multispecies forest plantations outyield monocultures across a broad range of conditions" in *Science* on May 20th(Figure 3-1-23), 2022, followed by a *Perspective* written by international well-known ecologist Jessica Gurevitch. Besides, this study also contributes to extend the field of biodiversity-ecosystem functioning and show their implications for real-world forestry applications.

Figure 3-1-23 The cover of *Science* magazine in which the paper was published

Capturing Missing Heritability by Using Graph Pangenome

As an important problem in quantitative genetics, it will help to understand the genetic mechanism of complex traits and provide theoretical support for related breeding work by addressing the problem of missing heritability.

Supported by the National Natural Science Foundation of China (Major Project 31991180), Dr. Sanwen Huang's team from the Shenzhen Institute of Agricultural Genomics, Chinese Academy of Agricultural Sciences, innovatively took advantage of the graph pangenome and multi-omics data to find back the "missing heritability" by addressing incomplete linkage of markers, allelic heterogeneity, and locus heterogeneity in tomato. The team also demonstrated the application of graph pangenome in molecular marker-assisted selection and genomic selection.

The researchers constructed the first tomato graph pangenome by integrating 838 tomato genomes and identified the most comprehensive genetic variant map of tomato to date. By studying more than 20,000 gene expression and metabolic traits, researchers found that the heritability calculated using all genetic variants was increased by 24% compared to single-nucleotide variants only. They also improved the power of genome-wide association analysis by combining a multi-locus model to address the problem of allelic heterogeneity and locus heterogeneity. By studying some agricultural important metabolic traits, the researchers identified some key genes that were associated with flavonoid metabolites and soluble solids for flavor. Furthermore, the researchers found that structural variants can improve the efficiency of gene selection when using as molecular markers. Therefore, a breeding chip with about 20,000 structural variants was designed to facilitate tomato genome-assisted breeding (Figure 3-1-24).

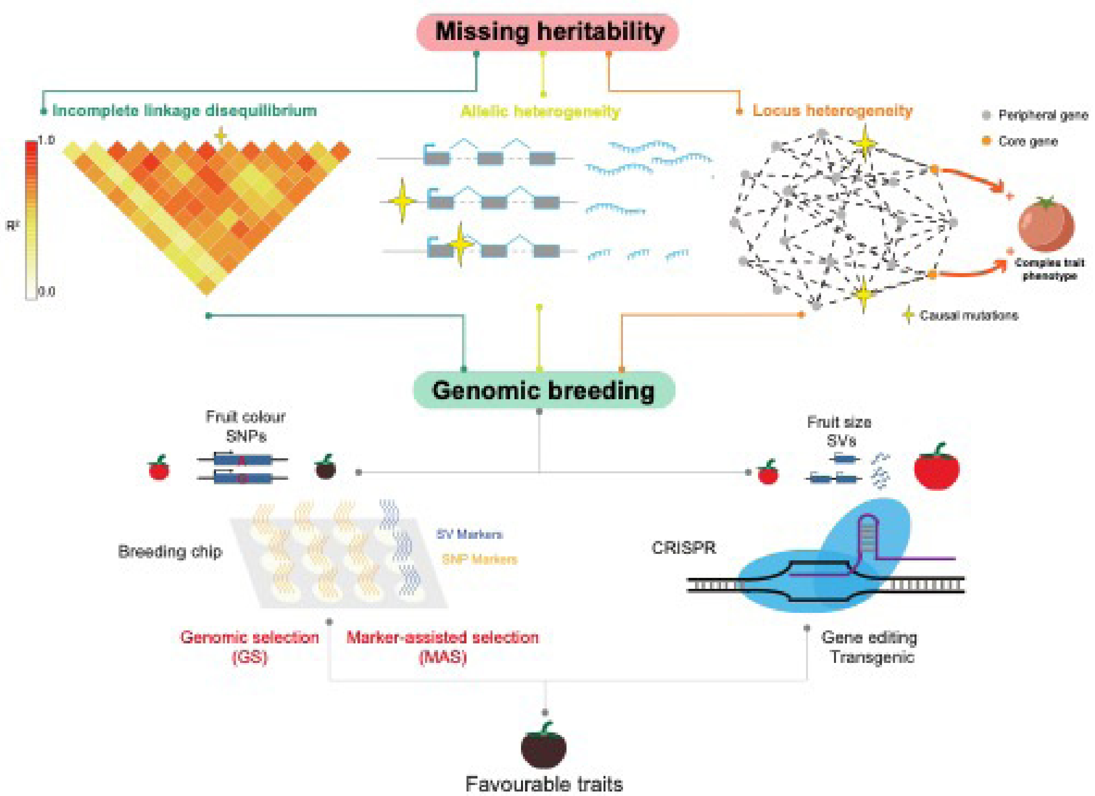


Figure 3-1-24 Solving the problem of missing heritability and empoweringtomato genome breeding.

The research entitled "Graph pangenome captures missing heritability and empowers tomato breeding" was published in *Nature* on June 9, 2022. This research is the most comprehensive study of the concept of graph pangenome by combining genomicsand quantitative genetics and provides new ideas for pangenome for crop breeding.

The Primordial Differentiation of Tumor Specific Memory $CD8^+$ T Cells as Bona Fide Responders to PD-1/PD-L1 Blockade in Draining Lymph Nodes

$CD8^+$T exhaustion is the key reason for the ineffective elimination of malignant tumors. Currently, blocking antibodies targeting the PD-1 (Programmed cell death 1, PD-1)/PD-L1 inhibitory signal pathway represent a FDA approved therapy by reinvigorating exhausted $CD8^+$T cell. At present, although this immune checkpoint blockade (ICB) therapy has achieved preferable results in a series of cancer types, it still faces great challenges, such as limited responding cancer species, few responding patients, and acquired drug resistance. Therefore, a more comprehensive understanding of $CD8^+$T cell response during tumorigenesis and the underlying mechanisms of ICB responsiveness are crucial to further improve the clinical efficacy of PD-1 ICB.

Supported by the National Natural Science Foundation of China (Key Program 32030041 and National Fund for Distinguished Young Scholars 31825011 and Excellent Young Scientists Program 82122028), Dr. LilinYe's team from the Institute of Immunology, the Third Military Medical University and their collaborators confirmed that a substantial proportion of tumor specific $CD8^+$T cells ($CD44^+TOX^-PD\text{-}1^{lo}TCF\text{-}1^+$) in the tumor draining lymph nodes, of both mouse tumor models and hepatocellular carcinoma patients, obtained the representative characteristics of classical memory $CD8^+$T cells, which were defined as TdLN-T_{TSM} (Tumor Draining Lymph Node Derived Tumor Specific Memory T cell).

Moreover, a series of *in vivo*adoptive transfer experiments further verified that TdLN-T_{TSM}functioned as the *bona fide* responders to PD-1/PD-L1 ICB (Figure 3-1-25). This work was officially published on the top life sciences journal *Cell* on October 27, 2022. To sum up this research, its innovation is mainly reflected in the following aspects: 1. It challenges the concept that during tumorigenesis, there are only exhausted T cells form but no tumor specific memory T cells; 2. It proposes the spatial and temporal mechanism of PD-1 ICB: it first expands TdLN-T_{TSM} cells and further drives these cells to differentiate into progenitor exhausted T cells(T_{PEX}) cells that migrate to the periphery and subsequently differentiate into terminal exhausted T cells (T_{EX}) cells in the tumor micro-environment (TME). In the TME, ICB may sustain the effector function of these newly differentiated T_{EX} cells to effectively execute tumor cells. This conclusion also suggests that the combination of PD-1 ICB and therapies aiming to remodel TME may lead to a better synergistic anti-tumor effect; 3. During lymphadenectomy in cancer patients, to purify and expand TdLN-T_{TSM} cells from resected tumor draining lymph nodes, and then transfer them to patients after surgery could be supplemented by immune checkpoint treatment, which may prevent tumor recurrence or metastasis post-surgery; 4. TdLN-T_{TSM} cells are superior to tumor infiltrating T cells (TIL) as candidates in anti-tumor adoptive T cell therapy.

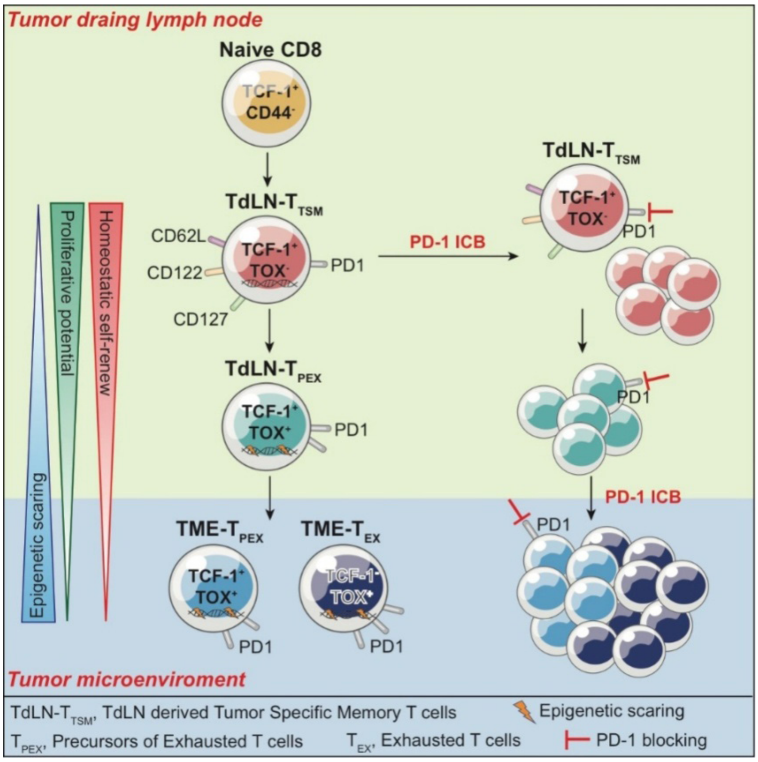


Figure 3-1-25 PD-1/PD-L1 ICB may exert anti-tumor effects in a temporal and spatial manner: it first expands T_{TSM} cells and further drives these cells to differentiate into T_{PEX} cells in TdLNs; subsequently, TdLN-derived T_{PEX} cells migrate to the periphery and finally differentiate into T_{EX} cells in the TME, whereby ICB may sustain the effector function of these newly differentiated T_{EX} cells to effectively execute tumor cells.

Origin of "Initial Oxygen" on the Early Earth

Cyanobacteria is one of the most important milestones in the history of Earth and life evolution, which directly led to the Great Oxidation Event (2.33~2.45 billion years ago) on the early Earth and drove the revolution in the surface Earth system. However, the origin of oxygenic photosynthesis remains a mystery. Nowadays, it is generally believed that the evolution of oxygenic photosynthesis in the ancestors of cyanobacteria happened in oxidizing environments, and hydrogen peroxide (H_2O_2) was the crucial substance to trigger the evolution of oxygenic photosynthesis. Thus, the source of H_2O_2 is the key to decipher the successful evolution of oxygenic photosynthesis.

Supported by the National Natural Science Foundation of China (Science Fund for Creative Research Groups 41921003, and National Science Fund for Distinguished Young Scholars 41825003), Profs. Hongping HE and Jianxi ZHU from the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences conducted a series of experiments to mimic the mechanical erosion of minerals and mineral-water reactions in the simulated Archean anoxic atmosphere. The experiments showed that the freshly fractured mineral surfaces that have a high energy readily reacted with water molecules and produced reactive oxygen species (ROS) such as H_2O_2 and O_2. Based on the experimental results and model calculations, the researchers proposed that in turbulent water environments such as shallow seas and river deltas, the continuous mineral-water interface reactions could produce sufficient ROS such as H_2O_2, leading to the formation of locally oxidized environments. These ROS could have caused oxidative stress in anaerobic photosynthetic bacteria that inhabited microbial mats or water bodies, and forced cyanobacteria ancestors to adapt to oxidant toxicity and innovate the metabolisms, initiating the evolution of oxygenic photosynthesis (Fig. 3-1-26). This scenario is well consistent with the phylogenetic dating of the emergence of ROS-detoxifying and -utilizing enzymes.

The finding of the abiotic origin of the "initial oxygen" on the early Earth, which involves mineral-water reactions, also provides a new perspective on the formation mechanism of stromatolites, the genesis of the Archean "oxygen oasis", and the oxidative mobilization of elements under the early highly reduced atmosphere. This study entitled "An Abiotic Source of Archean Hydrogen Peroxide and Oxygen that Predates Oxygenic Photosynthesis" was published on *Nature Communications*.

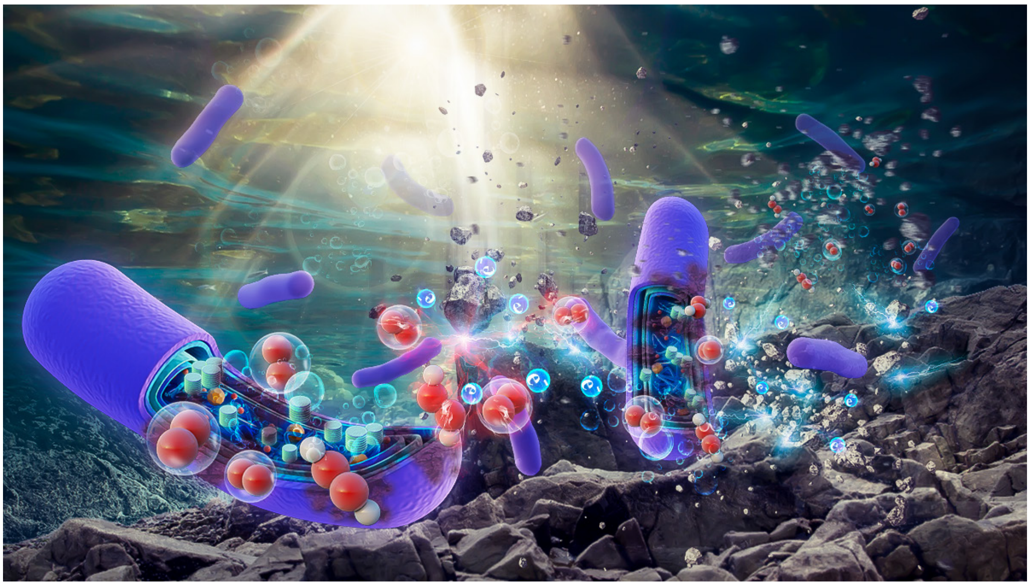


Figure 3-1-26 Reactive oxygen species (e.g., H_2O_2 and O_2) generated at mineral-water interfaces caused evolutionary pressure on the ancestors of cyanobacteria.

Spatiotemporal Dynamics of the Global Lake Surface Area and the Associated Carbon Emissions

Lakes play a major role in global hydrological and biogeochemical cycles and underpin vital ecosystem functions and services. However, rapid lake changes have been identified worldwide in response to changing climate and escalating human activities, threatening the ecosystem services provided by these lacustrine habitats. A spatially explicit understanding of lake size changes is essential for evaluating the associated ecological, environmental, and societal impacts. Supported by the National Natural Science Foundation of China (General Program 41971304), Dr. Lian Feng and his research group members from the Southern University of Science and Technology (SUSTech) have made significant progress in identifying the extent of global lakes and the associated spatiotemporal changes of lake inundation area.

The researchers solved the issues of global lake boundaries delineation on the basis of a deep-learning semantic segmentation algorithm (U-Net). Besides, by combing the Global Surface Water Occurrence (GSWO) dataset, they constructed a global lake dataset called GLAKES (Fig. 3-1-27), which comprised 3.4 million lakes with surface area >0.03 km^2 over the past four decades (from 1984 to 2019). Based on GLAKES, they provided a first spatially explicit estimate of the global lake surface water area dynamics among three different periods (1984-1999, 2000-2009, 2010-2019). From the beginning (1980–1990s) to the end (2010s) period, the lake area increased across all six continents analyzed with a net change of +46,278 km^2. Regarding with this, researchers confirmed that the human-regulated reservoirs (56%) instead of the lakes under the glacier and permafrost regions were found to contribute most to the overall lake expansion (Fig. 3-1-28). The research further revealed the outsized role of small lakes which supplied a disproportionately large contribution to global lake expansion and lacustrine carbon emissions over the past four decades at both global and regional scales. Although small lakes comprised only 15% of the total lake area, they accounted for 46.2% of the overall net areal increase and dominated the lake area variability in half of the global inland lake regions. In addition, small lakes were found accounting for 25% and 37% of the global CO_2 and CH_4 emissions, and representing 45% and 59% of the lake CO_2 and CH_4 emissions increase, respectively (Fig. 3-1-29).Their findings underscored the urgent need for future management efforts focused on small lakes, given their crucial roles in regulating local hydrologic cycles and inland water-related carbon emissions.

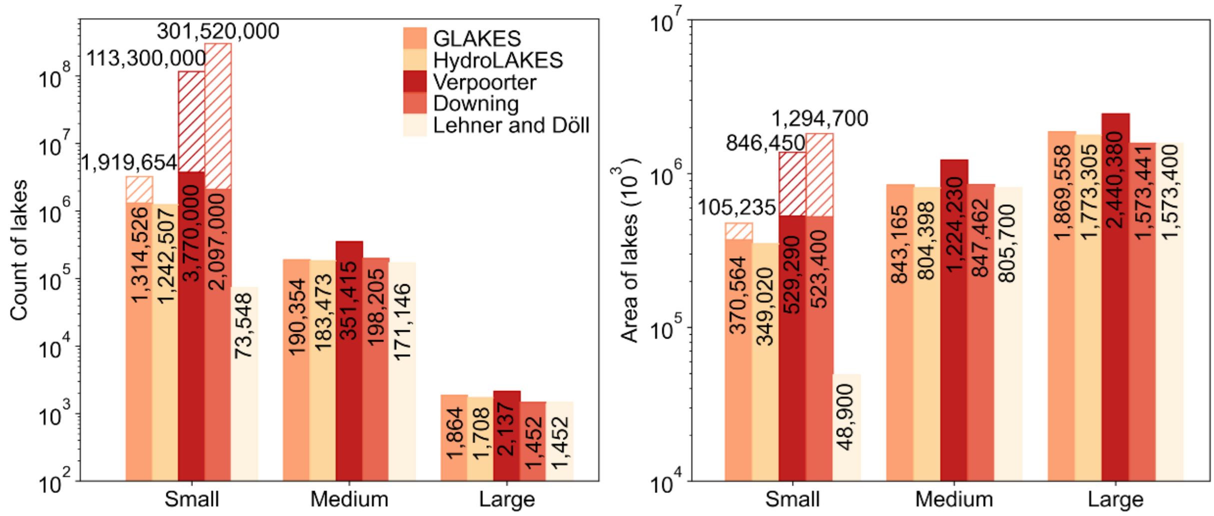


Fig 3-1-27 Comparison of the total lake numbers and lake area among different global lake datasets for the three lake size groups.
(Large: >100 km^2, Medium: 1-100 km^2, Small: <1 km^2)

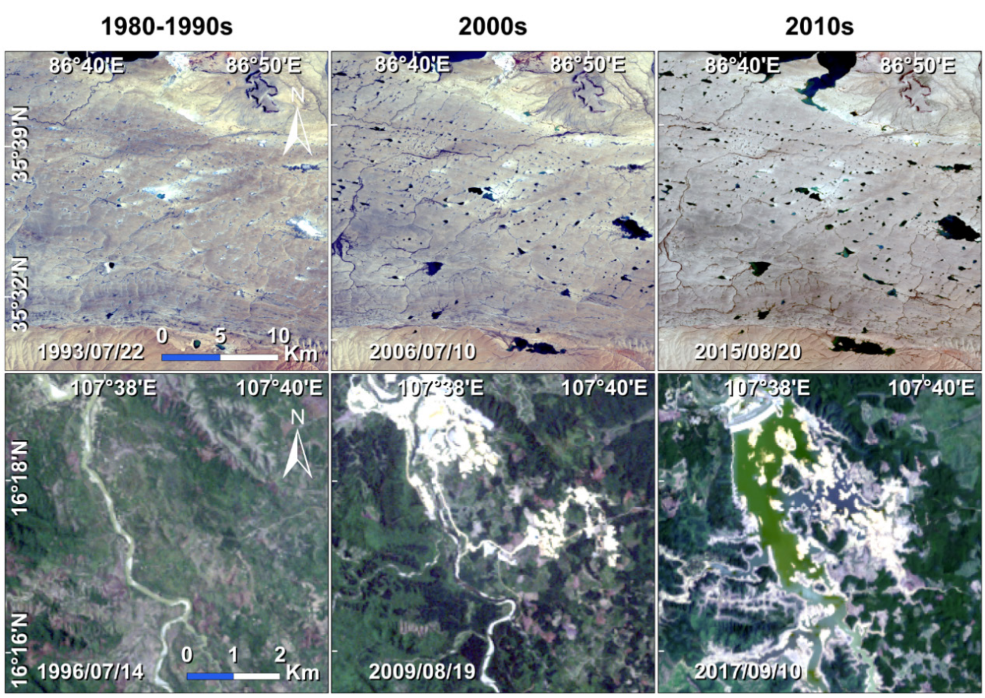


Fig. 3-1-28 Examples showing the inundation area changes of typical lakes from the 1980-90s to the 2010s

Their research paper, entitled "Mapping global lake dynamics reveals the emerging roles of small lakes," was published online on Oct 1, 2022, in *Nature Communications*, a top-tier journal documenting major advances in fundamental sciences.

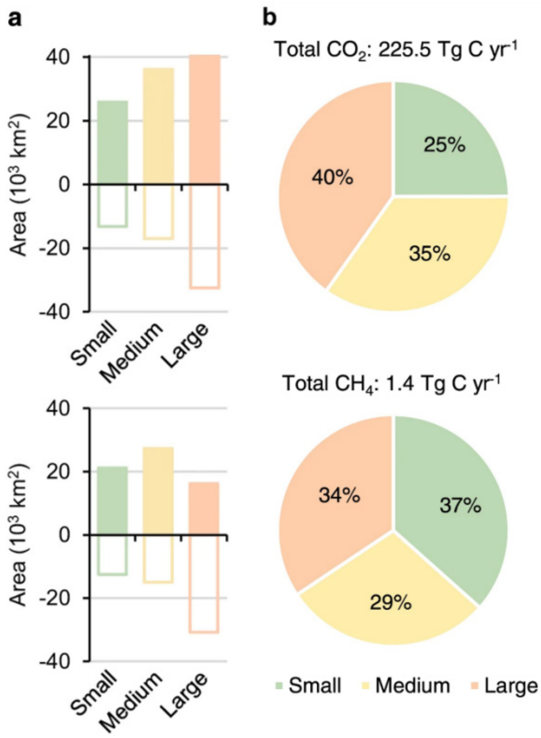


Fig. 3-1-29 The outsized roles of small lakes in regulating global lake area changes and inland water-related carbon emissions

Marine Anoxia Linked to Abrupt Global Warming during Earth's Penultimate Icehouse

Earth is currently experiencing the Cenozoic icehouse climate that started 34 million years (Myr) ago. However, global temperatures have risen rapidly over the last couple of centuries, which accelerates polar glacial ablation and aggravates marine anoxia, and in turn, leads to significant loss of biodiversity and impacts world's largest fisheries. Where will global warming take us in the future? Substantial uncertainties exist regarding modeling results based on current observations. For this reason, many scientists are focusing on understanding past episodes of carbon emission and ocean deoxygenation, particularly under icehouse climate conditions. The Late Paleozoic Ice Age (LPIA, 360–280 million years ago) is the only geological period that recorded a transition from an icehouse to a greenhouse climate since the appearance of advanced plants and a terrestrial ecosystem. The LPIA is also the only period characterized by low atmospheric CO_2 and high O_2 concentrations, comparable to modern day conditions. Therefore, it is critical to study carbon emissions and their consequences during the LPIA in order to better understand the processes and feedbacks of the icehouse Earth system, and thus better predict future environmental and biodiversity changes.

Supported by the National Natural Science Foundation of China (General Program 42072035, Key Programs 91955201, and 41630101), an international research team led by Dr. CHEN Jitao from the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, studied carbon and uranium isotopes, and major and trace elements of the upper Carboniferous strata at the Naqing and Narao sections in the Luodian region, Guizhou Province, southern China (Fig. 3-1-30). They utilized the global carbon-cycle model LOSCAR and paleo CO_2 concentrations to simulate a total amount of 9,000 Gt C emitted over a period of 300,000 years, causing an increase in the sea-surface temperature of ~4°C. They also modelled an increase in the areal extent of the anoxic seafloor from 4% to 22%, causing a dramatic decrease in biodiversity. The study further finds that warming-induced marine anoxia may be more pronounced in a glaciated rather than an unglaciated period (Fig. 3-1-31).

The study explores, for the first time, the driving mechanisms, and influences on marine redox conditions and ecosystems, of global warming in an icehouse climate state. It provides an ideal, deep-time geological analogue for the global warming and marine de-oxygenation of the modern icehouse world. The study, entitled "Marine Anoxia Linked to Abrupt Global Warming during Earth's Penultimate Icehouse", was published in *Proceedings of the National Academy of Sciences of the United States of America* (PNAS) on May 2, 2022. The finding was reported by many international and domestic media, including the *Science Daily* and *Chinese CCTV news (Xinwen Lianbo)*, immediately on its publication. The study has currently been positively referenced by many high-impact journals such as *Nature* and *Nature Communications.*

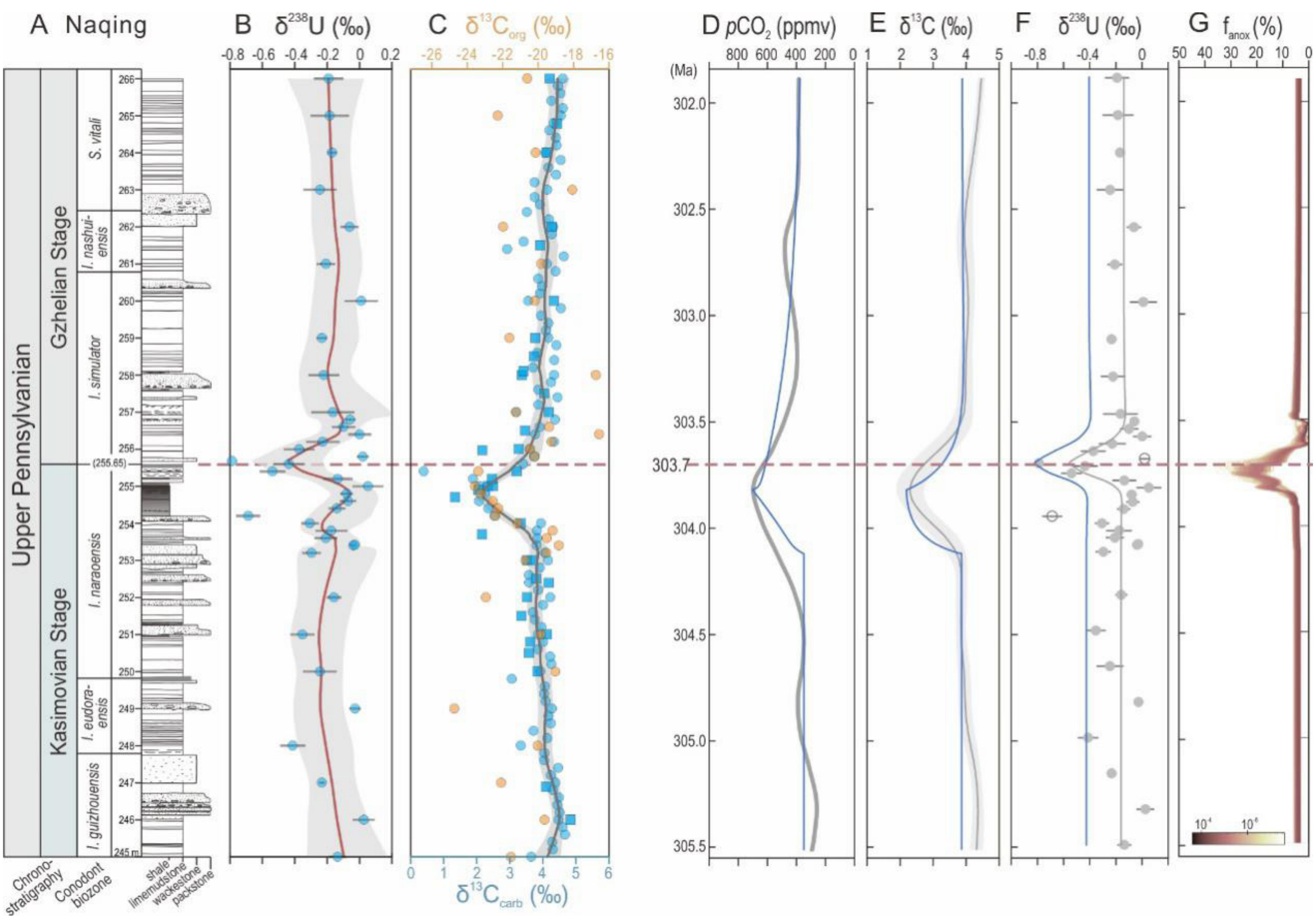


Fig. 3-1-30 Paired δ^{238}U and δ^{13}C data from the Naqing section in South China exhibiting pronounced negative excursions in δ^{238}U and δ^{13}C immediately below the Kasimovian-Gzhelian boundary (KGB), and Global C-cycle (LOSCAR) model results and U mass-balance modeling results across the KGB.

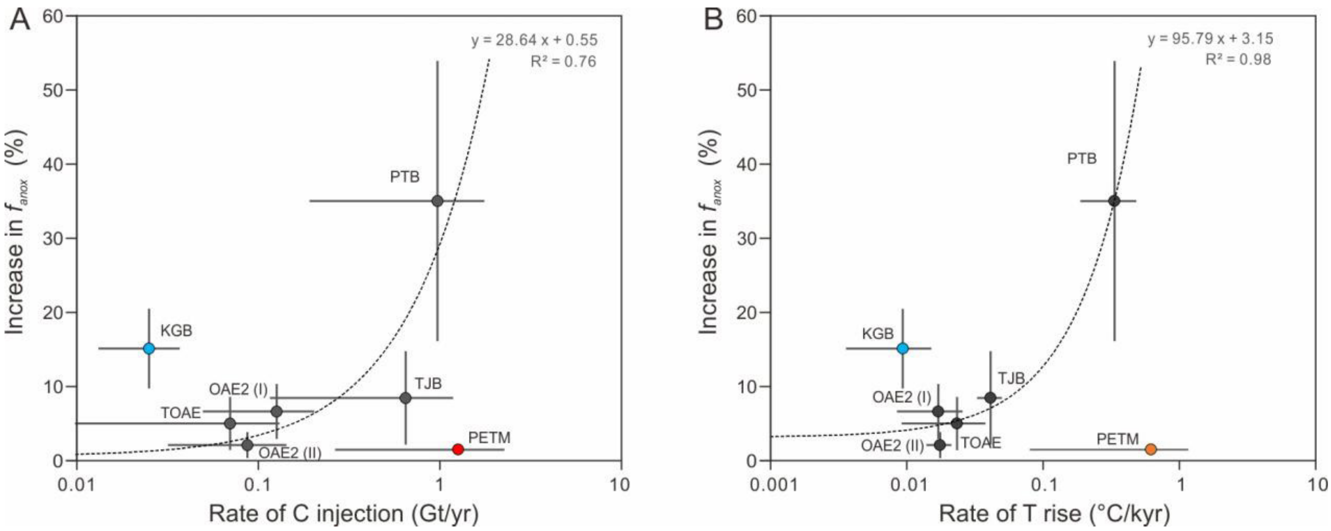


Fig. 3-1-31 Comparison between the KGB warming event and greenhouse C-perturbation events over the last 300 Myr, indicating that the KGB warming had a more extreme impact on the marine redox landscape relative to its rate of C injection and SST increase than the other events.

Initiation, Development, and Maturation Mechanism of the Western Pacific Plate Subduction

The theory of plate tectonics is the base of Solid-earth Science. Although it has been proposed for over 50 years, the key scientific question of how a plate starts to subduct is still not well understood. The rock records of this process are well preserved in the forearc of the Izu-Bonin-Mariana (IBM) island arc in the Western Pacific, which has been the research focus of the global geoscience community. Supported by the National Natural Science Foundation of China (Excellent Young Scientists Fund 41922020), Prof. Hong-Yan Li, Dr. Xiang Li, and Prof. Yi-Gang Xu from the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, together with international collaborators, carried out a detailed geochemical study on the IBM forearc igneous rock samples and proposed a new subduction initiation-development-maturation model.

Previous studies suggest that IBM represents the best example of spontaneous subduction initiation on the Earth, which is driven by the vertical foundering of the ancient Pacific plate (relative to the Philippine Sea plate) due to gravity. Based on the solid constraints on the source composition of the IBM forearc basalts and boninites, as well as the temperature-pressure conditions for the subducted slab's dehydration/melting, this study revealed that subduction of the IBM was initiated by the process of lateral convergence of the Pacific plate under the proto-Philippine Sea plate (Fig. 3-1-32), rather than the vertical foundering as previously suggested. This process might be a passive response to the adjustment of the global plate tectonic. The IBM subduction initiation occurred at the transition fault between the proto-Philippine Sea plate and the Pacific plate, where lateral low-angle convergence of the Pacific plate beneath the proto-Philippine Sea Plate took place. In this region, sediments and altered oceanic basalts of the upper Pacific plate were scraped off at the nascent trench, producing an accretionary wedge. The rapid foundering and retreat of the initial subducted slab resulted in extensive decompression melting of the nascent mantle wedge to form the forearc basalts (51.9 ~ 51.3 Myr). As the subsidence of the subducted slab continued, the gabbroic oceanic crust was heated rapidly and melted. The slab melts metasomatized the nascent mantle wedge, triggering its melting to form low silica boninites. After the high-angle subduction formed, the early accreted sediments and basalts could be subducted into the mantle. Due to the "icing" effect of the subducted slab in the early stage, the temperature of the interface between the nascent mantle wedge and the subducted slab would be lowered, prohibiting the melting of the newly subducted sediments and basalts; and the subducted slab could only release fluid to induce the melting of the residual mantle of the low silica boninite, creating the high silica boninites (51.3-50.3 Myr). With the further evolvement of the subduction zone, newly subducted materials were imported continually, and the nascent mantle wedge could be further cooled. After 50 Myr, magmatic activity migrated ~80 km westward to Bonin Islands (48 ~ 46 Myr), and the island arc developed to the mature stage after 44 Myr. This study reveals that serpentinite did not contribute to the melting/dehydration processes of the subducted slab during the subduction initiation, contrasting to the mature island arc.

This study was published in *Nature Communications* on February 22, 2022, entitled “Boron isotopes in boninites document rapid changes in slab inputs during subduction initiation”.

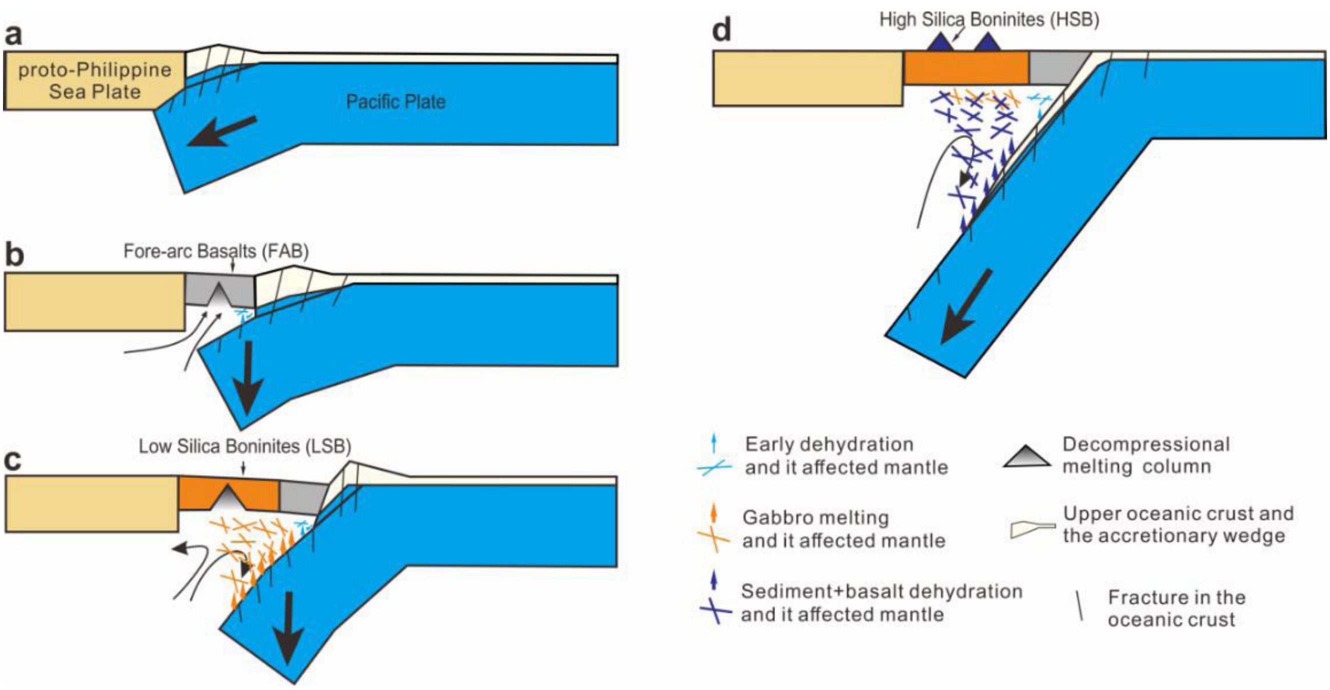


Figure 3-1-32 Cartoons depicting the subduction initiation of the Western Pacific plate

Study on the Mechanism of Low Latitude Forcing for the Paleoclimate Evolution

The oceans are giant heat reservoirs of the earth’s climate system. The Indo-Pacific Warm Pool (IPWP) is the region with the highest sea surface temperature (SST) and the largest reservoir of warm water on Earth and serves as a "steam and heat engine" for global climate today. Studying the past change of ocean heat content (OHC) and its regulation on the ocean-continental energy/water cycle can not only remedy the shortage of instrument observations, but also effectively improve the accuracy of hydrological climate prediction in the context of global warming.

Supported by the National Natural Science Foundation of China (Basic Science Center Program 42188102, Major Research Plan 91958208, General Programs 41976047 and 42176053), Prof. Zhimin Jian and his research group from the State Key Laboratory of Marine Geology of Tongji University, in collaboration with oversea scholars, have achieved important progress in underlying mechanisms of how the low-latitude Indo-Pacific regulate Asian monsoonal energy and moisture changes on orbital timescales. The related research was titled "Warm pool ocean heat content regulates ocean-continent moisture transport" and published in *Nature* on October 19, 2022. In this study, Zhimin Jian and his collaborators had reconstructed SST and thermocline water temperature (TWT) on the basis of the Mg/Ca ratios of the tests of planktonic foraminifera species *Globigerinoides ruber* and *Pulleniatina obliquiloculata*, respectively, from ten deep-sea sediment cores. The calcification depths of *P. obliquiloculata* are estimated at 110-160 m water depth (upper thermocline). Further, they reconstruct upper (0-200 m) OHC in the IPWP for the last 360,000 yr based on the SSTs and TWTs. This proxy reconstruction is generally comparable with the simulated annual mean upper OHC changes from the Community Earth System Model, in terms of both the amplitude and the pattern. At the same time, the residual $\delta^{18}O$ of surface seawater ($\delta^{18}O_{sw}$, with the ice-volume effect removed) reconstructed from *G. ruber* is not only consistent with the OHC change in the IPWP but also are out-of-phase of precession cycle with Chinese speleothem $\delta^{18}O$, and further confirmed by transient simulation with the water isotope climate model GISS_ModelE2-R.By combining modern observations, geochemical proxies, and numerical simulation with isotope-enabled air–sea coupled model, this study explored the moisture and latent heat transport using upper OHC (more than surface temperature) from the warm pool, measured the monsoonal hydrological cycle intensity via ocean–continent oxygen isotope gradient, and provided a new explanation for the source and dynamics of water vapor in Asian stalagmites (Fig. 3-1-33).

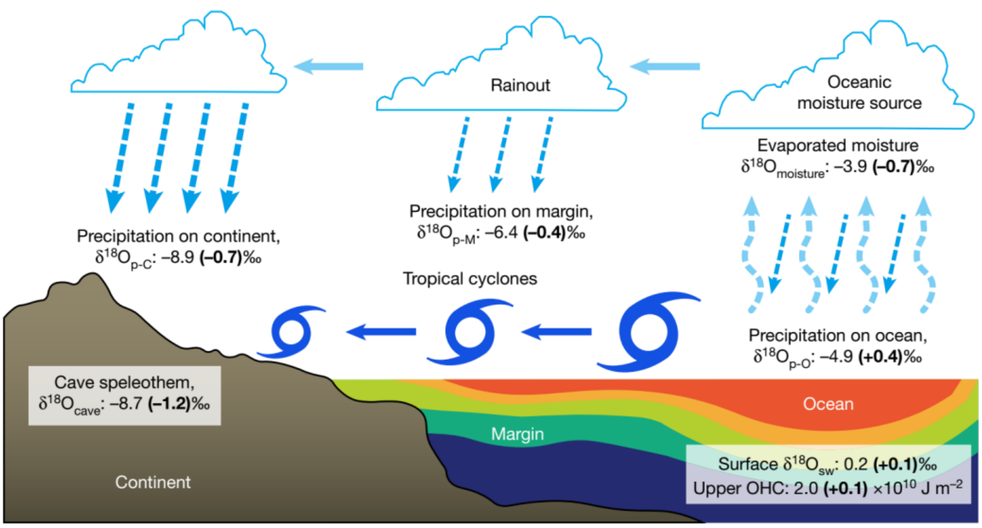


Figure 3-1-33 Ocean-continent $\delta^{18}O$ fractionation coupled with OHC and monsoon

After the research was published online, it was widely reported by the American Association for the Advancement of Science (AAAS), Sci-Tech Daily, Phys.org and overseas media such as those in Germany and the Philippines, as well as by domestic media such as CCTV News, Science Network and Wen Wei Po. This research demonstrated the great role of low-latitude climate and upper ocean dynamics in regulating global climate changes from an energetic viewpoint for the first time, which not only broadens a new research area of energetics in paleoceanography and paleoclimate, but also provides a new insight for the sea-land hydrothermal cycle.

Strong Feedback of Global Warming on the Potential of Biomass-Based Negative Emission Technology Under Delayed climate Mitigation

To achieve the target to limit global warming within 2 °C at the end of this century, many of the mitigation scenarios considered by Intergovernmental Panel on Climate Change assume that atmospheric temperature exceeds 2 °C in the short term, but global warming can be reduced to 2 °C by implementing large-scale negative emissions based on bioenergy with carbon capture and storage technology (BECCS). Delayed climate mitigation actions can reduce crop yields, lower the potential of BECCS, and threaten the production of agricultural crops. This feedback of climate change on the potential of BECCS is overlooked in the integrated assessment models, which has important impacts on estimating the social-ecological tipping point of climate change and the effectiveness of national mitigation commitments.

Supported by the National Natural Science Foundation of China (General Program 41877506), the group of Prof. Rong Wang from Fudan University in cooperation with several domestic and foreign groups had conducted research on the feedback of climate change on the mitigation potential of bioenergy by considering comprehensively the interactions between energy, climate, technology and agriculture in the latest Earth system model. Based on the model coupling social-economic systems and Earth system, the effectiveness of the various starting point to initiate large-scale BECCS negative-carbon technology to mitigate global warming was evaluated in the period from 2030 to 2100. The research found that the feedback of negative emissions technology has a large impact on the long-term trend of future climate change. Affected by the negative effects of climate change on crop yields, the potential of food production and the mitigation potential of BECCS will decrease remarkably, reducing capacity to achieve the 2 °C target of the Paris Agreement and threatening global food production. Furthermore, the study considers the influence of the shortage of food crops on global food supply. When the onset of BECCS is deferred from 2040 to 2060, developing countries with the shortage of food supply in 2100 will increase from 81 to 90. If these countries expand the cropland area or utilize excessive nitrogen fertilizer to meet the demand for food, the emissions of greenhouse gas would further increase to accelerate the rate of global warming.

The study entitled ‘Delaved Use of Bionergy Crops Might Threaten Climate and Food Security’ was published on *Nature* on 7th September, 2022.

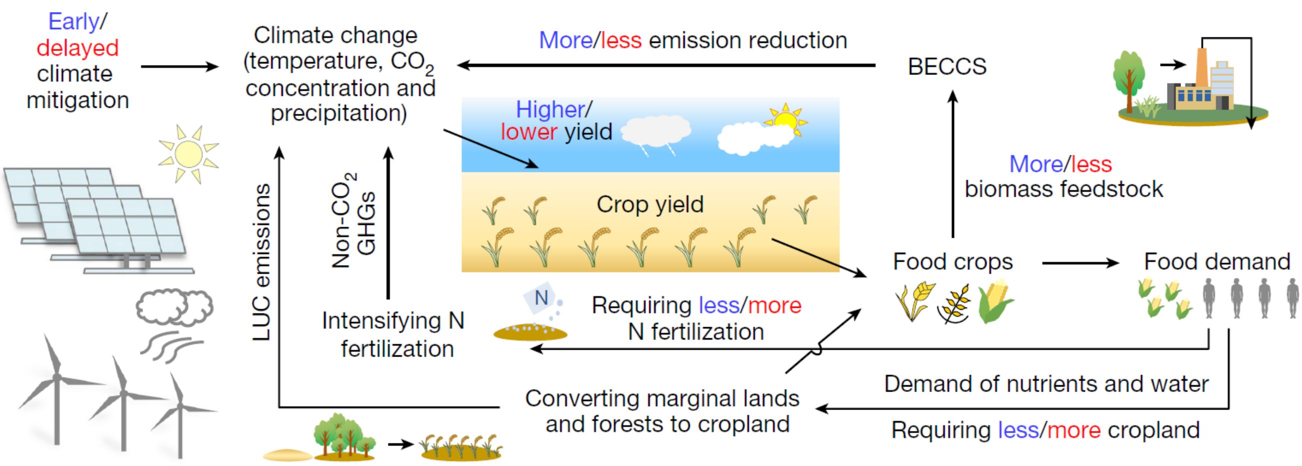


Figure 3-1-34 Feedback of global warming on crop yields in the Earth system model

Designing Ultra-Strong Yet Ductile Nanostructured Alloys

Under the support of the National Natural Science Foundation of China (Key Program 51931004, Young Scientist Fund 51601067 and General Program 52171011), Professor Ding Xiangdong and Professor Ma En from Xi'an Jiaotong University, Associate Professor Han Shuang from Jilin University, and Professor Sha Gang from Nanjing University of Science and Technology, in collaboration with Professor Liao Xiaozhou of the University of Sydney and others, have made important progress in developing ultrahigh-strength yet ductile nanostructured alloys. The relevant research results, entitled "Uniting Tensile Ductility with Ultrahigh Strength via Composition Undulation", have been published online in *Nature* on April 13, 2022.

When the grain size of the metallic materials is reduced down to the nanometer scale, the strength of the material will be greatly improved according to the Hall-Petch relationship. However, when nanocrystalline metals are plastically deformed, it is extremely difficult for dislocations to accumulate inside such tiny grains, which deprives the material most of its strain-hardening capability. As a result, the material is prone to plastic instability during deformation, leading to strain localization and subsequent failure. The trade-off between strength and ductility has become an important factor hampering the development of high-performance metallic materials reinforced with nanostructures.

In response to this key scientific issue, the research team proposed a novel mechanism for the strain hardening of ultra-high-strength nano-metals, and designed a novel high-performance alloy following this new path. Using NiCo alloy as a model material, a hierarchical nanostructure consisted of nano-sized grains (26 nm) and intra-granular multi-nanoscale composition fluctuations (1-10 nm) was constructed inside a face-centered cubic single-phase solid solution alloyvia pulsed electrodeposition.

The intentionally exacerbated compositional fluctuations contribute to the obvious fluctuations of the stacking fault energy and the lattice strain field. Such fluctuations occur at the spatial scale that can effectively interact with the moving dislocations, thereby changing the dislocation dynamics towards dislocation propagation in a wavy and intermittent manner. This, on the one hand, promotes the entanglement and effective storage of dislocations inside the nanograins, improving the strain hardening ability of the material; on the other hand, it improves the strain rate sensitivity of the dislocation flow and improves the strain rate hardening ability. Under the combined effect of strain hardening and strain rate hardening, the nanocrystalline alloy exhibits a unique combination of strength and ductility at ultra-high flow stress level, which is far beyond those previously reported single-phase face-centered cubic metal (including traditional solvent-solute solid solution, Fig. 3-1-35, Fig. 3-1-36): the nanocrystalline alloy shows a yield strength as high as 1.6 GPa and an ultimate tensile strength up to 2.3 GPa, together with a tensile elongation to failure of 16%.

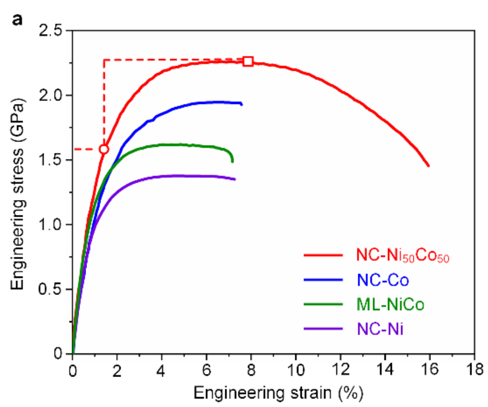


Fig.3-1-35 A representative engineering tensile strain–stresscurve of the NC NiCo alloy. The tensile curves of NC Ni, NC Co and ML NiCoalloys are also included for comparison.

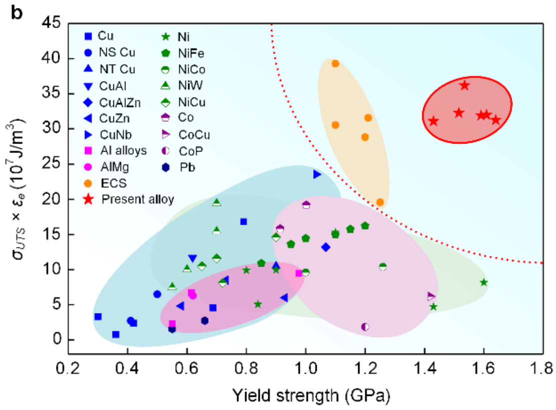


Fig. 3-1-36 Yieldstrength versus the product of the ultimate tensile strength (σ_{UTS}) and tensilestrain to failure (ε_e). The tensile properties of the present NC NiCo alloys (labeled as red pentagrams) standout, compared with not only previous NC metals but also electrodepositedconcentrated solid solutions (ECSs).

Electromechanical Coupling Technology and Integrated Design Platform for High-density Flexible Antenna and Their Application

Large high-density flexible antennas are widely used in land, sea, air, sky and other fields. They are the "eyes" and "ears" of their equipment. With the support of the National Natural Science Foundation of China (Major Program 51490660, Excellent Young Scientist Fund 51522507, and General Proram 51975447), the team of academician Duan Baoyan from Xidian University is committed to the technical innovation and major engineering application research of electromechanical coupling of large high-density flexible antennas.

There are many problems between the shape, structure, manufacturing accuracy, service environment of large high-density flexible antenna and antenna performance, such as unclear multiple nonlinear coupling relationship, unclear high-dimensional and multi-factor influence mechanism, and difficult to achieve accurate design and performance assurance. In response to this, the team explored the mechanism of interaction between structural factors, manufacturing processes and environmental factors and the electromagnetic/thermal/mechanical performance of large high-density flexible antennas. Then a multi-field coupling theoretical model is systematically established among electromagnetic field, structural displacement field, and temperature field. Several key technologies are broken through such as coupling information transmission between multiple fields, multidisciplinary integrated modeling, time-varying uncertainty measurement, quantitative analysis and design of shape control, error control and compensation, etc. The theory and method of electromechanical coupling design, fine manufacturing and performance guarantee are proposed and a comprehensive design platform is developed. The optimal configuration of antenna comprehensive performance and quality assurance design during service life are realized. It has been successfully applied to major equipments such as "China Sky Eye", also known as the FAST (Fig. 3-1-37. Five-hundred-meter Aperture Spherical Radio Telescope), China's first electrostatic forming film antenna, and the first radar of a certain type.

The innovative achievements of the project have opened up a new field of antenna technology research in China, made it move towards a new stage of electromechanical coupling, and led the leapfrog development of high-performance electronic equipment. The related achievements have won the first prize of the National Science and Technology Progress Award.

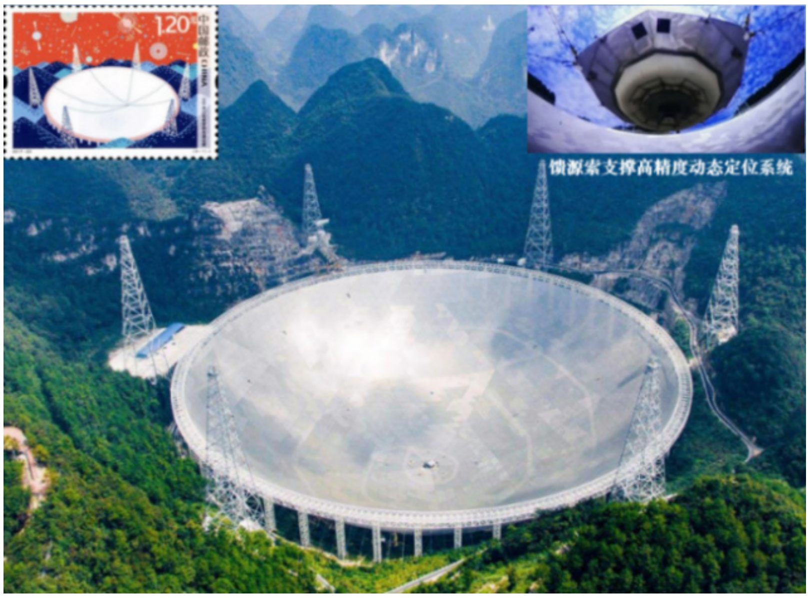


Fig.3-1-37 “China Sky Eye” 500m radio telescope

From Mechanism to Engineering: a Compact and Green Technology for the Treatment of Produced Water from Offshore Heavy Oil Fields

Professor Yang Qiang’s team from East China University of Science and Technology has made significant progress in uncovering the mechanism for demulsification and oil-water separation using a physical method and in its engineering applications, under the support of the National Natural Science Foundation of China (Excellent Young Scientist Fund 51722806, National Science Fund for Distinguished Young Scholars 52025103). Based on the research outcome, professor Yang’s team has developed engineering equipment for the treatment of produced water from a super-giant offshore heavy oil field in the Bohai Sea, resolving the bottleneck restricting productivity improvement of offshore heavy oilfields with high water content. Hence, Professor Yang, the team leader, was awarded the 2022 Xplorer Prize (the field of energy and environment).

The exploitation of offshore oil and gas resources is an important measure to safeguard national energy security. The treatment of produced water, the largest volume byproduct in offshore crude oil production, is essential to avoid marine environment pollution. However, the stubborn fine and emulsified oil droplets, as well as the existence of asphaltene, suspended solids, dissolved organic matter, and other multi-pollutant components in the produced water, make the treatment difficult and challenging. To tackle this issue, professor Yang’s group developed a real-time in-situ testing system to study the dynamic behavior of oil droplets in produced water, such as collision, coalescence and demulsification. The mechanism for oil droplet coalescence in water under the influence of the repulsive electrostatic double-layer force, the short-range hydration force, and the steric effects were clarified. Based on the fundamental understanding, the group invented a novel technology that improves the demulsification efficiency by shortening the droplet coalescence time from seconds to milliseconds, attributing to the precursor oil film on the oleophilic fiber.The heavy petroleum hydrocarbons in droplets are thus efficiently recovered from produced water as resources instead of pollutants by this physical method without additional chemical agents.

The invented technology was successfully applied to a super-giant offshore heavy oilfield for produced water treatment with the designed capacity of 24,000 m^3/d. In addition to an 80% reduction in floor space, the industrial application of this new technology contributes to an apparent decrease in sludge amount and an increase in oil resource recovery. Without the limitation from produced water treatment, the platform could increase its crude oil production by over 200,000 m^3 per year. This compact and green technology, regarding the comprehensive index of floor space and capacity, the critical parameter of offshore platforms, and the cost of water treatment per ton, accomplished the world-leading level. The achievement solves the offshore heavy oil fields' produced water treatment problem under harsh conditions. It firmly supports the exploitation of offshore oil and gas resources, and the protection of marine ecological environment.

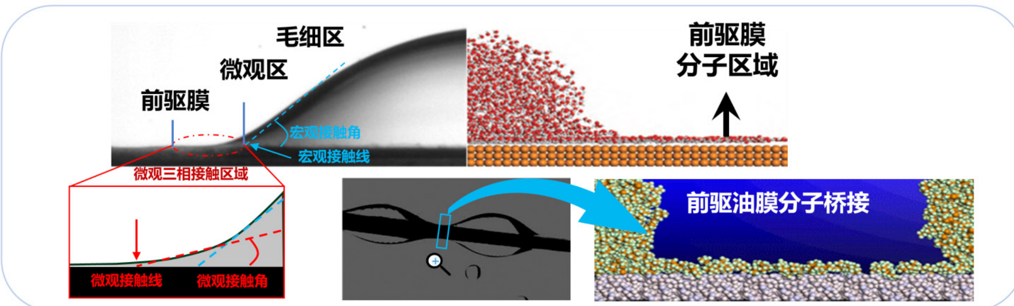


Fig.3-1-38 Microscopic mechanism of rapid coalescence of oil droplets induced by precursor oil film

WHP: Wellhead Platform 井口平台，后续字母为标号
CEP: Central Equipment Platform 中心平台，后续字母为标号
FPSO: Floating Production Storage and Offloading 浮式生产储油船
EPP: Electric Power Platform 岸电平台

Fig.3-1-39 Offshore engineering installation

Research on Thermal/Electrical Integrated Rectification

With the support of the National Natural Science Foundation of China (General Program 51976096, Special Fund for Research on National Major Research Instruments 51827807, Key Program 52130602), Prof. Zhang Xing, Assoc. Prof. Wang Haidong from the School of Aerospace Engineering, and Assoc. Prof. Lv Ruitao from the School of Materials Science and Engineering in Tsinghua University, worked together to successfully develop the first two-dimensional (2D) in-plane heterojunction thermal/electrical integrated rectifier, which achieved a maximum electrical rectification ratio of 10^4 and a thermal rectification ratio of 96% on the 2D heterojunction interface with a thickness of only 0.7 nm. This result sets a new record of thermal rectification efficiency at nanoscales. This research, entitled "Simultaneous Electrical and Thermal Rectification in a Monolayer Lateral Heterojunction", was published on *Science* on Oct. 14, 2022.

Chip is a "bottleneck" problem in China's core technology. With the gradual decreasing of chip's size, it poses new challenges to the fields of material science and thermal science. The research team synthesized a monolayer $MoSe_2$-WSe_2 in-plane heterojunction material by using an atmospheric pressure chemical vapor deposition method, and prepared suspended H-shaped sensing devices with different heterojunction interface angles by using high-precision nano-positioning and electron beam lithography technologies (Fig. 3-1-40). The experimental results show that the monolayer 2D heterojunction rectifier can withstand a large bias voltage over 60 V. At this time, the local hot-spot temperature rise of the device is reduced by 20% compared with the temperature rise under the condition without thermal rectification. The research results are expected to change the traditional route of chip cooling only by external equipment.

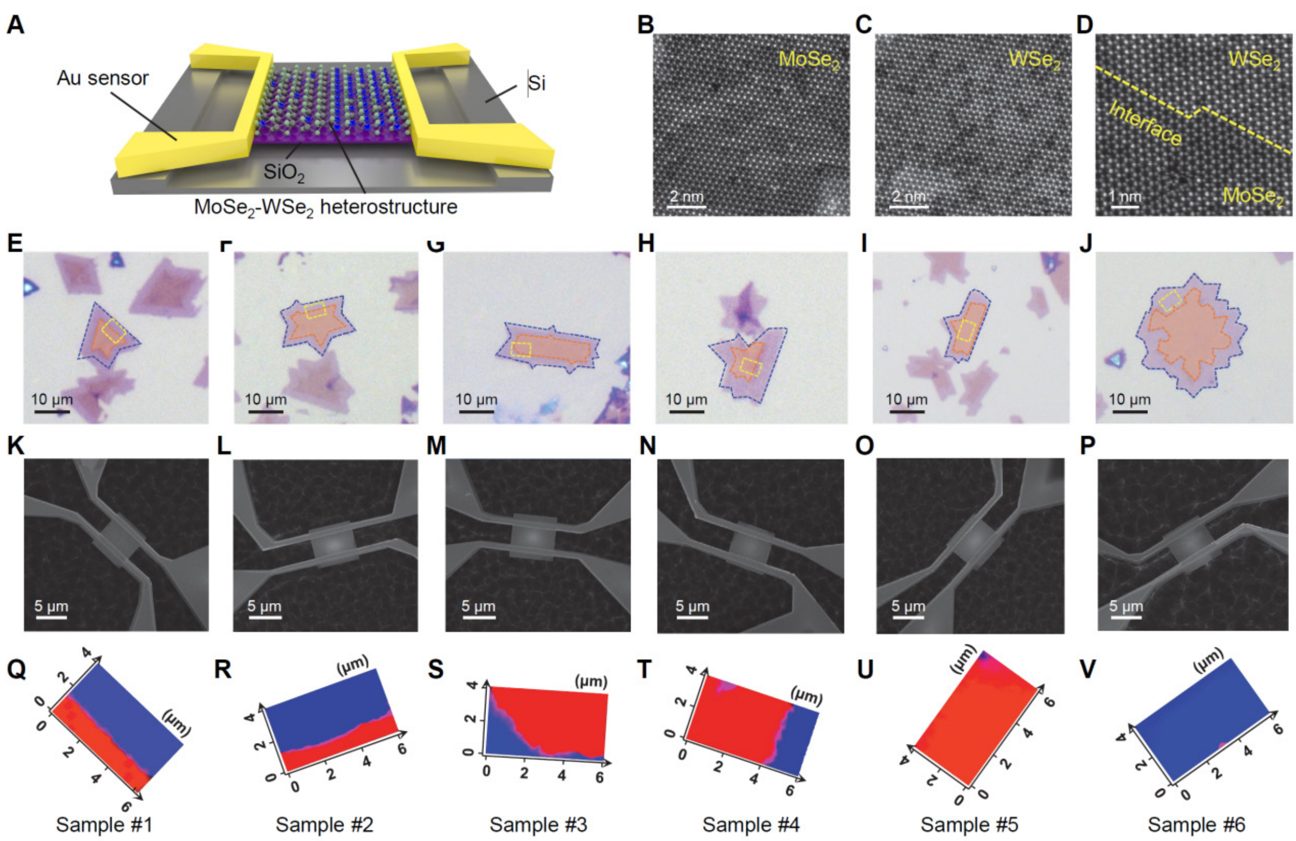


Fig. 3-1-40 Fabrication and characterization of $MoSe_2$-WSe_2 heterojunction rectifier with different interface angles

By enhancing the thermal conductivity of semiconductor material itself, the heat dissipation problem of high-power chips can be fundamentally solved, and the innovation for paradigm of chip's thermal design can be realized.

The Principles and Technology of Deep-sea Sediment Coring and Exploration with In-situ Temperature and Pressure Preservation

Under the support of the National Natural Science Foundation of China (Special Fund for Research on National Major Rsearch Instruments 51827901), a team led by academician Xie Heping from Shenzhen University and Sichuan University has successfully developed a deep-sea sediment (natural gas hydrates) coring system with in-situ temperature and pressure preservation. During the "Shared Voyage of Deep-sea and Abyssal Expedition and Equipment Sea Trial" on September 23, 2022, which was organized by the Hainan Deep-Sea Technology Innovation Center, the in-situ temperature and pressure-preserving deep-sea sediment (natural gas hydrate) coring system was installed on China's 4,500-meter-class deep-sea manned submersible, the Deep-sea Warrior, and completed the designated operation in an area in the South China Sea at a depth of 1370 meters, obtaining deep-sea sediment (natural gas hydrates) samples with an in-situ pressure of 13.8 MPa and a temperature of 6.51℃, filling a global technological void in deep-sea sediment sampling with in-situ temperature preservation, and achieving an international breakthrough in temperature and pressure-preserving deep-sea sediment sampling. Multiple media and institutions reported the groundbreaking achievement, including China Science Daily, Science Net, CCTV News, Newsroom Live, Hong Kong Commercial Daily, Oxford University, etc.

Since 2018, the team led by Xie Heping has dedicated itself to the research of deep in-situ condition-preserved coring and testing technology and device, focusing on overcoming the bottleneck of deep-sea sediment fidelity coring technology. The team started from scratch and achieved innovation in the principles and a breakthrough in technology, independently developing a coring technology with multi-directional self-triggering of pressure preservation, active + passive enhanced coupling insulation, which is suitable for the harsh low-temperature and high-pressure environment of the deep-sea. This has led to the creation of a complete set of devices for deep-sea sediment (natural gas hydrate) sampling capable of in-situ temperature and pressure-preserving coring, in-situ fidelity sample relocation and testing, with

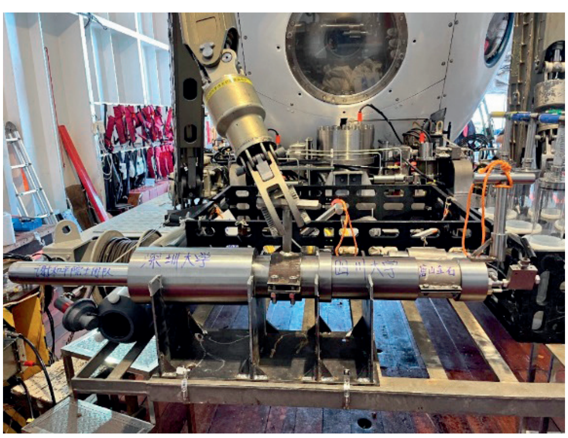


Figure 3-1-41 The deep-sea sediment (natural gas hydrate) coring system with temperature and pressure preservation installed on the "Deep-sea Warrior" ship

Figure 3-1-42 The deep-sea sediment (natural gas hydrate) coring system with temperature and pressure preservation in operation

independent intellectual property rights in China. A completely new system of principles and technologies for fidelity exploration of deep-sea resources has been established, realizing China's localization and autonomy in deep-sea fidelity exploration technology and equipment.

The successful deep-sea in-situ fidelity coring operation marks China's attainment of global leadership in deep-sea sediment (natural gas hydrate) temperature and pressure-preserving coring technology, providing technical support for the exploration and development of China's deep-sea resources and ocean science exploration.

Study of Graphite-to-Diamond Direct Transformation

Graphite and diamond are the most common carbon materials in nature, which have been widely developed and utilized by human beings for thousands of years. Synthetic diamond, transformed from graphite under high pressure and high temperature, was not successfully synthesized until the middle of the 20th century. The direct transformation from graphite to diamond usually occurs in a "black box" of high pressure and high temperature, and understanding the transformation mechanism has remained a significant challenge ever since the first synthesis of diamond.

Supported by the National Natural Science Foundation of China (Major Program 52090020 and Major Research plan 91963203), the research team led by Prof. Yongjun Tian and Zhisheng Zhao from Yanshan University, observed and determined the coherent interfaces between graphite and diamond nanodomains for the first time in partially transformed graphite samples treated under static high pressure and high temperature, and elucidated the graphite-diamond transformation mechanism: the graphite layers are locally bonded into coherent interface with two rhomboid and two rectangular structural motifs, the coherent interface then advances to the graphite region and transforms graphite into diamond. The various combinations of the four structural motifs produced a variety of coherent interface structures, leading to rich substructures (stacking faults, twins, diamond polytypes, etc.) in the transformed diamond regions. This new solid-solid phase transformation mechanism, different from the classical nucleation and growth mechanism as well as concerted shear mechanism, may work for other covalent materials, such as IVA elements and IIIA-VA compounds.

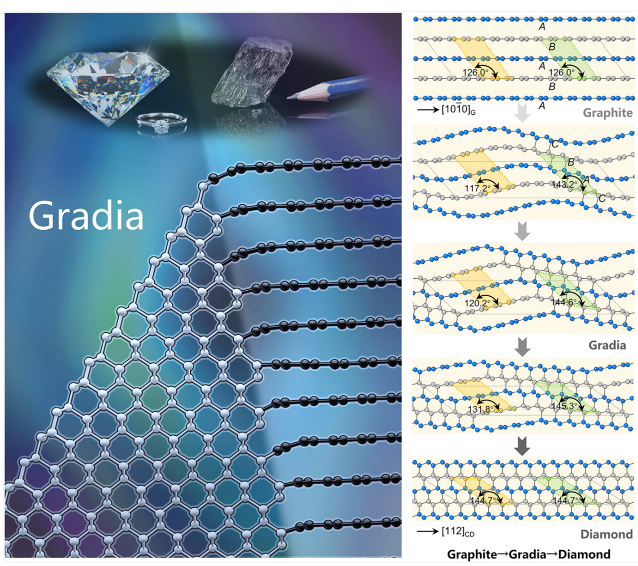


Figure 3-1-43 Structure of graphite-diamond hybrid carbon (Gradia) and the transformation process from graphiteto diamond.

The research team termed the hybrid carbon material with coherent graphite-diamond interfaces as Gradia. Gradia possesses an excellent combination of mechanical and electrical properties. Depending on the proportions of graphite and diamond in Gradia, Knoop hardness is adjustable between 51 and 115 GPa; room-temperature electrical resistivity is adjustable between 8×10^{-4} and 4.9×10^{5} Ω·m; fracture toughness is so high that it cannot be measured with the indentation method. With combined properties advantages of graphite and diamond that are tunable by changing the proportions of graphite and diamond, Gradia provides opportunities in pursuing desired combination of mechanical and electronic properties, such as simultaneous super hardness, high toughness and electrical conductivity.

This study clarifies the direct phase transformation from graphite to diamond, which has puzzled the scientific community for more than half a century, and finds a new category of solid-solid phase transformation. Beyond the transformation mechanism, the newly discovered hybrid carbon materials, Gradia, mark a major step towards nanostructure and properties engineering in diamond-related materials, and provides insight in developing next-generation high-performance materials. Gradia has the unprecedented comprehensive performances of high electrical conductivity and ultrahigh hardness, strength and toughness, superior to those of traditional graphite, diamond, carbon/carbon composites and structural ceramics. At present, the research team is developing the preparation technology and has successfully synthesized the decimeter-sized block, laying the foundation for large-scale application of Gradia. Gradia is an original high-performance carbon material with independent intellectual property rights in China, which has applied for patents in China, the United States, Japan and Europe. The current research result entitled "Coherent interfaces govern direct transformation from graphite to diamond" has been published online in *Nature* on July 6, 2022.

Realization of Device-Independent Quantum Key Distribution Based on Quantum Entanglement

Quantum Key Distribution (QKD) enables two remote users to share information-theoretical security keys. By combining with one-time pad encryption, QKD ensures unconditionally secure communication in principle. However, traditional QKD schemes usually require the users to have a certain understanding or trust on the underlying devices. In realistic conditions, the possible defects of the devices might become a side channel for attackers to threaten system security, causing potential security risks. Device-independent QKD (DI-QKD) is based on the fundamental test of quantum entanglement, and provides a new set of QKD protocols that do not depend on the specific functions and characteristics of the devices. The practical security of DI-QKD can be guaranteed by violating the Bell's inequality without any calibration of the devices. Although DI-QKD has attracted a lot of worldwide scientific attention during the past decade, the realization of DI-QKD is challenging. For example, in the optical system, the existing theories require the detection efficiency of the system to be ≥ 90%, which is far beyond the reach of current technology.

Under the support of the National Natural Science Foundation of China (Key Program 62031024, General Program 61771443), the research team led by Prof. Jian-Wei Pan, Prof. Feihu Xu and Prof. Qiang Zhang from the University of Science and Technology of China conducted explorations and innovations from both theoretical and experimental aspects. They proposed a novel theoretical protocol, developed a high-efficiency optical quantum entanglement system and performed the first proof-of-principle demonstration of DI-QKD.

In theory, the team proposed a DI-QKD protocol based on random post selection. As shown in Figure 3-1-44, by randomly adding noise to the measurement results and eliminating the results that contain little relevant information, they effectively enhanced the system's tolerance to loss and noise, making it possible to realize DI-QKD with current technology. In experiment, as shown in Figure 3-1-45, they used a periodically poled nonlinear crystal of potassium titanium phosphate to realize spontaneous parametric down-conversion and performed the optimization of spatial optical path parameters to prepare a high-efficiency quantum entanglement source. By combining with high-performance superconducting single-photon detector, the research team makes the overall detection efficiency of the system up to 87.5%, which exceeds all the related experiments reported in the past. At the same time, by adjusting the placement angle of the nonlinear crystal to limit its reflection of parametric light, the fidelity of the quantum state generated in the experiment can reach 99.5%, so that the system performance can meet the requirements of the theoretical protocol. On this basis, they realized the principle demonstration of DI-QKD based on the all-optical system for the first time. The experimental results show that the secret key rate of the system reaches 466 bps, and the secure key can be generated over 220 m optical fiber.

The theory paper entitled "Device-Independent Quantum Key Distribution with Random Postselection"and the experiment paper entitled "Toward a Photonic Demonstration of Device-Independent Quantum Key Distribution" were published in *Physical Review Letters* in March 1st 2022 and July 27th 2022, respectively. These results are of great significance for revealing the inherent connection between the fundamental test of quantum mechanics and quantum information processing, developing secure key distribution and building the future quantum Internet. The experimental result was quoted in the scientific background of "The Nobel Prize in Physics 2022".

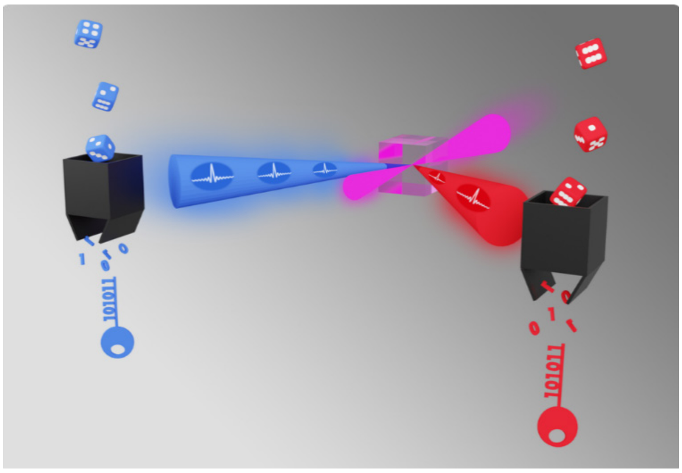


Figure 3-1-44 The schmetic diagram of DI-QKD.

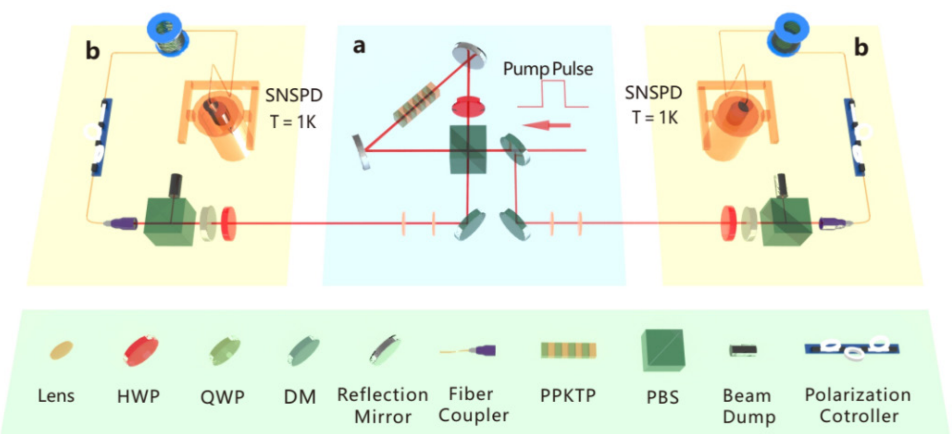


Figure 3-1-45 The experimental setup of DI-QKD. HWP, half-wave plate; QWP, quarter-wave plate; DM, dichroic mirror; PPKTP, periodically poled potassium titanyl phosphate; PBS, polarizing beam splitter; SNSPD, superconducting nanowire single-photon detector.

Research on Heterogeneous Integrated Millimeter-wave Radar and its Application

At present, the continuation of Moore's Law has faced serious challenges, which calls for new development direction of integrated circuits. Three-dimensional (3D) heterogeneous integration technology can break the limits on system performance and functionality set by the single semiconductor process, to achieve high-performance and multi-function electronic systems, which is one of the new development directions for the integrated circuits in the post-Moore era. One key application of the heterogeneous integration technology is to develop miniaturized, high power and low noise millimeter wave radar for important application fields, such as Unmanned Systems and Internet of Things (IoT).

The group of Prof. Mao Junfa and Prof. Zhou Liang at Shanghai Jiao Tong University have conducted research on millimeter-wave heterogeneous integrated circuits, which were funded by the National Natural Science Foundation of China (Excellent Young Scientist Fund 61822112 and Key Program 61831016). Their research focuses on three aspects, including millimeter-wave heterogeneous integrated circuit design methods, millimeter-wave heterogeneous integration fabrication process, and system test characterization methods. The group has demonstrated the multiperformance-multifunctional co-design of heterogeneous integrated circuits and its measurement principle, revealed the mechanism of heterogeneous interface generation, and established the quantification and regulation methods of the fabrication process. On this basis, a photosensitive composite film and a 3D wet-dry etching method have been developed and established for silicon-based MEMS fabrication process to precisely embed heterogeneous chips of different materials and thicknesses. It eliminates bubbles in the dielectric layer, large gaps in the reserved conductive silver paste and large inter-chip embedding offset errors, which usually result in deviations and misalignment between the chip pins and the photolithography plate. As a result, the interconnection length between chips and between chip and passive device has been significantly reduced, achieving a minimum pitch of 5 mm and an interconnection through-hole loss of only 0.15 dB. The compound semiconductor interconnection structure is compatible with the CMOS semiconductor device back-end process. Based on the aforementioned hetero-integration technique, a W-band millimetre-wave radar (Figure 3-1-46) has been developed with 3D integration of a silicon-based phase-locked loop (PLL) chip, a SiGe transceiver chip, a GaN power amplifier(PA) chip and passive components, such as packaged antennas and capacitors. The 3D integrated W-band millimetre-wave radar has a 6 dB increase in output power, a detection range of more than 1000 m and a maximum resolution of better than 0.08 m (as shown in Fig. 3-1-47) as compared with the ones fabricated by conventional integration method. Meanwhile, the size of the system has been reduced by more than 80% with the weight of only 78 g. Its comprehensive performance is better than that of the single process integrated radar in the same frequency band reported in the latest literature and is used in a major national project.

The results of the study, entitled "Low-Loss Heterogeneous Integrations with High Output Power Radar Applications at W Band", were published in June 2022 in the IEEE Journal of *Solid-State Circuits (JSSC)*. The work has broken through a long-standing process bottleneck that has hindered 3D heterogeneous integration in the millimeter-wave band, and has formed a process platform that is open to the public, which will help to promote the rapid development of China's integrated circuit technology sector.

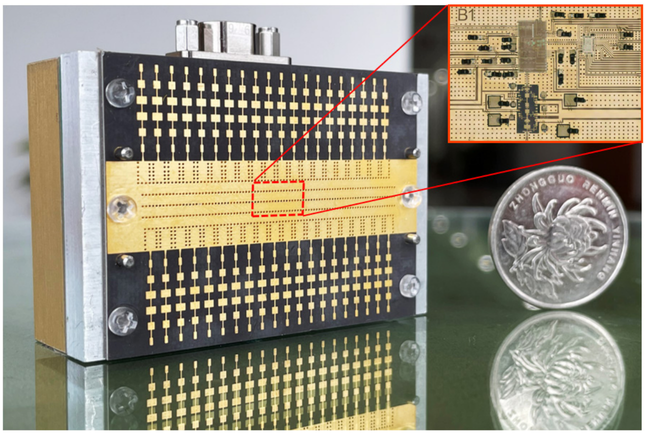
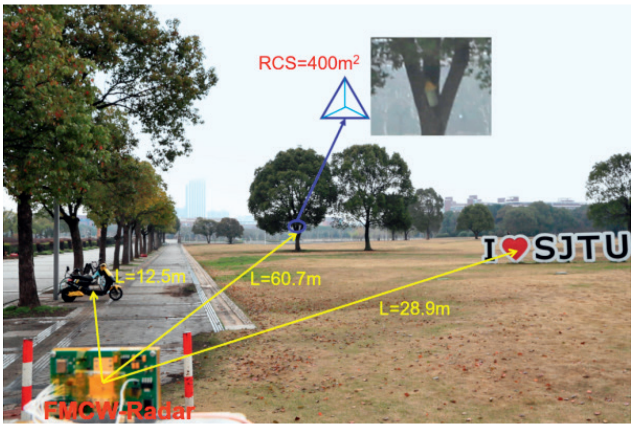
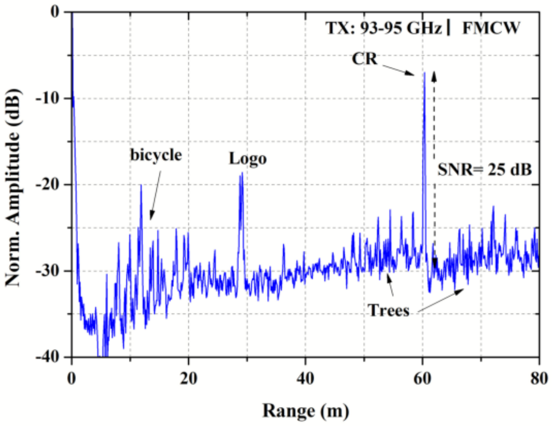


Figure 3-1-46 A heterogeneously integrated W-band millimetre-wave radar



(a)



(b)

Figure 3-1-47 (a) Image of range detection experiment using the frequency modulation continuous wave (FMCW) radar and (b) corresponding range measurement results

Robust and Adaptive Deep Learning for Head Disorder Detection from CT

Head disorders, such as brain ischaemia, haemorrhage, tumours, and skull fracture, greatly affect the structure and function of the head and brain, causing high morbidity and mortality. Recently, deep learning has shown promising results for computer-aided diagnosis (CAD). However, it should be noted that a large-scale and high-quality training dataset, which is expensive and difficult to construct, is always necessary for building an accurate and generalizable deep-learning-based CAD system. Therefore, innovating new deep learning techniques to build accurate and generalizable CAD systems in a cheap and efficient way is an important and hot research topic recently.

Supported by the National Natural Science Foundation of China (Special Fund for Research on Major National Research Instruments 61727808, Creative Research Group 62021002, National Fund for Distinguished Young Scholars 81825012), the interdisciplinary research team co-led by Prof. Qionghai Dai from Tsinghua University and Prof. Xin Lou from the Chinese PLA General Hospital recently reported their breakthrough in robust and adaptive deep learning for head disorder detection from CT

(1) To address the requirement for accuracy, generalizability, and explainability, the team proposed a novel robust and adaptive deep learning system, which utilized the low-quality annotations extracted automatically from free-text diagnosis reports to build the disorder recognition and localization models for head CT. The system could detect common head disorders, including brain ischaemia, haemorrhage, tumours, and skull fracture, with leading accuracy, generalizability, and explainability.

(2) To address the robust learning problem due to the low-quality annotations, the team proposed a self-supervised label confidence evaluation algorithm, based on which confidence-guided deep neural networks were constructed. In this way, the wrong supervision given by mislabeled annotations could be suppressed, such that we could train a robust and accurate model on them.

(3) To address the localization error caused by the inexact annotations, the team proposed a weighted multi-instance learning framework, and constructed an attention-guided decision visualization module.

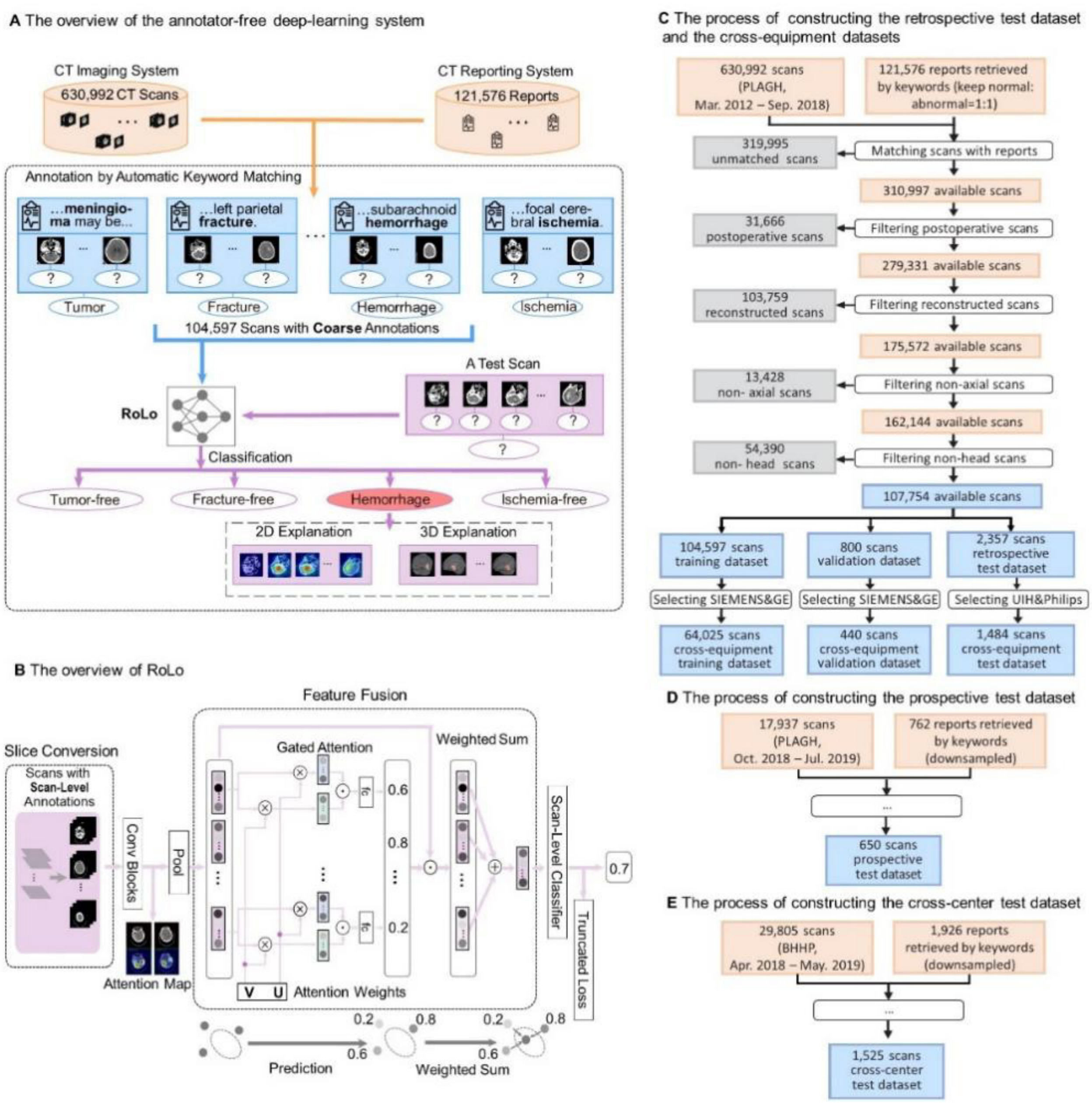


Figure 3-1-48 Overview of Robust and Adaptive Deep Learning for Head Disorder detection from CT

Based on them, the system was capable of precisely localizing lesions in multi-dimensional imaging data, and providing visualizable clues for decision understanding.

Based on the above technology innovation, the team developed a CAD system for head disorder detection from CT. The system was comprehensively tested in multiple centers in China. The retrospective, prospective, and cross-center tests demonstrated the superior diagnosis performance in practice. This research was published in *Lancet Digital Health*, on June 17th, 2022. Several experts commented that the system achieved impressive results, and showed superiority on accuracy, generalizability, explainability, and efficiency. The application of the innovative algorithm and system may help to improve the clinical diagnosis accuracy for head disorders, and provide powerful tools for precision medicine.

Swarm of Micro Flying Robots in the Wild

Under the support of the National Natural Science Foundation of China (Young Scientists Fund 62003299, Basic Science Center Program 62088101), a research team from the College of Control Science and Engineering and the Huzhou Institute of Zhejiang University, led by Dr. Fei Gao and Prof. Chao Xu, have made progress in the field of micro aerial-robot swarm. This research, titled "Swarm of Micro Flying Robots in the Wild," was published online as a cover paper on *Science Robotics* on May 5, 2022.

The problem of navigating from structured artificial environments to uncertain outdoor environments for aerial robot swarms is a well-known challenge, facing major difficulties with computational, sensing, and communication limitations. Inspired by bird flocks, the research team decoupled the temporal and spatial parameters in the calculation of trajectory planning, achieving a linear complexity mapping between optimization variables and intermediate variables in the trajectory parameterization process. In this way, they established an efficient temporal and spatial optimization technology, ensuring the safety, dynamical feasibility, time optimality, and trajectory smoothness of micro aerial swarms. Therefore, even in extremely complex and narrow environments, the developed micro aerial swarm can plan high-quality trajectories in milliseconds, greatly improving the efficiency and scalability of task execution.

The micro aerial swarm in this research is independent of external positioning and computing facilities. Using only onboard computers, cameras, and other sensors, the team broke through multiple core technologies such as perception, positioning, trajectory generation, and multi-agent communication in complex forest environments. The aerial swarm can complete tasks such as trajectory sharing, reciprocal collision avoidance, cooperative flight, and multi-agent target tracking through wireless communication between each other. In the swarm, each aerial robot is only the size of a palm and weighs less than a can of cola. In real-world experiments, the team validated a swarm with 10 drones and in simulations a swarm with 50 drones. The developed swarm system has a 2.5 m/s flight speed in narrow spaces, 10 m/s flight speed in open spaces, and 10 minutes hovering time, and can autonomously reach a designated location and return in complex environments (Figure 3-1-49).

This research enabled the autonomous flight of aerial swarms in near-ground, highly dense, and irregular natural complex environments. Its technology is at the leading level in terms of intelligence, agility, cooperation, robustness, and other aspects of aerial robot swarms. Moreover, this work has been reported by mainstream media such as the Chinese government website, Xinhua News Agency, Science and Technology Daily, American Association for the Advancement of Science, The Times, and Agency France-Presse.

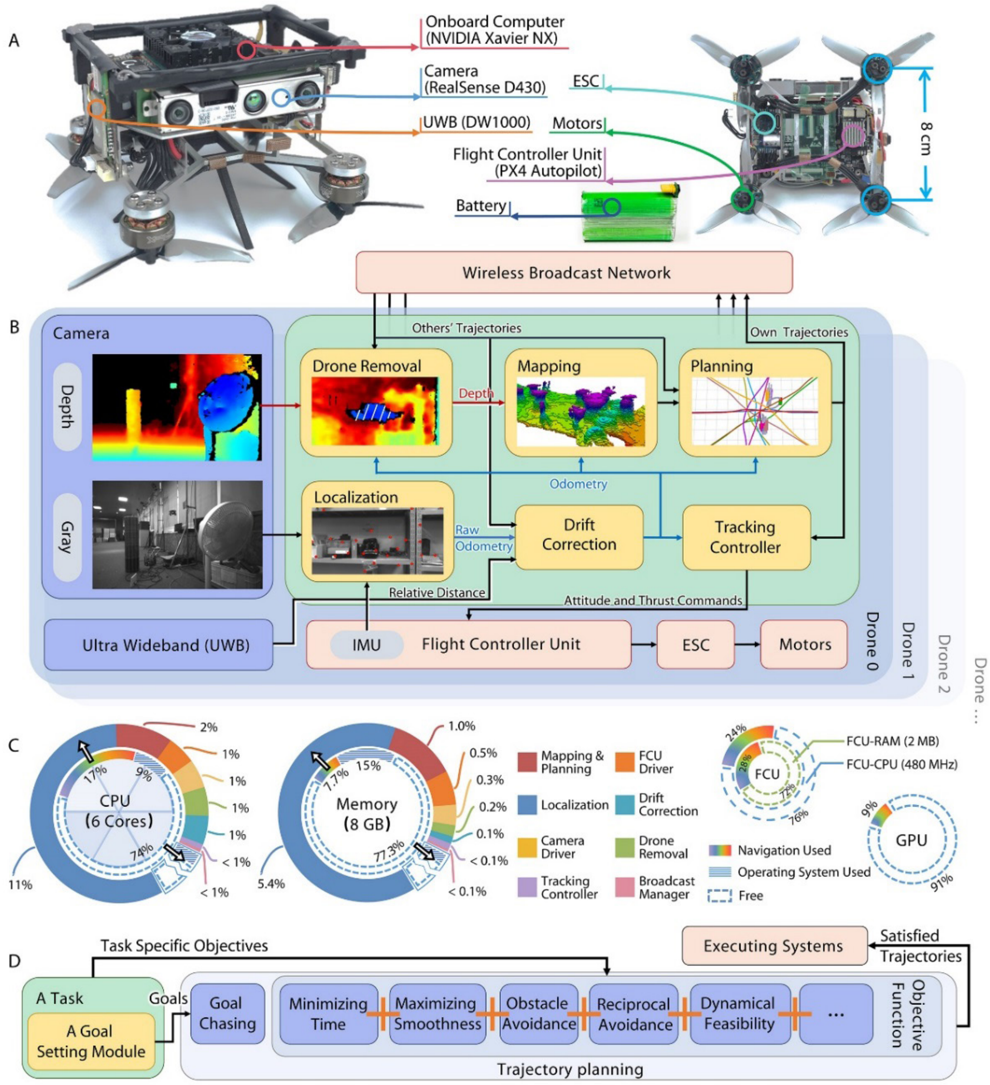


Figure 3-1-49 System Architecture

"Atomic Lego" Solid-state Quantum Simulator

Accurately describing complex systems and their evolution, such as quantum many-body systems, is far beyond the computational capabilities of traditional computers. For example, calculating physical properties of 100 interacting electrons has exceeded the capability of the most powerful computer. This has become one of the most pressing challenges in the research field of future computing.

Under the support of the National Natural Science Foundation of China (Key Program 62034004, Excellent Young Scientist Fund 62122036, National Fund for Distinguished Young Scholars 61625402, Creative Research Group 61921005), a collaborative team led by Prof. Feng Miao from Nanjing University adopted the "Atomic Lego" approach to build a brand-new computing hardware, i.e. solid-state quantum simulator, and realized significant progress in simulating complex quantum system and investigating its dynamic evolution. Primary breakthroughs are listed below.

(1) The team constructed a new solid-state quantum simulator based on graphene moiré superlattice

(Fig. 3-1-50a), and successfully simulated the isospin extended Hubbard model with tunable intrinsic degrees of freedom (Fig. 3-1-50b), opening up a new avenue to study the evolution laws of complex quantum systems.

(2) In this simulator, the team successfully simulated a quantum many-body system comprised of 10000 interacting electrons, observing a new type of electronic crystal: generalized isospin Wigner crystal. The quantum melting process of this electron crystal exhibits "quantum two-step criticality" (Fig. 3-1-50c), confirming the existence of a critical intermediate phase for the first time.

(3) The team observed "quantum pseudo criticality" for the first time (Fig. 3-1-50d), revealing that the type of quantum criticality in the melting process of Wigner crystals depends on the dimension of the intrinsic degrees of freedom. This result resolved the long-standing controversy over the quantum melting process of Wigner crystals.

The above research progress was published in *Nature* on September 14, 2022, titled "Tunable quantum criticalities in an isospin extended Hubbard model simulator". This work was also reported by the *Nature News & Views*, appraising that "The authors' work therefore offers a platform in which the simplest possible simulator can be tuned to exhibit complex quantum phase transitions". Meanwhile, Academician Xie Xingcheng from Peking University and Prof. Fan Zhang from UT Dallas wrote a Research Highlight article in *National Science Review* to highly praise this work. This work not only enables the in-depth understanding of complex systems and accurately predicting of their evolutions, but also takes a key step towards the future development of high-density integratable, highly tunable, and easy-to-read solid-state quantum simulators for different future application scenario.

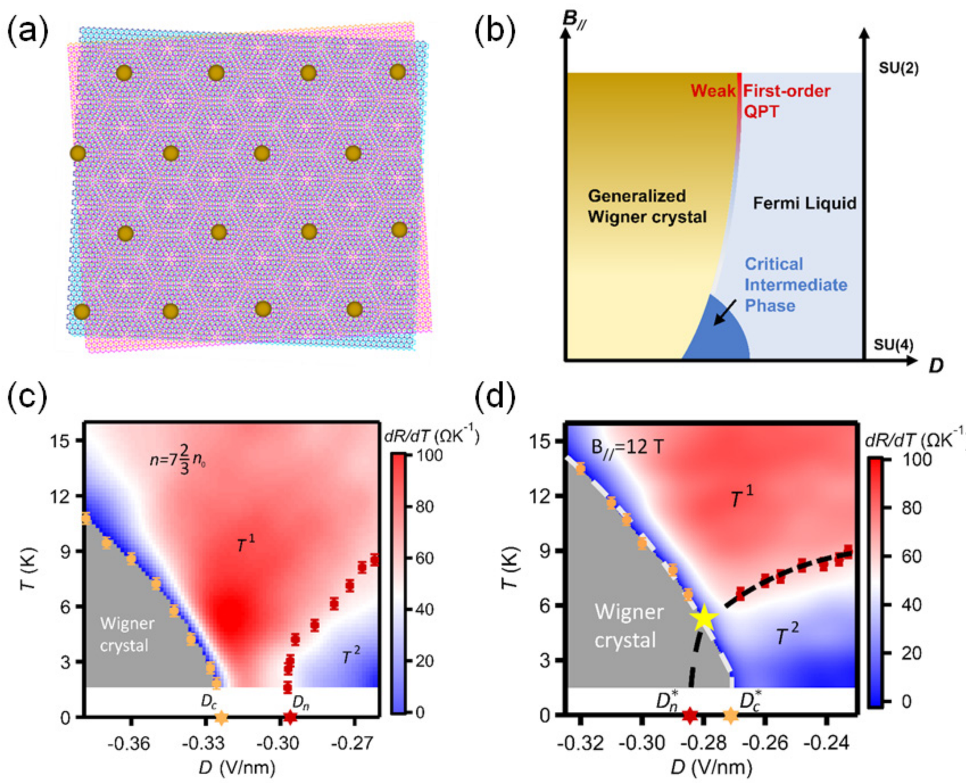


Figure 3-1-50 (a) Atomic Lego-like moiré superlattice and generalized isospin Wigner crystal. (b) Quantum simulator with tunable intrinsic degrees of freedom. (c) Quantum two-stage criticality. (d) Quantum pseudo criticality.

Research on Sub-1-Nanometer Gate Length Transistors

Gordon Moore, the co-founder of Intel, put forward the famous "Moore's Law" in 1965. As the core component of the chip, transistors with smaller gate-length can integrate more transistors on the chip and improve the performance. However, in recent years, with the physical size of transistors entering the nanoscale, the short channel effect is becoming more and more serious, which makes the development of new structures and new materials extremely urgent. According to IRDS 2021, the gate length of transistors in the mainstream industry will always be larger than 12 nm. How to further reduce the critical size of transistors has aroused the interest of a wide range of researchers. Academics have explored the very short gate length transistor. In 2012, the Japanese Institute of Industry and Technology reported that a V-shaped junction-less transistor based on silicon on insulator was realized, with an equivalent physical gate length of only 3 nanometers. In 2016, the University of California, Berkeley and Stanford University reported that the planar molybdenum sulfide transistor based on carbon nanotube with a physical gate length down to 1 nm.

Supported by the National Natural Science Foundation of China (Excellent Young Scientist Fund 62022047, General Program 61874065) and other programs, Professor Ren Tian-Ling's team and collaborators from the School of Integrated Circuits of Tsinghua University have made new progress in the research of ultra-small gate-length transistors. For the first time, a transistor with sub-1 nm gate length has been realized and has good electrical performance. The relevant achievements are entitled Vertical MoS_2 transistors with sub-1-nm gate lengths, and were published online in the top academic journal *Nature* on March 9, 2022.

In order to further break through the gate length below 1 nm, the research team skillfully used the ultra-thin single atomic layer thickness of graphene film with excellent conductivity as the gate, and controlled the vertical MoS_2 channel switch through the graphene lateral electric field, thus achieving an equivalent physical gate length down to 0.34 nm. By depositing metal aluminum on the surface of graphene and natural oxidation, the shielding of the vertical electric field of graphene surface is completed. This study found that, because the single-layer molybdenum disulfide film has higher effective electron mass and lower dielectric constant than the bulk silicon material, the transistor can be effectively turned on and off

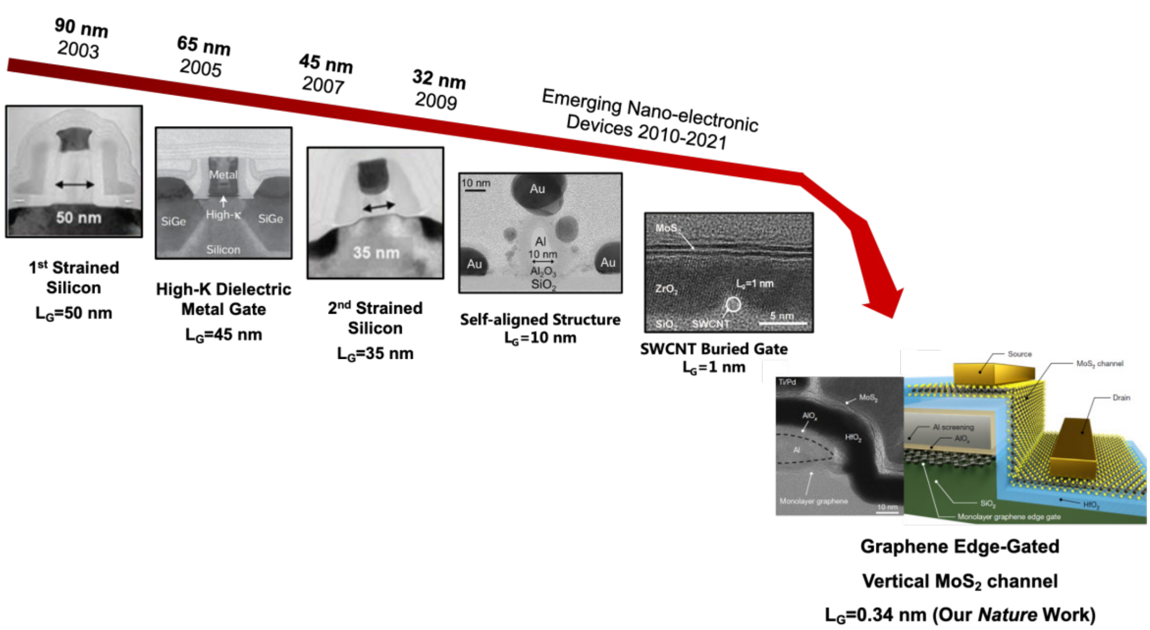


Figure 3-1-51 With the development of Moore's Law, the gate length of transistors is gradually reduced. In this work, a transistor with sub 1 nanometer gate length is realized.

under the control of the ultra-short sub 1 nanometer physical gate length. Its off-state current is down to pA level, the switching ratio can reach 10^5, and the sub-threshold swing is about 117 mV/dec. A large number of experimental test data results also verify the large-scale application potential of this structure.

This work promotes the gate size to the sub-1 nanometer level, and provides a reference for the application of two-dimensional films in future integrated circuits.

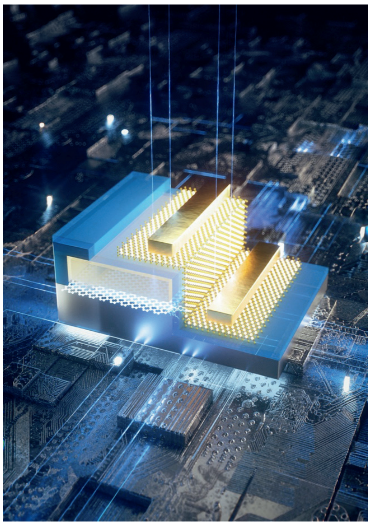


Figure 3-1-52 Sub-1 nm transistor device structure.

The Existence of an Optimal Deterministic Contract in Moral Hazard Problems

Moral hazard problems have broad applications in economics and social management, and it is one of the important research fields of modern economic study. The key scientific issue is the designing of an optimal incentive contract which induces the agent to put optimal effort under the environment of information asymmetry. More importantly, to analyze the properties of the optimal incentive contract offered by the principal, a basic prerequisite is whether the optimal incentive contract exists. Theoretically, without any priori assumptions on the payment (e.g., sequential compactnessor uniform boundedness), the existence of an optimal contract is an open and challenge problem.

Supported by the National Natural Science Foundation of China (Major Program 72192800, Young Scientist Fund 71803202), the research team of Professor Ke Rongzhu from Zhejiang University and Assistant Professor Xu Xinyi from Sun Yat-sen University proposed a new method for investigating the existence of a deterministic solution to pure moral hazard problems under a general setting, achieved the following new results.

(1) A necessary and sufficient condition is provided for the existence of a an optimal contract in the classical moral hazard setting wherein the agent's utility is separable between money and effort, and the utilities of the principal and agent are concave in money.

(2) A series of easy-to-check conditions are offered for a better application in real-world scenarios and complements to the existing literature. In any of the following situations, the existence of the optimal deterministic contract in moral hazard problem can be verified, thus providing a theoretical basis for subsequent characterization and analysis: (i) the ratio of asymptotic marginal utility is unbounded; (ii) the agent's marginal utility from payment tends to zero; or (iii) the outcome or signal space is finite.

(3) An affirmative answer is provided to Hölmstrom's conjecture that bonuses work less often than penalties via the comparison between extreme bonuses contracts and extreme punitive contracts, based on Mirrlees' classical settings.

This research, titled "The Existence of an Optimal Deterministic Contract in Moral Hazard Problems", was online published on *Economic Theory* on October 29, 2022.

A common application scenario of the above theory is to confirm the existence of optimal contracts in financing arrangements where entrepreneurs have moral hazard (that means the efforts of entrepreneurs are unobservable, and the interests of entrepreneurs and investors are not completely allied).If the entrepreneur is protected by a limited liability constraint (so that when the project fails, the entrepreneur cannot be extremely punished), the funder is also limited by a budget constraint (so that when the project is successful, it is impossible to maximize the rewards for entrepreneurs), then, according to the team's theory, there exists an optimal financing contract (e.g., some combination of debt and equity), which guarantees the return on investment of investors without damaging the enthusiasm of entrepreneurs.

The approach can apply to multi-agent settings and the cases in which the agent utility is quasi-separable. In addition, this method can also be extended to the design and analysis of complex incentive problems in platform economics.

Research on Operations and Management of Dynamic Ridepooling Service

As a representative of shared mobility services, dynamic ridepooling, e.g., DidiPinche, UberPool, is widely regarded as a promising way to serve more people while producing less emissions and congestion. Previous studies, based on 170 million taxi orders in New York in 2011, have shown that dynamic ridepooling can allow for almost all taxi trips in New York to be shared, resulting in a delay of no more than two minutes for passengers and a reduction of taxi fleet size by 30%. However, transforming the potential of dynamic ridepooling into real benefits requires sophisticated operations and management. Due to the real-time service requirement and the unpredictable arrival of ridepooling demand over time and space, there is a lot of difficulty in implementing an attractive and profitable dynamic ridepooling service.

With the support of the National Natural Science Foundation of China (Creative Research Group Program 72021002, Excellent Young Scientist Fund 72022013), the Tongji University research team led by Professor Xiaoning Zhang has achieved the following innovative results on several key operational and management issues associated with dynamic ridepooling services:

1. A model is established to capture the complex matching and competing relationship among ridepooling demand between different origin-destination (OD) pairs on general road networks. The model explains the mechanism that determines the matching probability of each OD pair and how the distribution of ridepooling orders over time and space affects the matching probability of each order.

2. The first method for prediction of matching probabilities is developed, expected ride distances and expected shared distances of orders between different OD pairs in general road networks. In addition to providing accurate predictions under diverse matching conditions and demand intensities, the method can serve as a useful basis for the improvement of matching policies and pricing strategies of dynamic ridepooling services.

3. A forward-looking matching policy is proposed that takes future matching opportunities into consideration, and a system optimal pricing strategy design method is developed that considers the interactions between different OD pairs. In comparison with myopic policies, the forward-looking matching policy can increase the total saved distance by 5%; and in comparison with separately optimizing the price for each OD pair, the proposed system optimal pricing strategy can increase the platform's profit by 8%.

The above studies were published in *Transportation Research* Part B and *Transportation Science* in December 2021 and March 2022, respectively. These research results provide a deeper understanding of the complex interrelationship within the ridepooling system, offer new powerful tools and methods to improve the operational efficiency of dynamic ridepooling, and have the potential to promote the dynamic ridepooling service to play a greater and more important role in alleviating congestion and reducing emissions in our future transportation system.

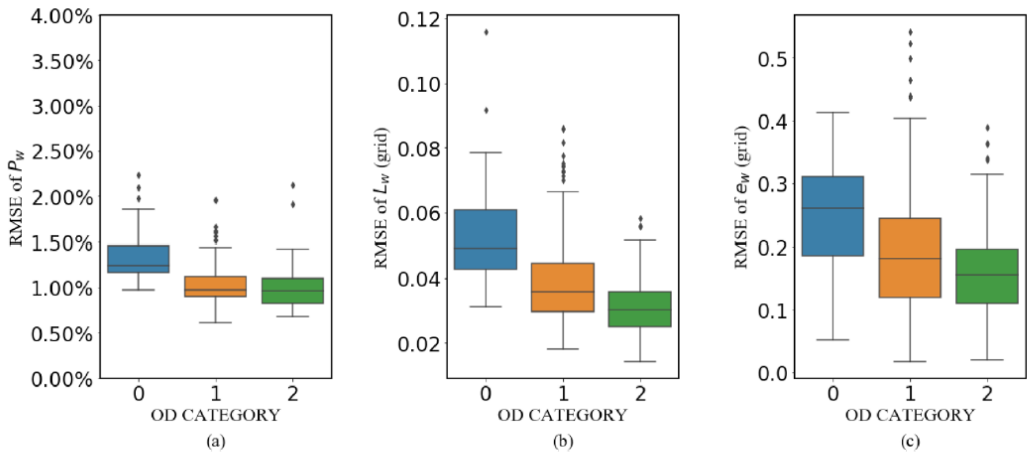


Figure 3-1-53 The Root Mean Square Errors (RMSEs) of the predicted matching probabilities (P_w), expected ride distances (L_w), and expected shared distances (e_w) of each OD category in a 30*30 grid network

Information Sharing Contract Design of Online Platforms

As one of the popular trading places, online platforms can use technical means such as 5G and IoT to capture the potential demand information of users, and provide standardized and personalized data sharing services for manufacturers and third-party sellers, thus substantially improving the operational efficiency of the national economy.

Supported by the National Natural Science Foundation of China (Major Program 72091210 and General Program 71971205), the teams of Professors Yu Yugang and Zha Yong from the School of Management, University of Science and Technology of China focus on the design of information sharing mechanism for online platforms, and study the platforms' information sharing services for upstream manufacturers and downstream third-party sellers under different operational models. Innovative findings are as follows.

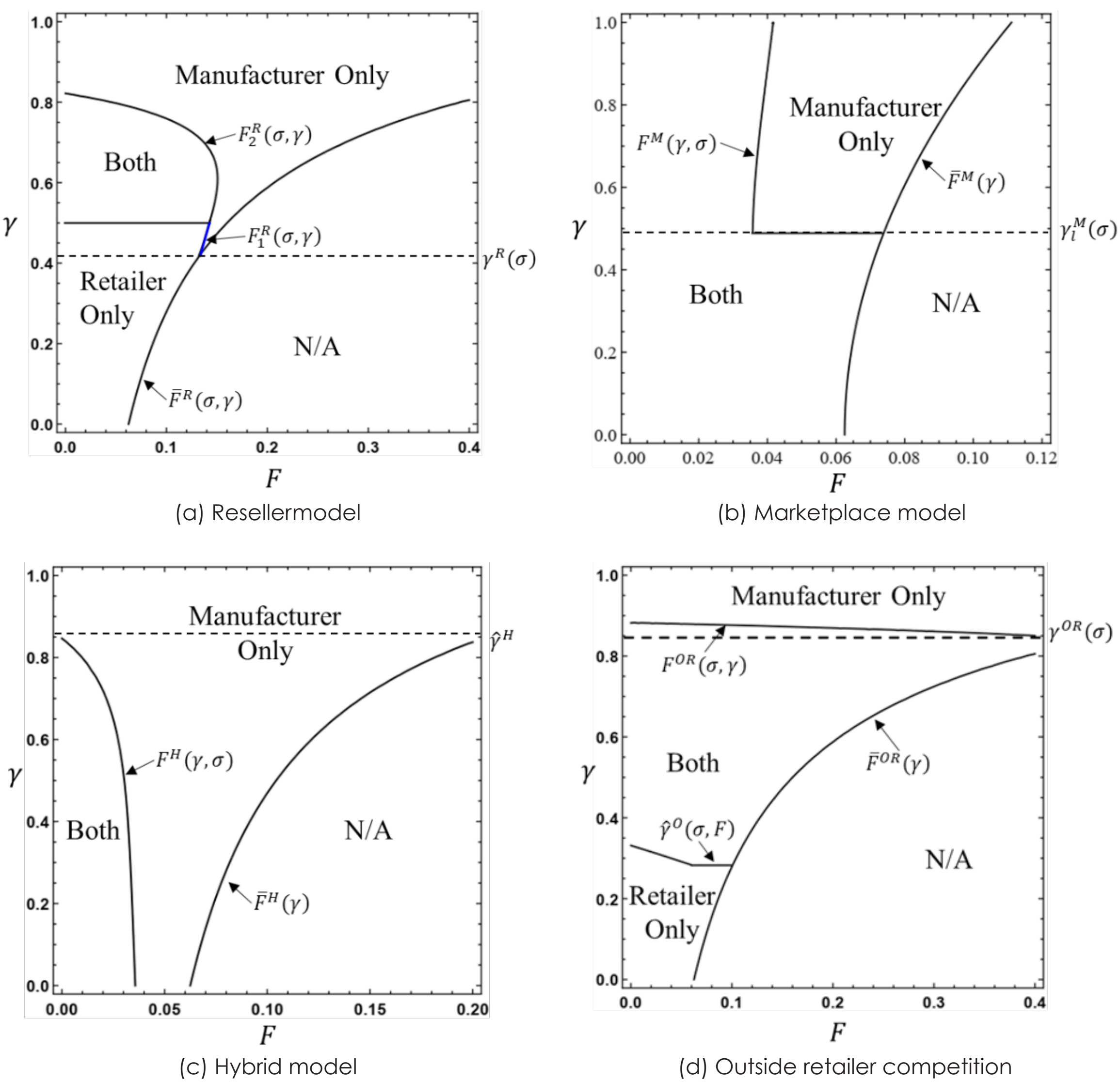
(1) It provides a theoretical foundation for the information sharing contract design of online platforms. The teams establish a standardized theoretical framework of information sharing with game theory, convex optimization, and backward induction methods, and propose the platforms' optimal information sharing strategies for multiple supply chain parties under different operational models (Figure 3-1-54). The teams also discuss how the manufacturer' choice of more flexible two-part tariff contract and outside retailer competition affect the platforms' strategies of information sharing.

(2) It reveals that competition intensity, accuracy of signal and order fulfillment cost are key factors for the platform in designing the information sharing contract. Who paying for order fulfillment cost is a key difference between online platforms when operating as resellers and marketplaces. The teams uncover that order fulfillment cost plays a critical role for the platform's design of information sharing devices and choice of the contracts by affecting the commission fee decision. In addition, the accuracy of predicted information does not affect the platform's information sharing strategy when it acts as the reseller role, but does when it acts as the marketplace role.

(3) It confirms the positive effect of information leakage on the platform's information sharing. Information leakage is a critical issue in the information sharing literature. Traditional research proposes that information leakage brings negative effects to the supply chains. The teams conduct in-depth discussions

on information leakage in the platform-based supply chain and disclose that the intensity of competition is a crucial factor affecting the manufacturer's decision on information leakage. When the competition intensity is strong and signal accuracy is moderate, the manufacturer will release the signal of low demand to lower the seller's incentive of order, which avoids the transfer of information value and weakens the negative impact of competition effect, thus bringing potential benefits to the platforms.

Entitled "Strategic Information Sharing of Online Platforms as Resellers or Marketplaces", the representative of the researches was published online on October 18, 2022 in the journal of *Marketing Science*. Relative findings of this study provide detailed guidance for platforms with different operational models on how to design information sharing contracts. In addition, this study reveals the intrinsic motivation why e-commerce platforms are willing to share information with upstream manufacturers from the information leakage perspective.



(a) Resellermodel (b) Marketplace model

(c) Hybrid model (d) Outside retailer competition

Figure3-1-54 Spatial Distribution of Online platform's optimal information sharing strategies

Research on Corporate Social Responsibility Based on China's Goal of Common Prosperity

"Companies have not only economic responsibility, legal responsibility, but also social responsibility and moral responsibility." Therefore, how to guide companies to fulfill their social responsibilities and promote companies to participate in the realization of the goal of common prosperity is a practical problem urgently to be discussed.

Supported by the National Natural Science Foundation of China (Major Program 72091314, Key Program 71632002, and General Program 71572003), Dr. Junkang Ji from Guanghua School of Management, Peking University, Dr. Zhi Huang from the University of Kentucky and Dr. Qi Li from the Chinese University of Hong Kong (Shenzhen) have made a great progress on the research field of Corporate Social Responsibility (CSR) by disclosing the influence of leaders' guilt on CSR behavior. Their study, entitled with "Guilt and Corporate Philanthropy", was published in the *Academy of Management Journal* in December 1, 2021.

This study has established guilt as a driver of CSR behavior. The authors conducted analyses through three methods including the quantitative analysis, qualitative interview and experiment. They argue that strategic decisions and actions not only affect firms financially but also have emotional consequences for firm leaders, which can affect firms' subsequent strategic decisions and actions. They collectively test the relationship between guilt and corporate philanthropy. The results provide converging evidence that companies' harm-inflicting decisions/actions can make leaders feel guilt toward those who are harmed, which then motivates them to make restitution through corporate philanthropy. This was particularly the case when the firms' leaders were directly involved in the decision-making and company actions cause greater harm (as shown in Figure 3-1-55).

This study has made two important contributions to the existing theory and literature: First, by creatively establishing guilt as a highly potent driver of CSR, this study offers a rare opportunity to shed some light on the importance of nonfinancial drivers when compared to a firm's financial bottom line, and stimulates more research into this new direction, especially with only a few studies having looked into the micro basis of CSR to date. In addition, this study also contributes to strategic management research by introducing guilt theory into the strategic management studies. This study proved that guilt of senior executives plays an important role in the process of firms' strategic decision-making and enriches the research of strategic management. Meanwhile, by introducing guilt into the analysis of firms' decision-making, this study also contributes to strategic management research on the role of emotions in strategic processes.

This study also has important practical implications for policy makers and business managers. On the one hand, company leaders can improve the relationship between themselves and employees,

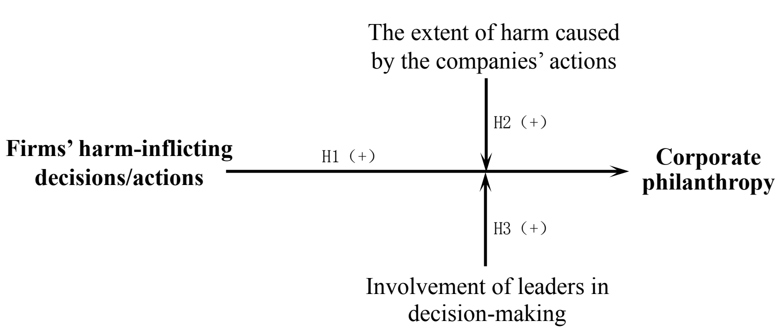


Figure. 3-1-55 Theoretical model of guilt and corporate philanthropy

as well as between the company and the public by expressing their feeling of guilt and implementing compensation, so as to enhance the internal cohesion and company image. On the other hand, the public can encourage firms to fulfill more CSR by arousing the guilt of leaders. This is beneficial for firms to link their development strategies with the national goal of common prosperity.

Study on Green and Inclusive Fiscal Stimulus Packages

Supported by the National Natural Science Foundation of China (Young Scientist Fund 71904201, Special Fund 72140002), Professor WANG Can's team from Tsinghua University assessed the short-term impacts of post-pandemic fiscal stimuli pledged by 26 countries on the economy and the labor market. Their findings revealed the trade-offs between effectiveness, equity, and greenness and support for policymakers to develop greener and more inclusive stimulus packages that simultaneously promote economic recovery, social equity, and climate mitigation. The research was published on 25 April 2022 as 'The Perceived Effectiveness and Hidden Inequity of Post-pandemic Fiscal Stimuli' in the *Proceedings of the National Academy of Sciences of the United States of America*.

The corona virus disease 2019 (COVID-19) pandemic, intertwined with the challenges of economic recession, social inequality, and climate change, has become one of the most serious challenges in human history. In response to the economic depression brought about by the pandemic, the world has committed trillions in fiscal expenditures to reboot the economy in the post–COVID-19 era, and the spending covers diverse areas from public health to education and research.

This study constructed an extended adaptive regional input–output (E-ARIO) model, using the big data for mobility and the information on pandemic lockdown measures, to assess the economic effectiveness and equity impacts of currently pledged stimuli and their green alternatives in 26 countries. The findings show that while the currently pledged stimuli are effective in keeping the economic recession short and shallow, they also create risks of widening income inequality. Low-carbon stimuli are more effective and more equitable (decreasing global income inequality by 2% to 3%) than currently pledged stimuli on the global level. Modifying the currently pledged stimuli toward more greenness has the potential to achieve a balance between greenness, equity, and effectiveness.

Study on the Issue of Digital Tokens by Monopoly Internet Platforms

Supported by the National Natural Science Foundation of China (Major Program 72192841), Yang You, associate researcher from HKU Shenzhen Institute, collaborated with Kenneth Rogoff from Harvard Economics on research about tokenization mechanism by the monopoly internet platform. The paper titled as "Redeemable Platform Currencies" establishes the theoretical framework, studies its optimal design, and related regulatory issues. The paper was published in the *Review of Economic Studies* on May 31st, 2022.

As technology blurs the boundary between finance and the internet, large monopoly internet companies issue digital currencies or tokens to facilitate transactions and payment within the platform. In principle, big tech and giant internet companies can take advantage of their large customer base to ensure token adoption, exchange, and circulation. Most experimental practice starts with internal token usage (e.g., Uber and Lyft cash), while others expand beyond the platform and embrace broader adoption (e.g., Alipay and WeChat pay). Meanwhile, more gaming platforms adopt digital currency for internal exchange and payment.

This research presents a simple, tractable model of redeemable (for goods but not for cash) platform tokens and proceeds to analyze a number of issues related to token supply policy and feature design. The central result is if the market consists entirely of platform consumers, it will not necessarily be optimal to make tokens tradable. That is, unless a platform anticipates significant outside adoption—which due to network effects and regulatory constraints, is not a realistic consideration for most issuers—there can be a strong case for making tokens non-tradable. This project further studies consumer surplus and shows that the monopoly platform tends to use the user's historical data to discriminate against consumers further and reduce consumer surplus for a higher profit. From a regulation perspective, regulators shall consider the fair use of historical data to protect consumers. This research shows that in a competitive environment, regulators do not need to restrict consumer data usage; however, in the existence of a monopoly, regulation on data usage is a necessary part of platform tokenization.

Extracellular Vesicles Mediate the Communication of Adipose Tissue with Brain and Promote Cognitive Impairment in Diabetes

Type 2 diabetes is associated with an increased risk of cognitive impairment. Glucose dysregulation is an established risk factor for cognitive impairment, but clinical trials have revealed that glycemic control has limited beneficial effects on cognitive function. Novel strategies capable of protecting against diabetic cognitive impairment are urgently required. Adipose tissue can secrete extracellular vesicles (EVs) as insoluble mediators, which have been reported to play a role in inter-organ communication and regulate the functions of recipient organs. However, little is known about whether EVs can mediate the communication between adipose tissue and the central nervous system, particularly in the exacerbation of brain pathology and cognitive impairment in diabetes. Supported by the National Natural Science Foundation of China (Key Program 82030026, Young Scientist Funds 82100868 and 82000775), Prof. Bi Yan's team at Department of Endocrinology, Drum Tower Hospital affiliated to Nanjing University Medical School revealed a new mechanism of cognitive impairment in diabetes by using fat transplantation and EVs tracking techniques. In this context, adipose tissue-derived EVs and their cargo miRNAs mediate inter-organ communication between adipose tissue and the brain, which promotes cognitive impairment in diabetes (Figure 3-1-56).

The main innovation results and application value are as follows: (1) By using fat transplantation and EVs tracking techniques, research revealed that adipose tissue-derived EVs and their cargo miRNAs mediate inter-organ communication between adipose tissue and the brain, which induce synaptic damage and subsequent cognitive dysfunction in diabetes. (2) By using deep RNA sequencing and transcriptome sequencing technology, research identified a series of key molecules in adipose tissue-derived EVs that cause cognitive impairment in diabetes and found that the common pathogenic molecule miR-9-3p in both humans and mice caused synaptic loss and further promoted cognitive impairment by targeting to down-regulate BDNF, a molecule crucial for the maintenance of synaptic function. (3) By using virus-mediated gene silencing techniques, research confirmed that targeting adipose tissue-derived EVs or their cargo miRNAs significantly prevents cognitive impairment in diabetes.

These results were published online in *Cell Metabolism* magazine entitled "Extracellular Vesicles Mediate the Communication of Adipose Tissue with Brain and Promote Cognitive Impairment Associated with Insulin" on September 6, 2022. This study revealed the previously unknown of adipose tissue-brain inter-organ communication, clarified the important role of adipose tissue-derived EVs and their cargo miRNAs in the occurrence of diabetic cognitive impairment, and provided an optional strategy for pharmaceutical interventions to treat cognitive impairment in diabetes.

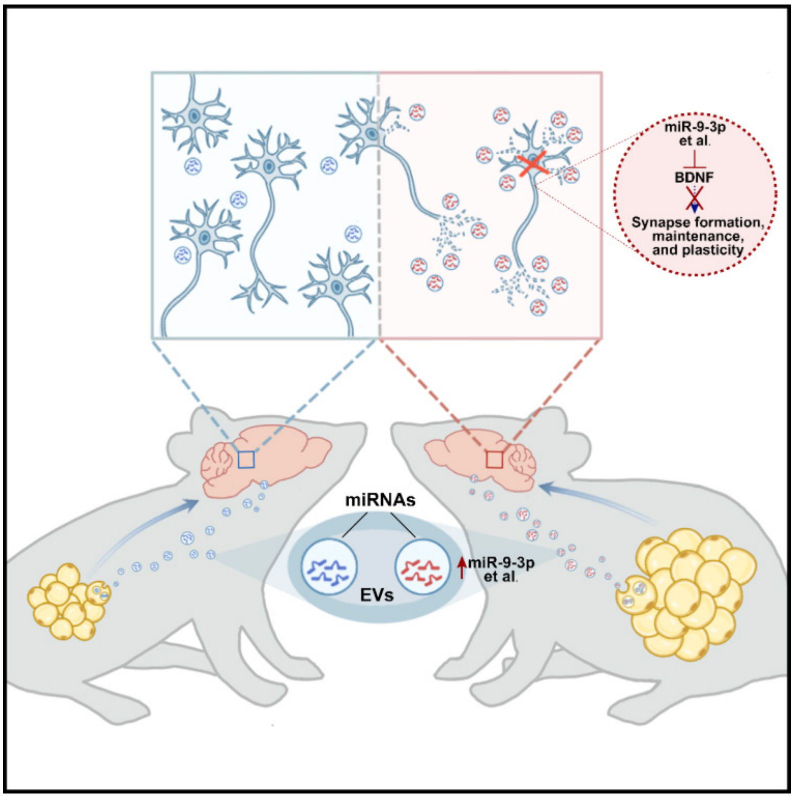


Figure 3-1-56 EVs and their cargo miRNAs mediate adipose tissue-brain inter-organ communication, inducing cognitive impairment in diabetes.

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Extracellular vesicles mediate the communication of adipose tissue with brain and promote cognitive impairment associated with insulin resistance

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Figure 3-1-57 Article Cover

Bone Marrow Hematopoiesis Drives Multiple Sclerosis Progression

With the support of the National Natural Science Foundation of China (Key Program 81830038, Major Research Plan 91949208, General Program 82171284), Drs. Qiang Liu and Fudong Shi from Tianjin Medical University General Hospital discovered abnormal bone marrow myelopoiesis in patients with multiple sclerosis (MS), and underlying immune mechanisms that drive MS progression. This research article was published in *Cell* on June 23, 2022, entitled "Bone Marrow Hematopoiesis Drives Multiple Sclerosis Progression" (Figure 3-1-58).

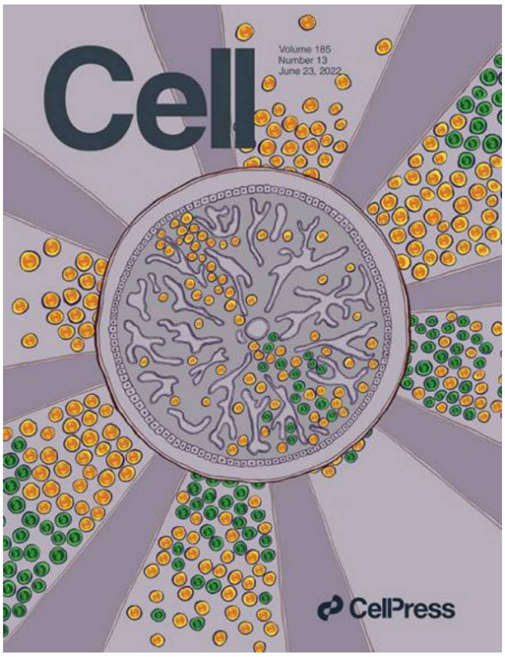


Figure 3-1-58 Cover page of Cell June 23, 2022

MS is a T cell-mediated chronic inflammatory disease of the central nervous system (CNS), and is the main cause of severe neurological disability in young adults. The authors comprehensively characterized the hematopoietic system in the bone marrow of MS patients. They found that myelin-reactive T cells preferentially migrate into bone marrow, a process guided by chemokine ligand C-X-C motif chemokine ligand 12 (CXCL12). Once arrive the bone marrow niche, myelin-reactive T cells produce C-C motif chemokine ligand 5 (CCL5) to activate HSCs, leading to augmented output of common myeloid progenitors (CMP) and granulocyte-monocyte progenitors (GMP). Lineage tracing revealed that bone marrow myelopoiesis augments the output of monocytes and neutrophils, which contribute to T cell autoimmunity and CNS inflammation (Figure 3-1-59). Based on above findings, they postulated that bone marrow hematopoietic cells may serve as a new target for future design of immune therapy to treat patients with MS. They have initiated new clinical trials to investigate the safety and efficacy of immune modulation targeting bone marrow to restrict CNS inflammation (NCT05154734, NCT05369351) and has been invited by Professor Maja Jagodic from Karolinska Institutet as board of European School of Neuroimmunology (ESNI) and Professor Wee Yong from Canadian Academy of Health Sciences as president of International Society of Neuroimmunology (ISNI) to give invited talks. This work has been commented by international journals including *Life Medicine* and *Clinical Translational Medicine*. International experts have provided critical evaluation of targeting bone marrow immunity for the treatment of MS to bring new hope for patients.

Previous understandings of MS were limited to autoreactive T cells in secondary immune organs such as lymph nodes without consideration of the central immune organ bone marrow and their potential role in MS pathogenesis. This study revealed the hematopoietic anomalies in patients with MS and their detrimental impact on MS pathology, leading to the identification of a new field regarding bone marrow immunity in the progression of CNS inflammatory diseases, which provides a new target for future design of new therapy to treat neuroimmune diseases.

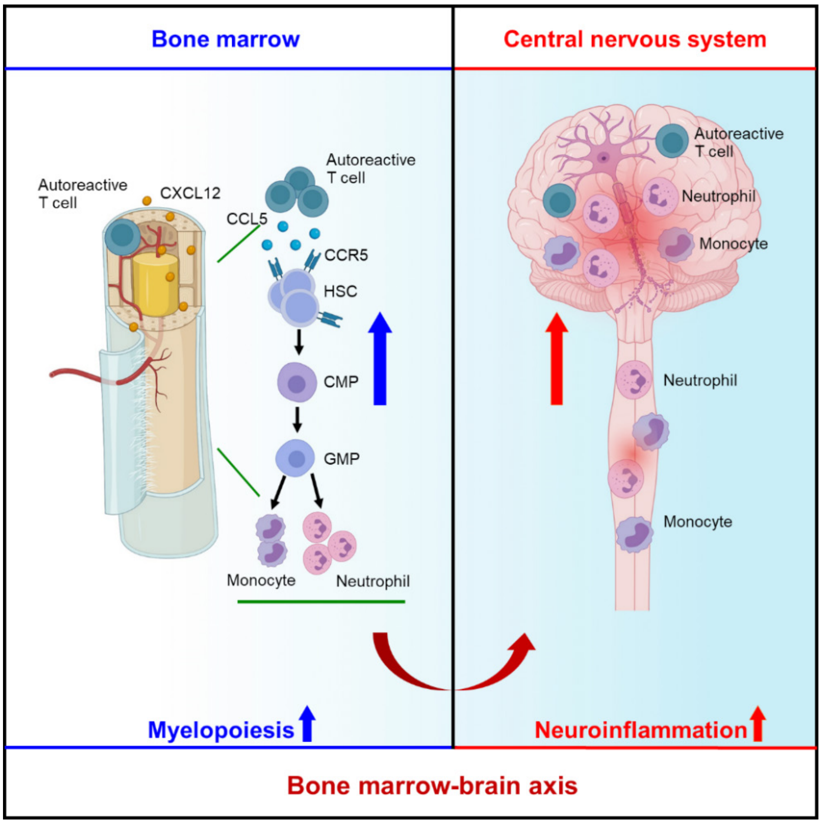


Figure 3-1-59 Bone marrow-brain axis in MS

Novel Strategy for Broad-spectrum COVID-19 Vaccine Immunogen Design

With the support of the National Natural Science Foundation of China (Major Program 81991491), Professor Ningshao Xia from Xiamen University, together with Professor Yi Guan from the University of Hong Kong, and Professor Hua Cao from Fujian Maternity and Child Health Hospital have developed a new strategy for the immunogen design of broad-spectrum COVID-19 vaccines, which was published in *Cell Host & Microbe* (Figure 3-1-60) on October 17th, 2022, with the title of "Lineage-mosaic and Mutation-patched Spike Proteins for Broad-spectrum COVID-19 Vaccine".

The continuous emergence of SARS-CoV-2 variants has brought great challenges to the effectiveness of the COVID-19 vaccines. The amino-acid substitutions at the antigenic sites of the spike protein may result in the escape of virus from naturally acquired or vaccine-induced immunity, thus it is urgent to develop next-generation COVID-19 vaccines with broad-spectrum protective effects. The importance of developing a broad-spectrum COVID-19 vaccine is to construct immunogens

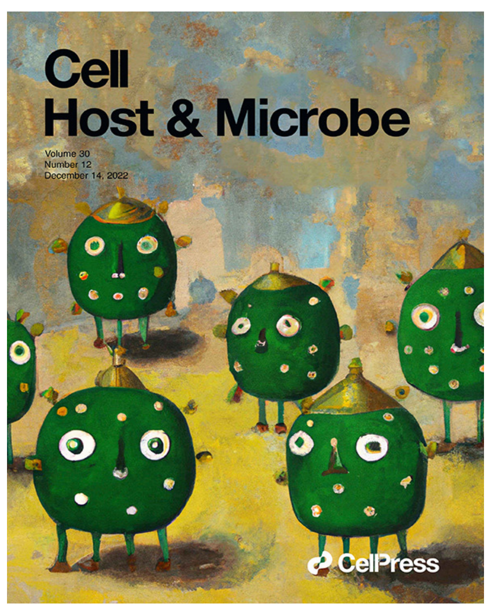


Figure 3-1-60 Cover of the Journal of *Cell Host & Microbe*

that can induce broad-spectrum protection. This study proposes a "Lineage-mosaic and Mutation-patched" strategy for immunogen design, which involves chimeric recombination and mutation of the S protein domain of variants with large antigenicity differences, then evaluation and screening of immunogen combinations to achieve a broad spectrum of antigenicity coverage. Chimeric immunogen (STFK1628x) with strong immunogenicity and antigenicity complementary to the prototype-S protein (STFK) was successfully constructed by combining the N-terminal domain (NTD) of the B.1.620 with RBD-S2 of the Gamma variant. In hamsters, a bivalent vaccine composed of STFK and STFK1628x elicited high titers of broad-spectrum neutralizing antibodies against 19 circulating SARS-CoV-2 variants, including Omicron sublineages BA.1, BA.1.1, BA.2, BA.2.12.1, BA.2.75, and BA.4/5 (Figure 3-1-61). To be noted, the antigen was generated before the emergence of Omicron variant, which suggested that the prospective antigen design and vaccine preparation by "Lineage-mosaic and Mutation-patched" strategy could be against future unknown variants. In conclusion, this study elucidated the antigenicity and immunogenicity of the S protein of SARS-CoV-2 variants, which could provide new strategy for the development of broad-spectrum vaccines against COVID-19.

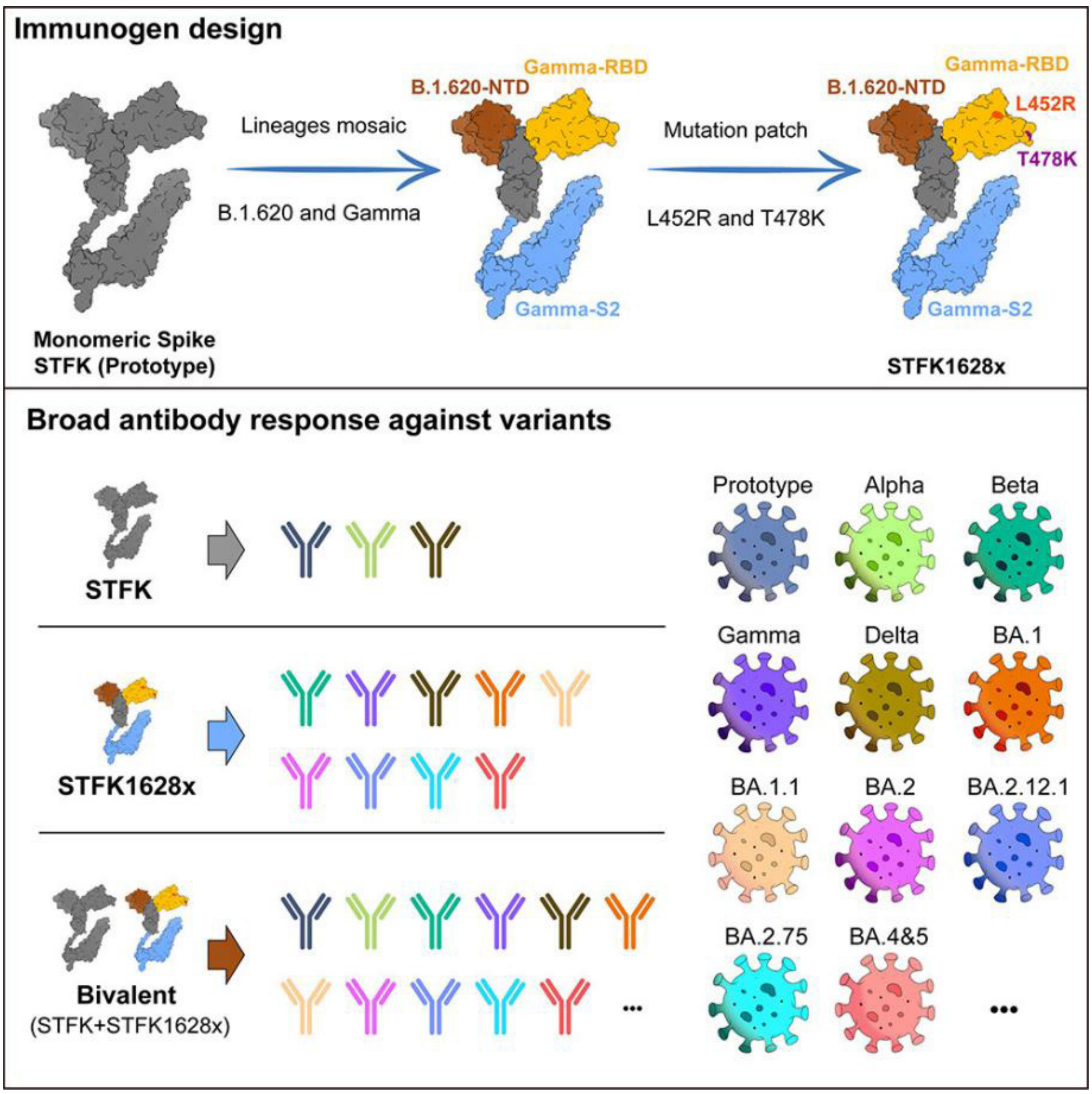


Figure 3-1-61 "Lineage-mosaic and Mutation-patched"immunogen construction strategy for inducing broad-spectrum neutralizing antibodies

Research of the Mechanisms Underlying the Interactions between Host and Mycobacterium Tuberculosis

Tuberculosis (TB) is a major chronic infectious disease caused by the pathogen *Mycobacterium tuberculosis* (Mtb). Growing evidence suggests an important role of inflammasome-pyroptosis pathway in host defense against pathogens including Mtb, but how pathogens evade this immune response remains largely unexplored. Identification of crucial Mtb effector proteins regulating host inflammasome-pyroptosis pathway could help elucidate the pathogenesis of TB and discover potential new targets for TB prevention and treatment.

With the support of the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars 81825014; Key Program 31830003; Excellent Young Scientists Fund 82022041), Prof. Cui Hua Liu's group at the Institute of Microbiology of the Chinese Academy of Sciences have made important progress in understanding the mechanism underlying the interactions between host and Mtb. The researchers reveal a novel immune evasion strategy by which Mtb hijacks ubiquitin to inhibit host pyroptosis, providing a new strategy for developing anti-TB treatment based on the interacting interface between host and Mtb (Figure 3-1-62).

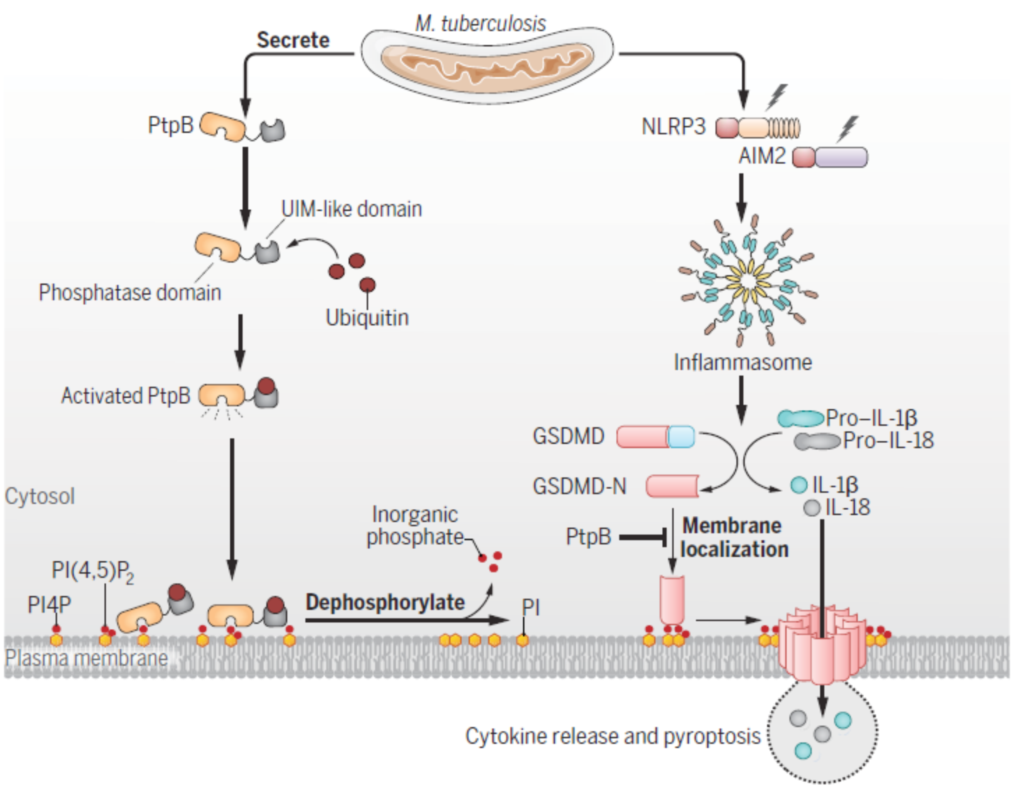


Figure 3-1-62 Schematic model showing the mechanism by which Mtb PtpB hijacks ubiquitin to inhibit host pyroptosis by altering host membrane phospholipid composition

The followings highlight the significance and novelty of this study: (1) Screening of the key effector proteins in Mtb: the researchers examined the whole genome of Mtb to predict secreted eukaryotic-like proteins, which were then subjected to screening for inhibitors of inflammasome-pyroptosis pathways using an inflammasome reconstitution system. Out of 201 predicted Mtb-secreted eukaryotic proteins, they identified PtpB as a key bacterial effector that is abundantly secreted by Mtb to inhibit both NOD-like receptor thermal protein domain associated protein 3 (NLRP3) and absent in melanoma 2 (AIM2) inflammasome pathways. (2) Illustration of host molecules targeted by PtpB to inhibit pyroptosis: They revealed that PtpB targets and dephosphorylates host plasma membrane phosphatidylinositol-4-monophosphate (PI4P) and phosphatidylinositol-(4,5)-bisphosphate [PI-(4,5)-P_2] to inhibit membrane localization of the N-terminal cleavage fragment of GSDMD (GSDMD-N), thus preventing GSDMD-mediated pyroptosis and immune responses. (3) Identifying specific activator of PtpB: They further discovered that PtpB interacts with ubiquitin via a ubiquitin-interacting motif (UIM)-like domain to enhance its phosphatase activity, which is required for PtpB-mediated inhibition of GSDMD immune functions.

Figure 3-1-63 Cover of the journal of *Science*

This study was published online in *Science* on October 14, 2022, titled “A Bacterial Phospholipid Phosphatase Inhibits Host Pyroptosis by Hijacking Ubiquitin” (Figure 3-1-63). This study reveals a previously unrecognized strategy by which pathogens inhibit pyroptosis and counteract host immunity by altering host membrane composition. Its results indicate a potential TB treatment by targeting the PtpB-Ub-phospholipid-pyroptosis axis.

Research of the Mechanisms of Heatstroke-induced Multiple Organ Damage

Heatstroke is a life-threatening condition characterized by extreme hyperthermia, systemic inflammatory response, circulatory failure, bleeding and coagulation disorders, and multi-organ dysfunctions that result from high temperature-induced dysregulation of body temperature and excessive heat accumulation. Heatstroke usually occurs in the summer when high temperatures are often accompanied with high humidity. However, the mechanisms by which hyperthermia causes organ injury and death are not fully understood.

Supported by the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars 81930059; General Program 81801888), Prof. Ben Lu’s team from the Third Xiangya Hospital of Central South University has made progress in understanding the mechanisms of how persistent high body temperature causes multiple organ damage and death, and shows that hyperthermia induces disseminated intravascular coagulation (DIC), multiple organ injury and death by triggering Z-DNA binding protein 1 (ZBP1) and receptor interacting protein kinase 3 (RIPK3)-dependent programmed cell death. These findings provide a new theoretical basis for the prevention and treatment of heatstroke (Figure 3-1-64).

The main innovations of this study include the following points. First, this study discovered an important role of RIPK3-dependent programmed cell death in the pathogenesis of heatstroke. By using a mouse model of heatstroke, the authors found that hyperthemia causes DIC, multiple organ injury and death through RIPK3-dependent programmed cell death. Second, this study identified ZBP1 as the key upstream molecule that activates RIPK3 and induces programmed cell death. Heatstroke-induced ZBP1 activation

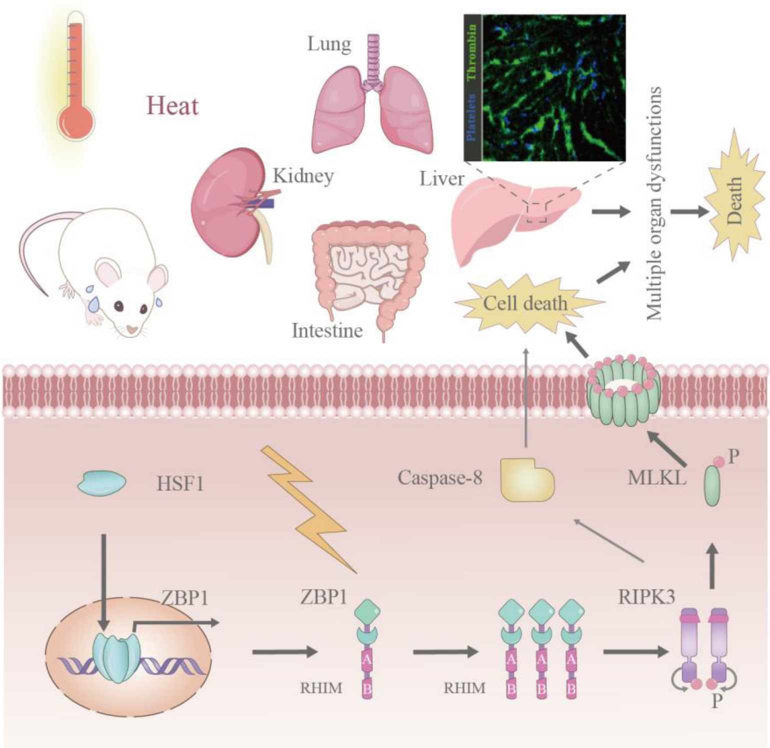


Figure 3-1-64 Model of molecular mechanisms of heatstroke-induced programmed cell death and multiple organ damage.

was dependent on its RHIM domain rather than Zα domain. These findings not only provide potential therapeutic targets to treat heatstroke, but also implicate the existence of intracellular heat sensor that could trigger programmed cell death in response to increased body temperature.

This study, published online in *Science* (Fig. 3-1-65) on May 5, 2022 and entitled "Z-DNA Binding Protein 1 Promotes Heatstroke-induced Cell Death", uncovers important roles of RIPK3-dependent programmed cell death in the pathogenesis of heatstroke, providing a new theoretical basis and potential therapeutic targets for the prevention and treatment of heatstroke.

Figure 3-1-65 Cover of the journal of Science

Metabolic Enzyme Functions as Protein Phosphatase in the Regulation of Gene Transcription and Tumour Growth

Metabolic enzymes, as the main participants in the metabolic process of life, can not only play their classical functions to provide necessary materials and energy for cells, but also modulate a variety of cellular activities and cancer progression through their noncanonical or non-metabolic (moonlighting) activities. In recent years, emerging evidence demonstrated that metabolic enzymes can function as protein kinases. However, whether a metabolic enzyme possesses protein phosphatase activity to regulate tumorigenesis and tumor progression is still unknown.

Gluconeogenesis is the synthesis of glucose or glycogen from non-carbohydrate precursors. Fructose-1,6-bisphosphatase (FBP) is a conserved metabolic phosphatase that catalyzes the rate-limiting hydrolysis of fructose-1,6-bisphosphate to fructose-6-phosphate during gluconeogenesis. In cancer cells, the metabolic activity of FBP1 is allosterically inhibited by accumulated adenosine monophosphate under energy stress.

Figure 3-1-66 Cover of the journal of *Nature Cell Biology*

Supported by the National Natural Science Foundation of China (Basic Science Center Program 82188102; Key Program 82030074; General Program 82173114), the research team led by Prof. Zhimin Lu from Institute of Translational Medicine, Zhejiang University uncovered a new moonlighting function of the metabolic enzyme FBP1 in regulation of gene transcription. This study entitled "Fructose-1,6-bisphosphatase 1 Functions as a Protein Phosphatase to Dephosphorylate Histone H3 and Suppresses PPARα-regulated Gene Transcription and Tumour Growth" was published on *Nature Cell Biology* on October 20, 2022.

In this study, researchers have found that upon energy stress, PERK phosphorylates FBP1 S170 in normal hepatocytes, which converted the FBP1 tetramer to monomers and exposed the NLS for FBP1-nuclear translocation. In the nucleus, S170-phosphorylated FBP1 interacted with PPARα. Importantly, FBP1 functioned as a protein phosphatase to dephosphorylate histone H3 pT11, thereby suppressing PPARα-mediated *β*-oxidation gene expression and promoting energy-stress-induced apoptosis.

However, in contrast to normal hepatic hepatocytes, HCC cells exhibited much greater OGT expression, leading to FBP1 S124 O-GlcNAcylation, which blocked PERK-mediated FBP1 S170 phosphorylation and its nuclear translocation. This inhibition abrogated the inhibitory effect of FBP1 on PPARα and resulted in greatly enhanced *β*-oxidation, leading to the increased energy production that supported tumor cell survival and liver tumor growth under energy stress conditions.

In summary, this study for the first time reported that metabolic enzyme FBP1 functioned as a protein phosphatase to inhibit tumor growth. However, this inhibition was abrogated by O-GlcNAcylation or low/loss of expression of FBP1 in tumor cells, resulting in tumorigenesis and tumor progression, underscored the potential to modulate the protein phosphatase activity and nuclear functions of FBP1 for the treatment of human cancer.

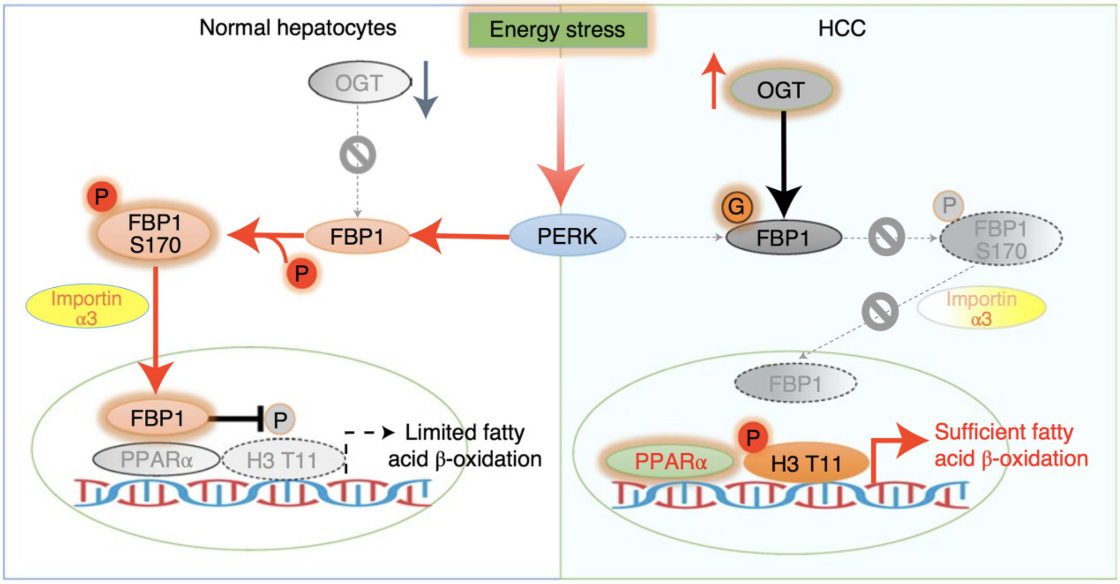


Figure 3-1-67 Molecular mechanism of FBP1 in differentially regulating chromatin as a protein phosphatase in normal hepatocytes and HCC cells

Research on Long-distance Free-space Dissemination of Time and Frequency at High

Supported by the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars T2125010 and 61825505), Professor Qiang Zhang from University of Science and Technology of China, along with collaborators from Shanghai Institute of Technical Physics, Xinjiang Astronomical Observatory of Chinese Academy of Sciences, National Time Service Center of Chinese Academy of Sciences, Jinan Institute of Quantum Technology, and Ningbo University, have achieved a high-precision free-space dissemination of time and frequency at the hundred-kilometer level for the first time in the world. This work effectively validates the feasibility of optical frequency standard comparison at high precision in satellite-to-ground links, taking an important step towards establishing a wide-area optical frequency standard network. The research findings, titled "Free-Space Dissemination of Time and Frequency with 10^{-19}Instability over 113 km," were published in *Nature* on October 5th, 2022.

In recent years, the instability of atomic clocks in the optical frequency band (optical clocks) based on ultra cold atoms in optical lattices has reached 10^{-19}, and it is expected to form a new generation of time and frequency standard (optical frequency standard). Combined with wide-area, high-precision time and frequency dissemination, a wide-area time and frequency network can be constructed, playing an important role in areas such as precise navigation and positioning, global time service, wide-area quantum communication, and testing of fundamental principles in physics. Furthermore, high-orbit space has a lower noise environment of gravitational field, and theoretically the instability of optical frequency standard and time-frequency dissemination can reach 10^{-21}. This has the potential for significant applications in the research of fundamental physics problems such as gravitational wave detections and dark matter searches.

However, the instability of traditional microwave-based satellite time-frequency dissemination is only at the level of 10^{-16}, which is unable to meet the demands of high-precision time and frequency networks. Although the instability of free-space time and frequency dissemination technology based on optical frequency combs and coherent detection can reach 10^{-19}, which is the development trend for high-precision time and frequency dissemination, previous related work had a low signal-to-noise ratio and short transmission distances, making it difficult to meet the needs of high-precision time and frequency dissemination in satellite-to-ground links.

The research group developed femtosecond laser technology with all polarization-maintaining fibers, achieving highly stable optical frequency combs with watt-level power output. Based on low-noise balanced detection and integrated optical fiber modules, combined with high-precision phase extraction post-processing algorithms, they achieved nanowatt-level high-sensitivity linear optical sampling detection, with single-shot optical time-domain measurement precision better than 100 femtoseconds. Furthermore, they improved the stability and detection efficiency of the optical transceiver telescopes. Building on these technical breakthroughs, the research group successfully achieved 113 km free-space time-frequency dissemination in Urumqi, Xinjiang. The time dissemination instability reaches the femtosecond level at 10000 seconds, while the frequency dissemination instability is less than 4×10^{-19} at 10000 seconds. The system's offset is $6.3\times10^{-20} \pm 3.4\times10^{-19}$, and it can tolerate a maximum link loss of up to 89 dB, far exceeding the typical expected value for medium and high orbit satellite-to-ground link losses (about 78 dB) (Figure 3-1-68).

In summary, this research has solved the challenging problem of long-distance (hundreds of kilometers) dissemination of time and frequency at high precision, fully demonstrating the feasibility of high-precision optical frequency standard comparison in satellite-to-ground links. It lays a solid foundation for constructing a wide-area time and frequency network, serving applications such as quantum communication, precise navigation, and global time service.

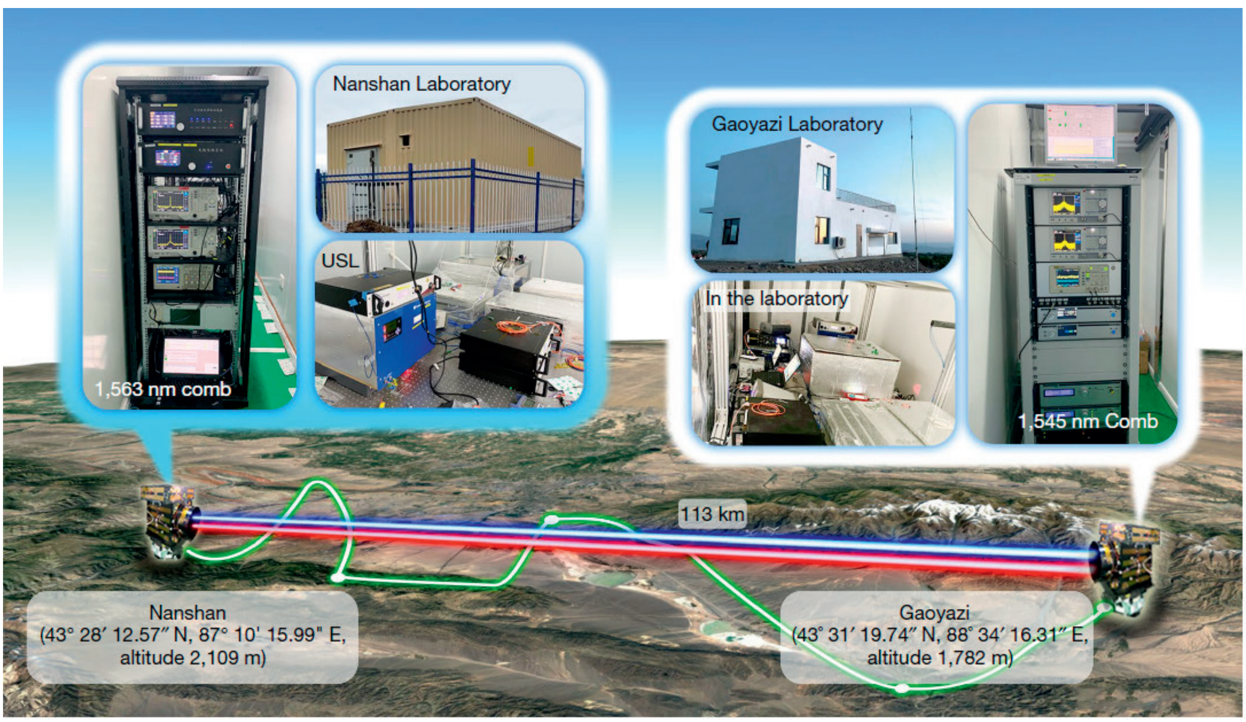


Figure3-1-68 Overview of the 113 km free-space high-precision time-frequency dissemination experiment

Research on Suppressing High-Dimensional Crystallographic Defects in DNA Self-assembly

Supported by the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars: T2125001, Major Program 21991134, General Program 21875003 and 21974113, and Key Program: 21735004), Prof. Wei Sun's group from Peking University and Prof. Zhi Zhu's group from Xiamen University, collaboratively explored the effective suppression of crystallographic defects in sub-10 nm pitch DNA arrays. The relevant finding, titled "Suppressing High-Dimensional Crystallographic Defects for Ultra-scaled DNA Arrays," was published in *Nature Communications* on May 16, 2022.

The rapid development of high-resolution nanofabrication methods continuously drives the miniaturization of nanodevices. However, limited by the diffraction limit of light, further resolution improvement of photolithography faces many challenges. Alternatively, precise self-assembly techniques, represented by the DNA self-assembly, exhibit single-molecule resolution and complex *in silico* developed morphologies, suggesting new possibility to scale the critical dimensions of nanodevices smaller than the resolution limit of photolithography. Currently, DNA self-assembly has been preliminarily applied to carbon-based and silicon-based devices with 10 to 20 nm critical pitches, surpassing the resolution limits of current extreme ultraviolet lithography. However, when the feature pitch of DNA self-assembly structures further scale to sub-10 nm, entropy-driven crystallographic defects emerge. As a result, line dislocations, as well as other high-dimensional defects, significantly increase, deteriorating the structural ordering of DNA self-assembly and challenging their applicability in high-resolution nanofabrication.

The research team used periodic DNA arrays as model systems, analyzed the morphologies of high-dimensional defects and their assembly dynamics, and explored the key parameters determining the formation of high-dimensional crystallographic defects. This study revealed that the formation of high-dimensional crystallographic defects was closely related to the dynamics of swinging single-stranded DNAs penetrating into neighboring lattices. As the sequence periodicities of DNA strands decreased, lattice penetration dynamics gradually surpassed the dynamics of correct assembly, leading to a dominant role of defect formation. As results, the smaller sequence periods were, the easier lattice defects formed, providing an inverse correlation between the periodicity of DNA sequences and the defect rate. To suppress the formation of high-dimensional crystallographic defects in ultra-scaled DNA arrays, it would be necessary to introduce orthogonal DNA sequence sets in neighboring unit cells, which increased the sequence periodicities without affecting the array morphology and selectively suppressed the defect formation dynamics. Based on this orthogonal sequence set strategy, DNA arrays with 7.5-nm line pitch was demonstrated, displaying defect rates more than two orders of magnitude smaller (below 1%) than traditional designs. The minimal array pitch based on the orthogonal sequence set was superior to the critical dimensions of next-generation extreme ultraviolet lithography. Low-defect DNA arrays could further serve as templates to facilitate the fabrication of high-density three-dimensional metal wire arrays (such as palladium and nickel, as shown in Figure 3-1-69).

In the field of biomolecules-directed high-resolution nanofabrication, this research will lay the foundation towards manufacturing functional materials arrays with sub-10 nm pitches. Meanwhile, because coherent quantum transports gradually dominate within sub-10 nm dimensions, this research could be potentially applied to construct solid-state quantum devices in the future.

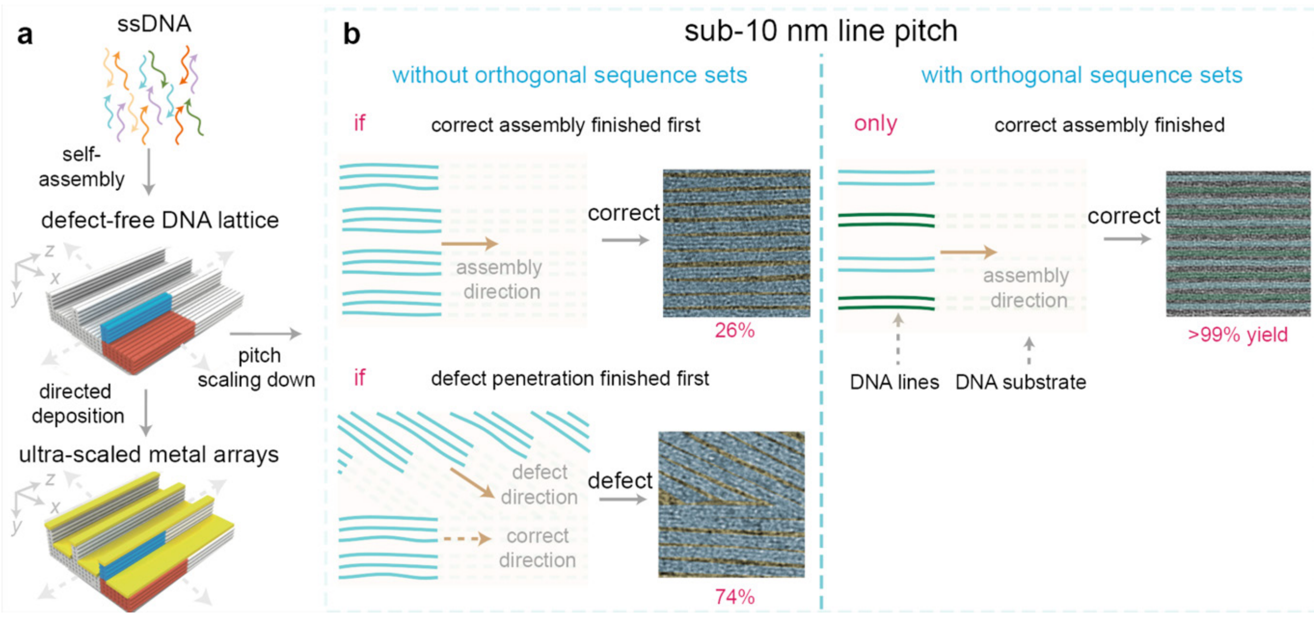


Figure 3-1-69 Suppression of high-dimensional crystallographic defects in DNA arrays with sub-10 pitch

Theoretical Study of Magnetoelectric Effects in Two-dimensional Materials

Supported by the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars T2125004, Young Scientists Fund 12004182, General Program 11774173 and 11674295), Professor Erjun Kan's group from Nanjing University of Science and Technology has revealed the mechanism of room-temperature electrical control of magnetic order in two-dimensional van der Waals systems. The related research article entitled "Toward Room-Temperature Electrical Control of Magnetic Order in Multiferroic van der Waals Materials" has been published in *Nano Letters* on May 31, 2022. In addition, they collaborated with Professor Hualing Zeng's group from the University of Science and Technology of China and Professor Lun Dai's group from Peking University to achieve a breakthrough in the research of room-temperature two-dimensional ferroelectric semiconductors. The related research article entitled "Room-Temperature Ferroelectricity in 1T'-ReS_2 Multilayers" has been published in *Physical Review Letters* on February 8, 2022.

Ferroelectric materials exhibit spontaneous polarization that can be controlled by an external electric field, which makes them promising for applications in sensors and information storage. With the rapid development of micro-nano integration circuit technology, the miniaturization, integration, and multifunctionalization of ferroelectric devices have become future trends. The study of ferroelectric properties at the nanoscale has been a focus of attention for new functional materials. However, as the size and thickness of materials decrease, nontrivial and non-negaligible interfacial effects and size effects arise. Integrating ferroelectricity, ferromagnetism, and magnetoelectric coupling properties in two-dimensional or low-dimensional materials to develop multi-stable, multi-functional nanoelectronic devices has become one of the main goals pursued by researchers.

Professor Kan's group and their collaborators have revealed the mechanism of room-temperature electrical control of magnetic phase transition in van der Waals two-dimensional magnetoelectric systems. They have designed a class of two-dimensional transition metal carbon/nitride materials with room-temperature ferromagnetism and ferroelectricity perpendicular to the surface. These materials have an atomic structure similar to the MXene family, exhibit good chemical stability, and can be prepared through methods such as chemical vapor deposition. The research results show the presence of significant spin-charge interactions in these two-dimensional magnetoelectric multiferroic systems (Figure 3-1-70). Reversal of the ferroelectric polarization direction leads to changes of spatial distribution of spins, which significantly affects the interlayer magnetic coupling and results in a ferromagnetic-to-antiferromagnetic phase transition, achieving room-temperature electrical control of magnetic phase transition.

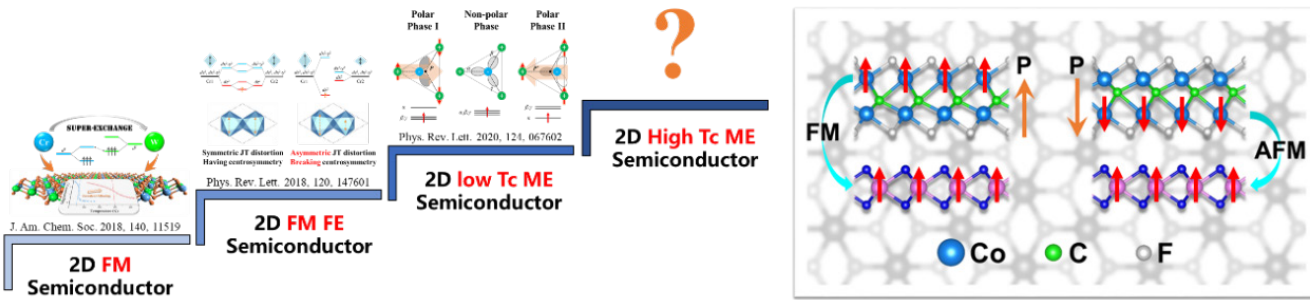


Figure 3-1-70 Room-temperature electrical control of magnetism in a van der Waals multiferroic system

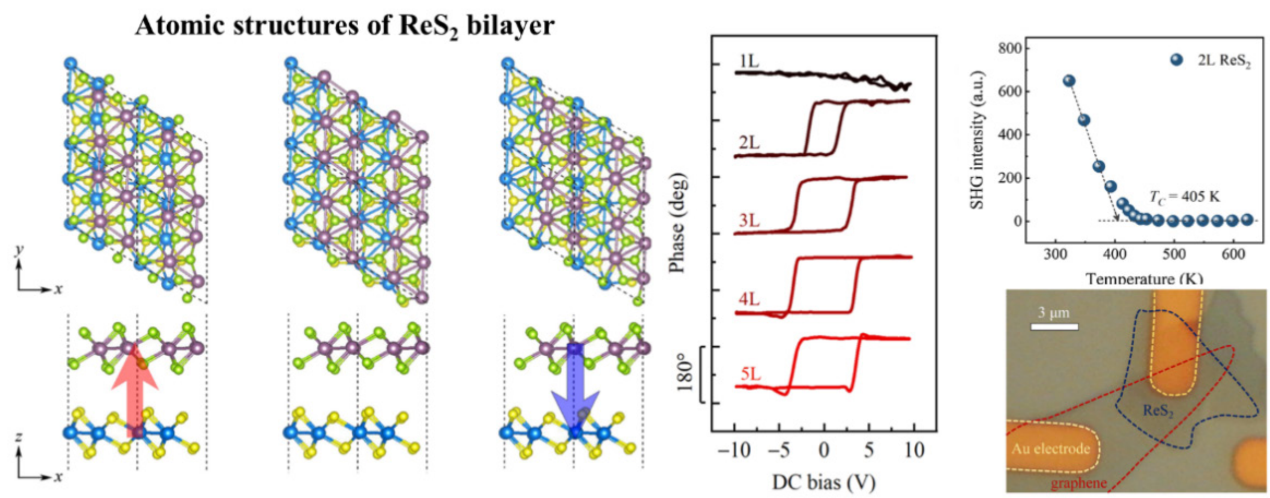


Figure 3-1-71 Theoretical prediction and experimental observation of ferroelectricity in ReS_2 bilayer

Furthermore, Professor Kan's group and their collaborators have successfully observed room-temperature ferroelectric polarization in two-layer and few-layer 1T'-phase rhenium disulfide (ReS_2) semiconductor (Figure 3-1-71) through a combination study of theory and experiments. They demonstrates that the Curie temperature of the out-of-plane ferroelectricity in bilayer ReS_2 is ~405 K, above room temperature. Based on the ferroelectricity of bilayer ReS_2, they have successfully fabricated ferroelectric tunnel junction devices, showcasing the application prospects of two-dimensional ferroelectric materials in the field of micro-nano electronic devices.

This series of achievements provide a new approach for the quantum state control of two-dimensional materials, offer new insights for achieving strong magnetoelectric coupling effects, and lay a theoretical foundation for the design and development of novel ferroelectric devices.

Photonic Tensor Processing Chip

Under the support of the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars T2225023) and others, Professor Zou Weiwen's team from Shanghai Jiao Tong University proposed the innovative concept that merges photonics and computational science. They have developed a novel photonic tensor processing chip that achieves high-speed tensor convolution operations. The related results are published in *Nature Communications* on December 28, 2022, under the title "High-Order Tensor Flow Processing Using Integrated Photonic Circuits".

The tensor form stacked from multidimensional data is an efficient form of data processing, which is conducive to discovering the intrinsic structural features in data and is widely used in radar, communication, artificial intelligence, life science and other fields. With the development of information technology, the speed of data generation is exploding, the multidimensional stacking of massive data and its efficient and fast processing become an important scientific challenge nowadays. To address the challenge, traditional electric processors usually adopt a generalized matrix multiplication (GeMM) strategy to transform higher-order tensor operations into matrix multiplication operations, turn multi-level nested loops into parallel operations, and improve the overall speed of tensor processing by increasing the number of computation cores. However, the GeMM strategy relies on a large amount of data duplication, which requires extra memory occupation and repeated communication costs between memory and processor, which is one of the core bottlenecks in improving the speed of multidimensional data tensor operations.

The research team proposed an interdisciplinary research idea to build the tensor processor based on photonic integration. It exploits the wideband high-speed characteristics of optics, raising the operation clock frequency to several tens of Gigahertz. It also leverages the advantages of multiple degrees of freedom (DoFs) of optics to directly represent the multiple dimensions of tensor data. This approach does not need to convert tensors to matrices so it can implement the processing from input tensors to output tensors in a flow fashion (Figure 3-1-72).

The research team designed and developed a photonic tensor processing chip (Figure 3-1-73). The chip comprehensively uses three DoFs of optics: wavelength, space, and delay. It has successfully verified high-speed tensor convolution operations with a clock frequency of 20GHz on multi-channel images, with a compute density of 588GOP/(s·mm^2). It is expected to reach 1TOP/(s·mm^2) by further increasing the scale of photonic integration. Using this chip, the research team built a convolutional neural network for video action recognition (Figure 3-1-74), with the convolutional layers of the network implemented on the photonic tensor processing chip. They achieved a recognition accuracy of 97.9% on the KTH video dataset, which was close to the ideal recognition accuracy of 98.9%. This research shows that integrated photonic chips can perform tensor flow processing at ultra-high clock frequencies. It solves the problem of extra memory occupation and access, and provides a new technical pathway for building high-performance computing, broadband signal processing and other advanced information systems.

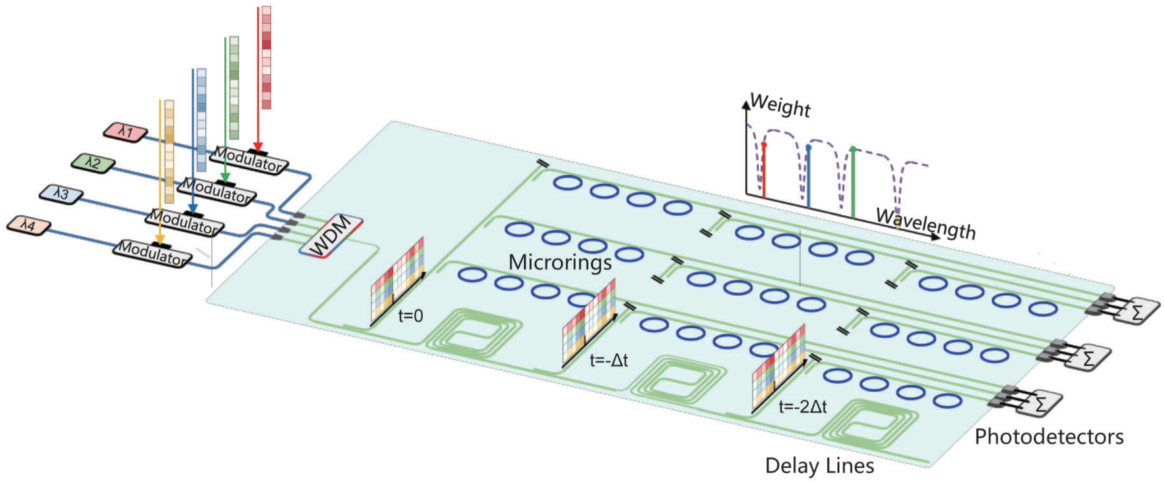


Figure3-1-72 Principle of the photonic tensor processing chip

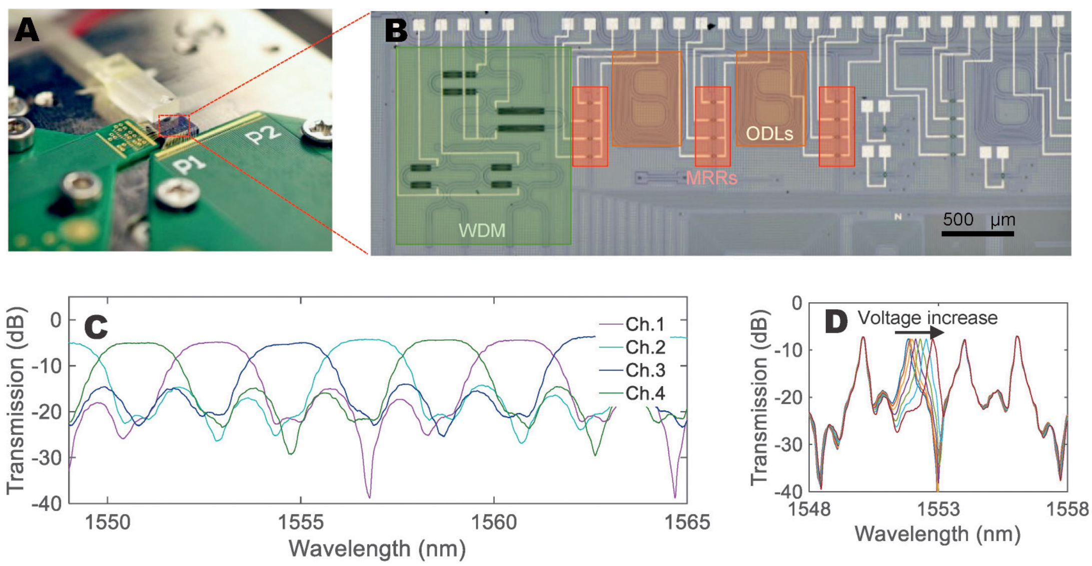


Figure 3-1-73 Photonic tensor processing chip

A. Packaging module of the chip; B. Micrograph of the die; C. Channel response of the integrated WDM; D. Channel response of the integrated microrings

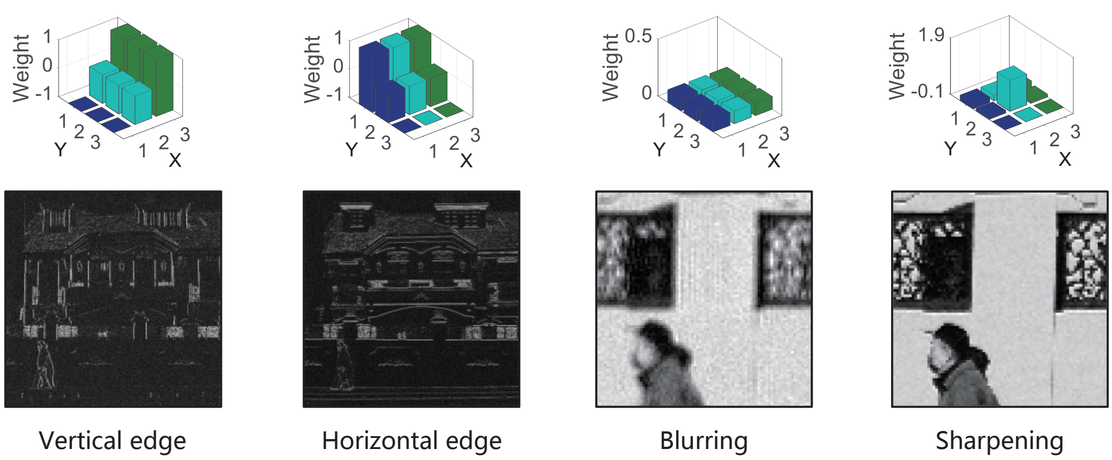


Figure 3-1-74 Results of multi-channel image convolution

Benchmarking Integration Algorithms of Spatial Transcriptomics

The spatial location of cells within tissues and organs is crucial for their specific functional roles. In recent years, various spatial transcriptomics technologies have been developed, enabling the detection of whole transcriptomes while preserving the precise spatial localization of cells. These technologies have been instrumental in studying cell subpopulations and their molecular mechanisms that play critical roles in development or disease progression.

However, current spatial transcriptomics techniques encounter two limitations: (1) sequencing-based spatial transcriptomics approaches currently do not achieve single-cell resolution, and (2) imaging-based spatial transcriptomics techniques have constraints in terms of the number of genes detected. To overcome these limitations, bioinformaticians have designed multiple algorithms to integrate spatial transcriptomics data with single-cell transcriptomics data, allowing for the prediction of cell type spatial distribution and/or individual cell's comprehensive transcriptomic information. These algorithms have significantly enhanced our understanding of spatial transcriptomics data and its relevance to biological and pathological processes. However, different algorithms operate on distinct principles and have varying scopes of applicability, making it challenging for researchers to select the optimal algorithm for predicting cell type and spatial gene expression distribution.

Under the support of the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars T2125012), Professor Kun Qu's team from the University of Science and Technology of China conducted a systematic evaluation of 16 integrative analysis algorithms for spatial transcriptomics and single-cell transcriptomics data in predicting cell type or spatial gene expression distributions. The study titled "Benchmarking Spatial and Single-Cell Transcriptomics Integration Methods for Transcript Distribution Prediction and Cell Type Deconvolution" was published in *Nature Methods* on May 16, 2022.

The research team has long been devoted to the development of algorithms and software for analyzing bioinformatics data. This study collected 45 pairs of spatial transcriptomics and single-cell transcriptomics datasets derived from the same tissue source and 32 simulated datasets. They designed multiple metrics to comprehensively evaluate the performance of the 16 integration algorithms in terms of accuracy, robustness, and computational resource consumption. The results demonstrated that Cell2location, SpatialDWLS, and RCTD algorithms performed better in predicting the spatial distribution of cell types. Tangram, gimVI, and SpaGE algorithms were identified as the top performers in predicting spatial gene expression distribution. Tangram, Seurat, and LIGER algorithms exhibited higher computational efficiency and were suitable for processing large-scale datasets (Figure 3-1-75).

The study summarized the characteristics, performance, applicability, and advantages of each algorithm, providing valuable references for researchers to improve algorithm performance. Additionally, the research team provided an analysis workflow for integrating spatial transcriptomics and single-cell transcriptomics data on GitHub, offering researchers analytical tools for data processing.

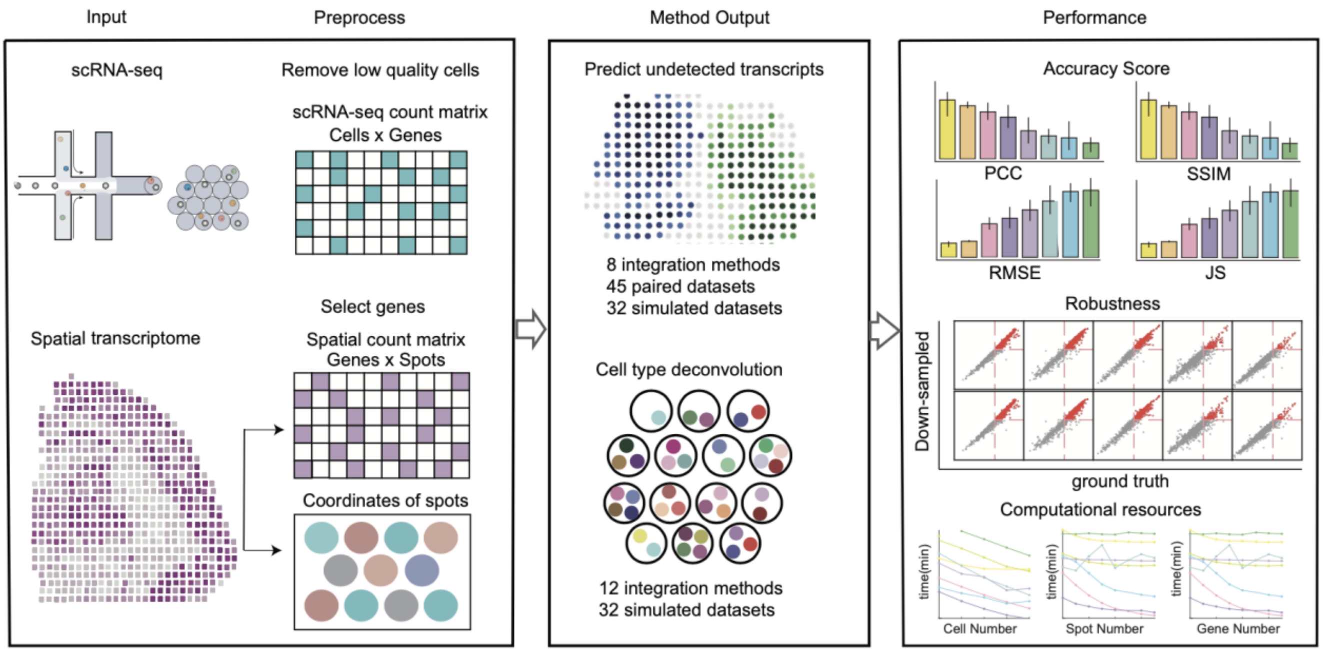


Figure 3-1-75 The workflow for benchmarking the performance of integration algorithms for spatial transcriptomics and single-cell transcriptomics data

Resolving the "Holocene Temperature Conundrum"

Over the past 20,000 years, the Earth's climate has undergone a significant transition from the cold glacial period to the warm Holocene, which is a crucial period for the origin and development of agriculture and human civilization. However, it has been a long-term debate as for how the climate has changed during the Holocene, and whether there was a thermal maximum during the mid-Holocene (approximately 8,000 to 4,000 years ago). Current, proxy and model data show diverging temperature trends between different reconstructions, which have been dubbed the 'Holocene temperature conundrum'. Seasonal biases (the warm-season contribution) of Holocene mean annual temperature (MAT) reconstructions from geological records were proposed as a possible cause of the mismatch with climate simulated temperature. Therefore, selecting a temperature-sensitive proxy to test the relationship between the proxy and seasonal temperature, determining whether or not the averaged seasonal or monthly temperatures show the same trend as the MAT computed in an independent way, and clarifying the contribution of each seasonal temperature to the MAT, are potentially one means of resolving the 'Holocene temperature conundrum'.

Under the support of the National Natural Science Foundation of China (Major Program T2192954, Basic Science Center Program 41888101, Key Program 41830322), Prof. Houyuan Lu and his research team members from the Institute of Geology and Geophysics, Chinese Academy of Sciences, along with their collaborators, analyzed mollusk fossils from geological records to reconstruct the changes in MAT and seasonal temperatures for northern China during the past 20,000 years. They have provided new evidence for the long-term trend of the MAT estimated from the four seasons; and for the contribution of different seasonal temperatures to the MAT over time. The study, titled "The Holocene temperature conundrum answered by mollusk records from East Asia" was published in *Nature Communications* on September 2, 2022.

The research team selected land snails as potential indicators of seasonal temperatures and MAT. First, 382 surface soil mollusk samples were systematically investigated covering a wide climatic gradient spanning a distance of approximately 1,000 km in northern China. They established the most comprehensive modern mollusk-climate datasets in East Asia, and a quantitative mathematical model of seasonal temperatures and MAT was then developed using a transfer function. They applied the mollusk-climate calibration model to two fossil mollusk records spanning the last 20,000 years from the Chinese Loess Plateau (CLP), which represents the history of seasonal temperature changes in the East Asian monsoon region (Figure 3-1-76).

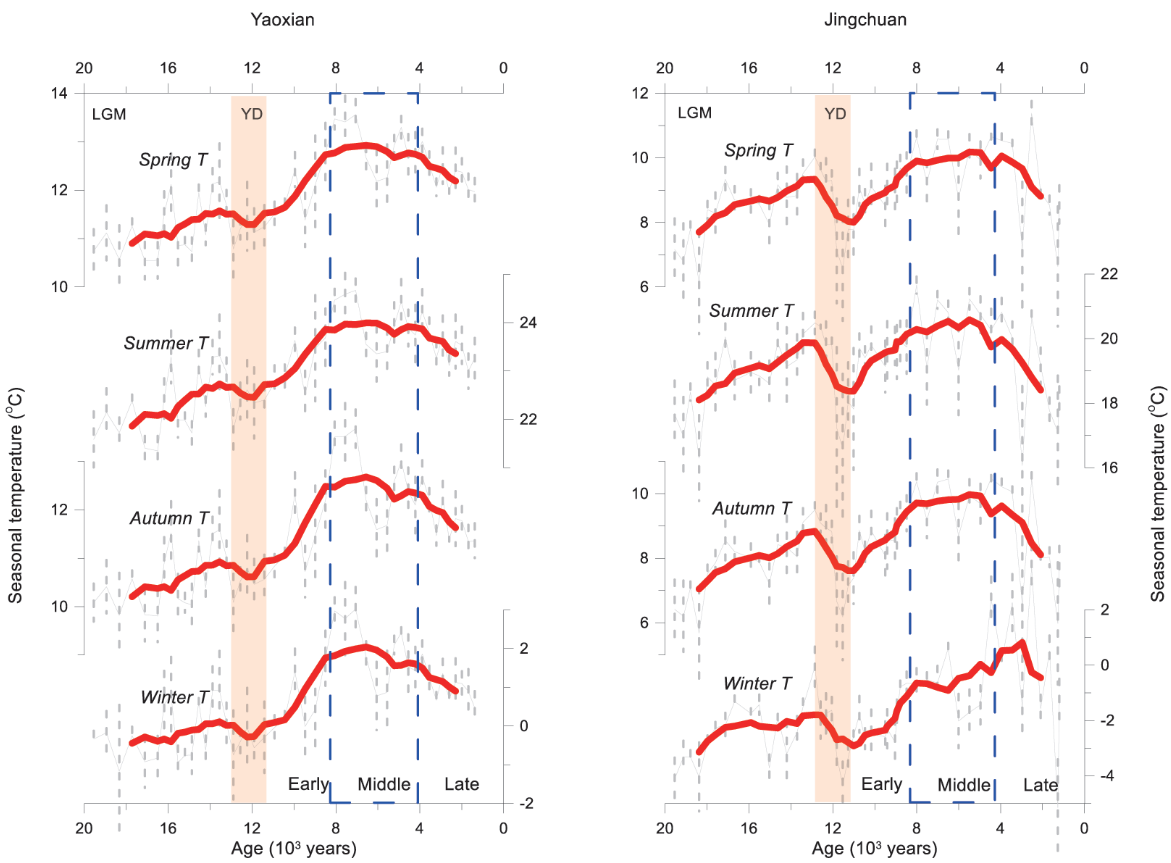


Figure 3-1-76 20,000-year reconstruction of seasonal temperature from the loess sequences at Yaoxian and Jingchuan on the Chinese Loess Plateau.

The study found that the MAT estimated from season-by-season temperature was consistent with the MAT reconstructed independently by the transfer function. The reconstructions showed a trend of increasing temperatures during the last deglaciation, a temperature peak during the early to mid-Holocene, and decreasing temperatures during the late Holocene (Figure 3-1-77). In general, the contribution of summer and winter temperature to MAT is significantly greater than that of spring and autumn temperatures. The relative contribution of each season varies over time and corresponds roughly with the seasonal insolation in each season. This suggests that Holocene temperature reconstructions are not universally biased towards a particular season.

Overall, this study has developed a method for quantifying seasonal climate parameters using mollusk assemblages. By reconstructing the seasonal temperature changes over the past 20,000 years, it has validated the existence of a consistent early to middle Holocene thermal maximum in East Asia, suggesting that seasonal bias in the proxies may not be the primary cause of the Holocene proxy-model mismatch, at least in East Asia. This record provides a typical geological case for addressing the controversy between reconstruction and simulation from the perspective of the four seasons.

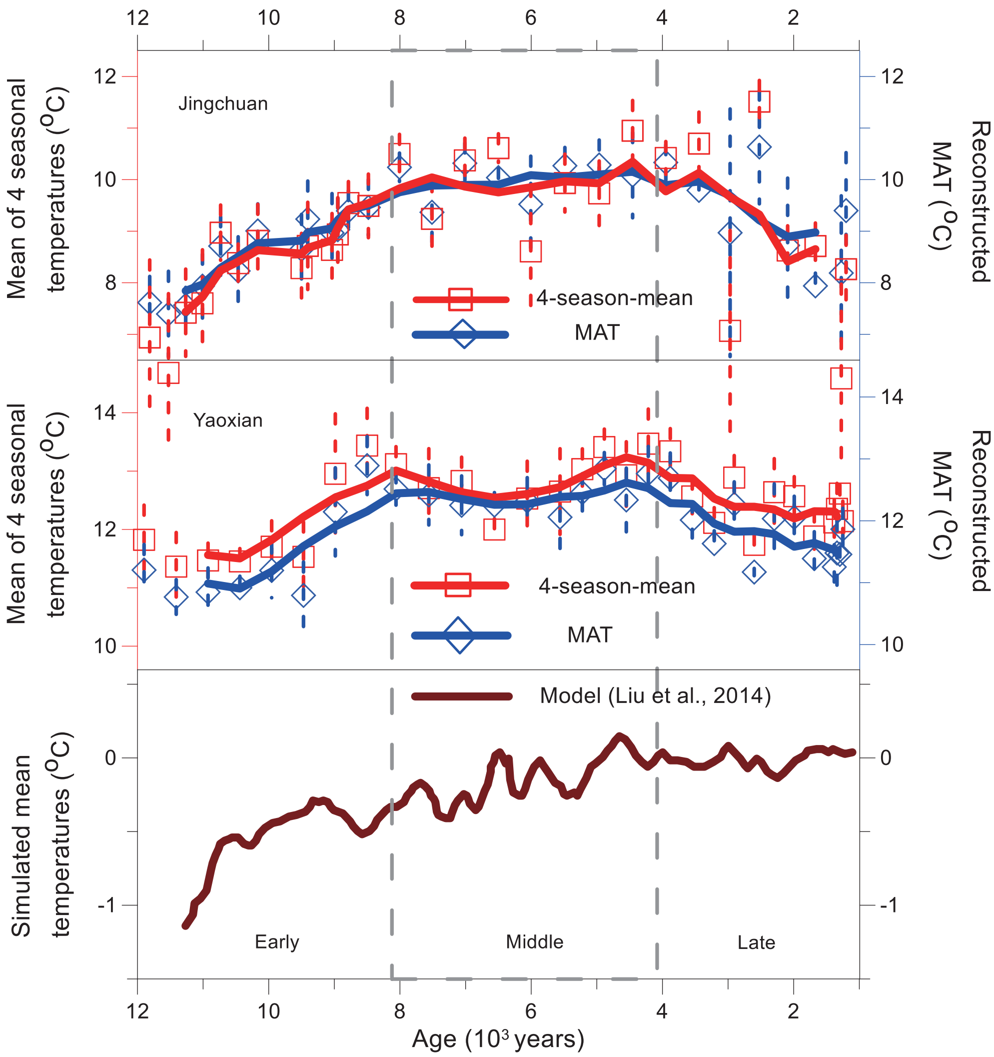


Figure 3-1-77 Holocene mean-four-season temperature (red squares and lines) from the loess sequences, and comparison with a direct reconstruction of MAT (blue diamonds and lines) and simulated mean temperatures.

PART 4

International (Regional) Cooperation and Exchange

NSFC

I. Advancing the funding of the Research Fund for International Scientists

In 2022, NSFC continued to carry out project funding for excellent international scholars. A total of 1,856 eligible applications for international young scientists (RFIS-I), excellent young scientists(RFIS-II), and senior scientists(RFIS-III) were received, of which 259 were funded, with a direct cost of 173 million yuan. On that basis, 13 outstanding projects were funded through the Pilot Group Program of the RFIS-III, a program designed to support high-level international research teams in key areas, with a direct cost of 48.07 million yuan. The pilot program and the quality of the funded international teams were highly praised by reviewers. The impactof the Research Fund for International Scientists has steadily increased, and its role in attracting and retaining outstanding international talents has gradually emerged. Making the utmost of the unique advantages of the National Natural Science Fund, NSFC formulated the "Work Plan for Pilot Implementation of the Global-Oriented Scientific Research Fund".

II. Continuing the promotion of Sustainable Development International Cooperation (SDIC) Program

In 2022, the SDIC program initiated by NSFC has entered a substantive implementation stage, providing opportunities for Chinese scientists to "go global", promoting the high-quality development of the Global South, achieving the United Nations Sustainable Development Goals, and building a community with a shared future for mankind. After extensive contacts and multiple rounds of communication, NSFC jointly released the Call for Proposals for the first-round cooperation in Chinese and English with 16 international scientific research funding agencies and international scientific organizations in April 2022, and received 136 project applications. After review by the expert group and consultation with international partner agencies, a total of 19 bilateral projects were funded, with a direct cost of 20.56 million yuan.

III. Promoting regional innovation and international (regional) exchanges and cooperation

By the end of 2022, NSFC has established stable partnerships with 101 funding agencies and international organizations in 54 countries (regions).

In terms of cooperation with America and Oceania, NSFC steadily carried out joint funding for cooperative research projects with the National Science Foundation (NSF), and continued to deepen and expand cooperation with the Bill and Melinda Gates Foundation; jointly organized scientific research exchange activities and promoted substantive cooperation with funding agencies in Brazil and Chile; and maintained close contact with New Zealand.

In terms of cooperation with Europe, NSFC continued to strengthen high-level dialogue with funding agencies and organizations in important European countries (regions), deepened the high-level strategic discussion mechanism with Europe, and held two consecutive high-level discussions and a series of exchange policy seminars with Science Europe, and held a high-level strategic seminar on interdisciplinary research with the U.K. Research and Innovation (UKRI); actively participated in intergovernmental scientific and technological cooperation mechanisms such as China-Switzerland, China-Europe, China-Russia, and China-Ireland, etc, and maintained close contact with the Chinese embassies in Germany, Finland, Sweden, and Ireland; renewed bilateral cooperation agreements with the Czech Academy of Sciences, and expanded and deepened cooperation with Turkey and Poland.

Regarding cooperation with Asia, NSFC actively consolidated cooperation with Japan, Israel, and South Korea, and strengthened regional cooperation between China, Japan, and South Korea. NSFC made a joint decision with the Israel Science Foundation (ISF) to continue joint solicitation and funding in the two fields of precision science and life medicine; participated in the 19th Meeting of Heads of Research Councils in Aisa (A-HORCS), Advanced the China-Japan-Korea Foresight Program by the research funding agencies of China, Japan and South Korea; and successfully co-hosted the 26th China-Korea Basic Science Joint Committee with the National Research Foundation of Korea (NRF).

In terms of cooperation with international organizations, NSFC gave full play to the platform role of international organizations, promoted NSFC to participate in global science and technology governance and multilateral joint funding in a more active manner, and promoted the transformation of science fund reform concepts and measures into international agendas and best practices. President Li Jinghai attended the 10th annual meeting of the Global Research Council (GRC) online, and gave a report entitled "Transforming the scientific research paradigm to meet global challenges"; actively participated in the work of the secretariat of the Belmont Forum (BF), participated in the 5th round of cooperation with the BRICS Science and Technology and Innovation Program, and renewed agreements with the United Nations Environment Program (UNEP), the International Center for Integrated Mountain Development (ICIMOD), and the International Center for Theoretical Physics (ICTP) to continue enriching forms of cooperation.

In terms of cooperation with Hong Kong, Macao and Taiwan,with the deep understanding of the central government's major arrangements for Hong Kong, Macao and Taiwan, NSFC adheres to the implementation of "one country, two systems", and promotes the integration of Hong Kong and Macao's scientific and technological strengths into the overall development of the country. NSFC actively participated in the meetings of the "Mainland and Hong Kong" and "Mainland and Macao" Science and Technology Cooperation Committee; carried out online and in-person exchanges with the Research Grants Council of Hong Kong (RGC), Beijing-Hong Kong Academic Exchange Center, Macao Science and Technology Development Fund (FDCT) and Taiwan's Li Kuo-Ting Foundation, to gradually optimize the funding layout, with the funding scale doubled in comparison with that of 2021; and also encouraged and supported mainland and Hong Kong scientists to host academic seminars on cutting-edge disciplines.

In terms of the work of the Sino-German Center for Research Promotion, NSFC continuously deepened the multi-level exchanges in joint funding, management practices, and inter-institutional strategic dialogues, by giving full play to the unique role of the Sino-German Center as a joint funding entity. In 2022, the Sino-German Center successfully held the "Sino-German Scientific Research Integrity Seminar".

With respect to bilateral and multilateral joint funding, in 2022, together with more than 20 partner agencies and international organizations from the United States, Canada, Europe, Japan, and Russia, NSFC funded joint research and exchange projects in sustainable regional systems, biodiversity, ecology and evolution of infectious diseases, global health, agriculture, healthy life trajectories initiative, climate change, enterprise innovation digital technologies, digital platforms, and other areas of natural science, and organized bilateral and multilateral seminars and workshops witha total investment of 692 million yuan.

IV. Typical research results

A new Role of Circadian Protein BMAL1 in Antagonizing Aging in Primates

Circadian rhythms regulate sleep-wake cycles, metabolism, immune function, and reproduction in mammals. These processes are coordinated by the circadian clock, a biochemical oscillator that integrates physiological input signals with distinct oscillatory phases to regulate rhythms in organismal physiology, behavior, and metabolism. Accumulating evidence indicates that aging in mammals is intricately linked with alterations in circadian rhythms. However, whether and how the circadian machinery directly regulates stem cell aging, especially in primates, remains poorly understood.

With the support of NSFC (Nos. 81861168034, 81921006, 81625009 and 91949209), Prof. Guang-hui Liu from Institute of Zoology, Chinese Academy of Sciences, Prof. Andy Peng Xiang from Sun Yat-sen University, Prof. Jing Qu from Institute of Zoology, Chinese Academy of Sciences, and Profs Huating Wang andHao Sun from Chinese University of Hong Kong, have collaborated to uncover a novel role of BMAL1 in regulating primate stem cell senescence by repressing the "jumping gene" LINE1. This study entitled "BMAL1 moonlighting as a gatekeeper for LINE1 repression and cellular senescence in primates" was published online in Nucleic Acids Research on March 15, 2022.

BMAL1, a transcription factor that initiates transcriptional-translational feedback loops that drive the oscillation of circadian genes, is an indispensable component of the molecular circadian. So far, the scientific link between BMAL1 and aging is unclear. In this study, researchers found that nuclear BMAL1 was reduced in senescent mesenchymal progenitor cells (MPCs) from both humans and monkeys, indicating that nuclear BMAL1 might have a conserved function in aging regulation in primates. To study the role of BMAL1 in regulating cellular homeostasis, researchers generated BMAL1-deficient human MPCs by CRISPR/Cas9 gene editing, and found that BMAL1 depletion led to accelerated cellular senescence. Interestingly, the function of BMAL1 in counteracting cellular senescence is independent of its C-terminal transactivation domain and thus uncoupled from its circadian activity. The mechanistic investigation demonstrated that BMAL1 interacted with proteins associated with heterochromatin and nuclear lamina, such as KAP1 and Lamin B1, to stabilize heterochromatin and repress LINE1. BMAL1 deficiency led to detachment of genomic lamina-associated domains (LADs) from the nuclear periphery, decreased H3K9me3 occupancy, and increased chromatin accessibility in LADs.

Further, BMAL1 occupies the LINE1 repetitive elements, and its deficiency causes LINE1 de-repression, which in turn activates cGAS-STING proinflammatory pathways. Importantly, blocking LINE1 activity can alleviate BMAL1 deficiency-induced cellular aging, suggesting that LINE1 repression is likely the mechanism through which BMAL1 regulates senescence. Finally, BMAL1 occupancy at LINE1 was reduced during senescence, and targeted BMAL1 deletion in a monkey model also led to LINE1 activation and tissue aging in vivo, indicating a conserved role of BMAL1 in moonlighting as a gatekeeper for LINE1 repression and cellular senescence in primates.

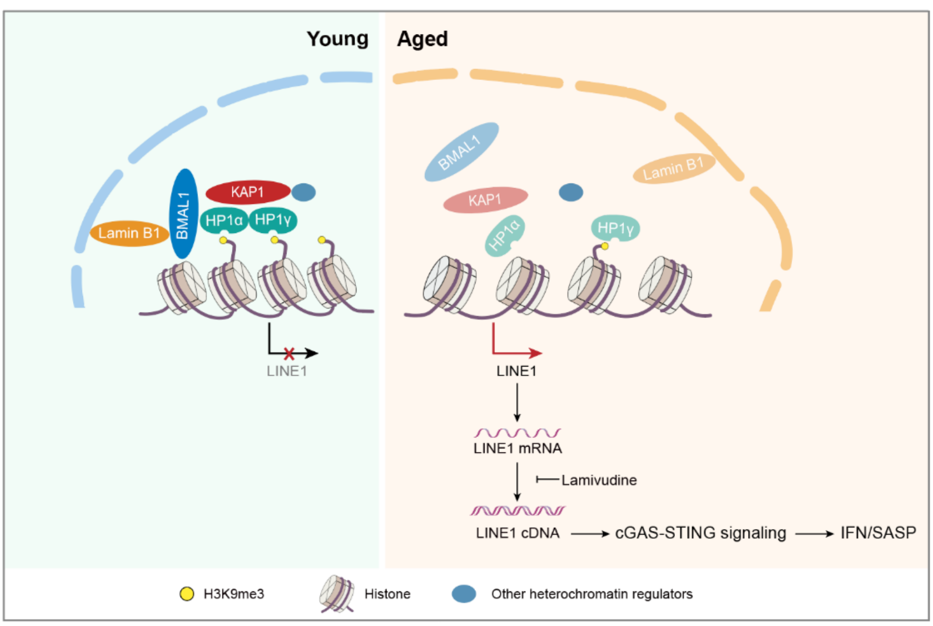


Figure Dampened BMAL1 occupancy on LINE1 elements leads to its derepression and thus activates cellular senescence through cGAS-STING pathway.

For the first time, this study identifies a novel function of BMAL1 independent of its transcriptional activity through which it regulates tissue and stem cell senescence. This research expands our understanding of the biological functions of core circadian clock proteins, sheds new light on an inextricable connection between circadian rhythm and aging regulation, and may provide a novel target for the treatment of aging-associated degenerative disorders in the future.

Correlation between Critical Temperature and Magnetic Energy in Cuprate Superconductors

Under the support of NSFC-DFG Joint Research Program, Basic Science Center Program and General Program, (Nos. 12061131004, 11888101, and 11974029), the research groups of Profs. Yuan Li and Yingying Peng from the School of Physics and the International Center for Quantum Materials, Peking University, have undertaken a joint research program in collaboration with scientists from Germany and the United Kingdom to study the mercury-family of high-T_c cuprate superconductors using photon scattering spectroscopy. The result uncovers a near-proportional relation between the superconducting critical temperature (T_c) and the magnetic interaction strength. The work has been published on Jun. 7, 2022 as an research article in *Nature Communications*, entitled "*Paramagnons and High-Temperature Superconductivity in a Model Family of Cuprates*". The importance of the work has been internationally recognized. On Nov. 18, 2022, the American Physical Society magazine *Physics Today* published a news article about recent developments in the research about the mechanism of high-T_c superconductivity, where this research result was explicitly mentioned.

In order to experimentally identify the driving force behind the mechanism for high-T_c superconductivity, an important strategy is to look for energy scales that are directly related to the value of T_c. For the high-T_c cuprate superconductors, a widely considered scenario is that magnetic interactions between electrons are crucial for the formation of the superconductivity. Resonant inelastic X-ray scattering and Raman scattering can directly probe the strength of magnetic interactions in these materials. In order to determine whether the interaction strength and T_c have definitive correlation, the joint research team employed a strategy of comparatively measuring materials within the mercury-family of cuprates, which have T_c as high as on the order of 100 K. This measurement strategy lets the leading quantities stand out and minimizes complexities related to details such as in the crystal structure. The experiments show that, from the first to the second member of the compound family, the energy of the full paramagnon spectrum has increased by about 20-30%, which quantitatively matches with the variation in the optimal T_c. By including data from additional cuprate families, the research unveils a nearly proportional relation between the optimal T_c and the paramagnon energy (Fig. 1). The discovery of such a clear correlation constitutes a significant step towards revealing a possible magnetically-driven superconducting mechanism.

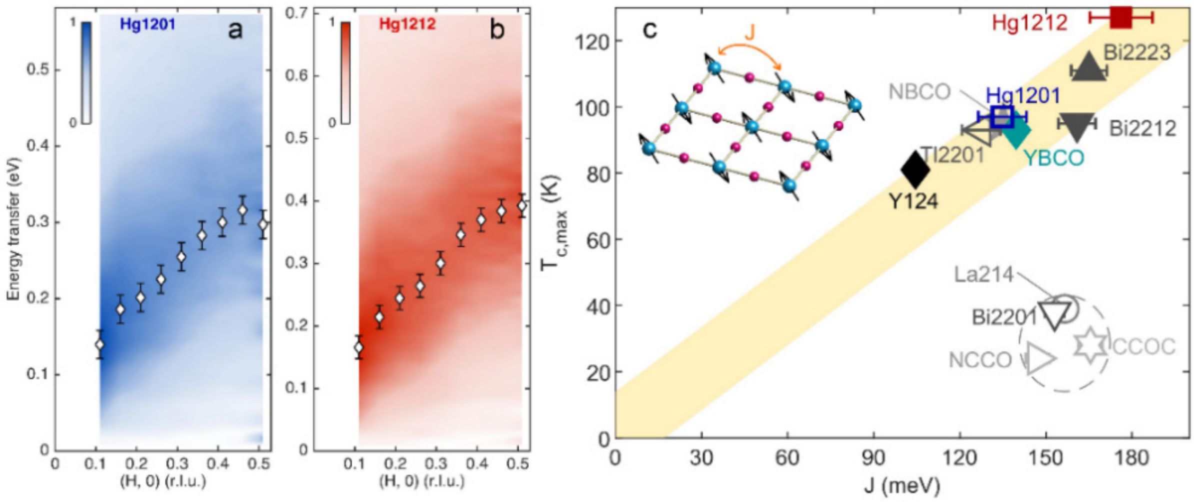


Figure 1. (a-b) Comparison of paramagnon spectra of Hg1201 and Hg1212. The vertical energy scale is chosen on purpose to be different by 30% between the two panels. (c) Correlation between the optimal T_c and the magnetic interaction strength in different high-T_c cuprates. Systems encircled by dashed lines to the lower-right corner of the plot are materials with relatively low T_c, presumably because of material-specific reasons such as disorder. They do not obey the near-proportional relation manifested by the higher-T_c systems.

Exploring Business Models for Carbon Emission Reduction via Post-consumer Recycling Infrastructures in Beijing: An Agent-based Modelling Approach

With the support of NSFC-NWO Joint Research Program ["Towards Inclusive Circular Economy: Transnational Network for Wise-waste Cities (IWWCs)" (No.: 72061137071)], this study evaluated the potential for carbon emissions reduction through post-consumer recycling activities in residential communities in Beijing.

The "Zero Waste City" initiatives in China calls for increasing household participation in the community recycling programs. A shift from a facility-oriented strategy to behavior-oriented norm building at the community level provides the local niches for emerging business models in post-consumer recycling. This paper proposes a framework based on the Theory of Planned Behavior to simulate the impact on the participation rate of households in community-based recycling program in the context of different recycling business models in Beijing. Firstly, a questionnaire survey was conducted in 2021 in Beijing (N = 1153) to test the key factors which affect household recycling behavior. Secondly, an agent-based model for community-based recycling which was developed in 2016 has been updated to incorporate the institutional change in the development of zero-waste city initiatives. Scenario analysis is adopted to compare the effects of introducing two new business models to the baseline situation that is prevalent at present. The settings for the two new business models represent the diversified directions of the upgrading of urban recycling sector: one is to improve the intelligence of the collection facilities to save labors, and the other is to involve the informal recyclers to provide door-to-door collection services in person so as to save time for the residents. Additional scenario shows the effects of norm-based solutions in combination with the two strategies addressed above in the long run. The simulation results show that the potential for carbon emissions reduction through post-consumer recycling in Beijing can range from 1 million tons per year at the basic scenario to more than 4.5 million tons per year in the community level norm-based solution scenario.

In conclusion, the proposal for sustaining the community-based new business models through the capture of value in the carbon emission reduction is put forward as a guideline for urban recycling infrastructure design.

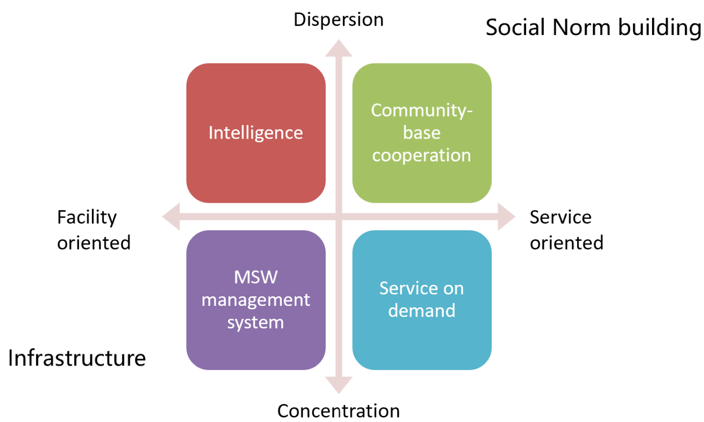


Fig. The two dimensions for the upgrading of urban recycling sector. (MSW: Municipal Solid Waste).

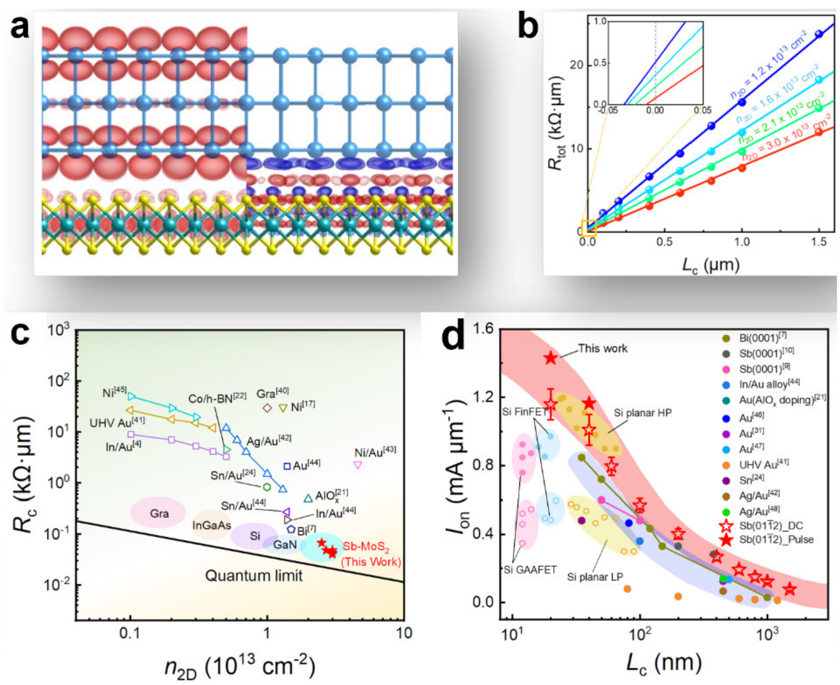
Approaching the Quantum Limit in Two-dimensional Semiconductor Contacts

The shrinking of CMOS scaling is approaching limit due to the quantum confinement. The latest reports of International Roadmap for Devices and Systems (IRDS) predicts that 2D semiconductors, represented by MoS_2, show great potential for 2 nm technology node and below to extend the Moore's Law.

The ohmic contact between metal and semiconductor is the dominated device characteristic for high-performance transistors with ultra-short channel length. Compared with silicon technology, 2D semiconductors with natural van der Waals gap exhibit significantly weak wave function coupling between metals and semiconductors, which makes it a great challenge to achieve ohmic contact. The ohmic contact with low contact resistance is one of the paramount bottlenecks that have stuck the high-performance 2D transistors for a long time. With the support of NSFC-RGC Joint Research Fund, Science Fund for Creative Research Groups Nos.: 61861166001; T2221003; Prof. Xinran Wang and Prof. Yi Shi from Nanjing University lead an international cooperation team with Prof. Jinlan Wang and Prof. Zhenhua Ni from Southeast University, Prof. Xidong Duan from Hunan University and Prof. Eric Pop from Stanford University to tackle this challenge. They realized ultra-low contact resistance for monolayer MoS_2 of 42 Ω·μm through enhancing the orbital hybridization between the semi-metal Sb and 2D channel, which is close to the quantum limit and surpasses silicon technology. The results were published in *Nature* (Jan. 11, 2023) entitled "Approaching the Quantum Limit in Two-dimensional Semiconductor Contacts".

Through first-principle calculations, they found a special phase of $(01\bar{1}2)$ in the semi-metallic Sb, which shows strong orbital distribution in the z direction. Even for van der Waals systems, the tight orbital overlap between Sb $(01\bar{1}2)$ and MoS_2 brings metal-Semiconductor band hybridization, which greatly improves the efficiency of charge transfer and carrier injection. Experimentally, they developed a high-temperature evaporation process for Sb $(01\bar{1}2)$ thin film deposition on MoS_2. Compared with Sb (0001) contacts, the monolayer MoS_2 transistors with Sb $(01\bar{1}2)$ contacts exhibit 3.47 times reduction in average contact resistance, and 38% improvement of average current density. Also, the uniformity for statistical results was greatly improved. Thanks to significant reduction of contact resistance, the MoS_2 transistor with a channel length of 20 nm exhibits current saturation characteristics at U_{ds} = 1V. The on-state current is as high as 1.23 mA/μm, which is almost 45% higher than the previous record. The performance of monolayer MoS_2, for the first time, surpasses the silicon CMOS under the same technology node, and satisfies the performance requirements of IRDS for 1 nm node. In conclusion, the excellent performance, stability and scalability of Sb (01$\bar{1}$2) contact technology for 2D monolayer is the most promising core technology in TMDs electronics in the post-silicon era, which will promote the development of 2D integrated circuits.

Thanks to the support of the NSFC-RGC, Prof. Xinran Wang of Nanjing University carried out cooperation with Prof. Jianbin Xu in the Chinese University of Hong Kong in the follow-up work of contact optimization in 2D organic semiconductor devices. In this work, an atomically sharp contact interface with contact resistance down to 14.0 Ω·cm is achieved and the overall device performance is improved to the best level so far. This work was accepted by *Nature Communications* on January 3, 2023 and will be published in the near future.



Semi-metal Sb(01T -2) for 2D ohmic contact
a) electronic distribution of Sb (01T-2) and MoS_2 with orbital hybridization; b) ultra-low contact resistance of monolayer MoS_2; c) performance benchmarking of mainstream technologies for contact resistance; d) the highest current density for monolayer MoS_2 with Sb(0112) contact.

An International Consensus on Precise Diagnosis Based on Positron Emission Tomography (PET) Molecular Imaging

With the support by NSFC International (Regional) Joint Research Program under MoUs (No.: 81761148029), the joint research teamled by Prof. Mei Tian of Fudan University, and scientists from Riken Biosystem Dynamics Research Center of Japan and Seoul National University of South Korea, has released an international collaborative work entitled "International Consensus on the Use of tau PET Imaging Agent ^{18}F-flortaucipir in Alzheimer's Disease". This work has been published in the Guidelines column of the

European Journal of Nuclear Medicine and Molecular Imaging on January 3, 2022.

Currently, PET is the only clinical molecular imaging modality which is used for precise diagnosis and evaluation of therapeutic response in cancer, neurological and cardiovascular diseases. ^{18}F-flortaucipir is a novel PET imaging probe targeted for tau pathology in patients with Alzheimer's disease (AD). Although ^{18}F-flortaucipir PET has been used in the early detection or differential diagnosis of AD, its clinical operation procedure varied in different centers, which hampers comparison across different centers and the further application.

To provide a regulatory reference for nuclear medicine practitioners, Prof. Tian led a team with co-investigators of A3 Foresight Program and experts from international top class hospitals and institutes (including China, Japan, Korea, the United States, Germany, Switzerland, and Spain), reached an international consensus on the use of ^{18}F-flortaucipir PET imaging in Alzheimer's disease. This consensus emphasized the standardized preparation of patients, synthesis of ^{18}F-flortaucipiris, imaging acquisition and reconstruction, as well as interpretation and report of the PET imaging findings. The specific workflow can be referred in Fig.1.

The contribution of this international consensus is to provide a standardized guidance for the use of PET imaging with ^{18}F-flortaucipir, which will largely benefit the promotion of international, multi-center clinical studies and collaboration, and eventually facilitate the early detection of Alzheimer's disease and precise patient management.

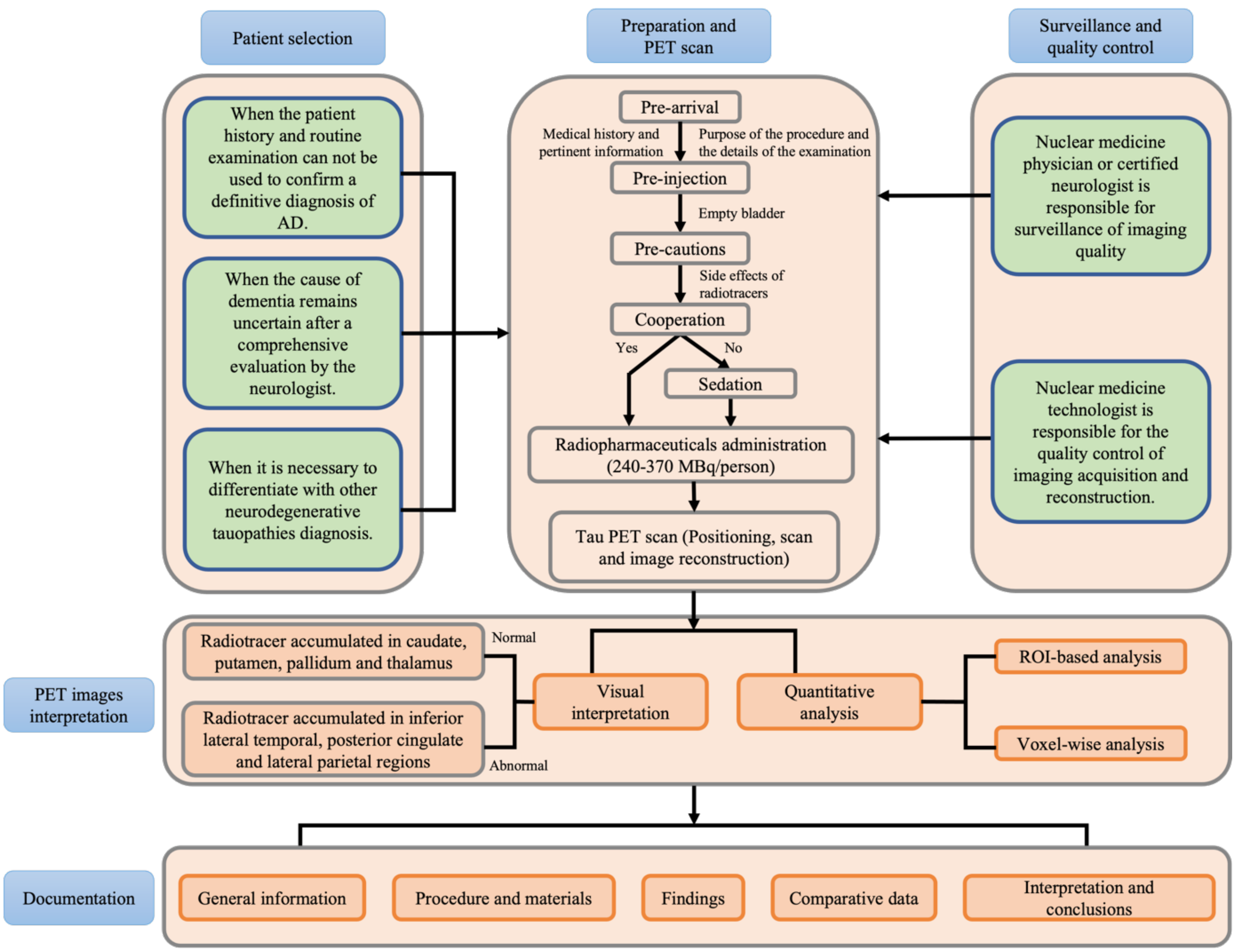


Fig. 1 Flowchart of ^{18}F-flortaucipir PET imaging and reporting procedures (updated)

Joint Study on the Regulation Mechanism of Balance between Maize Yield and Drought Resistance

Supported by NSFC [International Regional) Joint Research Program under MoUs and General Program (Nos.: 32061143031, 91940301, 92035302), Mingqiu Dai's group, together with Feng Li's and Lin Li's groups at Huazhong Agricultural University, and their CIMMYT (International Center for Wheat and Maize Improvement) collaborator Dr. Sarah Hearne, for the first time, recovered the genetic and molecular mechanism of the balance between yield and drought resistance of maize, which laid the theoretical foundation and provided excellent genetic resources for precision breeding of maize with both high resistance and high yield. The results of this study were published in *Nature Biotechnology* on October 13, 2022 with a title "The Role of Transposon Inverted Repeats in Balancing Drought Tolerance and Yield - related Traits in Maize".

Based on the analysis of small RNA (sRNA) transcriptomes and RNA transcriptomes from hundreds of natural maize populations, the collaborated teams cloned eQTL*DRESH8*, a super hot spot on chromosome 8 that regulates sRNA expression and drought response. *DRESH8* is a sequence consisting of transposons element-inverted repeat, TE-IR. The results of gene editing transgenic experiments showed that *DRESH8* was a causal variant regulating drought resistance and sRNA expression in maize population. Yield investigation and evolutionary analysis showed that *DRESH8* could mediate the selective balance between drought resistance and yield: in an environment with sufficient rainfall, farmers may choose to plant maize with *DRESH8* to increase yield; while, in a drought environment, farmers choose to plant maize without *DRESH8*, which can remove the inhibiting effect of *DRESH8*-derived sRNAs on drought-resistant genes, thus improving maize drought resistance. Further studies showed that genome-wide TE plays an extensive role in maize drought response by forming IR structures. In addition, there were dozens of eQTL hotspots with TE-IR structural variation, and the potential target genes regulated by these TE-IR-derived sRNA were enriched in the genes related yield and stress resistance, suggesting that TE-IR may play a general role in regulating the balance between environmental adaptability and yield traits of maize.

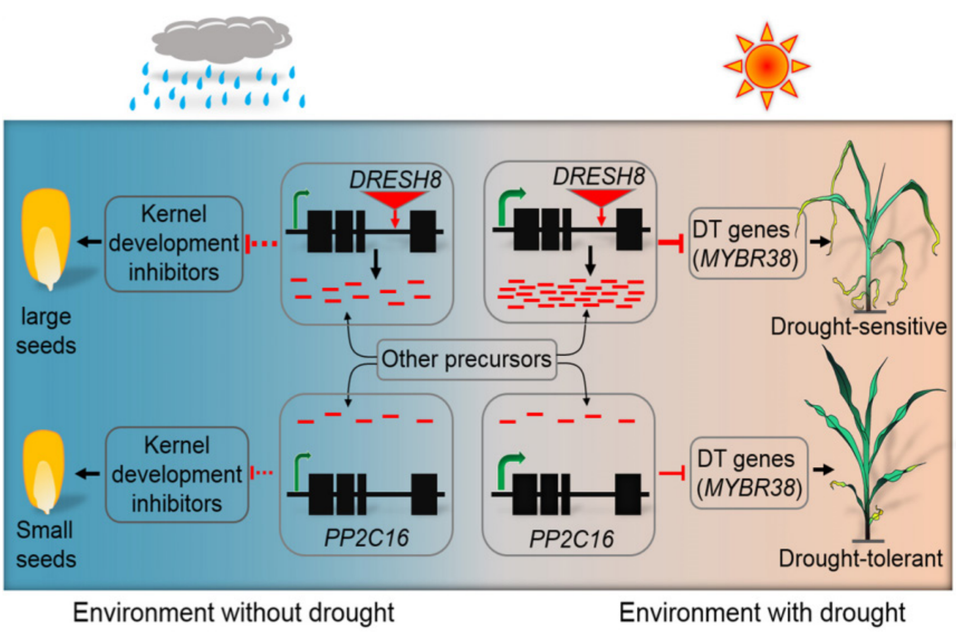


Figure *DRESH8* regulates the balance of maize yield and drought resistance

This study identified a large number of environment-specific genetic regulators related to drought adaptation and yield traits, revealing for the first time the key genetic and molecular mechanisms, by which TE is involved in the post-transcriptional regulation of genes through the formation of IR structures, thus balancing crop yield and environmental adaptation. This balance mechanism driven by TE-IR structure lays a theoretical foundation for precise and design breeding of crops with high drought resistance and high yield, and provides excellent genetic resources.

Identification of Resistance Genes and Discovery of New Resources for Rice Black-streaked Dwarf Disease

With the support of NSFC International (Regional) Joint Research Program under MoUs (No.: 31761143012), Jiangsu Academy of Agricultural Sciences (JAAS), Guangdong Academy of Agricultural Sciences (GAAS) and International Rice Research Institute (IRRI) formed an international cooperation team aiming at identifying the resistance gene of rice black-streaked dwarf virus disease (RBSDVD) and discovering new resource. New Phytologist published the results related of the study as a research paper "An Aspartic Protease 47 Causes Quantitative Recessive Resistance to Rice Black-streaked Dwarf Virus Disease and Southern Rice Black-streaked Dwarf Virus Disease" on 12 January 2022.

Upon infected by rice black-streaked dwarf virus (RBSDV) and southern rice black-streaked dwarf virus (SRBSDV), the rice plants will show severe symptoms, including serious stunted growth, poor seed setting rate, which may result in more than 50% yield reduction in average.Presently, there is a lack of effective means to control these two diseases; thus, they were called the "cancer" of rice. Southern rice black-streaked dwarf disease (SRBSDVD) and rice blast are the only two rice diseases that are listed in Category A of Crop Diseases and Insect Pests by the Ministry of Agriculture and Rural Affairs of China, and they are the only two Category A rice disease in this list. To date, stable and resistance resources to these two rice black-streaked dwarf virus diseases have not been discovered in rice, and the resistance genes of these two viral diseases have never been identified, which leads to limited progress in the resistance breeding of these two diseases.

In order to break the technical bottleneck of lack of resistance resource of rice black-streaked dwarf virus disease, the joint teamfully utilized in phenotype identification system of rice viral diseasein JAAS team, the rice genomic research technique in GAAS team, and the diverse rice resources provided by IRRI, to carry out the resistance resources screening and resistance gene identification research (Figure 1). Through the close cooperation of the three teams, more than 500 rice core germplasm resources from 59 countries were collected by IRRI and both field trial and artificial inoculation test were conducted to evaluate the RBSDVD resistance. The highly resistant accession was also subjected to antibiosis and virus accumulation tests to exclude the interfering from the insect resistance. Then the strongest RBSDV resistance variety W44 was screened out (from IRRI) (Figure 2); Constructing populations with this resource, combined with the genome-wide association study (GWAS), RNA sequencing analysis and transgenic verification, the joint team confirmed the aspartic protease gene *OsAP47* as the functional gene in the main quantitative trait locus (QTL) *qRBSDV6-1* as the functional gene. This is the first RBSDV and SRBSDV resistance gene to be cloned and functionally verified in the world. Further comparative genomic analysis of more than 500 germs and 3,000 sequenced rice showed that the resistance haplotype Hap1 of *OsAP47* only exists in *Indica*, and its geographical distribution is mainly in the South Asia and West Africa. The above research findings are of great significance to breeding improvement all over the world (Figure 2).

Figure 1 Chinese scholars and IRRI jointly carry out the screening of resistance resources and identification of resistance genes of the RBSDVD

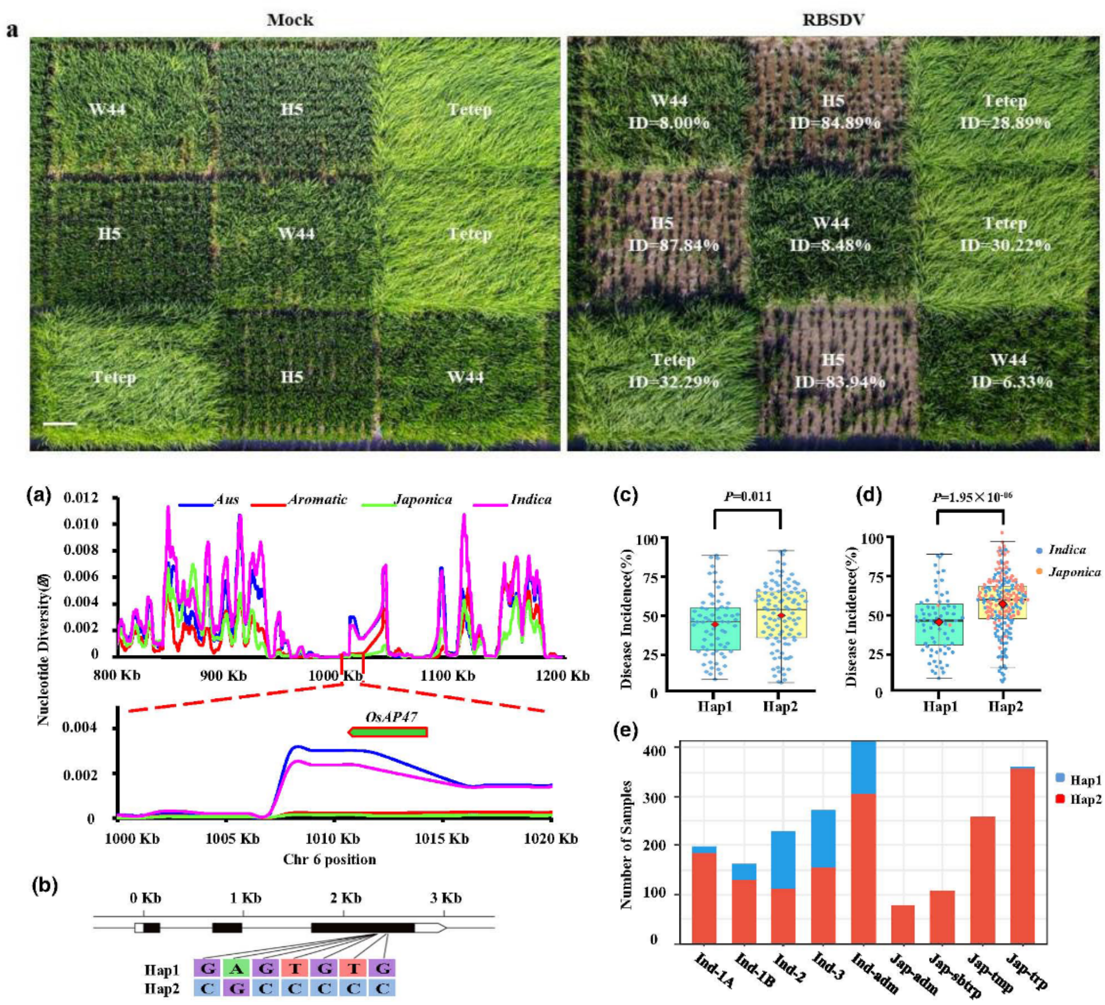


Figure 2 Field resistance of W44 to RBSDV and haplotype analysis of OsAP47 in rice natural populations

Enantioselective Ullmann Coupling Enabled by Novel Chiral 2,2′-Bipyridine Ligand

Generously supported by the Research Fund for International Young Scientists of NSFC (No. 22150410339), Dr. Saima Perveen, Assistant Professor at Xi'an Jiaotong University, achieved a nickel-catalyzed asymmetric Ullmann coupling reaction enabled by unique chiral bipyridine ligand SBpy based on the previous works of Prof. Pengfei Li's team, and demonstrated the potential applications by versatile transformation of the products and formal total syntheses of three natural products.

Chiral ligands are the key element of stereo control in asymmetric catalysis. Among them, many chiral phosphines have been widely used in enantioselective transition-metal-catalyzed reactions. However, bipyridine, a type of classical and widely used ligand, still lacked generally effective chiral version. The development of chiral bipyridine ligands has been faced with the following difficulties. First, it is difficult to introduce chiral elements into the pyridine ring. Second, it is difficult to modify the structure of the chiral pyridine backbone. Third, the improvement of stereoselectivity is often accompanied by decreasing catalytic activity when substituents are introduced to adjacent positions of the nitrogen atoms. To meet these challenges, the group developed a novel class of chiral bipyridine ligand named SBpy which had a [6-5-3] rigid ring structure that minimized the proximal steric hindrance and achieved a highly tunable distal chiral pocket. The rational design overcame the contradiction between stereoselectivity and catalytic activity.

Axially chiral biaryls are ubiquitous structural motifs in a myriad of natural products, bioactive compounds and chiral organic materials, as well as essential and privileged structural units in a variety of efficient chiral ligands and catalysts. Dr. Saima Perveen synthesized a series of optically pure axially chiral biphenyl and binaphthalene dialdehyde compounds with high efficiency and selectivity, by using the newly prepared (+)-DTB-SBpy ligand. Subsequently, she successfully demonstrated the versatility of biaryl dials

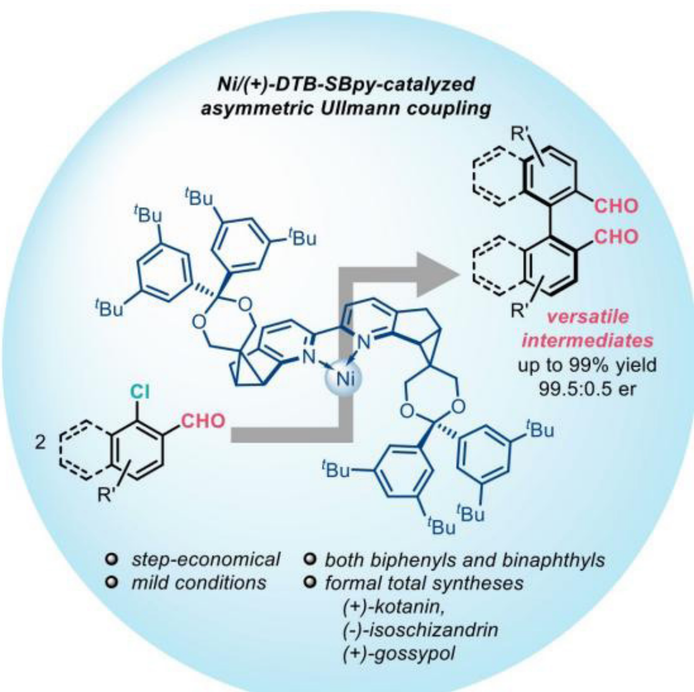


Figure Chiral bipyridine ligands and the asymmetric Ullmann reaction as key synthetic intermediates for a number of axially biaryl catalysts and ligands. She further applied the reaction in concise and efficient formal total syntheses of three natural products (+)-kotanin, (-)-isoschizandrin and (+)-gossypol.

The results have clearly demonstrated the effectiveness of the rationally designed novel chiral bipyridine ligands SBpy, and provided new tools for selective synthesis of chiral molecules as well as new conceptual insights for designing related chiral catalysts. The recent publication of this work on October 4, 2022 in *Angewandte Chemie International Edition* has immediately received wide attention from the community.

Revealing the Relationship between Point Defects and Electrochemical Properties of Li-rich Cathode Li_2MnO_3 via First-principles Calculations

Compared with traditional cathode materials, layered Li-rich oxide cathodes (LOC) are considered as promising candidates for next-generation Li-ion battery cathode materials due to their higher energy density. However, the operate voltage and capacity degradation during cycle induced by irreversible oxygen loss and structural transformation limit their commercial applications. “Defect engineering” is the commonly used method to optimize their electrochemical properties.

To reveal the “lattice defect-performance” relationship and provide a strategy for lattice modification of the electrochemical performance of Li-rich cathode, the researchers from the Sino-German Cooperation Group “Integrated Computational Materials Engineering of Electrochemical Storage Systems” have investigated the common cation disorder mixing defect in Li_2MnO_3, the mother phase of layered LOC, by the first-principles calculations. The calculations revealed the double-sided effect of the Li-rich region caused by the disordered cation mixing, which is favorable to Li diffusion but unfavorable to O stability, and propose a strategy to improve the stability of the Li-rich cathode structure by appropriately reducing the Li content and doping with electrochemically active transition metals. Meanwhile, the connection between the *d* electron period of the doped transition metal and the electrochemical activity, delithiation voltage, O stability and Li diffusion performance of Li_2MnO_3 was constructed by the calculations, and it was demonstrated that *4d* and *5d* transition metal doping could better stabilize O in Li_2MnO_3 and improve its cyclic stability. This study elucidated the nature of cationic disordered defect in Li_2MnO_3 at the atomic scale, and established the connection between defects and Li_2MnO_3 performance, which could provide a theoretical basis for the “defect engineering” of LOC design. In addition, the regularity between the *d*-electron configuration of the doped transition metals and the electrochemical performance of doped Li_2MnO_3 provides a theoretical reference for a more reasonable selection of doping elements for LOC. The works have been published in international journals, such as *Physical Review Materials* ([May, 2022) and *Nanoscale* (September, 2022)].

The work is supported by NSFC and DFG of Germany (Grant No.: GZ 1528). Prof. Yong Du from Central South University (CSU) and Prof. H. Seifert from KarlsruherInstitut für Technologie (KIT) are the PI of the project. The project used the ICME (Integrated Computational Materials Engineering) strategy to design Li-ion batteries for the first time worldwide. Simulation methods of CALPHAD, first-principles calculations, phase-field method, and finite element method in combine with experiments are integrated in the project.

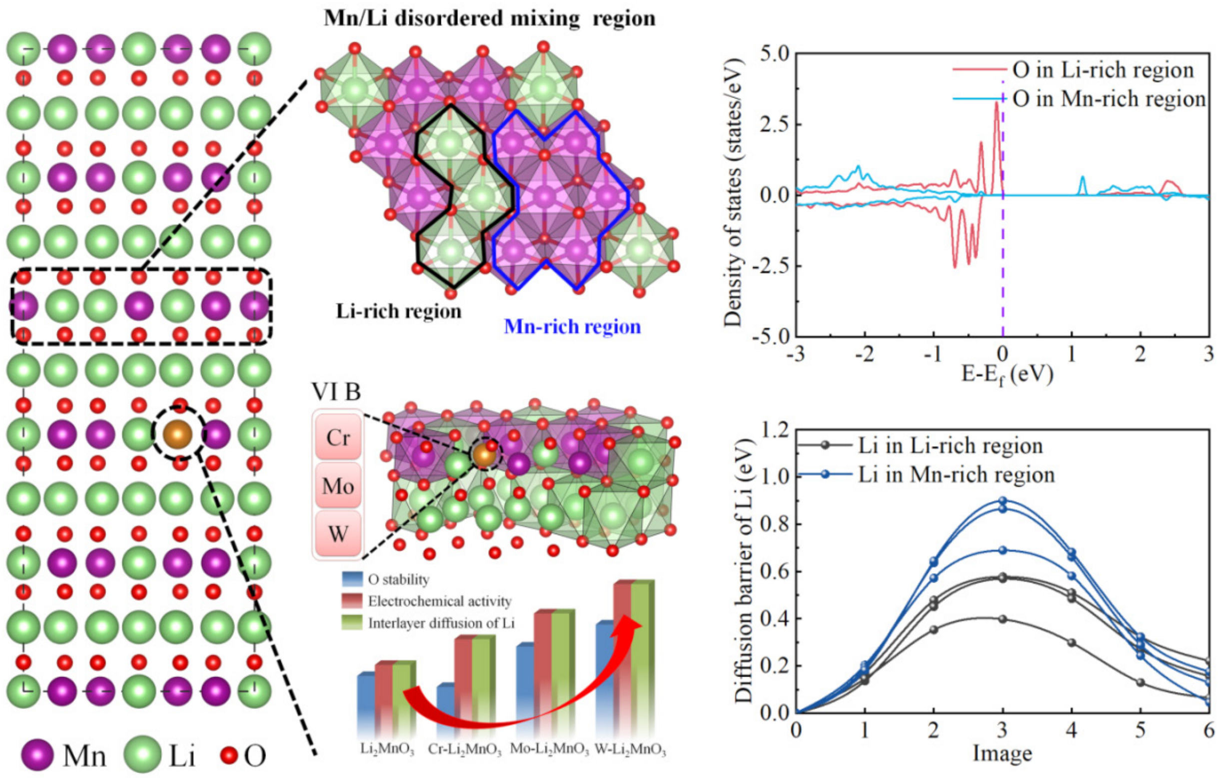


Figure 1 The effect of disordered cation mixing and transition metal doping on the electrochemical performance of Li_2MnO_3

PART 5

Research Integrity

NSFC

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In accordance with the work arrangements of the Opinions on Further Strengthening the Construction of Scientific Integrity, the Opinions on Further Carrying Forward the Spirit of Scientists and Strengthening the Construction of Work Style and Academic Atmosphere, and the Opinions on Strengthening the Ethical Governance of Science and Technology issued by the General Office of the CPC Central Committee in tandem with the General Office of the State Council, NSFC continued to promote the study style, research integrity and ethics by thoroughly launching the Action Plan for Improving the Academic Atmosphere of the National Natural Science Fund, which is systematically deployed in five aspects: education, motivation, regulation, supervision and punishment.

I. Strengthen the education and publicity of research integrity and ethics

Firstly, multiple measures were taken to increase the publicity of the construction ofstudy style and research integrity. The NSFC's Guide to Research Integrity Standards and the Introduction to Research Norms and Research Integrity Education were basically finalized for publication. NSFC took an active part in the research integrity education activities organized by the National Leading Group on Scientific Ethics and Academic Norms Popularization and Education and the Joint Meeting for Research Integrity Construction. NSFC held the "2022 National Scientific Ethics and Academic Atmosphere Construction Publicity Month" activity with relevant departments to promote the spirit of scientists, and jointly promote the spread of research integrity, norms and fine work style. Secondly, NSFC continued to promote warning education. In 2022, NSFC completed the editing, production and online release of warning educational cartoons of 5 typical cases, and the scientific and technological community responded positively. The punishment decisions of 86 respondents of research misconducts were disclosed in 4 batches, which received positive social response. Thirdly, the role of research institutions was further strengthened. NSFC publicized its new measures of research integrity, research ethics and academic atmosphere through various forms such as research institution training meetings, research integrity training meetings and NSFC program guidelines, and the main responsibilities and key roles of research institutions in the construction of scientific research integrity were further strengthened. The awareness of the "four parties" of the National Natural Science Fund (applicants/participants, review experts, research institutions, and NSFC staff) was further enhanced to consciously maintain the sound work style, form a joint force for the construction of research integrity, and jointly create a clean and positive scientific research environment. Fourthly, international cooperation was further promoted. The Sino-German Seminar on Research Integrity was successfully held by NSFC and DFG (Deutsche Forschungsgemeinschaft), with a focus on the connotation of research integrity and the construction of research integrity culture. In-depth exchanges and discussions were held on the core values and strategic thinking of the Chinese and German funding institutions on the construction of research integrity, as well as the formulation of relevant norms and measures for research integrity and the investigation and punishment of scientific misconducts.

II. Promote the institutionalization of research integrity

Firstly, the Science and Technology Progress Law of the People's Republic of China was conscientiously implemented, and the revision of the Constitution of NSFC Supervisory Committee and NSFC Measures for the Investigation and Handling of Misconducts in Scientific Research were completed. The types of scientific misconducts were further classified and adjudication measures, the scope of application on respondents, and the investigation and adjudication procedures were improved. It was highlighted to resolutely prevent asking for help, or putting good words for certain applicants and other behaviors during the review process, and resolutely prevent the respondents recorded in the database of serious dishonesty in research integrity to undertake or participate in applying for or implementing NSFC projects. Secondly, cross-departmental cooperation was further enhanced in the construction of research integrity and academic atmosphere. The Ministry of Science and Technology and other 22 departments jointly revised and issued the Rules on Investigation and Treatment of Dishonesty in Scientific Research, which supplemented and refined the types of dishonesty in scientific research, detailed the division of responsibilities for investigation and adjudication, improved the investigation and treatment procedures, and added relevant provisions on third-party intermediary service institutions and joint punishment in the field of science and technology. Thirdly, NSFC steadily promoted the establishment of a system for joint disciplinary measures in the field of scientific research. NSFC formulated the Work Plan on Further Implementing Joint Punishment in the Field of Scientific Research to Implement Integrity Review of NSFC Projects and the Work Plan on Implementing Joint Punishment on NSFC Project Reviewers Found with Serious Dishonesty in Research Integrity and Marked in NSFC Information System, which provided rules for adjudicating and punishing relevant applicants/participants of serious dishonesty in research integrity, relevant research institutions and review experts.

III. Improve the management mechanism of key links in scientific research integrity supervision

Firstly, high similarity check of applications was strictly carried out. An upgrade of the similarity check system was completed in 2022. Based on the inspection results, 112 cases of high similarity of applications were investigated, and 96 respondents were punished seriously, 35 of whom were notified and criticized. Secondly, review requirements were strengthened. NSFC's mobilization and deployment meeting for proposal review work in 2022 was organized to fully implement the working philosophy of "Science is fundamental and impartiality is life", and effectively carry out the application review work with a high degree of political consciousness and pragmatic work style, so as to create a clean and positive review atmosphere. Thirdly, on-site supervision of the panel review meetings was further strengthened. The supervision plan was improved to strictly adhere to the disciplinary norms of panel review. Reminders of duty performance were sent to applicants and panel reviewers to earnestly fulfill their commitments in the Letter of Commitment. On-site supervision was conducted for a total of 316 review groups of 34 review meetings of National Outstanding Youth Science Fund projects, Outstanding Youth Science Fund projects, Key Projects, General Projects, Youth Science Fund Projects and Regional Science Fund Projects from NSFC's 9 science departments, and an impartiality survey was conducted of the panel review experts. Fourthly, special investigation and survey was conducted to obtain an in-depth understanding of the status quo and causes of issues related to the impartiality of analysis and review. Questionnaire surveys were conducted on review experts, applicants, management staff of applicant institutions, and NSFC staffers regarding the conflict of interest and the "asking for help and putting a word for certain applicants" during the application review process. A total of 1670 valid questionnaires were collected, and the results of the questionnaire feedback were deeply analyzed, and the views and attitudes of the "four parties" were systematically sorted out, which provided basis and suggestions for further measures.

IV. Carry out supervision and inspection of project funds

According to the 2022 Implementation Plan for Supervision and Inspection on Funds of NSFC Grants, the supervision and inspection kick-off meeting was held in Guiyang City, Guizhou Province, to start on-site inspection of selected NSFC projects from 15 awardee institutions. And field research was carried out in Guizhou University, Guizhou Medical University, Guizhou Academy of Agricultural Sciences and other hostinstitutions, to listen to opinions and suggestions on strengthening the main responsibility of PIs and awardee institutions, implementing the reforms of funding policies for Central Government-funded research programs, implementing NSFC project management measures, difficulties encountered in the process of fund management, and reform measures for promoting "streamlining administration and delegating power, improving regulation, and upgrading services ". At the same time, the 84 awardee institutions in Jiangsu, Xinjiang and Qinghai provinces (autonomous regions) were urged to rectify those problems found in the supervision and inspection conducted in 2021, to further improve financial accounting, standardize project fund management, and order the relevant awardee institutions to complete the return of out-of-range expenditures, indirect costs crowding out direct costs and other irregular funds.

V. Strengthen the investigation and handling of research misconduct cases, and effectively implement joint punishment

Firstly, high-quality investigation and adjudication was conducted for research misconduct allegations. In 2022, NSFC received 536 allegations, reports, and investigation leads, and has concluded 533 of them. After deliberation of 244 cases of serious misconducts by all members of NSFC Supervision Committee and approval by the Executive Meeting of NSFC, 397 respondents and 6 awardee institutions have been penalized. Among them, 82 respondents were notified of public criticism; 74 funded projects were withdrawn and the allocated funds were recovered; 112 project applications were withdrawn from review. Secondly, joint punishment was promoted. According to the Work Plan on Further Implementing Joint Punishment in the Field of Scientific Research and Implementing Integrity Audit of NSFC Projects and the Work Plan on Implementing Joint Punishment for NSFC Reviewers Recorded in the Database of Serious Dishonesty in Scientific Research, a joint disciplinary integrity audit was carried out to applicants and participants, applicant institutions and their cooperative research institutions before the final approval of NSFC projects, to ensure that the respondents registered in the database of serious dishonesty in scientific research would not undertake or participate in NSFC projects during the punishment period. Meanwhile, joint disciplinary measures were implemented against NSFC reviewers who are recorded in the database of serious dishonesty in scientific research. In 2022, NSFC completed the first joint disciplinary integrity review of nearly 270,000 review experts in the database, and classified and marked 160 reviewers with different types of dishonest behaviors such as illegal crimes, plagiarism, falsification and tampering in NSFC information system, restricting their participation in NSFC application reviews. Thirdly, investigation and punishment was conducted on violations of management and use project funds. In 2022, a total of 47 complaints and reports were received about the illegal management and use of NSFC project funds, and 16 cases were concluded according to established procedures.

PART 6

Organization

NSFC

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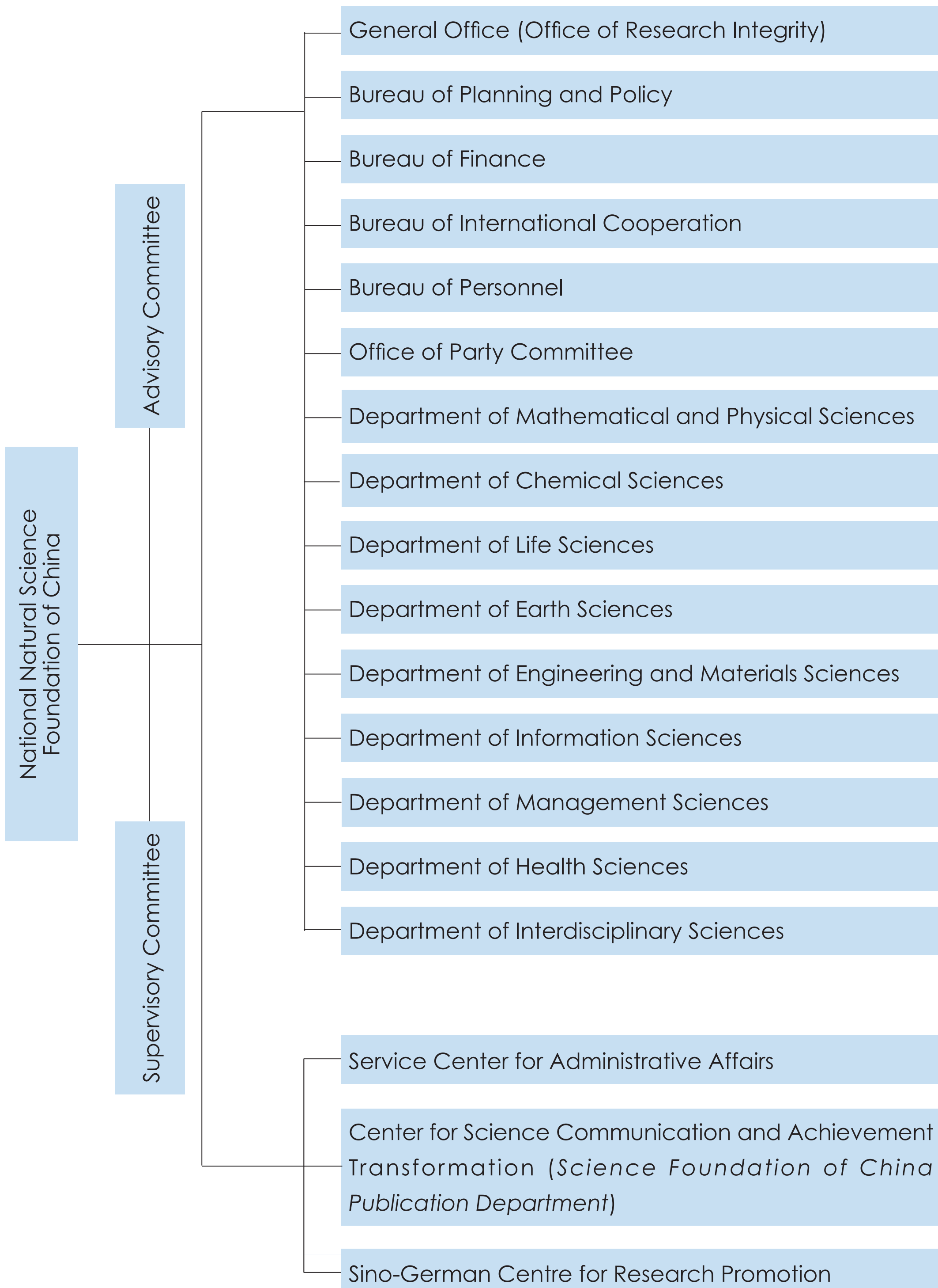
Organizational Structure

1. Organizational Chart



2. Members of the 8th Council of NSFC

President: Li Jinghai

Vice Presidents: Xie Xincheng, Hou Zengqian, Gao Ruiping, Lu Jianhua

Secretary General: Han Yu

Members: Ma Hongbing, Wang Hongyang, Wang Enge, Lv Zhaoping, Zhu Rixiang, Liu Changsheng, Sun Changpu, Yan Chunhua, Shen Zhulin, ZhangXi, Zhang Guangjun, Chen Zuoning, Chen Xiaohong, Zhao Xiaozhe, Zhong Denghua, Kang Le, Pan Aihua

3. Members of the 5th Supervisory Committee of NSFC

Director: Chen Yiyu

Deputy Directors: Zhu Zuoyan, He Minghong

Members:Wang Yizheng, Wang Hongyan, Wang Jiancheng, Wang Yuefei, Zhu Bangfen, Zhu Weitong, Liu Ming,Liu Zhihua, Yan Shouke, Yan Jinghua, SuXianyue, Li Zhaohu, Li Zhenzhen, Shao Feng, Zhou Xingshe, Zheng Yongfei, Yao Zhujun, Gao Xiang, Huang Haijun, Cui Xiang, Jiao Nianzhi

4. NSFC Staff

A. Permanent staff

The budgeted staff quota at NSFC is 309. By December 31, 2022, NSFC has 234 permanent staff, of whom 131 are males and 103 females; and 225 hold a professional technical position (title). The average age of the permanent staff is 44.2. The distribution of their gender, ages, academic degrees and professional titles is demonstrated in Figure 6-1-1, Figure 6-1-2, Figure 6-1-3 and Figure 6-1-4.

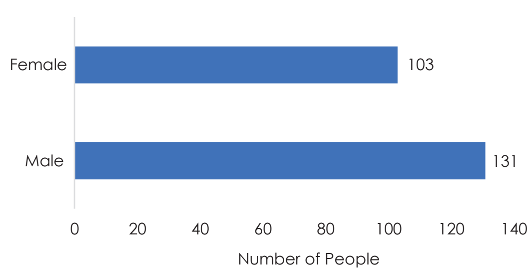


Figure 6-1-1 Gender distribution of NSFC staff

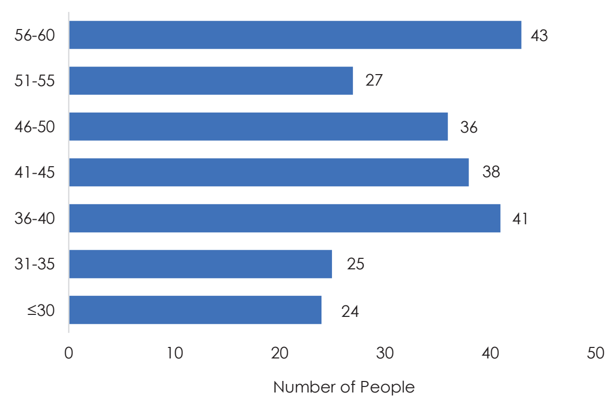


Figure 6-1-2 Age distribution of NSFC staff

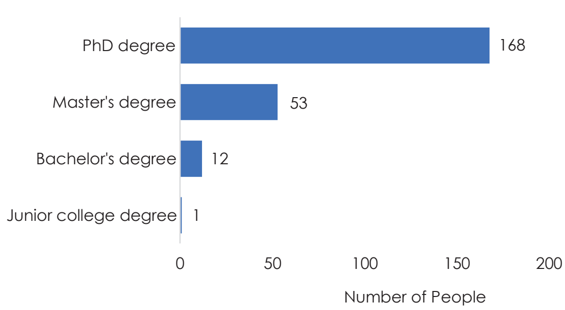


Figure 6-1-3 Academic degrees of NSFC staff

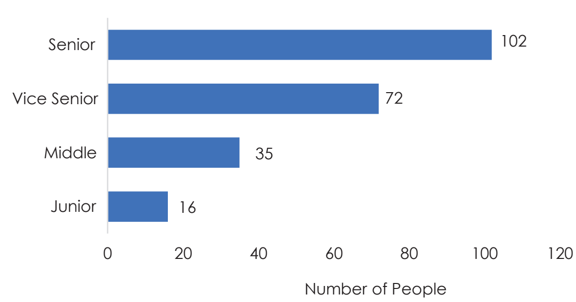


Figure 6-1-4 Academic ranks (titles) of NSFC staff

B. Rotational Program Directors

By December 31, 2022, there are 146 Rotational Program Directors on duty at NSFC, including 112 men and 34 women; 138 have a Ph.D. degree; 71 have a senior academic rank (title) and 67 have anassociate senior academic rank (title).

5. Leaders of the Bureaus, Departments and Subordinate Units of NSFC

Leaders of NSFC's Bureaus and Departments

(As of December 31, 2022)

Bureaus and Departments	Leaders
General Office (Office of Research Integrity)	Wang Cuixia (F), Guo Jianquan, Jing Yaxing, Zhang Fengzhu (F), Li Dong (F, Director of Information Center)
Bureau of Planning and Policy	Wang Yan (F), Yang Liexun, Yao Yupeng, Fan Yingjie (F)
Bureau of Finance	Zhang Xiangping(F), Wang Kun (F)
Bureau of International Cooperation	Zou Liyao, Zhang Yongtao, Yin Wenxuan (F)
Bureau of Personnel	Lv Shumei (F), Wang Wenze, Liu Ning(Director of Office of Retirement Affairs)
Office of Party Committee	Zhu Weitong (F), Yang Feng, Huang Baosheng
Department of Mathematical and Physical Sciences	Jiang Song(concurrently), Dong Guoxuan, Meng Qingguo
Department of Chemical Sciences	Yang Xueming(concurrently), Yang Junlin, Zhan Shige (F)
Department of Life Sciences	Li Peng(F, concurrently), Xu Yanying (F), Lv Qunyan (F)
Department of Earth Sciences	Guo Zhengtang(concurrently), Yu Sheng, Zhang Chaolin
Department of Engineering and Materials Sciences	Qu Jiuhui(concurrently), Wang Qidong, Miao Hongyan
Department of Information Sciences	Hao Yue(concurrently), Liu Ke, He Jie
Department of Management Sciences	Ding Lieyun(concurrently), Liu Zuoyi
Department of Health Sciences	Zhang Xuemin(concurrently), Sun Ruijuan(F), Gu Ruisheng, Yan zhangcai
Department of Interdisciplinary Sciences	Tang Chao (concurrently), Chen Yongjun, Pan Qing

Leaders of NSFC's Subordinate Units

(As of December 31, 2022)

Unit	Leaders
Service Center for Administrative Affairs	Feng Wen'an, Shi Xinghe
Center for Science Communication and Achievement Transformation (Science Foundation of China Publication Department)	Peng Jie (F), Tang Longhua, Zhang Zhimin
Sino-German Center for Research Promotion	Yin Wenxuan (F, concurrently)

APPENDIX

NSFC

2022 ANNUAL REPORT

NSFC

I. Important Activities of NSFC in 2022

January

On January 5, the meeting on Fund Management Regulations for NSFC Grants was held in Beijing. Vice President Gao Ruiping attended the meeting and delivered a speech. Financial managers from 122 host institutions participated in the meeting via video.

On January 10, the Second High-Level Strategy and Policy Dialogue between NSFC and Science Europe was successfully held via videoconference. Li Jinghai, President of NSFC, and Marc Schiltz, President of the Governing Board of Science Europe and Secretary General of the National Research Foundation of Luxembourg, attended the event and delivered keynote speeches.

On January 11, NSFC held a summary meeting on Party History Learning and Education, and Li Jinghai, Party Secretary and President, attended the meeting and made a summary report on party history learning and education. Comrade Duan Yuying, head of the 25th Steering Group of the Central Committee for Party History Study and Education, attended the meeting and delivered a speech. Gao Fu, Hou Zengqian, Gao Ruiping, Lu Jianhua and Han Yu, members of the Party History Study and Education Leading Group, attended the meeting and Wang Chengwen, Deputy Head of the Party History Study and Education Leading Group, presided over the meeting.

On January 19, the Third Beijing Matchmaking Meeting for Excellent Achievements funded by NSFC was held in Beijing. Vice President Gao Ruiping attended the opening ceremony and delivered a speech. Relevant leaders of Beijing Municipal Science and Technology Commission and Fengtai District People's Government attended the meeting.

On January 7 and 27, NSFC held a meeting on the Assessment and Evaluation of NSFC Basic Science Center Projects and the Review of Extended Funding in Beijing, to assess and evaluate the first batch of pilot implementation of 2016 Basic Science Center projects and the extended funding. Vice President Gao Ruiping attended the meeting and delivered a speech.

February

On February 15, the CPC Leading Group of NSFC issued the Work Program of NSFC on Further Improving the Funding System of Science Funds.

March

On March 7, the women's committee of the CPC Leading Group of NSFC held an activity to celebrate the International Women's Day of March 8, 2022 and the Second Micro-management Forum for Intellectual Women. Vice President Gao Ruiping, member of the Executive Committee of All-China Women's Federation, and Vice President Wang Chengwen attended the event.

On March 14, NSFC Committee held a meeting to convey the spirit of the Fifth Session of the 13th National People's Congress and the Fifth Session of the 13th National Committee of the Chinese People's Political Consultative Conference. Li Jinghai, Secretary of the CPC Leading Group and President of NSFC, presided over the meeting and conveyed the spirit of the Fifth Session of the Thirteenth National People's Congress, while Yang Wei and Gao Fu, members of the Thirteenth National Committee of the Chinese People's Political Consultative Conference, conveyed the spirit of the Fifth Session of the Thirteenth CPPCC.

On March24,the5th Plenary Meeting of the 8th NSFC Council was held in Beijing. Wang Zhigang,Minister of Science and Technology attended the meeting and delivered a speech. The meeting deliberated and adopted the work report "Continuous Promotion of Systemic Reform to Meet Challenges and Embrace the Future" made by President Li Jinghai, the report "Further strengthening scientific research integrity,The Construction of credit and study Style Provides Strong Support for Deepening the Reform of Science Fund" made by Director of the Supervision Committee Chen Yiyu and the Executive Summary of NSFC Budget and Funding Performance Report 2021and Budget and Funding Plan 2022.

On March 24,the 13th Plenary Session of the 5th Supervision Committee of NSFC was held in Beijing. Director of the Supervisory Committee Chen Yiyu and Deputy Director He Minghong presided over the meetings of Life and Health Sciences Special Committee and General Committee respectively. Vice President Wang Chengwen, Li Xiaonan from Bureau of Science and Technology Audit, National Audit Office, and Liu Yao from the third discipline inspection and supervision division of the Supervisory Teamat Ministry of Science and Technology accredited by the Central Commission for Discipline Inspection attended the meetings.

On March 25, NSFC held the 2022 Meeting on Comprehensive Strict Governance of the Party. Li Jinghai, NSFC Party Secretary and President, attended the meeting and delivered a speech, while Wang Chengwen, member of the party group, Vice President and Secretary of the Party committee of the organization, presided over the meeting. Members of NSFC leadership and the responsible comrades of the Discipline Inspection and Supervision Group of the State Supervision Committee in the Ministry of Science and Technology attended the meeting.

April

On April 12,NSFC held a mobilization and deployment meeting for the review of applications in 2022. President Li Jinghai, Vice Presidents Gao Ruiping and Wang Chengwen attended the meeting and gave remarks. Vice President Gao Fu presided over the meeting. Vice Presidents Xie Xincheng, Lu Jianhua, and Secretary-General Han Yu attended the meeting.

On March 25, NSFC held the 2022 Meeting on Comprehensive Strict Governance of the Party. Li Jinghai, NSFC Party Secretary and President, attended the meeting and delivered a speech, while Wang Chengwen, member of the party group, Vice President and Secretary of the Party committee of the organization, presided over the meeting. Members of NSFC leadership and the responsible comrades of the Discipline Inspection and Supervision Group of the State Supervision Committee in the Ministry of Science and Technology attended the meeting.

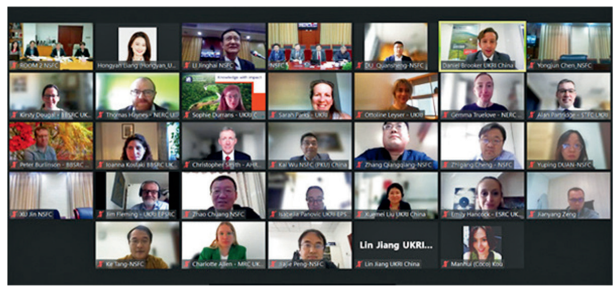
On April 28, NSFC held a lecture on the newly revised Audit Law and invited Li Xiaonan, second-level inspector of the Science and Technology Audit Bureau of the Audit Commission, to give a lecture. Li Jinghai, Party Secretary and President, attended the meeting and delivered the concluding remarks. Gao Ruiping, member of the Party Group and Vice President, presided over the meeting, and Wang Chengwen, member of the Party Group and Vice President, attended the meeting.

On April 29, NSFC had a meeting between the main leading comrades of the Party Committee of NSFC and its new members. Wang Chengwen, member of the party group, Vice President and Secretary of the Party Committee, attended the meeting and delivered a speech.

May

On May 7, NSFC organized and carried out the activities of confidentiality publicity and education in the organs (units), with Secretary General Han Yu giving a lecture on the topic of confidentiality, and Han Zhiyong, Deputy Decretary-General, presiding over it, and all the leading cadres above the directorate level of the committee and the personnel involved in confidentiality participated in the activities.

On May 12, a high-level strategic seminar on interdisciplinary research between NSFC and UK Research and Innovation was successfully held by videoconference. Li Jinghai, President of NSFC, and Ottoline Leyser, Chief Executive Officer of UKRI, attended the meeting and delivered speeches.



On May 13, Vice President Xie Xincheng attended the Fifth Meeting of the Eighth Expert Advisory Committee of the Department of Chemical Sciences of the Natural Science Foundation of China.

On May 16, Vice President Hou Zengqian attended the Fifth Meeting of the Eighth Expert Advisory Committee of the Dpartment of Earth Sciences of the Natural Science Foundation of China and delivered an opening speech.

On May 18, Vice President Hou Zengqian attended the First Meeting of the Eighth Expert Advisory Committee of the Department of Management Sciences of the Natural Science Foundation of China in 2022 and delivered an opening speech.

On May 19, Vice President Gao Fu attended the Fifth (Expanded) Meeting of the Eighth Expert Advisory Committee of the Department of Life Sciences of the Natural Science Foundation of China.

On May 27, Vice President Gao Fu attended the Fifth Meeting of the Fifth Expert Advisory Committee of the Department of Medical Sciences of Natural Science Foundation of China.

From May 31 to June 3, at the joint invitation of the National Commission for Science, Technology and Innovation (SENACYT) of Panama and the National Science Foundation (NSF) of the United States, Li Jinghai, President of NSFC, participated in the 10th Annual Meeting of the Global Research Council (GRC) online.

June

On June 6, Li Jinghai, Secretary of the CPC Leading Group and President of NSFC, attended the press conference on "Implementing Innovation-driven Development Strategy to Build a Strong Science and Technology Country", introduced the situation of the science fund in the past ten years and responded to reporters' questions.

On June 16, the 14th plenary meeting of the 5th Session of the Supervisory Committee of NSFC was held in Beijing. Chen Yiyu, Director of the Supervisory Committee, and He Minghong, Deputy Director of the Supervisory Committee, presided over the meeting of the Committee on Life Medicine and the meeting of the Committee on Comprehensive Specialization, and Mr. Wang Chengwen, Member of the CPC Leading Group and Vice President of NSFC, attended the meeting.

On June 21,Vice President Xie Xincheng attended the 5th Meeting of the 8th Expert Advisory Committee of Department of Mathematics and Physical Sciences.

On June 22, Premier Li Keqiang chaired a State Council executive meeting to improve the funding system of the Natural Science Foundation. The meeting pointed out that NSFC has played an important role in promoting scientific research and cultivating talents. The meeting also stressed the importance to deepen the reform, increase the input of basic research, applied basic research, cross-science, strengthen the support of young talents, play a guiding role in the fund, use the policy of deductions to attract enterprises to collaborate on research and deepen international scientific research cooperation.

On June 23, Vice President Lu Jianhua, attended the fourth meeting of the First Expert Advisory Committee of the Department of Interdisciplinary Sciences of the Natural Science Foundation of China.

On June 28, Wang Chengwen, Member of the CPC Leading Group, Vice President and Secretary of the Party Committee, delivered a special Party lecture on the topic of "Promoting the deep integration of Party building and professional work, and providing strong political guarantee for the deepening reform of the NSFC" to the members of the Party Committee of the Organ, the Discipline Inspection Committee of the Organ, and representatives of the departments in charge of and linked to the organ, as well as some of the Party branches.

July

On July 1, Li Jinghai, Secretary of the CPC Leading Group and President of NSFC, gave a special Party lecture to all Party members and cadres of the NSFC under the title of "Continuously Deepening Reform, Taking the Initiative to Create the Future, and Welcoming the Victory of the 20th CPC National Congress with Practical Actions". Gao Ruiping, member of the CPC Leading Group and vice president, Han Yu, member of the CPC Leading Group and secretary-general, attended the event, and Wang Chengwen, member of the CPC Leading Group, Vice President and Secretary of the Party committee of the organization, presided over the event.

On July 21, Secretary General Han Yu, attended the signing ceremony of the strategic cooperation agreement between the Center for Science Communication and Achievement Transformation of NSFC and the Administrative Committee of Chongqing Hi-Tech Zone and delivered a speech.

On July 28, the National Center for Science and Technology Evaluation (NCSTE) organized the first plenary meeting of the Expert Group on Performance Evaluation of Grants Management of the Science Departments of the Natural Science Foundation of China and the Promotion Meeting of Evaluation Pilot Work in Beijing. NSFC President Li Jinghai attended the meeting and delivered a speech, while Vice President Wang Chengwenand Secretary General Han Yu attended the meeting. Members of the Evaluation Expert Group and the Evaluation Coordination Group attended the meeting.

August

On August 4, a meeting on the supervision and inspection of funds for NSFC projects was held in Guiyang. Vice President Wang Chengwen attended the meeting and delivered a speech.

On August 21-22, Li Jinghai, Secretary of the CPC Leading Group and president of NSFC and leader of the Leading Group of Targeted Support Work, led a team to Naiman County, Tongliao City, Inner Mongolia Autonomous Region to carry out the research and supervision of targeted support for rural revitalization. Han Yu, member of the CPC Leading Group and Secretary-General and Han Zhiyong, Deputy Secretary-General, accompanied the research.

On August 23, Secretary General Han Yu awarded the certificate and nameplate of the first batch of "National Science Popularization Education Bases" from 2021 to 2025 to the Naiman Desertification Research Station of the Chinese Academy of Sciences.

On August 27, the Advisory Committee of NSFC held a special meeting in Qinzhou, Guangxi Zhuang Autonomous Region, chaired by Yang Wei, Director of the Advisory Committee. Secretary General Han Yu attended the meeting.

On August 31, Gao Ruiping, member of the CPC Leading Group and Vice President, attended the opening ceremony of the 2022 NSFC Training Course for Party Affairs Cadres on Party Building and Professional Work Capacity and delivered a pepspeech.

September

On September 1, the 19th Online Meeting of Heads of Research Councils in Asia (A-HORCs) was successfully held. NSFC Vice President Xie Xincheng, Lee Kwang Bok, Chairman of the National Research Foundation (NRF) of Korea, and Sugino Tsuyoshi, Chairman of the Japan Society for the Promotion of Science (JSPS), led their delegations to attend the meeting.

On September 1,Center for Science Communication and Achievement Transformationof NSFC held a seminar with Clarivate Analytics (Beijing) to discussthe future pathway for Fundamental Research after its inclusion in Web of Science database. Secretary General Han Yu attended the meeting.

On September 5, NSFC held the 2022 Alert Education Assembly. Li Jinghai, NSFC party secretary, President and Lan Chijun, Deputy Head of the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection and Supervision of the State Supervisory Commission in the Ministry of Science and Technology attended the meeting and delivered a speech. Member of the party group and Vice President Gao Fu and party group member Gao Ruiping, party group member and Secretary General Han Yu attended the meeting and party group member, Vice President and Secretary General of the party committee Wang Chengwen presided over the meeting.

From September 14 to 18,the panel review of Joint Fund Program for Regional Innovation and Development was held in Beijing. Vice Presidentof NSFC and Deputy Director of Joint Funds Management Committee Gao Ruiping attended the meeting and gave remarks.

On September 15,the 15th plenary session of the 5th Supervisory Committee of NSFCwas held in Beijing. Committee Director Chen Yiyu and Deputy Director He Minghong chaired the meetings of Life and Health Sciences Special Committee and General Committee respectively. Vice President Wang Chengwen, and Deputy Head of the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection and Supervision of the State Supervisory Commission of the CCDI in the Ministry of Science and Technology attended the meeting.

On September 16, NSFC held a special tutorial report on the study of Xi Jinping's Economic Thought Learning Outline and Xi Jinping's Talks on the Governance of the Country (Volume IV). Li Jinghai, Secretary of the CPC Leading Group and President, attended the event and delivered a speech, while Gao Fu, Xie Xincheng, Hou Zengqian, Gao Ruiping, Wang Chengwen and Lu Jianhua, members of the CPC Leading Group and the leadership team, attended the event.

On September 26-27, the Sino-German Seminar on Research Integrity was successfully held. Li Jinghai, President of NSFC, and Katja Becker, President of the German Research Foundation (DFG), delivered opening speeches and keynote reports on behalf of the two foundations. Wang Chengwen, Vice President of NSFC, and Axel Brakhage, Vice President of DFG, co-chaired the meeting and gave a report, while Heide Ahrens, Secretary General of DFG, and He Minghong, Deputy Director of Supervisory Committee of NSFC, attended the meeting and gave a report. The meeting was held on September 28, 2012 at NSFC.

On September 28, NSFC held a meeting to promote the quality improvement of primary-level party organization construction. Vice President Wang Chengwen, member of the CPC Leading Group and Secretary of the Party Committee of the leading CPC Leading Group, attended the meeting and delivered a speech.

October

On October 9, Gao Bo, head of the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection of the State Supervision Commission of the People's Republic of China (CCDIC) in MoST, and a member of the CPC Leading Group of MoST, visited NSFC and met with the CPC Leading Group of the NSFC and the leading members of the CPC Leading Group for a symposium to listen to the relevant reports. NSFC President Li Jinghai presided over the meeting.

From October 10 to 13, the Times Higher Education World Academic Summit was held in New York. NSFC President Li Jinghai was invited to attend the Summit as a keynote speaker anddelivered a speech online.

On October 16, NSFC organized all party members and cadres to watch the opening session of the 20th National Congress of the Communist Party of China.

On October 24, the CPC Leading Group of NSFC held a meeting to convey the spirit of the 20th CPC National Congress and the 1st Plenary Session of the 20th CPC Central Committee. Secretary of the CPC Leading Group and President of NSFC Li Jinghai presided over the meeting. Members of the CPC Leading Group took turn to speak on the work implemented.

On October 28, the China-EU High-level Roundtable on Scientific Research Review jointly organized by NSFC and Springer Nature Publishing Group was successfully held by combining online and offline methods, and Xie Xincheng, Vice President of NSFC, attended the meeting and delivered a welcoming speech. Representatives of renowned universities, research institutes and funding agencies from China, the UK, Germany, Sweden and other countries attended the meeting.

November

On November 2-3, the 2022 (Enlarged) Meeting of the CPC Leading Group of the National Natural Science Foundation of China was held in Beijing. Guided by Xi Jinping's thought of socialism with Chinese characteristics in the new era, all the meeting participants studied and implemented the spirit of the 20th CPC National Congress, pushed forward the implementation of General Secretary Xi Jinping's important instructions on scientific and technological innovation, especially basic research, comprehensively summarized the effectiveness of the systematic reform of NSFC, analyzed the problems in the deepening of the reform, and studied the further promotion of the paradigm change of scientific research and the enhancement of the ability to concentrate on scientific problems.

Focusing on the two key points of "promoting the change of scientific research paradigm" and "enhancing the ability to crystallize scientific problems", the participants studied the ideas and measures to further promote the deepening reform, accelerate the construction of a new era science fund system with "advanced concept, standardized system, fairness and efficiency", promote the high-quality development of basic research, and enhance the quality development of the science fund. It will accelerate the construction of a new era science fund system with "advanced concept, standardized system, fairness and efficiency", promote the high-quality development of basic research, and provide solid support for the realization of high-level scientific and technological independence.

On November 10, the 25th Joint Committee Meeting of the Sino-German Science Center was successfully held by video. The Executive Chairman of the meeting was Xie Xincheng, Vice President of NSFC and Chinese Chairman of the Board. Han Yu, Secretary General of NSFC and Chinese member of the Board, Zhang Xi, President of Jilin University, and Prof. Axel Brakhage, Vice President of DFG and German Chairman of the Board, attended the meeting.

On November 11, the Organization Department of the CPC Central Committee attended the meeting of the leading cadres of NSFC, announcing the decision of the Central Committee: Dou Xiankang was appointed as the Secretary of the CPC Leading Group of NSFC, and Li Jinghai ceased to hold that position.

On November 15, NSFC organized a 2022 information confidentiality and security seminar, study and publicity of personal information security protection law and data security protection law, Secretary General Han Yu presided over the seminar.

On November 17, the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection of the State Supervision Commission of the People's Republic of China in the Ministry of Science and Technology and the CPC Leading Group of the Natural Science Foundation of China convened the 1st meeting of the CPC Leading Group of 2022 on the topic of comprehensively governing the Party strictly, focusing on the following issues: "conscientiously studying and implementing the spirit of the 20th National Congress of the CPC, thoroughly implementing the Opinions on Strengthening Rectification of the Inspections and the Application of Achievements, deepening the follow-up and rectification of the central inspections, and persistently pushing the comprehensively governing the Party strictly to the vertical. The meeting centered on the theme of "conscientiously studying and implementing the spirit of the 20th CPC National Congress, deeply implementing the Opinions on Strengthening Rectification and Application of Results of Inspection, deepening the follow-up rectification work of the central inspection, and persistently pushing the Party in a comprehensive and rigorous manner to a deeper depth. Gao Bo, head of the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection of the State Supervision Committee of the CCDI in the Ministry of Science and Technology, attended the meeting and delivered a speech; Dou Xiankang, Secretary of the CPC Leading Group, presided over the meeting and delivered a speech; and Li Jinghai, President of NSFC, made a written speech. The relevant leaders of the Second Supervision and Inspection Office of the State Supervision Commission of the Central Commission for Discipline Inspection were invited to the meeting to give guidance. Members of the CPC Leading Group and leadership, Lan Chijun, Deputy Head of the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection and Supervision of the State Supervisory Commission of the CCDI in the Ministry of Science and Technology and other comrades attended the meeting.

On November 17, the 9th meeting of the Joint Leading Group on Discipline Development Strategy Research of NSFC and the Chinese Academy of Sciences (CAS) was held. Li Jinghai, Chairman of the Joint Leading Group and President of NSFC, and Gao Hongjun, Chairman of the Joint Leading Group and Vice President of CAS, attended the meeting and delivered speeches. Han Yu, Deputy Lead of the Joint Leading Group, Member of the CPC Leading Group and Secretary General of the Natural Science Foundation of China, presided over the meeting.

On November 18, Dou Xiankang, Secretary of the CPC Leading Group of NSFC, gave a lecture on the theme of "Follow the Party Forever and Strive for a New Journey--In-depth Study and Implementation of the Spirit of the 20th CPC National Congress" for the party members and cadres of the NSFC. Members of the CPC Leading Group attended the activity, and Vice President Gao Ruiping presided over the activity.

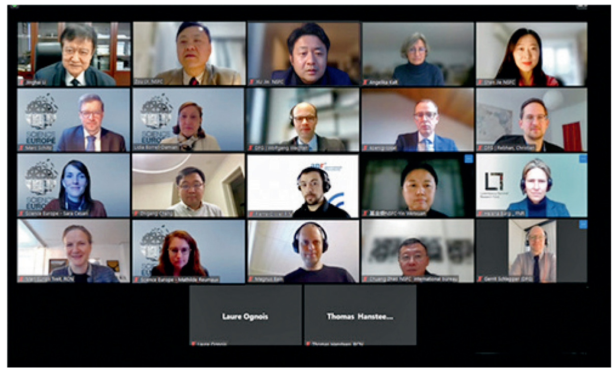
On November 23, NSFC held primary-level party organizations to learn the spirit of the twentieth party and party building work exchange meeting. Dou Xiankang, Secretary of the CPC Leading Group, attended the meeting and delivered a speech, and Gao Ruiping, member of the CPC Leading Group and Vice President, presided over the meeting. The Party Committee of the organ, the responsible comrades of the grassroots Party organizations and other full-time and part-time Party cadres of more than 110 people participated in the meeting through online and offline means.

December

On December 2, the 2022 plenary session of the Advisory Committee of the NSFC was held in Beijing, chaired by Yang Wei, Director of the Advisory Committee, with 17 members attending the meeting. Li Jinghai, President of NSFC, Dou Xiankang, Secretary of the CPC Leading Group, Vice Presidents Xie Xincheng, Gao Ruiping, and Secretary General Han Yu attended the meeting.

From December 8 to 10, the Third Global Health Symposium, supported by the NSFC, Bill & Melinda Gates Foundation (BMGF) and Shenzhen Municipal Health Commission (SZMHC), and hosted by National Clinical Research Center for Infectious Diseases (NCCRICID) of Shenzhen and Shenzhen Third People's Hospital (SZTHPH) of Shenzhen, was held successfully online. Vice President Xie Xincheng attended the meeting and delivered an opening speech via live video connection.

On December 15, the Third High-Level Strategy and Policy Dialogue between NSFC and Science Europe was held by videoconference. Li Jinghai, President of NSFC, and Marc Schiltz, President of the Council of Science Europe and Secretary-General of the National Research Foundation of Luxembourg, attended the event and delivered speeches.



On December 21, the fourth meeting of the Joint Leading Group of NSFC - Chinese Academy of Engineering on "China's Engineering Science and Technology Development Strategy for the Next 20 Years" was held. Li Xiaohong, President of the Chinese Academy of Engineering and Chairman of the Joint Leading Group, and Li Jinghai, President of the NSFC and Chairman of the Joint Leading Group, attended the meeting and delivered a speech. Secretary General Han Yu, Deputy Chairman of the Joint Leading Group, attended the meeting.

On December 30, the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection of the State Supervision Commission of the People's Republic of China in MoST and the CPC Leading Group of the Natural Science Foundation of China convened the 2nd meeting of 2022 on the topic of "Comprehensive and strict governance of the Party", focusing on the topic of "earnestly studying and comprehending the spirit of the instructions given by leaders of the Central Commission for Discipline Inspection of the People's Republic of China and the State Supervision Commission of the People's Republic of China and resolutely eliminating the stubborn disease of "greeting" of evaluation experts with fundamental measures. The meeting was organized around the theme of "seriously studying and understanding the spirit of the instructions given by the leaders of the Central Commission for Discipline Inspection and the State Supervisory Commission, and resolutely eradicating the stubborn disease of evaluation experts being 'greeted' with fundamental measures. Lan Chijun, Deputy Head of the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection and the State Supervision Commission of the CCDI in the Ministry of Science and Technology, Gao Ruiping, member of the CPC Leading Group and Vice President of NSFC, and Han Yu, member of the CPC Leading Group and Secretary General, attended the meeting and delivered a speech. The meeting was chaired by Gao Ruiping.

II. Shuangqing Forum

Shuangqing Forum is a strategic academic seminar established by NSFC based on the management of science fund grants to promote the change of scientific research paradigm, carry out strategic research on disciplinary development, promote the cross-disciplinary and integration of disciplines, improve the system of science fund system and the management and operation mechanism, and improve the management level of science funds. Shuangqing Forum mainly discusses forward-looking, comprehensive and cross-cutting scientific issues oriented to the world's scientific frontiers and the major needs of the country, as well as the major policy issues on the management of science fund grants, and contributes to the construction of a new era of science fund system with advanced concepts, standardized system, fairness and high efficiency.

In 2022, Shuangqing Forum implemented the decision-making and deployment of the deepening reform of the Science Foundation and the "14th Five-Year Plan" of the foundation, adhered to the "Four Orientations", and focus on the promotion of the development of basic research in accordance with the new trend of the current development of science and technology and the new requirements for the construction of a strong scientific and technological country. Focusing on the two main points of promoting scientific issues and paradigm change in scientific research as put forward by the CPC Leading Group, NSFC emphasized the integrationand convergence of disciplines, aimed to better support the sciencefunding, and attached importance to playing the role of leading scientific development and supporting the major needs of the country. Throughout the year, a total of 23 sessions of Shuangqing Forum were held (Exhibit 2-1), with 916 expertsattending. Among them, 21 were hosted by the Science Department and 2 by administrative bureaus (offices); 10 were on basic science issues at the frontiers of science, 11 were on in-depth scientific issues oriented to the strategic needs of national development (Attachment 2-1 and Attachment 2-2), and 2 were on major policy and management issues related to the development and improvement of the science fund system.

In 2022, in order to well publicize the results of the Forum and enhance academic influence, Shuangqing Forum explored a synergistic publicity approach with *Fundamental Research* and *Bulletin of National Natural Science Foundation of China* as the main body, supplemented by publications, such as *National Science Review* and *Chinese Science Bulletin*. Special topics and special issues around the 13 issues of the Forum were organized. *Fundamental Research*officially published 4 issues of special topics of the Forum (including 26 academic articles), and *Bulletin of National Natural Science Foundation of China* has officially published 5 articles of the Forum's review and 3 issues of special topics of the Forum (including 32 academic articles).

Figure 2-1 Green Carbon Science: The Scientific Foundation under the Dual Carbon Target Standard

Figure 2-2 Key Basic Scientific Problems and Countermeasures of National Carbon Neutrality

Appendix Table 2-1 2022 "Shuangqing Forum" Subject Directory

Issue 299: Neuro-Immune Interaction and Regulation (March 23-24, 2022)	Issue 314: Original Innovation and New Research Paradigms in Cell Biology (August 25-26, 2022)
Issue 300: Mathematical Planning Algorithms in Management (April 14-15, 2022)	Issue 315: Basic Research Strategies in the Context of Security and Development (August 30, 2022)
Issue 304: Detection and Early Warning of Atmospheric Transmission of Viruses and Microorganisms (March 29-30, 2022)	Issue 317: Polymer Depolymerization, Recycling and High-Value Conversions (November 19-20, 2022)
Issue 305: Integrated Chip Frontier Technology (April 25-26, 2022)	Issue 318: Scientific Basis for Smart Manufacturing of Chemicals (November 17-18, 2022)
Issue 306: Supply Chain Resilience and Supply Chain Security (April 28-29, 2022)	Issue 319: Digital Decoding of Immunity (September 29, 2022)
Issue 307: Carbon-Neutral Energy and Environmental Policy Research (May 5-6, 2022)	Issue 320: Cross-cutting Explorations in Surface Science (November 11-12, 2022)
Issue 308: The Time Traveling Planet Project: Historical Reconstruction and Future Prediction of Changes in the Earth's Climate and Environment Reconstruction and Future Projections of Earth's Climate and Environmental Change (April 22, 2022)	Issue 321: Pre-plate Tectonics and Continental Origins (November 12-13, 2022)
Issue 309: Two-dimensional and topological spin physics (August 1-2, 2022)	Issue 322: Data Science from a Crosscutting Research Perspective (November 14-15, 2022)
Issue 310: Relying on Big Science Devices to Promote International Science and Technology Cooperation (August 3, 2022)	Issue 323: Transmission of Arboviral Infections and Cross-border Immune Adaptation Mechanisms (November 16-17, 2022)
Issue 311: Chemical Engineering Science Basis for Transformative Energy Storage Technologies (August 4-5, 2022)	Issue 324: Theory and Technology of Automation and Intelligence for Dual Carbon Targets (19 November 2022) (November 19, 2022)
Issue 312: Nanophotonics and Photonic Chip Physics and Applications (August 12-13, 2022)	Issue 325: Basic Science Issues of Multidimensional Synergies for Carbon Reduction and Pollution Reduction (December 19-20, 2022)
Issue 313: Major Basic Science Issues of Herbology in the New Era (August 17-18, 2022)	

III. NSFC Policy Files

According to the Regulations of the National Natural Science Foundation, as of December 31, 2022, a total of 38 administrative normative documents related to the organization and management of science funds, procedure management, fund management, and supervision and security have been formulated and implemented.

Administrative Normative Document System of NSFC

- **Organization and Management**
  - National Natural Science Foundation of China Regulations
  - Regulations of the Supervisory Committee of NSFC
  - Regulations of the Advisory Committee of NSFC
  - Management Measures for NSFC Working Methods of the Expert Advisory Committee of Scientific Departments in NSFC
  - Management Measures for Evaluation Experts of NSFC
  - Rules for the Management and Implementation of the Regional Liaison Network of NSFC
  - Rules for the Implementation of the Registration Administration of Dependent Units of NSFC
- **Procedure Management**
  - Management Measures for General Program of NSFC
  - Management Measures for Key Program of NSFC
  - Management Measures for Major Program of NSFC
  - Management Measures for International (Regional) Cooperative Research Program of NSFC
  - Management Measures for International (Regional) Exchange Program of NSFC
  - Management Measures for the Research Fund for International Young Scientists of NSFC
  - Management Measures for Tianyuan Fund for Mathematics of NSFC
  - Management Measures for Young Scientists Fund of NSFC
  - Management Measures for Excellent Young Scientists Fund of NSFC
  - Management Measures for National Science Fund for Distinguished Young Scientists of NSFC
  - Management Measures for Fund for Less Developed Regions of NSFC
  - Management Measures for Science Fund for Creative Research Groups of NSFC
  - Management Measures for Special Fund for Research on National Major Research Instruments of NSFC
  - Management Measures for Major Research Plan of NSFC
  - Management Measures for Joint Funds of NSFC
  - Management Measures for Special Projects of NSFC Procedures for the Change Management of NSFC Projects (for Trial Implementation)
- **Fund Management**
  - Measures for Fund Management of NSFC
  - Supplementary Notice of Minister of Finance on Issues Relevant to Fund Management of NSFC Funded Projects
  - Notice of the Ministry of Finances to NSFC on Further Improving Science Fund Projects and Fund Management
- **Supervision and Guarantee**
  - Measures for Evasion and Confidentiality Management in Project Evaluation of NSFC
  - Code of Conduct for Project Evaluation Experts of NSFC
  - Rules for the Implementation of the Supervisory Work of NSFC Subsidized Projects Assessment Meeting
  - Measures for Project Review Management of NSFC Measures for the Management of Research Achievements of NSFC Funded Projects
  - Measures for Investigation and Handling of Scientific Research Misconduct of NSFC Funded Projects
  - Management Measures for Information Disclosure of NSFC
  - Complaint Rules of the NSFC
  - Interim Measures for the Audit Work of NSFC
  - Measures for the Supervision and Inspection of NSFC Funded Projects