



NSFC

NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA
2024 ANNUAL REPORT



National Natural Science Foundation of China



NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA **2024 ANNUAL REPORT**



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FOREWORD

In 2024, under the guidance of Xi Jinping Thought on Socialism with Chinese Characteristics for a New Era, the National Natural Science Foundation of China (hereinafter referred to as NSFC) comprehensively implemented the spirits of the 20th CPC National Congress and its second and third plenary session, studied the spirit of National Conference on Science & Technology, and thoroughly put President Xi's important speeches and directions on science, technology and innovation especially basic research into practice. In accordance with decisions of the CPC Central Committee and the State Council, and the work plan of the Science and Technology Commission of the CPC Central Committee, NSFC adhered to the idea of directing the precious S&T resources to the front-line researchers who are most capable of innovation, executed the institutional reform tasks, focused on quality improvement, continuously optimized the funding management system, and completed the funding management of 2024.

NSFC emphasized the forward-looking, strategic and systematic plan for basic research, so as to lay a solid foundation for sci-tech self-reliance. We continued to scientifically formulate and implement the annual funding plan, received 403.9 thousand proposals from 2502 host institutions, and approved 54.9 thousand awards with a total funding amount of 33.571 billion yuan. We encouraged free exploration and emphasized original innovation, by approving 20,758 awards for General Program and 183 awards for Original Exploratory Program. To strengthen forward planning, we launched 3 Major Research Plans including "Basic research on atomic-level manufacturing", approved 745 awards for Key Program, and planned for 48 projects for Major Program. To enhance the construction of scientific research infrastructure and platform, we approved 71 awards for Special Fund for Research on National Major Research Instruments. We also pushed the restructuring of National Key Laboratory system in 14 areas including mathematics and physics, astronomy and space.

NSFC focused on the cultivation of young talents in order to build an elite cadre of scientists for basic research. We strengthened the cultivation of reserve forces for basic research, and piloted the funding of basic research projects for young students. We funded 1412 grants in the first two rounds of doctoral student projects, and 141 grants in the second round of undergraduate student projects. For the first time, we conducted a conclusion evaluation and continued funding for the National Science Fund for Distinguished Young Scholars (hereinafter referred to as "DYS Program"). Among them, 41 projects that demonstrated significant progress were granted continued funding, while 9 projects were rated "Poor". The evaluation results were sent back to the host institutions as a reference for scientific research evaluation. A separate track was set up for the Basic Science Center Program to provide more young talents with the opportunity to take on and play a leading role. A total of 8 projects were selected and funded. We piloted and advanced the reform of the review of the DYS Program for clinicians, and funded a total of 24 projects. Moreover, we strengthened support for young talents in Hong Kong and Macao, and funded 21 DYS grants, 29 grants for Excellent Young Scientists Fund (hereinafter referred to as "EYS"), and 95 grants for Young Scientists Fund. And we actively supported young and middle-aged scientists to undertake major types

of projects and attracted outstanding young talents to participate in the peer review. The funding of the Excellent Young Scientists Fund (overseas) were carried on smoothly.

NSFC implemented new functions and tasks, and took on the management of funding for applied basic research. We fulfilled the main responsibilities, studied and formulated detailed rules for the management of Key Special Program, organized the compilation and release of 10 Calls for Proposals for Key Special Program including "Gravitational Wave Detection" and completed the review, and took over the management of Major Special Program in brain science and brain-like research. We strengthened the overall planning of science fund projects and other national science and technology plans, formulated an optimization plan for the project initiation procedures of Major Research Program, revised the management regulations for the use of macro-control funds, and continued to impose the limit on the number of major types of projects. We continued to strengthen the institutional construction of the Administrative Center for China's Agenda 21 and the High-tech Research and Development Center, and enhanced their professional management capabilities. We finished the acceptance, compliance check, review and approval of the proposals for the 2024 Call for Key Special Program. A total of 1,168 projects were approved, 1,253 mid-term inspections were completed, and 444 comprehensive performance evaluations were conducted. We actively promoted the compilation of the "Fifth National Assessment Report on Climate Change", and advanced the research and publicity of the achievements of the "Carbon Neutrality Technology Development Roadmap". And we announced the top ten scientific advancements in China for 2023.

NSFC optimized the diversified investment mechanism of the science fund and enhanced the funding performance of the Joint Fund. We steadily expanded the scale of the Joint Fund, with 5 local governments and 8 central enterprises joining the Joint Fund for Regional/Corporate Innovation and Development, and 3 new joint funds were established with relevant industry departments. In the year 2024, 3.463 billion yuan of outsourced funds were attracted, equivalent to 9.68% of the central government's fiscal input. A total of 1,306 joint fund projects were funded in 2024. We strengthened the leverage effect of the central government's fiscal funds, increased the ratio of cooperation investment between the pilot program and large technology enterprises from 1:4 to 1:6, and established a joint fund for basic research with Sinopec. To attract the talents and promote scientific and technological innovation in Xinjiang, we established a Joint Fund for Young Scientists (Xinjiang). We strengthened the leading role of enterprises in scientific and technological innovation, and newly approved 52 enterprise research and development institutions to be registered as host institutions.

NSFC strengthened the strategic consultation on science and technology and reform the establishment of the second Advisory Committee. Based on the mission for the new era, the seat-based system was reformed and a new advisory committee was established, consisting of 48 scientists who are active on the front line of scientific research and have high international academic influence. Focusing on the major fundamental and interdisciplinary research demands, we actively carried out the organization and refinement of the National Key Research and Development Program proposals. We gave full play to the strategic scientist role of the NSFC Advisory Committee and its institutional advantage of mobilizing the strength of various disciplines, and organized the thorough discussion of the 10 Calls for the Key Special Program of which NSFC is the lead agency. In a timely manner, we responded to major national decisions and plans as well as major sudden demands, and completed the consultation and argumentation for

9 projects proposed to be funded by macro-control funds, among which 7 were approved. In response to the major research demands of national science and technology development during the “15th Five-Year Plan” period, we initiated the reserve research on the topic proposal of the National Key Research and Development Program in the field of basic research and the research on major funding management policies.

NSFC optimized the funding management system and continuously promoted the reform and development of the National Natural Science Fund. We implemented the mid-term monitoring of NSFC’s “14th Five-Year Plan”, conducted research on the planning compilation methods, and initiated the strategic research and deployment for the compilation of NSFC’s “15th Five-Year Plan”. The revision of the “Regulations on the National Natural Science Foundation of China” was advanced and approved by the executive meeting of the State Council. We strengthened the support for strategic and policy research, deepened strategic research cooperation with the Chinese Academy of Sciences and the Chinese Academy of Engineering, promoted the publication of the “China Engineering Science and Technology 2040 Development Strategy” series of books, enhanced the strategic discussion and management support functions of the “Shuangqing Forum”, promoted the joint construction of a strategic intelligence cooperation network for basic research, and built a platform for interdisciplinary and cross-disciplinary discussion. We continued to carry out the annual performance evaluation, conducted in-depth research on the performance assessment of scientific departments’ funding management, and cooperated with the Ministry of Finance to conduct a special evaluation of the Excellent Young Scientists Fund.

NSFC actively expanded international cooperation and exchanges, and steadily advanced the pilot implementation of Global Science Research Funding Program. Firstly, we implemented the consensus reached through head-of-state diplomacy and expanded the cooperation network. We steadily advanced the construction of the China-France Carbon Neutrality Center, facilitated the signing of *the Memorandum of Understanding on Carbon Management Cooperation between China and the United States*, promoted the renewal of the China-EU Flagship Cooperation Program, signed three new cooperation agreements and renewed ten others, and carried out joint funding with the United States, the United Kingdom and other countries as well as Hong Kong and Macao SARs, with a total funding of 470 million yuan. Secondly, Department of International Programs has been under full operation, and initiated the Global Science Research Funding Program. We funded 25 grants for Science Fund for Joint Creative Research Group, 315 grants for Research Fund for International Scientists, and 87 grants for Key International (Regional) Cooperative Research Program; established and implemented the NSFC-CERN Special Program of the International Cooperation Research Program on Major Scientific Infrastructure, and funded 10 projects. In collaboration with the Ministry of Education, we established and launched the “Special Program for Outstanding International Students to Pursue Doctoral Studies in China (Pilot)” with 39 projects funded. Thirdly, we continued the “Sustainable Development International Cooperation Program”, with 41 funded projects. We carried out in-depth technology transfer and South-South cooperation under the Belt and Road Initiative and promoted the establishment of the BRICS International Research Center for Deep-sea Resources. Lastly, we strengthened international cooperation in key areas such as climate change and the ocean. We led the negotiations on technical issues of the United Nations Framework Convention on Climate Change and participated in the consultations of the Intergovernmental Panel on Climate Change (IPCC)

as the coordinator of the "Group of 77 + China", and steadily advanced the United Nations Decade of Ocean Exploration and China's international cooperation program on Ocean Drilling.

In 2025, under the guidance of Xi Jinping Thought on Socialism with Chinese Characteristics for a New Era, NSFC will grasp and implement the spirits of the 20th CPC National Congress and its second and third plenary session, President Xi's important speeches and remarks on S&T innovation especially basic research, and the spirits of National S&T Conference and Central Economic Work Conference. In accordance with the decisions and plans of the CPC Central Committee and the State Council, we will thoroughly implement the arrangements of the National Science and Technology Work Conference, accurately grasp the overall pattern of China's science and technology work and the new mission of the National Natural Science Fund, and adhere to the concept of investing valuable scientific and technological resources in the most innovative front-line scientific researchers. We will make overall plans for basic research, applied basic research and talent cultivation, strengthen the forward-looking and leading layout in the field of basic research, continuously improve the funding performance, and better play the unique role of the science fund in the national innovation system.

Prof. Dr. DOU Xiankang
President of NSFC

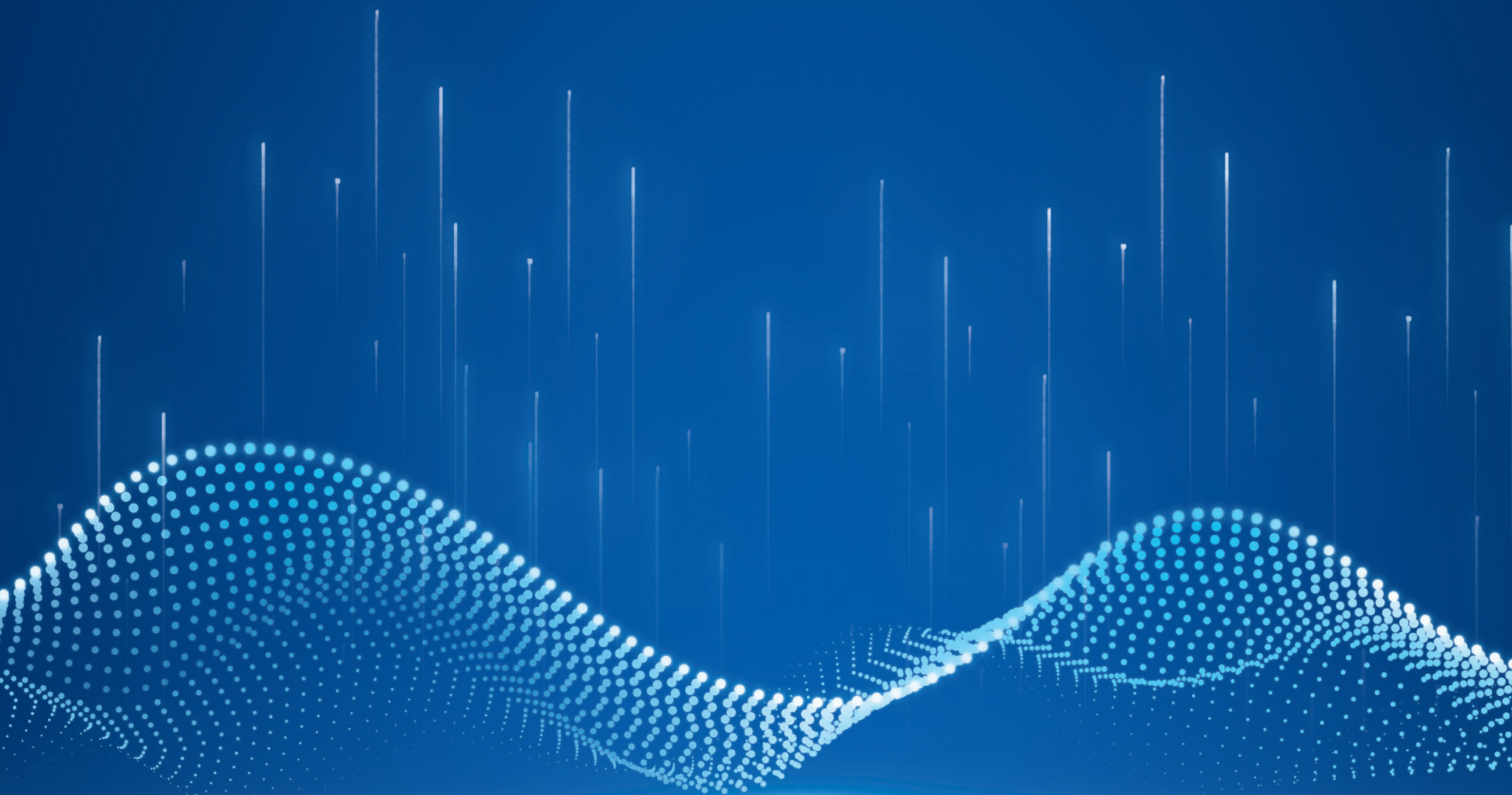


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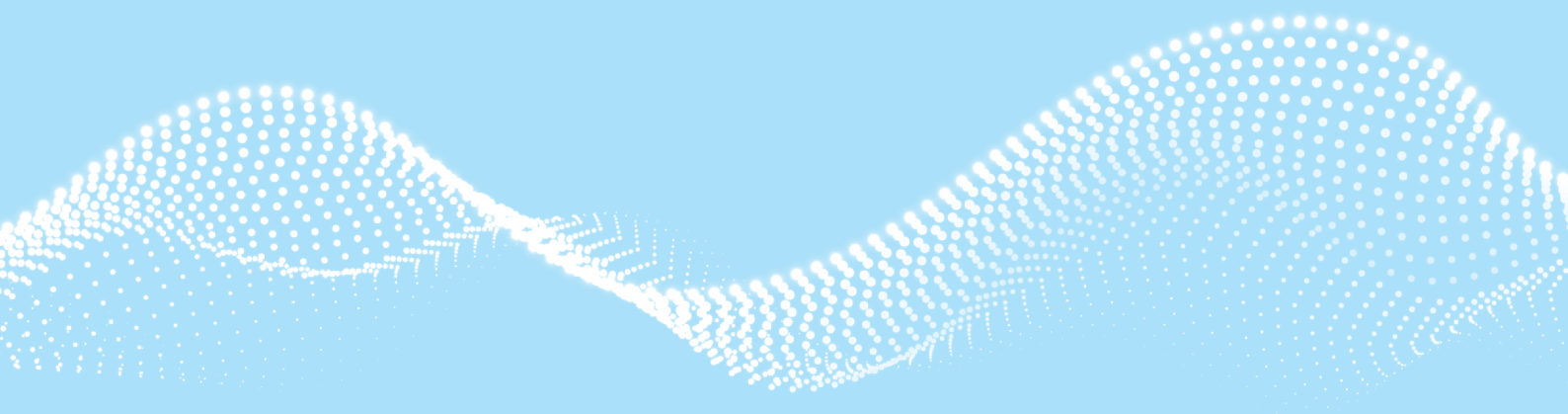
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PART 1

Overview



NSFC



I. Reform Measures

In 2024, NSFC implemented the decisions and plans of the CPC Central Committee and the State Council, embraced its new position, shouldered its new mission, comprehensively deployed basic and applied basic research, strengthened the cultivation of scientific and technological talents, steadily advanced the implementation of various reform tasks, continuously improved the funding performance, and supported the construction of a science and technology power with high-quality basic research.

NSFC deepened the reform of the talent support system and mechanism. We steadily advanced the pilot program of basic research for young students, starting the funding at an earlier stage, so as to select talents as early as possible. We carried out the grading evaluation and continuous funding for the National Science Fund for Distinguished Young Scholars, promoted the resolution of the "labeling" problem of talent programs, and established a long-term stable support mechanism for outstanding talents. For the Basic Science Center programs, a separate track was set up for young teams, selecting the first batch of 8 outstanding young teams for funding with high intensity, in an effort to direct the precious scientific and technological resources towards the most innovative and dynamic scientific researchers. The age limit for women to apply for the National Science Fund for Distinguished Young Scholars has been extended to 48 years old, and the cultivation of leading female scientific and technological talents has been strengthened, with 7 female researchers having benefited from this policy. The reform of the clinicians' research evaluation system was piloted in the National Science Fund for Distinguished Young Scholars. Special reviews were organized and separate funding plan were set up. 24 clinical medical talents were funded. We also strengthened the cultivation of scientific and technological talents in Hong Kong and Macao. Following the Young Scientists Fund and the Excellent Young Scientists Fund, the National Science Fund for Distinguished Young Scholars were further open to the SARs. The funding mechanism and review criteria remain the same for the three programs in Hong Kong and Macao as well as for the Mainland, to ensure a level playing field and merit-based selection.

NSFC expanded diversified investment in basic research. By the end of 2024, 32 provinces (autonomous regions and municipalities) had joined the Joint Fund for Regional Innovation and Development, 20 enterprises had joined the Joint Fund for Corporate Innovation and Development, and 12 Joint Funds had been established with 11 industry sectors. Joint Funds of the New Era have attracted 22.76 billion yuan from outside NSFC. We strengthened the leading role of enterprises in scientific and technological innovation, and further promoted the registration of research and development institutions of central enterprises with basic research conditions as host institutions to take the lead in applying for and undertaking joint fund projects. We optimized the application limit policies for the Joint Fund for Corporate Innovation and Development and the Ye Qisun Science Fund to attract more outstanding teams to focus on the development challenges of the sponsors and jointly tackle them. We also explored a new model of joint funding by increasing the ratio with the joint funders to 1:6, so as to strengthen the leverage effect of the central government's finance.

NSFC promoted organized basic research. We earnestly fulfilled the responsibilities of overseeing the National Key Research and Development Program and the National Major Science and Technology Special Project, took over the management of the 10 key special projects of the National Key Research and Development Program, compiled the annual program guidelines, and completed the project review and approval. We initiated the management and takeover of the National Science and Technology Major Project on Brain Science and Brain-like Research, organized discussions on "Brain Science, Brain Computing and Brain-like Research" and "Review and Prospect of Brain Science", completed the summary of the first phase of takeover, and promoted the strategic research of the second phase. We optimized the management of major types of projects of the National Science Fund, improved the post-assessment working mechanism for the National Major Scientific Research Instrument Development Program (recommended by departments),



conducted in-depth research on the National Major Scientific Research Instrument Development Program, and Major Program, etc., proposed ideas for optimizing management, steadily and orderly promoted the reform of major program types, and effectively enhanced the funding performance.

NSFC strengthened international (regional) open cooperation in science and technology. We explored channels and potential for bilateral (multilateral) cooperation, built a global cooperation network based on cooperative agreements with 106 funding agencies or international organizations in 54 countries/regions, deepened policy dialogues with overseas partners, and actively participated in global science and technology governance. We fully launched the deployment of Global Scientific Research Fund program, increased support for international talents, and upgraded the "Pilot Group Program of the Research Fund for International Senior Scientists" to the "Science Fund for Joint Creative Research Group", funding the first round of 25 awards. And we jointly established with the Ministry of Education the "Special Program for Outstanding International Doctoral Students" to fund outstanding international students to study and conduct research in China. Moreover, we established Special Program of Major Scientific Infrastructure International Cooperation Research with the European Organization for Nuclear Research (CERN) to support Chinese researchers to participate in the international collaborative research at CERN.

NSFC consolidated and deepened the achievements from its special campaign to rectify the deep-seated problem of undue influence". Adhering to the principle of "positive guidance, strict enforcement, extreme defense, and severe penalties", we achieved full coverage of the special rectification from correspondence review to panel review, further strengthened the supervision and restraint on the authority of program management, to ensure the fairness and impartiality of peer review. We further implemented the action plan for the construction of an academic atmosphere that integrates education, motivation, regulation, supervision and punishment, strengthened publicity and education in various forms, severely punished the subjects of misconduct, and enhanced the awareness of all parties to resist review misconduct. We also improved the review rules and the scientific research integrity system to provide a more scientific and standardized institution for preventing and punishing misconduct, including undue influence.

NSFC optimized the application review mechanism. In light of the new situation and requirements for the development of basic research, NSFC simplified the four attributes of scientific questions to two attributes of research, namely, "free exploration basic research" and "goal-oriented basic research", and implemented category-specific reviews for General Program, Young Scientists Fund, and Key Program, etc.. We strengthened the role of panel review by improving the display method of correspondence review opinions during the panel meeting for proposals that require defense, taking relevant measures to enhance the confidentiality of panels' voting results, guiding panelists to make academic judgments more objectively, and relieving them from any worries with regard to voting. We have also had strict requirements on budget preparation for Special Fund for Research on National Major Research Instruments. In accordance with the principles of goal relevance, policy compliance, and economic rationality, the project budget should be carefully prepared. Applications for funds that exceed the actual demand significantly will not be funded.

II. Overview of Budget & Outlays and Funding

(I) Overview of Budget and Outlays

In 2024, the fiscal budget of NSFC was 36,331.6405 million yuan, of which the budget for project funding was 35,772.7018 million yuan. In 2024, NSFC completed the appropriation of project funds with a total amount of 35,137.7803 million yuan, of which the direct cost was 29,921.8215 million yuan, and the indirect cost was 5,215.9588 million yuan. The fiscal budget statistics of NSFC in 2024 are shown in Table 1-2-1.

Table 1-2-1 2024 NSFC Fiscal Budget and Outlays (in million yuan)

	Program Type	Fiscal Budget	Fiscal Outlays
1	General Program	13,170.1585	13,103.2696
2	Key Program	2,292.5724	2,261.7063
3	Major Program	967.6928	935.5704
4	Major Research Plan	912.0710	892.9880
5	International (Regional) Joint Research Program	759.0038	749.9404
6	Young Scientists Fund	7,774.0517	7,725.2171
7	Excellent Young Scientists Fund	1,309.8974	1,303.9038
8	National Science Fund for Distinguished Young Scholars	1,773.4946	1,702.7778
9	Science Fund for Creative Research Groups	516.9555	516.1555
10	Fund for Less Developed Regions	1,427.4848	1,407.4828
11	Programs for Joint Funds	760.0570	760.0570
12	Special Fund for Research on National Major Research Instrument	951.0150	944.5132
13	Basic Science Center Program	1,140.6398	1,140.6398
14	Special Fund for Emergency Programs	1,592.3711	1,316.3097
15	Tianyuan Fund for Mathematics	68.4	67.88
16	Research Fund for International Young Scientists	273.3014	264.9542
17	International (Regional) Exchange Program	33.5349	15.0007
18	Global Science Fund Program	5.00	2.9414
Total		35,772.7018	35,137.7803



(II) Overview of Funding

In 2024, NSFC invested a total of 39,645.1636 million yuan to fund various types of projects, of which: the direct cost was 33,581.1207 million yuan, and the indirect costs of 1214 host institutions were 6,064.0429 million yuan. The project funding statistics of NSFC in 2024 are shown in Table 1-2-2.

Table 1-2-2 2024 NSFC Project Funding Statistics (in million yuan)

	Program Type		Number of Projects	Funding Amount		
				Direct Cost*	Indirect Cost	Total
1	General Program		20758	10137.11	3023.9097	13161.0197
2	Key Program		745	1679.7	492.6303	2172.3303
3	Major Program		48	708.01	207.6462	915.6562
4	Major Research Plan		419	816.28	209.2046	1025.4846
5	International (Regional) Joint Research Program		350	643.57	186.6089	830.1789
6	Young Scientists Fund		23226	6967.8		6967.8
7	Excellent Young Scientists Fund		654	1308		1308
8	National Science Fund for Distinguished Young Scholars	New	433	1699.6		1699.6
		Continued	41	320.8		320.8
9	Science Fund for Creative Research Groups		43	424	86	510
10	Fund for Less Developed Regions		3519	1108.23	335.2369	1443.4669
11	Programs for Joint Funds		1306	3672.62	692.4345	4365.0545
12	Special Fund for Research on National Major Research Instrument		71	836.9964	190.2456	1027.2420
13	Basic Science Center Program	New	18	1070	207.2342	1277.2342
		Continued	4	239.0955	45.0141	284.1096
14	Special Fund for Emergency Programs		2237	1446.105	287.6368	1733.7418
15	Tianyuan Fund for Mathematics		155	70		70
16	Research Fund for International Young Scientists		315	198.82	59.6466	258.4666
17	International (Regional) Exchange Program		443	40.7538		40.7538
18	Global Science Fund Program		74	193.63	40.5945	234.2245
Total			54859	33581.1207	6064.0429	39645.1636

*Statistics of indirect costs include those not approved in previous years.

**Lump-sum payment system has been adopted for Young Scientists Fund, Excellent Young Scientists Fund, National Science Fund for Distinguished Young Scholars and Young Students Basic Research Program under Special Fund for Emergency Programs.

III. Overview of Concluded Projects

In 2024, 44,851 projects supported by NSFC were concluded. Among the numerous achievements coming out of the concluded projects, 319 national awards including 90 National Natural Science Awards, 172 National Science and Technology Progress Awards, and 57 National Technology Invention Awards were received; 5,561 provincial and ministerial awards; 1,809 international patents on invention and 46,709 domestic patents on invention were obtained.

The statistics of research achievements from the concluded projects supported by NSFC in 2024 are shown in Table 1-3-1.



Table 1-3-1 Research Achievements Coming Out of the Concluded Projects Supported by NSFC in 2024

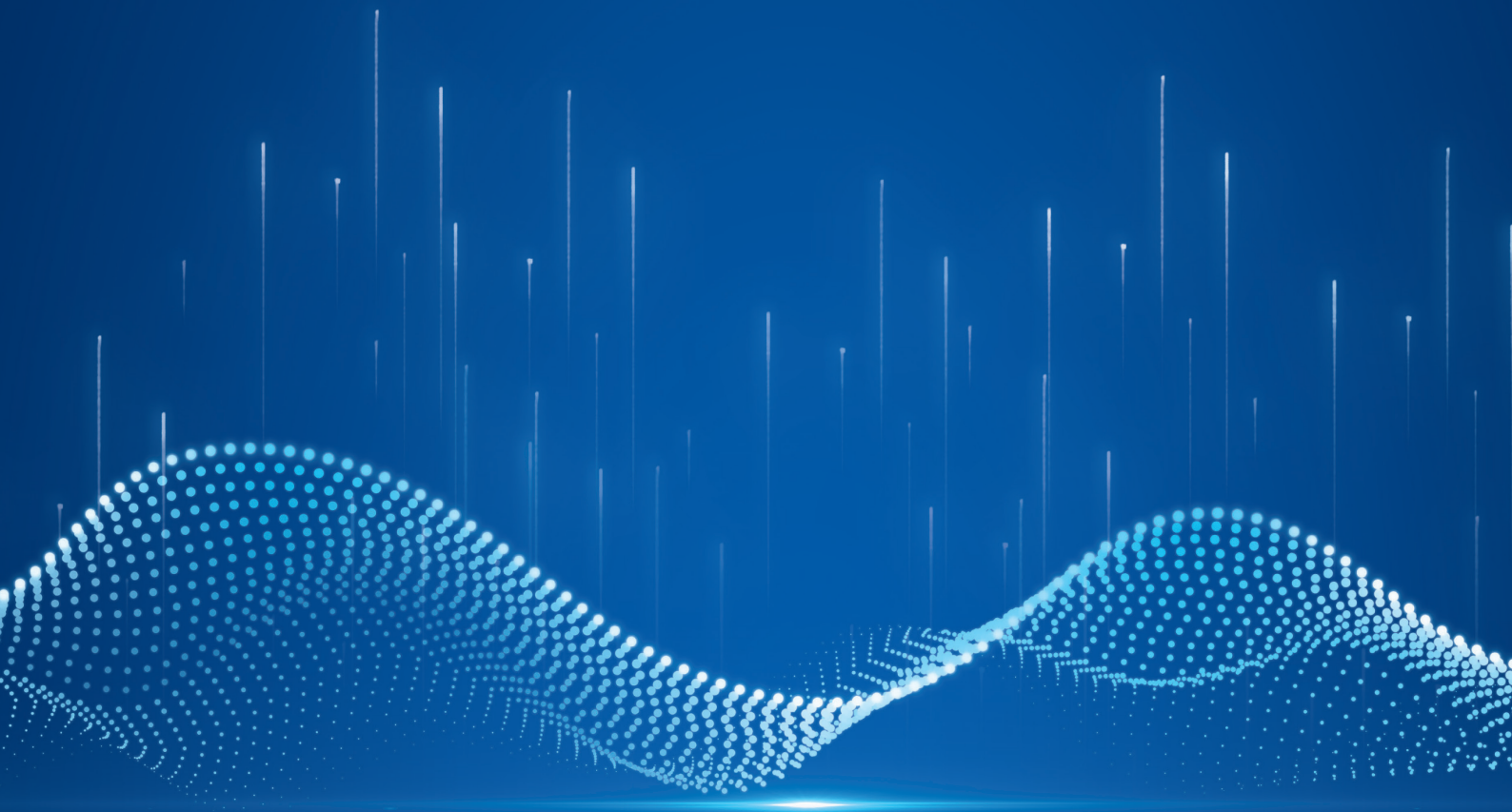
Research Achievements	Program Type															
	General Program	Key Program	Major Program	Major Research Plan	Young Scientists Fund	Fund for Less Developed Regions	Excellent Young Scientists Fund	National Science Fund for Distinguished Young Scholars	Science Fund for Creative Research Groups	Joint Research Fund for Overseas Chinese Scholars and 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	18468	668	216	522	18136	2925	623	196	38	21	759	86	4	635	928	
Publications	Keynote Speeches at International Academic Conferences	4183	1248	634	317	916	100	462	362	262	4	187	165	57	582	
	Keynote Speeches at Domestic Academic Conferences	8445	1908	1138	459	1583	346	885	514	308	23	253	97	178	655	
	Journal Papers	240878	28546	16807	9250	107075	26636	10655	7679	6868	277	4002	1899	2739	11167	
	Conference Papers	19730	2745	657	417	8222	1668	883	468	154	59	382	0	174	747	
	SCI-indexed research articles	144236	17544	6879	5227	62481	11560	7369	4847	4436	111	10660	2139	1260	902	6716
Patents	EI-indexed research articles	2598	357	187	70	1155	444	122	113	57	2	174	28	6	50	132
	Monographs	2598	357	187	70	1155	444	122	113	57	2	174	28	6	50	132
	International	883	140	50	43	406	88	71	72	37	0	72	64	11	1	40
Awards	Domestic	26807	3271	1629	787	12757	3193	1461	1144	1129	23	3007	892	226	170	1242
	National level	184	55	35	10	27	3	12		23	19	2	26	6	4	17
	Provincial/Ministerial level	2740	291	142	75	1013	288	167	99	75	2	230	31	5	21	146
Talents Trained	Postdoctoral Fellow	2207	627	305	283	704	54	203	258	157	11	55	78	46	268	
	PhD Students	21424	399	2020	1332	2819	749	997	1221	1418	51	557	256	292	1425	
	Master Students	52947	5271	2904	1307	11758	7362	1740	1024	1127	65	819	82	630	1799	

Note:

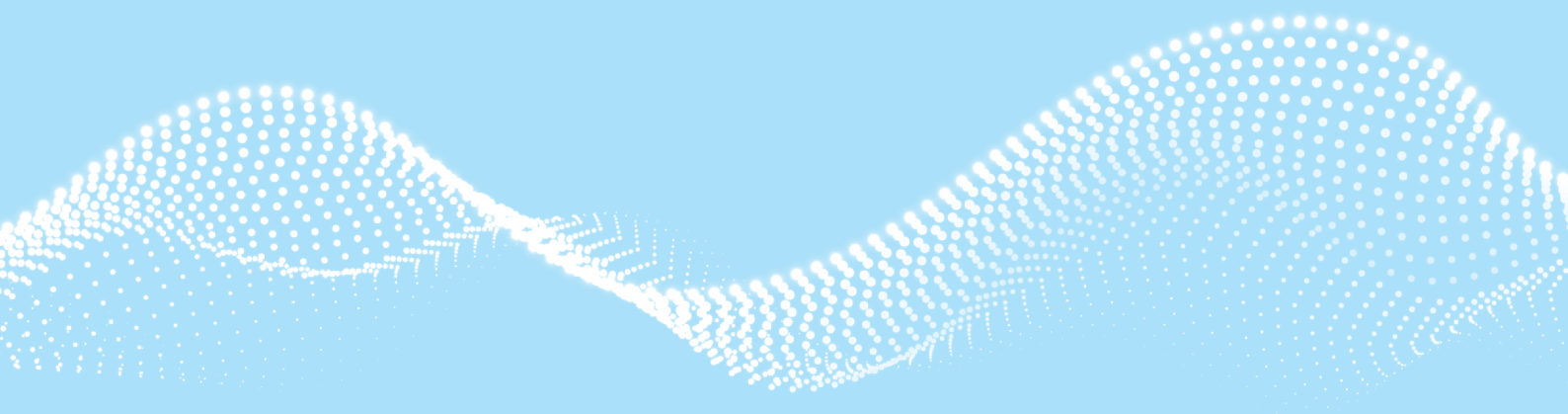
1. Data source: Concluding Reports submitted by PIs
2. International (Regional) Cooperation & Exchange Program includes International (Regional) Joint Research Program, Research Fund for International Scientists, and International (Regional) Exchange Program.
3. Statistics of Tianyuan Fund for Mathematics are included in Fund for Special Purpose Program

PART 2

Funding Statistics and Selective Introduction of Projects



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 2024, a total of 119, 636 applications were received for the General Program. Based on the nature of the scientific questions, these applications were divided into four categories, including Category I ground-breaking applications, category II frontier-extending applications, category III bottleneck-breaking applications, and category IV crossing-disciplines applications. 3.81% of the total applications were under category I, 44.66% under category II, 46.78% under category III, and 4.75% under category IV.

Statistics on applications and funding for General Program projects in 2024 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 the project teams is shown in Figure 2-1-2.

Table 2-1-1 Application and Funding Statistics of the General Program in 2024
(by Scientific Department)

(Unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding	Average Funding per Project ^①	Success rate ^② (%)
Mathematical and Physical Sciences	12939	1 889	94 480.00	50.02	14.60
Chemical Sciences	15 146	2 024	101 162.00	49.98	13.36
Life Sciences	25 839	3 218	160 890.00	50.00	12.45
Earth Sciences	14 940	2 241	107 568.00	48.00	15.00
Engineering and Materials Sciences	32 414	3658	175 891.00	48.08	15.00
Information Sciences	18 650	2 203	110 150.00	50.00	11.81
Management Sciences	6 256	841	34 050.00	40.49	13.44
Health Sciences	51 798	4 684	229 520.00	49.00	9.04
Total or average	177 982	20 758	1 013 711.00	48.83	11.66

Note: ①Average funding =Direct funding amount /No. of awards (the same below)

②Success rate= No. of applications/ No. of awards (the same below)

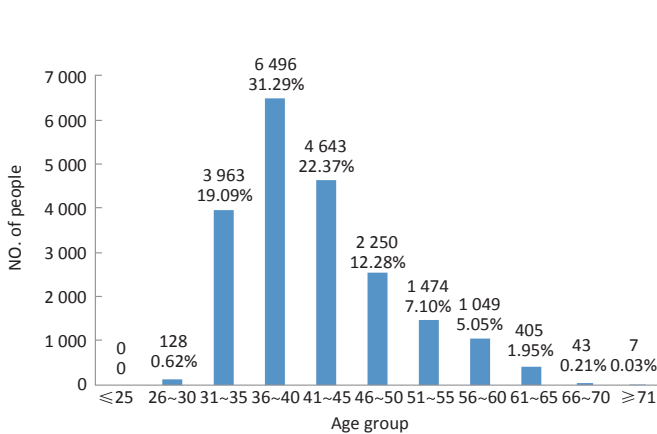


Figure 2-1-1 Age Distribution of Principal Investigators of General Program Projects in 2024

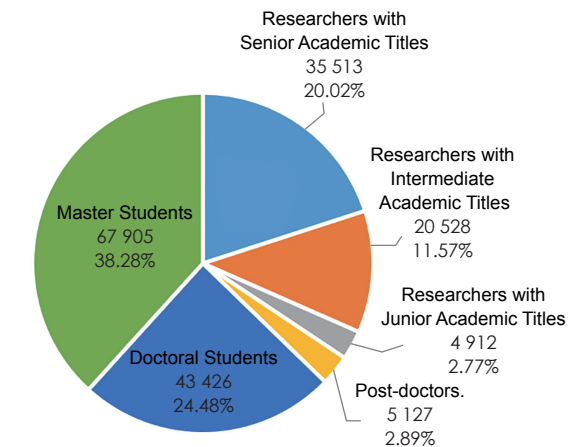


Figure 2-1-2 Professional Structure of Members of Research Groups for General Program Projects in 2024

**Table 2-1-2 Statistics of General Program Projects by Region in 2024**

(Unit: 10,000 yuan)

No.	Region	Projects	Direct Funding	No.	Region	Projects	Direct Funding
1	Beijing	3 266	159 531.99	17	Jilin	377	18 511.39
2	Shanghai	2 223	108 257.04	18	Henan	323	15 915.89
3	Jiangsu	2 148	104 671.38	19	Gansu	219	10 768.23
4	Guangdong	2 135	104 379.69	20	Shanxi	157	7 731.34
5	Hubei	1 208	58 510.24	21	Yunan	154	7 551.56
6	Shaanxi	1 158	56 891.09	22	Hebei	146	7 182.39
7	Zhejiang	1 080	52 795.31	23	Jiangxi	104	5 037.39
8	Shandong	1 010	49 435.84	24	Guangxi	68	3 321.78
9	Sichuan	813	39 830.29	25	Hainan	63	3 137.50
10	Hunan	766	37 223.39	26	Guizhou	61	3 027.00
11	Liaoning	623	30 528.23	27	Xinjiang	47	2 310.39
12	Anhui	595	29 035.46	28	Neimenggu	23	1 116.39
13	Tianjin	586	28 564.24	29	Ningxia	10	492.00
14	Heilongjiang	487	23 664.67	30	Qinghai	5	246.00
15	Fujian	459	22 429.22	31.	Tibet	1	50.00
16	Chongqing	443	21 563.67		Total	20 758	1 013 711.00

1.2 Key Program

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

In 2024, a total of 4514 applications were received for the Key Program. Based on the nature of the scientific problems, these applications were divided into two categories, Category I discovery-based applications, and category II goal-oriented applications. 35.14% of the total applications were under category I, 64.86% under category II.

Statistics on applications and funding for key projects in 2024 are shown in Table 2-1-3. The age distribution of project leaders is shown in Chart 2-1-3, and the composition of the project is shown in Chart 2-1-4.

Table 2-1-3 Application and Funding of Projects of Key Program Projects in 2024

(by Scientific Department)

(Unit:10,000 yuan)

Scientific Departments	Application received	Awards	Direct Funding	Average funding per project*	Success Rate (%)
Mathematical and Physical Sciences	561	91	20 930.00	230.00	16.22
Chemical Sciences	321	67	15 410.00	230.00	20.87
Life Sciences	747	110	24 150.00	219.55	14.73
Earth Sciences	659	108	24 840.00	230.00	16.39

(continued)

Scientific Departments	Application received	Awards	Direct Funding	Average funding per project*	Success Rate (%)
Engineering and Materials Sciences	769	105	24 150.00	230.00	13.65
Information Sciences	433	105	24 150.00	230.00	24.25
Management Sciences	181	32	5 140.00	160.63	17.68
Health Sciences	843	127	29 200.00	229.92	15.07
Total or average	4 514	745	167 970.00	225.46	16.50

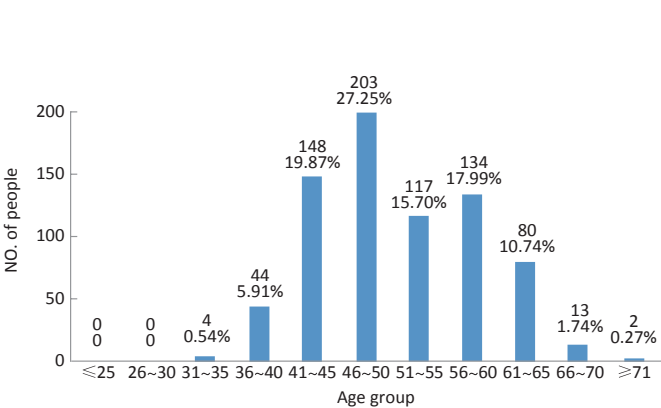


Figure 2-1-3 Age Distribution of Principal Investigators of Key Program Projects in 2024

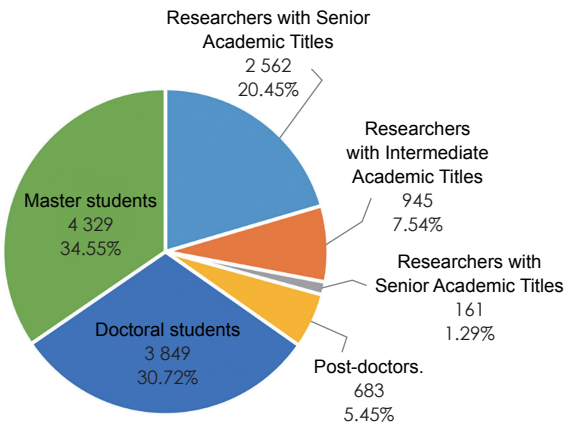


Figure 2-1-4 Project Team Composition of Key Program Projects funded in 2024

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 deploying, gives full play to the supporting and leading role in enhancing China's original innovation ability of basic research.

In 2024, a total of 109 applications were received for Major Program projects. 48 grants were approved, with a total direct cost of 70,801,000 yuan.

Statistics on applications and funding for Major Program projects in 2024 are shown in Table 2-1-4.

Table 2-1-4 Application and Funding Statistics of Major Program Projects in 2024
(by Scientific Department)

(Unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding	Average Funding per Project*
Mathematical and Physical Sciences	9	6	9 000.00	1 500.00
Chemical Sciences	19	6	9 000.00	1 500.00
Life Sciences	15	5	7 500.00	1 500.00
Earth Sciences	11	6	9 000.00	1 500.00
Engineering and Materials Sciences	10	6	8 957.50	1 492.92



(continued)

Scientific Department	Applications	Projects	Direct Funding	Average Funding per Project*
Information Sciences	12	6	8 914.00	1 485.67
Management Sciences	7	3	3 570.00	1 190.00
Health Sciences	14	4	5 977.50	1 494.38
Interdisciplinary Sciences	12	6	8 882.00	1 480.33
Total or average	109	48	70 801.00	1 475.02

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 superior strengths so as to form a cluster of projects with relatively unified goals or direction. 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 economy, social development and national security.

Statistics on applications and funding for Major Research Plan projects in 2024 are shown in Table 2-1-5.

Table 2-1-5 Applications and Funding of Major Research Plan Projects in 2024

(Unit: 10,000 yuan)

No.	Title of Project	Applications	Approved	Direct Funding
1	Digital Decoding of Immunity	136	20	3 698.00
2	Scientific Foundations of Critical Metal Metallurgy	1	1*	406.00
3	Panoramic Dynamics and Intervention Strategies of Coronavirus-Host Immune Interactions	166	29	4 000.00
4	Fundamental Research on High-Performance Materials with Ordered Functional Units	140	18	2 108.00
5	Atomic-Scale Manufacturing: Fundamental Research	32	11	7 300.00
6	Explainable and Generalizable Next-Generation AI Methods	1	1*	700.00
7	Post-Moore Era: Fundamental Research on Novel Devices	268	34	3 520.00
8	Cluster Construction, Function, and Multilevel Evolution	54	15	7 000.00
9	Deep Earth Dynamics and Planetary Habitability	48	15	4 698.00
10	Precise Construction of Hierarchical Chiral Matter	73	25	4 855.00
11	Scientific Foundations and Control Mechanisms of Efficient Multiphysics Flight	1	1*	350.00
12	Mineralization Dynamics of Supernormal Enrichment of Strategic Critical Metals	56	19	4 171.00
13	Fundamental Theories and Key Technologies of Future Industrial Internet	16	7	3 500.00
14	Scientific Basis of Electromagnetic Energy Equipment Under Extreme Conditions	120	17	4 100.00
15	Mechanisms of Microbial-Driven Elemental Cycling in the Hydrosphere	35	4	2 100.00

(continued)

No.	Title of Project	Applications	Approved	Direct Funding
16	Decoding the Glycan Code of Life	5	3	318.00
17	Construction and Manipulation of Second-Generation Quantum Systems	186	41	4 250.00
18	Spatiotemporal Network Regulation of Glycolipid Metabolism	10	2	600.00
19	Information Decoding and Ordered Regulation of Tissue Regeneration and Repair	19	2	800.00
20	Molecular Functional Visualization in Tumor Evolution and Therapy	346	16	2 934.00
21	Multisphere Interactions in the Earth System of the Western Pacific	65	5	1 680.00
22	RNA-Based Research Empowering Drug Innovation	1	1*	920.00
23	Battery Systems Beyond Conventional Technologies	1	1*	700.00
24	Scientific Foundations of Integrated Chip Frontier Technologies	217	32	3 850.00
25	Intelligent Software Fundamentals for Human-Machine-Object Fusion	87	23	3 600.00
26	Surface and Interface Science Foundations for Future Technologies	1	1*	700.00
27	High-Precision Quantum Control and Detection	538	49	4 830.00
28	Scientific Foundations of Critical Metal Metallurgy	134	26	3 940.00
Total		2 757	419	81 628.00

*Note: In the funding statistics, for those with only 1 application refer to strategic research projects, which are designed to support the expert advisory group in conducting strategic research, project tracking, thematic workshops, and academic exchanges.

1.5 International (Regional) Cooperative Research Program

The International (Regional) Cooperative Research projects fund researchers to follow the international science frontiers, effectively use international scientific and technological resources, conduct substantive international cooperation research on the principle of equal cooperation, mutual benefit and results sharing. 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 scientific and technical personnel with a solid foundation of collaboration to conduct joint research with overseas partners on global scientific frontiers and shared human challenges. The program should fully leverage the academic strengths of both the applicants and the foreign teams, and demonstrate the necessity and complementarity of the collaboration. It encourages Chinese scientists to organize or participate in, and large international (regional) collaborative research by use of large international scientific facilities and partners.

The MoU-based Cooperative Research project aims to expand bilateral and multilateral cooperation within the framework of inter-organizational agreements, makes full use of the coordination mechanism of international scientific and technological organizations in cross-border scientific research programs, promotes Chinese scientists to participate in, plan and carry out regional cross-border research projects with important scientific significance, and actively advances cooperation with countries and regions along the "Belt and Road" area and the SDIC program initiated by NSFC; and continues to strengthen cooperation and exchanges with scientists from Hong Kong, Macao and Taiwan.

Statistics on applications and funding for Key International (Regional) Cooperative Research projects in 2024 are shown in Table 2-1-6 and 2-1-7.

**Table 2-1-6 Application and Funding of Projects of Key International (Regional) Cooperative Research Program in 2024**

(unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding	Average Funding per Project*
Mathematical and Physical Sciences	24	5	1 120.00	224.00
Chemical Sciences	26	5	1 200.00	240.00
Life Sciences	91	16	3 840.00	240.00
Earth Sciences	64	11	2 640.00	240.00
Engineering and Materials Sciences	73	13	3 120.00	240.00
Information Sciences	62	11	2 640.00	240.00
Management Sciences	26	5	1 000.00	200.00
Health Sciences	118	21	5 040.00	240.00
Total or average	484	87	20 600.00	236.78

Table 2-1-7 Application and Funding of Projects of MoU-based Cooperative Research Program in 2024

(unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding	Average Funding per Project*
Mathematical and Physical Sciences	203	21	3 280.00	156.19
Chemical Sciences	216	23	3 928.00	170.78
Life Sciences	519	57	9 808.00	172.07
Earth Sciences	479	55	9 448.00	171.78
Engineering and Materials Sciences	716	48	7 264.00	151.33
Information Sciences	355	30	5 470.00	182.33
Management Sciences	130	7	1 219.00	174.14
Health Sciences	276	22	3 340.00	151.82
Total or average	2 894	263	43 757.00	166.38

1.6 Young Scientists Fund

The Young Scientists Fund (YSF) project supports young science and technology personnel to conduct basic research on independently selected topics within the funding scope of the National 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 2024, the YSF continues to open to researchers at host institutions from the Hong Kong SAR and Macao SAR on a pilot basis, of which the funding mechanism and review metrics remain unchanged.

The application and funding statistics of 2024 YSF projects are shown in Table 2-1-8 and Table 2-1-9. Statistics of professional and technical positions of project leaders are shown in Figure 2-1-5, and statistics of degree are shown in Figure 2-1-6.

Table 2-1-8 Application and Funding of Projects of Young Scientists Fund in 2024
(by Scientific Department)

(Unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding	Success Rate (%)
Mathematical and Physical Sciences	10 077	2 294	68 820.00	22.76
Chemical Sciences	12 541	2 112	63 360.00	16.84
Life Sciences	20 994	3 094	92 820.00	14.74
Earth Sciences	11 292	2 300	69 000.00	20.37
Engineering and Materials Sciences	23 950	3 978	119 340.00	16.61
Information Sciences	13 482	2 719	81 570.00	20.17
Management Sciences	8 299	1 113	33 390.00	13.41
Health Sciences	48 854	5 616	16 8480.00	11.50
Total or average	149 489	23 226	696 780.00	15.54

Note: 70 220 proposals from male PIs and 13 354 are granted; 79 269 from female, 9 872 are granted.

Table 2-1-9 Statistics of Projects for Young Scientists Fund by Region in 2024

(Unit: 10,000 yuan)

No.	Region	Application	Awards	Direct Funding	Success rate (%)
1	Beijing	16 044	3 324	99 720.00	20.72
2	Guangdong	14 183	2 409	72 270.00	16.99
3	Jiangsu	14 300	2 389	71 670.00	16.71
4	Shanghai	11 577	1 969	59 070.00	17.01
5	Zhejiang	10 703	1 595	47 850.00	14.90
6	Shandong	9 541	1 246	37 380.00	13.06
7	Shaanxi	6 788	1 148	34 440.00	16.91
8	Hubei	6 796	1 144	34 320.00	16.83
9	Sichuan	6 964	1 051	31 530.00	15.09
10	Hunan	4 859	841	25 230.00	17.31
11	Anhui	6 928	755	22 650.00	10.90
12	Henan	5 143	720	21 600.00	14.00
13	Liaoning	4 164	559	16 770.00	13.42
14	Chongqing	3 808	540	16 200.00	14.18
15	Tianjin	3 370	495	14 850.00	14.69
16	Fujian	2 362	465	13 950.00	19.69
17	Heilongjiang	3 134	460	13 800.00	14.68
18	Jilin	2 760	288	8 640.00	10.43
19	Shanxi	2 210	280	8 400.00	12.67
20	Hebei	2 320	242	7 260.00	10.43
21	Jiangxi	1 479	209	6 270.00	14.13



(continued)

No.	Region	Application	Awards	Direct Funding	Success rate (%)
22	Gansu	2 011	202	6 060.00	10.04
23	Yunnan	1 624	181	5 430.00	11.15
24	Hainan	1 022	149	4 470.00	14.58
25	Guangxi	1 569	130	3 900.00	8.29
26	Guizhou	1 137	114	3 420.00	10.03
27	Hongkong	996	91	2 730.00	9.14
28	Xinjiang	231	78	2 340.00	33.77
29	Neimenggu	777	70	2 100.00	9.01
30	Ningxia	357	42	1 260.00	11.76
31	Macao	239	17	510.00	7.11
32	Qinghai	71	17	510.00	23.94
33	Tibet	22	6	180.00	27.27
Total/average		149 489	23 226	696 780.00	15.54

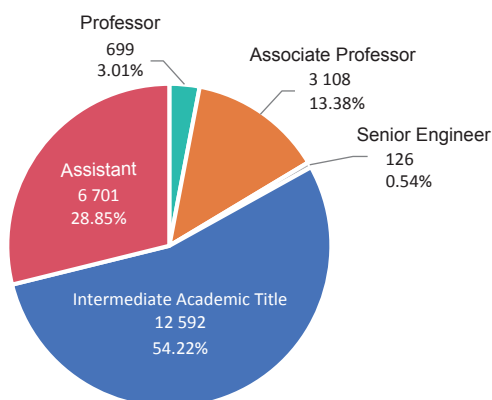


Figure 2-1-5 Academic titles of Project PIs funded by Young Scientists Fund in 2023

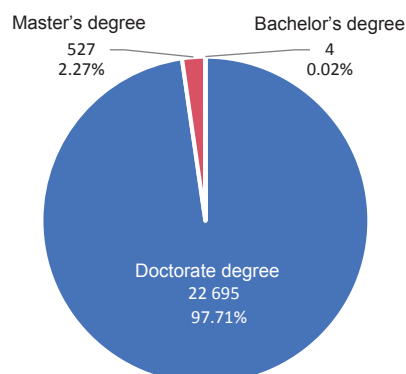


Figure 2-1-6 Academic degrees of PIs supported by Young Scientists Fund in 2023

1.7 Excellent Young Scientists Fund

The Excellent Young Scientists Fund (EYSF) project 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 excellent academic talents who are expected to enter the forefront of world science and technology.

To support the technological innovation and development 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 the central financial science and technology plan, and to contribute to the building of a strong science and technology country, since 2019, NSFC has opened applications for the Excellent Young Scientists Fund (Hong Kong and Macau) to researchers affiliated with host institutions in Hong Kong and Macau. Starting in 2024, the Excellent Young

Scientists Fund (Hong Kong and Macau) has been integrated into the main EYSF. The funding model and evaluation criteria remain consistent with those for applicants from mainland host institutions, ensuring equal treatment, fair competition, and merit-based selection.

The 2024 EYSF Program received 8,394 applications. After peer review, 654 projects have been approved for funding with a direct funding of 2 million yuan per project on a contract-based finance system. The total funding stands at 1.308 billion yuan.

The statistics of application and funding for EYSF projects in 2024 is shown in Table 2-1-10.

**Table 2-1-10 Application and Funding of Projects of Excellent Young Scientists Fund in 2024
(by Scientific Department)**

(Unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding
Mathematical and Physical Sciences	985	74	14 800.00
Chemical Sciences	1 017	88	17 600.00
Life Sciences	1 130	89	17 800.00
Earth Sciences	861	60	12 000.00
Engineering and Materials Sciences	1 440	116	23 200.00
Information Sciences	1 134	95	19 000.00
Management Sciences	240	23	4 600.00
Health Sciences	1 061	78	15 600.00
Interdisciplinary Sciences	526	31	6 200.00
Total or average	8 394	654	130 800.00

Note: There were 6315 applications from male applicants, of which 498 were funded; and 2079 from female applicants, of which 156 were funded; 223 from Hong Kong and Macau, of which 29 were funded.

1.8 National Science Fund for Distinguished Young Scholars

The National Science Fund for Distinguished Young Scholars (DYS) 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, attracts overseas talents, and cultivates a group of academic leaders to enter the forefront of the international science and technology community.

To further strengthen support for cultivating leading scientific talents in Hong Kong and Macau, and in active response to calls from the science and technology communities of these regions to expand the openness of the National Natural Science Fund, NSFC has opened applications for DYS to researchers from Hong Kong and Macau host institutions starting in 2024. The funding model and evaluation criteria remain consistent with those for applicants from mainland host institutions, ensuring equal treatment, fair competition, and merit-based selection.

In 2024, a total of 5957 applications were received for DYS. After peer review, 433 applicants got 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 finance system. The total funding was 1.6996 billion yuan.

The application and funding statistics of the National Science Fund for Distinguished Young Scholars in 2024 are shown in Table 2-1-13.

**Table 2-1-11 Application and Funding of Projects of the National Science Fund for Distinguished Young Scholars in 2024**

(Unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding
Mathematical and Physical Sciences	775	52	19 120.00
Chemical Sciences	733	55	22 000.00
Life Sciences	713	51	20 400.00
Earth Sciences	587	42	16 800.00
Engineering and Materials Sciences	954	78	31 200.00
Information Sciences	731	53	21 200.00
Management Sciences	159	13	3 640.00
Health Sciences	782	60	24 000.00
Interdisciplinary Sciences	523	29	11 600.00
Total or average	5 957	433	169 960.00

Note: There were 4979 applications from male applicants, of which 368 were funded; and 978 from female applicants, of which 65 were funded; 138 from Hong Kong and Macau, of which 21 were funded.

Since 2024, NSFC conducted its first performance evaluation and extension funding review for DYS. Among the 199 grant recipients whose funding periods ended in late 2023, 160 applied for extension funding, with 41 funded. The statistics of application and funding for the 2024 DYS (Extension Funding) are presented in Table 2-1-12.

Table 2-1-12 Application and Funding of Projects of the National Science Fund for Distinguished Young Scholars (Extension Funding) in 2024

(Unit: 10,000 yuan)

Scientific Department	Applications	Grants	Funding amount
Mathematical and Physical Sciences	19	5	3 760.00
Chemical Sciences	24	6	4 800.00
Life Sciences	21	5	4 000.00
Earth Sciences	14	4	3 200.00
Engineering and Materials Sciences	33	8	6 400.00
Information Sciences	24	6	4 800.00
Management Sciences	5	2	1 120.00
Health Sciences	20	5	4 000.00
Total or average	160	41	32080.00

Note: There were 142 applications from male applicants, of which 39 were funded; and 18 were from female applicants, of which 2 were funded;

1.9 Science Fund for Creative Research Groups

The Science Fund for Creative Research Groups project 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 role to play in the forefront of international science.

In 2024, a total of 392 applications were received for the Fund. After peer review, 43 groups were supported, 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 project was 2 million yuan.

The statistics of application and funding for Innovation Research Group projects in 2024 are shown in Table 2-1-13.

Table 2-1-13 Application and Funding of Projects for the Science Fund for Creative Research Groups in 2024

(Unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding
Mathematical and Physical Sciences	38	5	4 800.00
Chemical Sciences	43	5	5 000.00
Life Sciences	52	5	5 000.00
Earth Sciences	50	5	5 000.00
Engineering and Materials Sciences	62	6	6 000.00
Information Sciences	53	5	5 000.00
Management Sciences	9	2	1 600.00
Health Sciences	44	5	5 000.00
Interdisciplinary Sciences	41	5	5 000.00
Total or average	392	43	42 400.00

1.10 Fund for Less Developed Regions

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

The statistics of application and funding for Fund for Less Developed Regions projects in 2024 are shown in Table 2-1-14. Figure 2-1-7 shows the age statistics of project leaders, and Figure 2-1-8 shows the situation of project members.

Table 2-1-14 Application and Funding of Projects of the Fund for Less Developed Regions by Funding in 2024

(Unit: 10,000 yuan)

No.	Region	Applications	Awards	Direct Funding	Success rate (%)
1	Jiang Xi	5 093	731	22 930.10	14.35
2	Guangxi	4 119	522	16 441.60	12.67
3	Yunnan	4 087	469	14 744.00	11.48
4	Gui Zhou	3 993	458	14 466.10	11.47
5	Xin Jiang	2 578	274	8 650.85	10.63
6	Gan Su	2 301	272	8 568.30	11.82



(continued)

No.	Region	Applications	Awards	Direct Funding	Success rate (%)
7	Hai Nan	1 512	259	8 178.45	17.13
8	Inner Mongolia	1 954	240	7 576.40	12.28
9	Ning Xia	1 103	143	4 492.75	12.96
10	Qing Hai	412	47	1 486.80	11.41
11	Shaanxi	475	44	1 401.65	9.26
12	Jilin	105	22	684.00	20.95
13	Hunan	178	16	509.00	8.99
14	Hubei	84	11	351.00	13.10
15	Tibet	99	7	216.00	7.07
16	Sicuan	81	4	126.00	4.94
	Total or average	28 174	3 519	110 823.00	12.49

Note: There were 17 581 applications from male applicants, of which 2296 were funded; and 10593 were from female applicants, of which 1223 were funded.

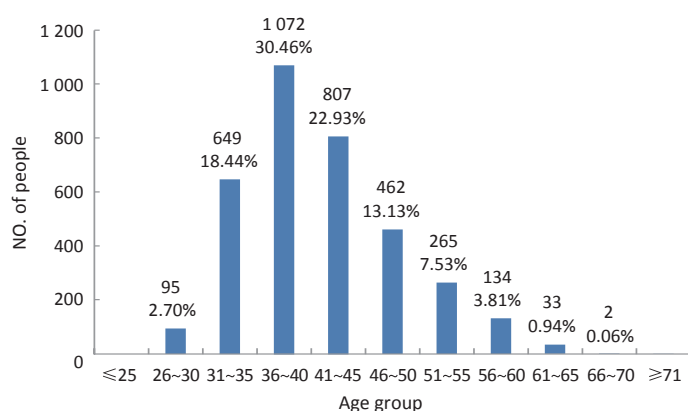


Figure 2-1-7 Age Distribution of Principal Investigators of Projects Funded by the Fund for Less Developed Regions in 2023

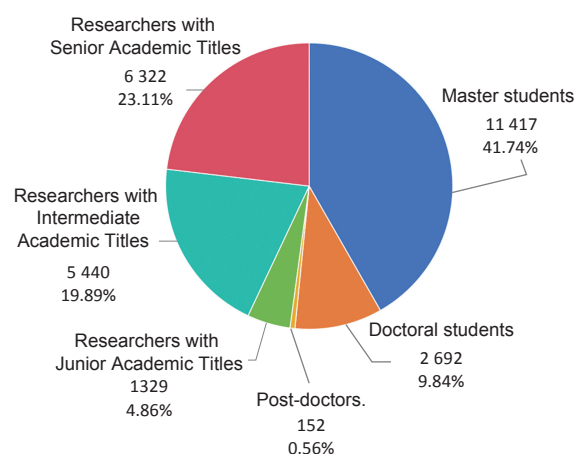


Figure 2-1-8 Research Team Composition of Projects Supported by the Fund for Less Developed Regions in 2023

1.11 Joint Funds

The Joint Funds are designed to give full play to the guiding role of the National Natural Science Fund, integrate social resources for basic research, promote the synergy of relevant sectors, enterprises and regions with higher education institutions and research institutes, foster scientific and technological talents, and enhance China's indigenous innovation capabilities in related research areas, industries and regions.

In 2024, a total of 1306 projects were funded under the Joint Funds with a direct funding of 3.673 billion yuan. A total of 830 projects were funded under the Joint Fund for Regional Innovation and Development with a direct funding of 2.255 billion yuan; a total of 221 projects were funded under the Joint Fund for Corporate Innovation and Development with a direct funding of 759 million yuan; a total of 255 projects were funded under the Joint Funds with industrial sectors with a direct funding of 659 million yuan.

The 2024 Joint Fund project application and funding statistics are shown in Table 2-1-15.

Table 2-1-15 Application and Funding of Joint Funds in 2024

(unit: 10,000 yuan)

No.	Joint Funds	Applications	Awards	Direct Funding
1	Joint Fund for Regional Innovation and Development	3 323	830	225 531.00
2	Joint Fund for Corporate Innovation and Development	1 410	221	75 851.00
3	NSAF Joint Fund	61	15	3 674.00
4	Joint Fund of Civil Aviation Research	68	18	3 780.00
5	Joint Meteorological Fund	86	22	6 460.00
6	"Qisun Ye" Science Foundation	595	91	23 570.00
7	Joint Fund for Geology	87	21	5 460.00
8	NSFC-GenerTec Joint Fund for Basic Research	54	11	3 466.00
9	NSFC-CR Joint Fund for Basic Research	163	32	8 198.00
10	NSFC-CR Joint Fund for Innovative Development	114	13	3 074.00
11	Joint Fund of Yellow River Water Science Research	136	32	8 198.00
Total		6 097	1 306	367 262.00

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

The Special Fund focuses on science frontier and national needs, and is guided by scientific goals. It supports the development of original scientific research instruments and core components that play an important role in promoting scientific development, exploring natural laws and exploring research fields, thus enhancing the country's original innovation ability.

In 2024, a total of 709 applications for the Special Fund for Development of National Major Research Instruments and Facilities were received. After peer review, 67 applications were funded, with a total direct funding of 519.6464 million yuan and the average direct costs was 7.7559 million yuan per project. The scientific departments recommended 48 applications and 4 of them got funded after peer review, with a total direct funding of 317.35 million yuan and the average funding intensity of direct costs was 79.3375 million yuan per project.

The statistics of application and funding for National Major Scientific Research Instrument Development Projects (free application) in 2024 are shown in Table 2-1-16.

Table 2-1-16 Projects funded in Special Fund for Development of National Major Research Instruments and Facilities (Open application) in 2024 (by Scientific Department)

(unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding	Average Funding per Project*
Mathematical and Physical Sciences	100	11	8 527.80	775.25
Chemical Sciences	79	7	5 324.02	760.57
Life Sciences	27	2	1 527.00	763.50
Earth Sciences	82	5	4 004.98	801.00



(continued)

Scientific Department	Applications	Projects	Direct Funding	Average Funding per Project*
Engineering and Materials Sciences	132	13	10 367.79	797.52
Information Sciences	218	20	15 405.03	770.25
Health Sciences	71	9	6 808.02	756.45
Total or average	709	67	51 964.64	775.59

1.13 Basic Science Center

The Basic Science Center program aims to concentrate and integrate domestic superior scientific research resources, target at the forefront of international science and far-sighted deployment, give full play to the advantages and characteristics of the national science fund system. It relies on high-level academic leaders, attracts and unites outstanding scientific and technological talents. Efforts will be made to promote the deep integration of disciplines, support researchers to study and explore in a long term, and strive to break through the frontiers of science, produce a number of internationally leading original achievements, seize the commanding heights of international scientific development, and form a number of highlands with academically important international influences.

The 2024 Basic Science Center program received 170 applications. After peer review, 18 projects were approved for funding, with a total direct cost of 1.07 billion yuan. Among them, Basic Science Center program (Type A) received 71 applications, with 10 projects approved for funding, totaling direct costs of 590 million yuan. The Basic Science Center program (Type B) received 99 applications, with 8 projects approved for funding, totaling direct costs of 480 million yuan.

The 2024 Basic Science Center project application and grant statistics are shown in Table 2-1-17.

Since 2022, the extension funding for Basic Science Center programs has been implemented. Among the Basic Science Center projects approved in 2018, 4 projects were granted extension funding, with a total direct costs of 2.390955 billion yuan.

Table 2-1-17 Application and Funding of Basic Science Center Project (Open application) in 2024 according to the Scientific Departments

(unit: 10,000 yuan)

Scientific Department	Applications	Projects	Direct Funding
Mathematical and Physical Sciences	21	2	12 000.00
Chemical Sciences	18	1	6 000.00
Life Sciences	19	4	24 000.00
Earth Sciences	22	2	12 000.00
Engineering and Materials Sciences	17	2	12 000.00
Information Sciences	21	1	6 000.00
Management Sciences	9	1	5 000.00
Health Sciences	15	2	12 000.00
Interdisciplinary Sciences	28	3	18 000.00
Total or average	170	18	107 000.00

1.14 Special Projects

The Special Projects support innovative research that needs timely funding, and scientific and technological activities related to the development of NSFC, etc. Special Projects are divided into Research Projects, Scientific and Technological Activities Projects, Original Exploration Projects and Special Projects for Scientific and Technological Management.

Among them, Research Projects are to fund research on timely implementation of the national strategic deployment in the fields of economy, society, science and technology, research on key scientific issues involved in major emergencies, and research with strong innovation and development potential and involving frontier scientific issues that need to be funded in time. The S&T Activities program is to fund strategic and management research, academic exchange, science communication, platform construction and other activities related to the development of NSFC. Original Exploration Projects aim to encourage researchers to put forward original academic thought, carry out exploratory and high-risk original basic research work, such as creating the new theory, new method, and revealing the new law, etc., with the purpose of achieving leading output from scratch, 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. Established in 2023, the Youth Student Basic Research Project adopts a dual selection procedure featuring school recommendation and expert review to fund outstanding undergraduate and doctoral students from high-level universities, thereby extending the funding to early-stage talents to facilitate scientific literacy fostering, stimulating innovative research, and ultimately building up the foundation for a high-level basic research workforce.

The funding statistics of this project in 2024 are shown in Table 2-1-18.

Table 2-1-18 Applications and Funding of Special Projects in 2024

(unit: 10,000 yuan)

No.	Types		Awards	Direct Funding
1	Research Projects	Comprehensive Research Projects of Scientific Departments	3 384	389
		Emergency Projects of Department of Management Sciences	300	24
		Theoretical Physics research Projects	197	87
		Intelligent Diagnosis and Treatment of Major Diseases	876	28
		Biological Mechanisms and Clinical Translation of Acupuncture	47	5
		Key Scientific Issues in Acupuncture Supported by High-Level Clinical Evidence	34	7
2	Scientific and Technological Activities	Comprehensive Scientific and Technological Activities of Scientific Departments	2 171	377
		Theoretical Physics Research Projects	54	20
		Shared Voyage Scientific Investigation Projects	23	14
		Tasks and Soft Research Projects entrusted by Bureaus and Offices	152	141
		Special funds for poverty alleviation	9	9
		Xiangshan Science Conferences	1	1
		Shared Voyage Strategic Research Projects	1	1



No.	Types		Awards	Direct Funding
3	Original Exploration Research Projects Based on Open Calls	Original Exploration research projects based on Open calls	191	87
	Original Exploration Research Projects Recommended by Experts	Original Exploration research projects recommended by experts	199	78
	Extended Original Exploration Research Projects	Extended Original Exploration research projects	33	18
4	Youth Student Basic Research Project (Undergraduate Students)	Youth Student Basic Research Project (Undergraduate Students)	145	141
5	Youth Student Basic Research Project (Doctoral Students)	Youth Student Basic Research Project (Doctoral Students)	1 535	810
Total			9 352	2 237

*Note: Youth Student Basic Research Project is on a on a contract-based finance system.

1.15 Tianyuan Fund for Mathematics

Tianyuan Fund for Mathematics is set up to pool the collective wisdom of mathematicians, explore funding methods that meet the characteristics and development laws of mathematics, and promote the building of a mathematical power. The Tianyuan Fund for Mathematics supports scientific and technical personnel, in line with the characteristics and needs of mathematics disciplines, develop scientific research, nurture young talents, promote academic exchanges, optimize the research environment, and disseminate mathematics culture, thereby enhancing the innovation ability of Chinese mathematics.

In 2024, the Mathematical Tianyuan Fund program received 565 applications, and 155 projects were funded with a total direct funding of 70 million yuan, and the average funding of direct costs was 451,600 yuan per project.

1.16 Research Fund for International Scientists

This Fund supports foreign researchers who come to China to carry out research work on their own interested topics within the funding 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 are further divided into 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 for Research Fund for International Scientists in 2024 are shown in Table 2-1-19.

Table 2-1-19 Application and Funding of Projects of Research Fund for International Young Scientists (by Scientific Department) in 2024

(unit: 10,000 yuan)

Scientific Department	RFIS-I			RFIS-II			RFIS-III			Pilot Group Program 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	173	23	656.00	95	9	696.00	95	12	1 911.00	363	44	3 263.00	173	23	656.00
Chemical Sciences	211	23	740.00	66	6	396.00	51	6	880.00	328	35	2 016.00	211	23	740.00
Life Sciences	425	49	1 680.00	96	9	679.00	94	9	1 440.00	615	67	3 799.00	425	49	1 680.00
Earth Sciences	143	17	540.00	46	4	280.00	48	6	944.00	237	27	1 764.00	143	17	540.00
Engineering and Materials Sciences	348	39	1 258.00	108	11	863.00	92	10	1 520.00	548	60	3 641.00	348	39	1 258.00
Information Sciences	155	17	520.00	63	5	320.00	61	7	1 120.00	279	29	1 960.00	155	17	520.00
Management Sciences	177	19	580.00	39	4	280.00	9	1	160.00	225	24	1 020.00	177	19	580.00
Health Sciences	118	13	420.00	37	4	319.00	71	6	960.00	226	23	1 699.00	118	13	420.00
Interdisciplinary Sciences	0	0	0	35	3	240.00	42	3	480.00	77	6	720.00	0	0	0
Total or average	1 750	200	6 394.00	585	55	4 073.00	563	60	9 415.00	2 898	315	19 882.00	1 750	200	6 394.00



1.17 International (Regional) Exchange Program

The International (Regional) Exchange Program encourages the PI 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, accelerate the steps of improving innovation ability, personnel training, and disciplinary development, and enhance the quality of on-going projects. Such projects can be divided into exchange projects based on mutual visits and academic workshop projects. The exchange project aims to deepen the understanding of international academic frontiers, building and developing the cooperative relationship with domestic and foreign counterparts, and laying a good foundation for wider and deeper international collaboration. It also helps to strengthen the publicity of research results funded by NSFC and enhance the international influence of scientific research in China.

The statistics of application and funding for International (Regional) Cooperation and Exchange Programs in 2024 are shown in Table 2-1-20.

Table 2-1-20 Application and Funding of Projects of International (Regional) Exchange Program in 2024

(unit: 10,000 yuan)

No.	Type	Applications	Projects	Direct Funding
1	Exchange Program under Agreements/MOU	1 179	260	3 301.40
2	International Conference under Agreements/MOUs	841	161	401.98
3	Academic Conference under Agreements/MOUs	152	22	372.00

1.18 Science Fund for Global Challenges and Sustainability

The aim of establishing the Global Science Fund is to increase openness to the world, build an international platform for basic research collaboration, and implement a fully open, inclusive, and flexible funding mechanism. It is also to extensively support the development of international scientific talent, serve as a mechanism for attracting and nurturing research talent, attract top foreign scientists to work in China, expand and deepen Sino-foreign joint research, pool global wisdom to address global challenges and serve national development needs, and foster an open innovation ecosystem with global competitiveness. In 2024, the Science Fund for Global Challenges and Sustainability newly introduced:

International Cooperation Fund on Major Scientific Infrastructure: Following the management model of major research initiatives, it supports Chinese and foreign researchers to conduct research and exchanges based on major scientific infrastructure (including scientific projects, facilities, and installations) both within and outside China, leveraging large-scale research platforms to attract and cultivate talent.

International Collaboration Fund for Creative Research Teams: It aims to promote international research collaboration, attract and support outstanding foreign academic leaders to establish and lead research teams in China, independently select research directions, and carry out innovative basic and applied basic research, with the goal of cultivating world-class research teams.

Pilot Program of Research Fund for Excellent International PhD Students: To advance the integrated development of education, science, and talent, and to promote the "Study in China" brand, the NSFC and the Ministry of Education have jointly launched this pilot program. It aims to attract outstanding young international students to pursue doctoral degrees in China and explore a funding mechanism for attracting and nurturing high-quality young scientific talent from around the world.

The application and funding statistics for the 2024 Science Fund for Global Challenges and Sustainability are shown in Table 2-1-21.

Table 2-1-21 Application and Funding of Science Fund for Global Challenges and Sustainability in 2024

(unit: 10,000 yuan)

No.	Type	Applications	Projects	Direct Funding
1	International Cooperation Fund on Major Scientific Infrastructure	11	10	3 933.00
2	International Collaboration Fund for Creative Research Teams	327	25	14 640.00
3	Pilot Program of Research Fund for Excellent International PhD Students:	255	39	790.00



2. Selective Introduction of Major Research Plan Projects

Fundamental Research of Atomic-level Manufacturing

The Major Research Plan of the National Natural Science Foundation of China (NSFC) "Atomic-level Manufacturing" was approved in 2024 and is set to commence in 2025 with an eight-year duration and a direct funding allocation of 200 million RMB.

Atomic-level manufacturing involves the precise application of energy to individual atoms, enabling the manipulation of individual atoms on a large scale for atomic-layer removal or construction at the atomic scale. This technique facilitates the creation of products with extreme performance capabilities that are unattainable using conventional manufacturing methods. Moreover, atomic-level manufacturing enhances machining precision to the atomic scale and enables cross-scale construction from the atomic layer, facilitating the creation of disruptive devices and innovative equipment with unique functionalities. This technique offers significant advantages and demonstrates immense development potential, making it a strategic focal point in global competition. It is expected to become a driving force for cultivating new productive capacities and competitive advantages, representing a critical opportunity in the quest to build a manufacturing powerhouse.

This major initiative focuses on advancing the frontier of atomic-level manufacturing research, addressing critical demands in areas such as advanced chips, national defense, aerospace, and new energy. These demands include high-performance components, meta-optical devices, and ultra-high-precision instruments. The initiative integrates multidisciplinary approaches from mechanics, physics, chemistry, materials science, and information technology. It aims to advance foundational theories and process methodologies in atomic-level manufacturing, fostering original innovation. The core challenge lies in achieving large-scale atomic manipulation, with a particular emphasis on efficiently regulating energy-matter interactions at the atomic scale. To address this challenge, the initiative will prioritize three key areas: the principles of large-scale atomic manipulation, the mechanisms of atomic-level ordered construction, and the theories and methods for atomic-level measurement and characterization.

The implementation period of this program spans eight years and is divided into two phases. The first phase (2025–2027) focuses on planning and deployment. During this stage, "seed projects" and "key support projects" will be initiated to align with the program's overall research objectives. After evaluating and reviewing the foundations laid by these early-stage projects, resources—including manpower, materials, and funding—will be concentrated to launch "integrated projects" that capitalize on the strengths and outcomes of various research directions. The second phase (2028–2032) emphasizes sustained execution and the synthesis of program outcomes.

With relatively stable and substantial support, this initiative aims to achieve breakthroughs in key areas and critical directions, thereby fostering the development of innovative concepts, theories, and methodologies in atomic-level manufacturing. These efforts will strengthen the nation's capacity for independent innovation in the manufacturing sector. In parallel, the initiative seeks to attract and nurture a research team with internationally advanced expertise, dedicated to multidisciplinary foundational studies in atomic-level manufacturing. Ultimately, these endeavors aim to drive transformative advancements in high-end chips, national defense, aerospace, and new energy fields.

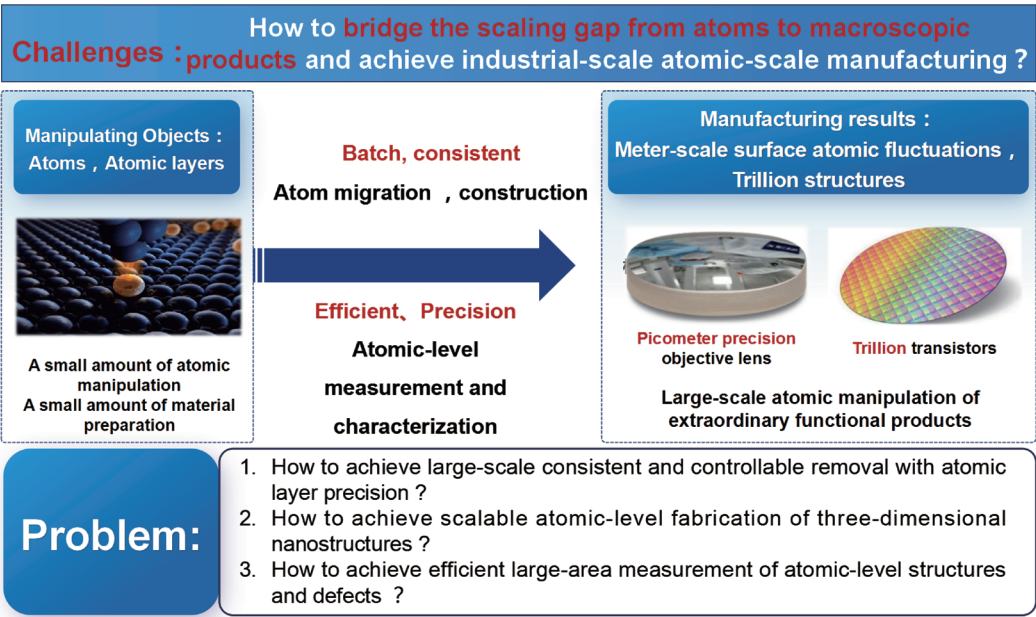


Figure 2-2-1 Atomic-level manufacturing and its impact on national strategic demands

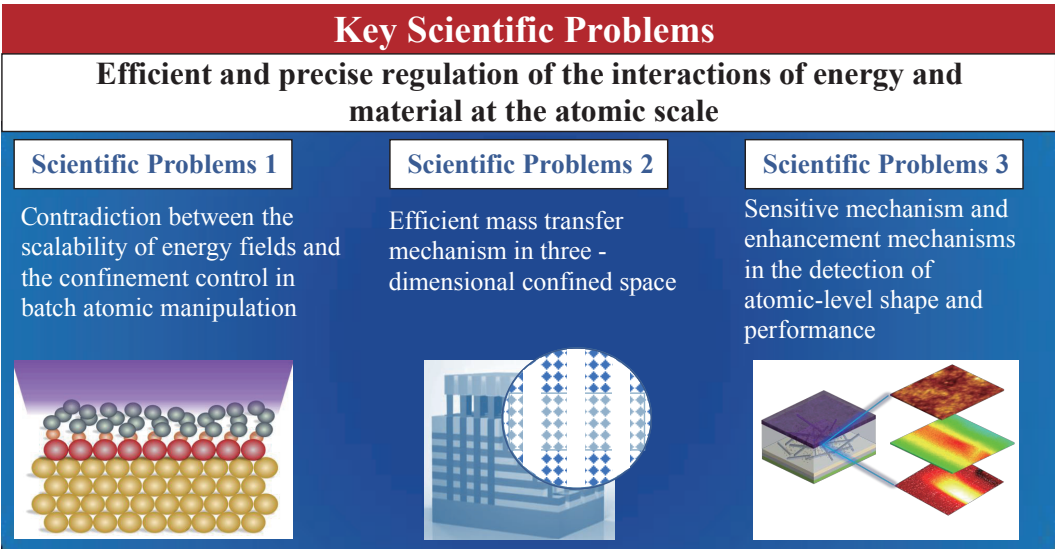


Figure 2-2-2 The key framework and multidisciplinary integration of atomic-level manufacturing

Empowering Drug Innovation Through Fundamental RNA Research

The Major Research Plan of the National Natural Science Foundation of China (NSFC) “Empowering Drug Innovation through Fundamental RNA Research” was approved in 2024 and is set to commence in 2025 with an eight-year duration and a direct funding allocation of 200 million RMB.

Ribonucleic acid (RNA), a fundamental component of life, serves as both a key mediator of genetic information expression and a critical regulator of biological processes. RNA research represents the cutting



edge of life sciences and holds immense potential for applications, particularly as the rapidly emerging RNA pharmaceutical industry becomes a pivotal driver of innovation. With advantages such as high target specificity, diverse therapeutic sites, superior efficacy, and shorter development timelines, RNA-based drugs are poised to become a transformative force, propelling the biopharmaceutical sector to new heights. This Major Research Plan seeks to address critical bottlenecks in RNA drug development by focusing on fundamental RNA research. Adopting an intelligence-driven research paradigm informed by comprehensive data, the plan aims to empower the entire innovation pipeline for RNA therapeutics within the framework of "One Health." Through its implementation, the Plan aspires to establish China as a global leader in RNA research and catalyze the growth of its RNA-based biopharmaceutical industry.

The Plan is designed to address the following core scientific challenges:

1. Developing High-Efficiency, High-Precision Methods for Characterizing RNA. The Plan will establish and optimize novel methodologies to accurately analyze RNA modifications, structures, and localization, with an emphasis on precision and dynamic monitoring. These advancements will not only elucidate RNA regulatory mechanisms but also provide theoretical support for optimizing RNA properties in drug development.

2. Uncovering Regulatory Principles Linking RNA Modifications, Structures, Localization, and Functions. By investigating how RNA modifications, structures, and localization influence biological functions, the Plan aims to unravel their regulatory roles in gene expression. Insights gained from this research will reveal novel RNA targets for drug design, facilitating more precise and effective therapeutic interventions.

3. Developing Foundational Technologies to Modulate RNA Functions in Key Physiological and Pathological Processes. The Plan will develop foundational technologies to manipulate RNA functions effectively. This includes leveraging artificial RNA-based interventions to regulate physiological and pathological processes or precisely modulating RNA molecules within these contexts, laying a foundation for innovative RNA therapeutics.

4. Intelligent RNA Target Discovery and Drug Development. By integrating data derived from emerging technologies, this Plan employs advanced artificial intelligence (AI) tools to identify potential RNA targets, predict their functions, and screen for druggable candidates with therapeutic potential. Furthermore, RNA molecule design and optimization algorithms will be developed to enhance the specificity, stability, and efficacy of RNA-based drugs and vaccines, providing robust support for innovative RNA drug development.

Driven by the urgent need for RNA-based drugs and vaccines, this Major Research Plan aims to advance RNA research by developing innovative tools and methodologies that will provide a comprehensive understanding of RNA regulatory mechanisms. It seeks to elucidate the dynamic changes in RNA during key physiological and pathological processes, identifying novel RNA-based targets for precision medicine and targeted disease interventions. In addition, the Plan will focus on the development of intelligent algorithms for RNA molecule design and optimization, leveraging global data to accelerate progress. It also aims to establish foundational technologies to support RNA-based drug development across human medicine, veterinary care, and agriculture. Ultimately, these efforts are designed to enhance human, animal, and ecological health within the "One Health" framework.

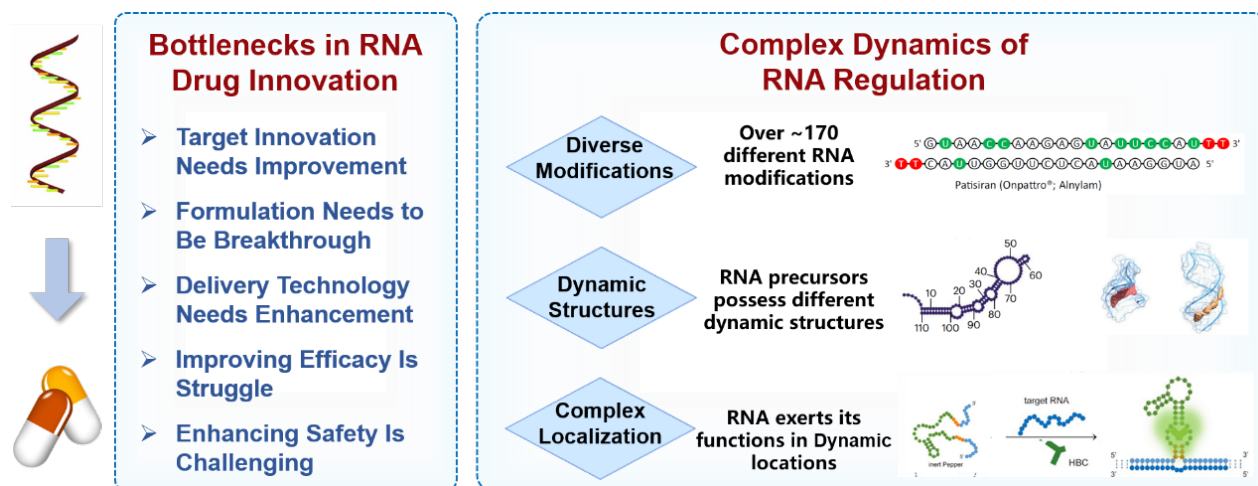


Figure 2-2-3 Challenges and difficulties in RNA drug innovation

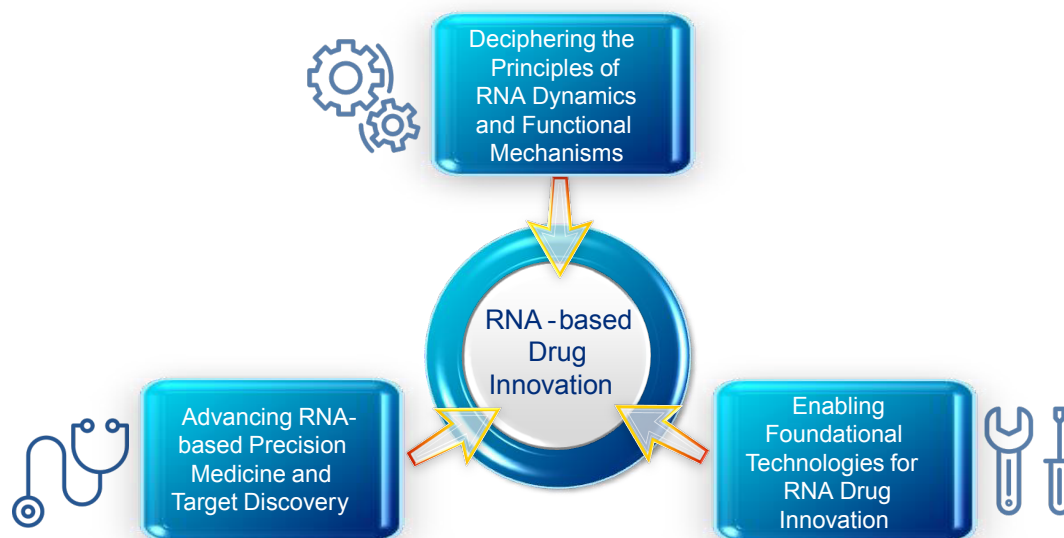


Figure 2-2-4 Key scientific issues

Fundamental Research of Intelligent Software for Human-Cyber-Physical Convergence

The Major Research Plan of the National Natural Science Foundation of China (NSFC) "Fundamental Research of Intelligent Software for Human-Cyber-Physical Convergence" was approved in 2024 and is set to commence in 2025 with an eight-year duration and a direct funding allocation of 200 million RMB.

The development of human-cyber-physical convergence and breakthroughs in machine learning technologies have driven the emergence of a new form of software, namely intelligent software. Intelligent software not only poses new challenges, opens up new opportunities, and ushers in a paradigm shift in software theory, methods, and technologies, but also presents an invaluable opportunity to achieve



breakthroughs in critical software. This major research plan aims to address three core scientific questions through interdisciplinary collaboration across scientific fields such as information theory and technology, mathematics, physics, materials science, engineering, and management. The goal is to establish the theoretical and methodological foundation and key technology system of intelligent software paradigms, achieving breakthroughs in areas such as the new theoretical foundations of mathematical and physical paradigms, new principles of engineering construction, new mechanisms for operational evolution, and new quality assurance mechanisms.

This major research plan program seeks to develop customized, integrated technologies for key industrial domains based on this new paradigm, laying the groundwork for an open-source ecosystem for intelligent software innovation in China and fostering the development and reserve of high-quality software talent in critical software domains.

This major research plan aims to address the following key scientific questions:

The Principles of Modeling Intelligent Software in Human-Cyber-Physical Convergence: Focus on breaking through the theories of representation and modeling for human-cyber-physical resources, enabling dynamic collaboration, autonomous growth, and automatic generation of software systems. This will facilitate ubiquitous software services and harmonious coexistence between human and machine intelligence, supported by open-source foundations.

The Mechanism of Developing and Operating Intelligent Software through Inductive-Deductive Integration: Expand traditional symbolic software into neuro-symbolic hybrid software, enabling system construction driven by both data and knowledge. This involves integrating manually coded development methods with machine learning-based automatic generation, building a common framework and core components for ubiquitous operating systems, and developing domain-specific operating system generation and customization tools. Additionally, it will construct general-purpose intelligent software development tools and platforms and achieve breakthroughs in the customization and integration of industrial software frameworks and components for specific domains.

Quality Assurance Methods for Building Self-Adaptive Autonomous Intelligent Software. Achieve breakthroughs in verifiable, sustainable, and lifecycle-spanning quality assurance methods. Address the challenges of combinatorial space complexity explosion under multi-objective quality assurance in the spatial dimension and support self-adaptive structural and behavioral adjustments in response to environmental and requirement changes in the temporal dimension. This will enable intelligent software to adapt and evolve in large-scale, highly dynamic, strongly heterogeneous, and widely distributed environments.

The overarching scientific goal is to explore the foundational theories of new paradigm for intelligent software, and to break through key technologies such as automation and crowd-intelligence-driven intelligent software development, software-defined approaches for ubiquitous operating systems, and domain-specific techniques to industry fields. Based on the new paradigm, this major research plan aims to construct innovative frameworks and integration methodologies for key industrial software, laying the foundation for an open-source and open ecosystem for intelligent software innovation. This aims to enhance China's innovation capabilities in mission-critical fields.

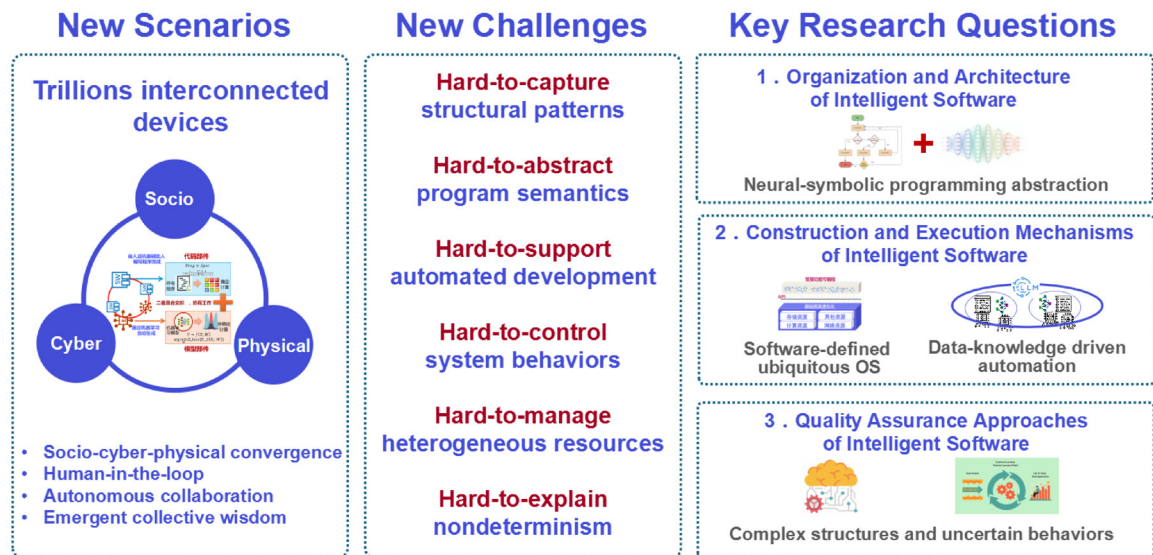
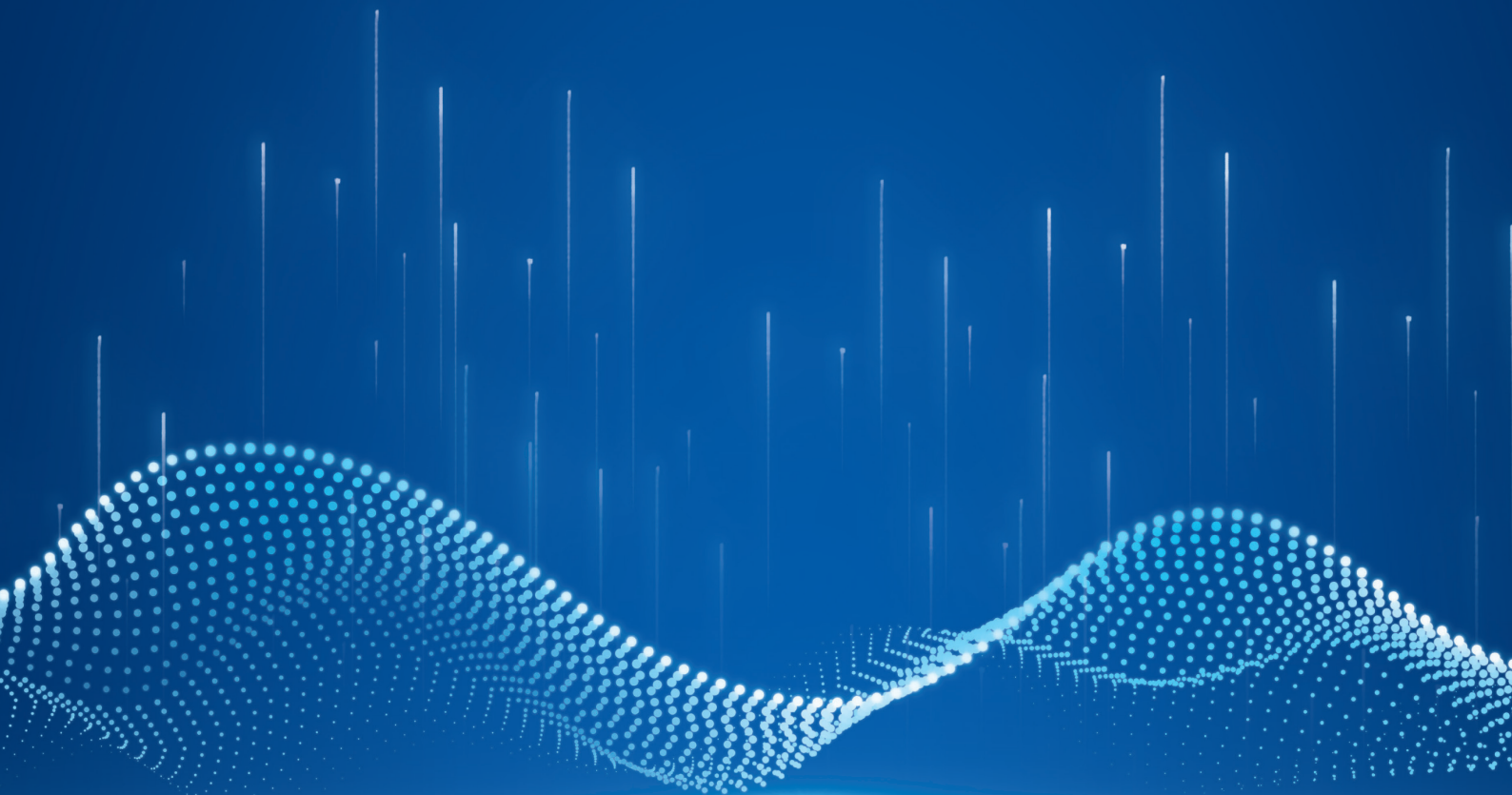


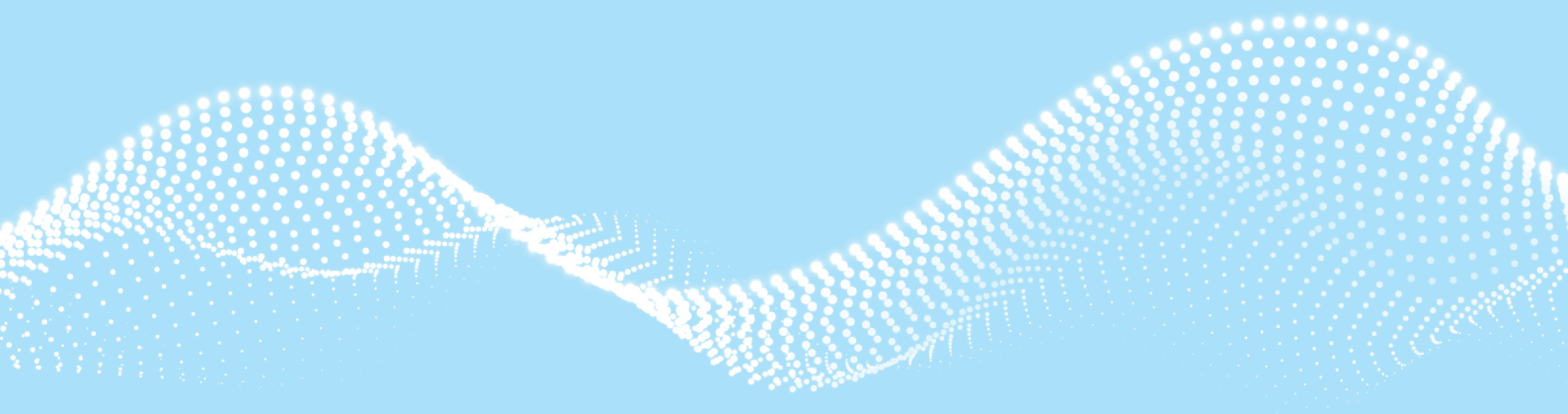
Figure2-2-5 Key Scientific Research Problems of Intelligent Software for Human-Cyber-Physical Convergence

PART 3

Funding Achievement Tour 2024



NSFC



1. Department of Mathematics and Physical Sciences

Quantum Algorithms for Partial Differential Equations

With the support of the National Natural Science Foundation of China (Special Fund Project 12341104, Key Project 12031013), Professors Jin Shi, Nana Liu and Dr. Yu Yue of Shanghai Jiao Tong University have made significant progress in the direction of quantum computing of partial differential equations. The results, titled “Quantum simulation of partial differential equations via Schrödingerisation”, will be published in *Physical Review Letters* in 2024.

Differential equations are at the core of scientific computing in physics, chemistry, engineering and other fields. Many of these equations are of high dimension and often contain small and multiple scales. At the same time, they require high-resolution and large-scale computation, which brings great difficulties to classical computing. Therefore, it is hoped that quantum computing can solve these computing bottlenecks. Quantum computers are designed according to the principles of quantum mechanics. Their basic operations follow the evolution properties of the Schrödinger equation, which is, starting from the initial quantum state (a unit vector in high-dimensional complex space), through the action of unitary operators, it evolves to a new quantum state. The quantum gates in quantum circuits must also be unitary matrices. However, most of the evolution operators of differential equations are not unitary, which means that quantum simulation cannot be performed directly. This is the essential difficulty of quantum computing to solve differential equations.

The “Schrödingerization” method developed by the team introduces a novel transformation (called warped phase transformation) to transfer all linear ordinary and partial differential equations into Schrödinger-type equations (the evolution operators are unitary) in a higher-dimensional Fourier space, so that quantum simulation can be performed. Another important feature of this scheme is that it is applicable to both qubits and continuous variable frameworks, the latter of which provides the possibility to build analog quantum computing devices that are expected to be easier to achieve in the near future. There is no need to discretize the partial differential equations. The D-dimensional linear partial differential equations can be directly mapped to a quantum system of (D+1) qumodes, and quantum simulation can be done with (D+1) qumodes.

Important linear PDEs include Black-Scholes equations in finance, radiation transport equations in radiotherapy design, Maxwell’s equations in communications, and elastic wave equations used in geological exploration, etc. The Schrödingerization method makes it more likely to develop analog quantum

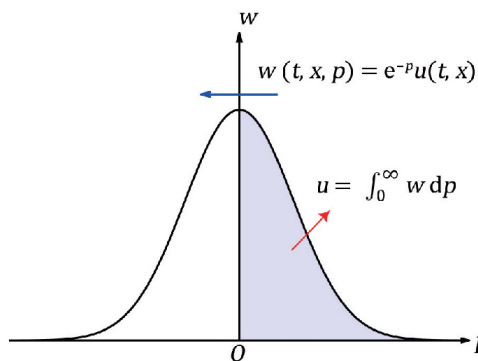


Fig 3-1-1 Graphic Illustration of Schrödingerization

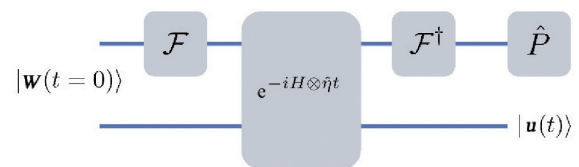


Fig 3-1-2 Quantum circuits for Schrödingerization



computing devices to solve some of these equations. The analog quantum simulation the team proposed is also suitable for some nonlinear PDEs such as Hamilton-Jacobi equations. In addition, Schrödinger equation makes it possible to design quantum circuits of these PDEs for future digital quantum computers.

This work significantly extends the domain of the problems in sciences and engineering that can be solved by quantum simulation, and opens many exciting new opportunities for the applications of quantum computing in these areas.

Mechanics Research on Stress and Deformation Perception using Deformable Origami Structures

Human skin is rich in stress and deformation receptors (collectively known as mechanoreceptors), which plays a crucial role in object recognition based on touch. Recent advancements in bioelectronics have enabled these mechanoreceptors to be activated rapidly and programmable, unlocking broad application possibilities in virtual reality (VR), augmented reality (AR), gaming, and therapeutic systems. However, achieving rich mechanical perceptions, especially with high fidelity and multimodal capabilities, remains a significant challenge for both academia and industry. This underscores the urgent need for novel mechanics designs and implementation methods to recreate diverse mechanical sensations.

Supported by the National Natural Science Foundation (Original Exploration Project No. 12350003), Professor Hanqing Jiang's team at Westlake University has made progress in the study of origami-based mechanical haptic reproduction.

Inspired by curved origami, the team developed a first-person, user-triggered haptic device for immersive VR experiences. Unlike traditional machine-triggered passive haptic devices, this device allows users to actively interact with objects in virtual environments, simulating a wide range of deformation sensations—from soft to hard textures, and even negative stiffness (e.g., the sensation of breaking or falling). The origami-based structure provides real-time tactile feedback, creating a more realistic and high-fidelity sensory experience.

Building on this foundation, the researchers further developed a wireless, real-time haptic interface that integrates a mechanically bistable mechanism inspired by Kresling origami pattern [Fig. 1]. This design stores and releases mechanical energy through the skin, offering diverse tactile experiences such as normal pressure, shear force, and vibrations, realistically mimicking natural touch. The team conducted mechanical analyses of the curved Kresling origami structures, designing and implementing an interactive interface that can integrate more closely with bioelectronics. The mechanically engineered interface is lighter, more flexible, and energy-efficient compared to traditional electrostatic or electromagnetic devices. This system is particularly suitable for biomedical applications, providing sensory substitution for users with visual or proprioceptive impairments. By integrating the deformable origami-based haptic device with smartphones, the study enhances user navigation and stability in virtual environments. Combining the principles of deformable origami with advanced bioelectronics, this interface offers a multifunctional, immersive, and energy-efficient solution for haptic experiences, with broad application potential in gaming, rehabilitation, and human-computer interaction.

The relevant finding was published under the title “*Bioelastic State Recovery for Haptic Sensory Substitution*” in *Nature* on November 6th, 2024.

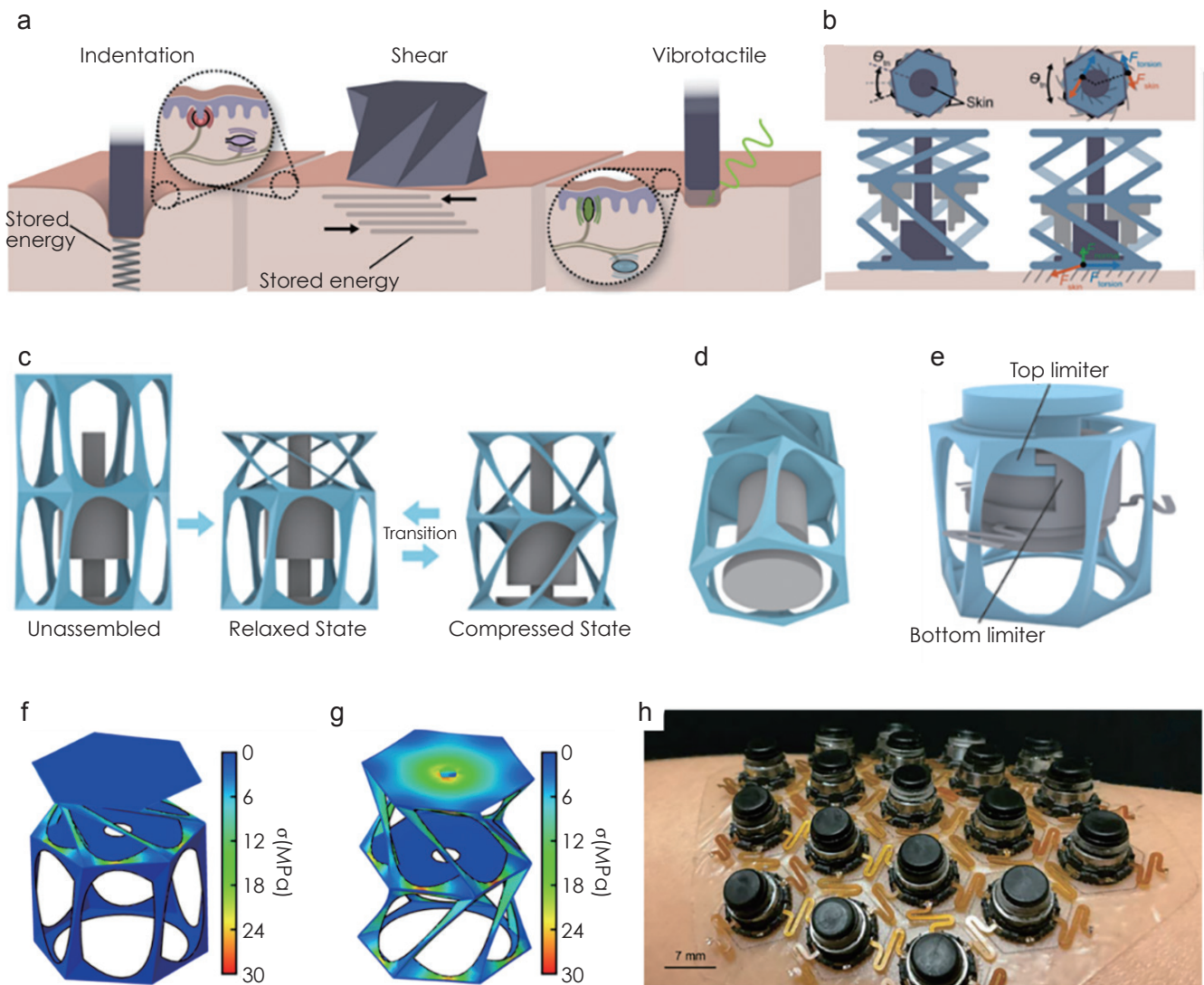


Figure 3-1-3 Stress and Deformation Perception using Deformable Origami Structures

Research on Hydrogen-Rich Atmospheric Hydrodynamic Escape of Low-Mass Exoplanets

Atmospheric hydrodynamic escape of exoplanets can be driven by planetary thermal energy, stellar tidal forces, or extreme ultraviolet radiation from stars, either individually or in combination. However, there has been no clear consensus on the specific roles each of these factors plays. Previously, researchers relied on complex calculations to determine which physical mechanism drives the hydrodynamic escape on a planet, and the conclusions were often unclear. With funding from the National Natural Science Foundation of China (12288102 and 11973082) and the Strategic Priority Research Program of the Chinese Academy of Sciences (XDB 41000000), research by Guo Jianheng from the Yunnan Observatory of the Chinese Academy of Sciences found that the driving mechanism of hydrogen-rich atmospheric hydrodynamic escape can be simply classified using the basic physical parameters of stars and planets (Figure. 1).

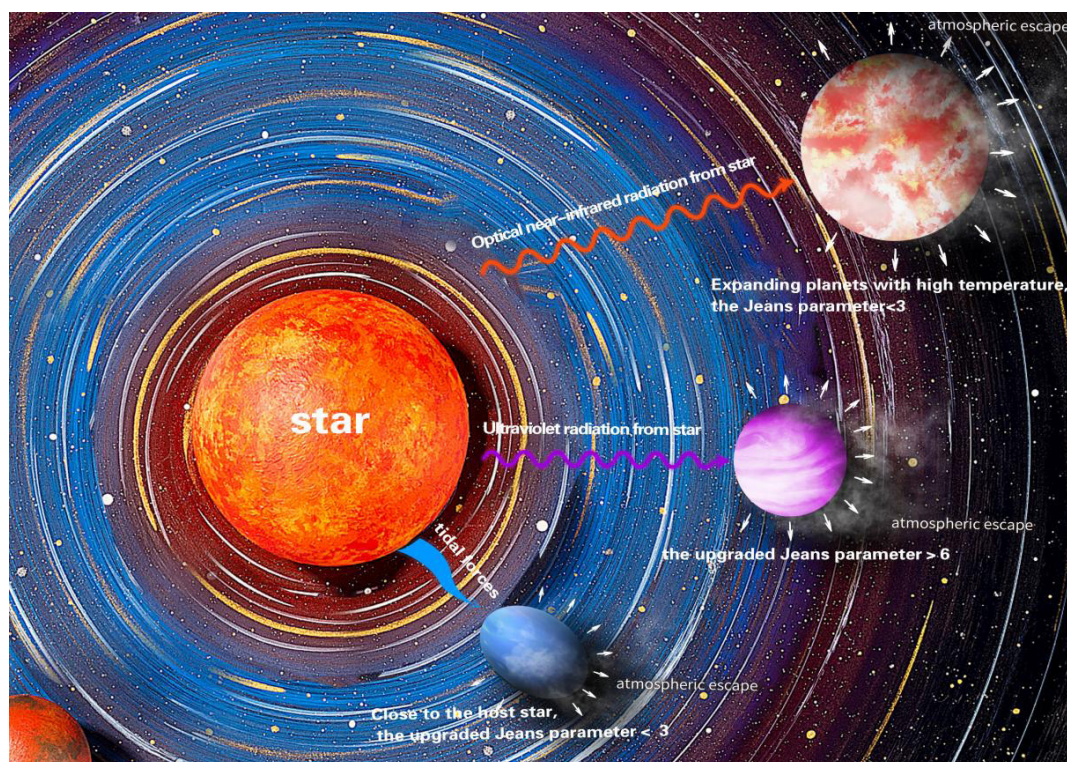


Figure 3-1-4 Schematic diagram of atmospheric hydrodynamic escape

The study conducted calculations and analyses on thousands of planets with masses less than twice that of Neptune. It was found that even without other external energy sources, high planetary temperatures on low-mass and large-radius planets can drive atmospheric hydrodynamic escape. This process requires the planet's "Jeans parameter"—a dimensionless parameter describing the ratio of gravitational potential energy to thermal energy—to be less than 3.5. However, when considering external energy-driven processes, such as stellar extreme ultraviolet radiation and tidal forces, the Jeans parameter is ineffective. In light of this, the authors proposed an "upgraded Jeans parameter" composed of basic physical parameters of stars and planets. The study indicates that when a planet is very close to its host star and the upgraded Jeans parameter is below 3, the planet experiences strong stellar tidal forces, and atmospheric escape is mainly driven by tidal forces; when the upgraded Jeans parameter ranges from 3 to 6, both stellar extreme ultraviolet radiation and tidal forces can trigger atmospheric escape; and when the upgraded Jeans parameter exceeds 6, stellar tidal forces become insignificant, and atmospheric escape is mainly driven by stellar extreme ultraviolet radiation heating.

The results of this study have deepened our understanding of the mechanisms of atmospheric hydrodynamic escape in exoplanets and provide an important reference for the theoretical research on whether a planetary atmosphere can be retained. The research findings were published on May 9, 2024, in *Nature Astronomy* under the title "Characterization of the regimes of hydrodynamic escape from low-mass exoplanets." The reviewers considered: "The authors have proposed a novel method to categorize atmospheric escape and systematize it, which is more robust than the classification based on the classical Jeans parameter, as the latter does not consider tidal effects."

Study of Singular Dielectric Nanolaser with Atomic-scale Field Localization

Achieving extreme localization of optical fields across various dimensions has long been a central frontier in the fields of laser physics and photonic devices. In the frequency domain, localized optical fields have driven significant scientific breakthroughs, such as Bose-Einstein condensation (2001 Nobel Prize in Physics), precision laser spectroscopy (2005 Nobel Prize in Physics), and gravitational wave detection (2017 Nobel Prize in Physics). In the time domain, advancements in localized optical fields led to the groundbreaking realization of attosecond lasers, a development recognized with the 2023 Nobel Prize in Physics. In the spatial domain, localized optical fields have profound implications for advancements in information technology and for exploring light-matter interactions under extreme conditions.

In 2009, the introduction of the plasmonic dispersion equation into laser design revolutionized laser miniaturization, enabling the construction of plasmonic nanolasers with sub-diffraction-limited mode volumes. However, this technology is constrained by the intrinsic ohmic losses of metallic materials, hindering further optimization. Meanwhile, in dielectric systems, there is currently no theoretical framework capable of surpassing the optical diffraction limit. Developing innovative theoretical approaches is therefore crucial to advancing spatially localized laser technology, paving the way for future breakthroughs in photonic science and technology.

Supported by grants from the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars, Project 12225402; Innovative Research Groups Project, 62321004; Major Research Plan Integration Project, 92250302), Professor Ren-Min Ma's research group at the Institute of Condensed Matter Physics and Materials Physics, School of Physics, Peking University, has proposed the singular dispersion equation. This work establishes a theoretical framework for overcoming the optical diffraction limit in dielectric systems and introduces a novel method for fabricating optical nanocavities with atomic-scale characteristics. This approach achieved the smallest laser mode volume to date. The resulting singular dielectric nanolaser pushes the characteristic scale of lasers to the atomic level, as illustrated in Figure 3-1-5. The study, titled "Singular dielectric nanolaser with atomic-scale field localization," was published in *Nature* on July 17, 2024.

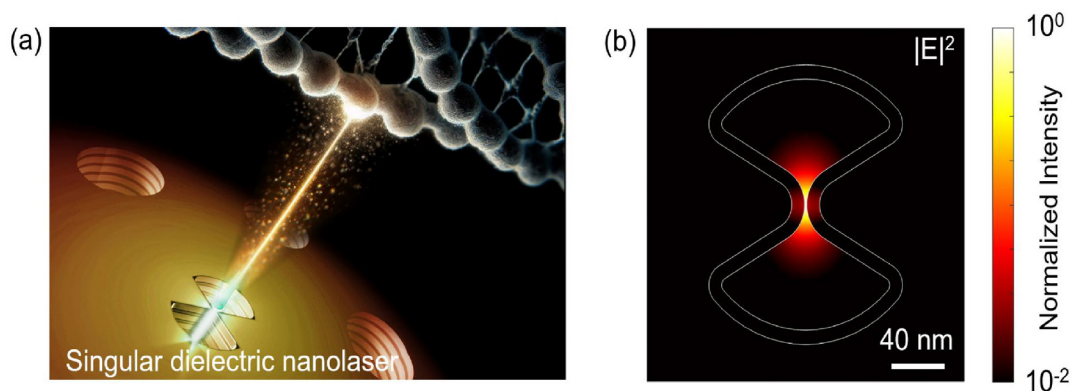


Figure 3-1-5 Singular dispersion equation and singular dielectric nanolaser. (a) Singular dispersion equation, and schematic of the singular dielectric nanolaser. (b) Electron microscopy image of the singular dielectric nanolaser. (c) Electron microscopy image of the central region of the singular dielectric nanolaser. (d) Electric field intensity distribution of the singular dielectric nanolaser. (e) Electric field intensity distribution in the central region of the singular dielectric nanolaser.



Following publication, *Nature Reviews Electrical Engineering* invited Professor Ma's team to write a feature comment article, outlining the historical development, challenges, latest advancements, and prospects in this field. Additionally, the work was highlighted by *Advanced Photonics*, which noted in its commentary: "The development of this groundbreaking dielectric nanolaser marks a pivotal milestone in the field of integrated photonics and quantum photonics, showcasing a substantial technical achievement." A review article in *Advanced Materials* further praised the study, stating: "These designs can achieve extreme light confinement and have emerged as a prominent topic of research in nanophotonics." Moreover, the research was selected as one of the "Three-Year Outstanding Achievements in Optical Metamaterials."

Discovery of the Spin Supersolid and its Giant Magnetocaloric Effect

Supersolid is a quantum state of matter that exists at nearly absolute zero temperature, exhibiting properties of both solid and superfluid. This state was proposed over half a century ago by theorists such as A.F. Andreev and I.M. Lifshitz from Russia, and Nobel Laureate A. Leggett from the UK, among others. However, despite advances in theoretical studies and cold atomic gas simulations, convincing experimental evidence of supersolidity in realistic solid materials has remained elusive.

Under the support of the National Natural Science Foundation of China (Grant Nos. 12222412, 11834014, 12141002, and 12074024 etc.), a research team including Professors Gang Su and Wei Li from the Institute of Theoretical Physics at the Chinese Academy of Sciences (CAS) and the University of Chinese Academy of Sciences; Professor Peijie Sun and Associate Professor Junsen Xiang from the Institute of Physics, CAS; and Associate Professor Wentao Jin from Beihang University, successfully synthesized a cobalt-based triangular-lattice quantum antiferromagnet, $\text{Na}_2\text{BaCo}(\text{PO}_4)_2$, and provided the first experimental realization of supersolidity in a quantum magnetic compound.

Through ultra-low-temperature neutron diffraction, the researchers confirmed that the out-of-plane spin components form a three-sublattice solid order that breaks the Z_3 discrete symmetry. The presence of interlayer incommensurate magnetic peaks suggests the existence of spin superfluid ordering. By conducting precise theoretical and experimental comparisons, they identified the spin supersolid states in this compound, as illustrated in Figures 1(a) and 1(b). Additionally, they developed the advanced adiabatic temperature measurement techniques, discovered a giant magnetocaloric effect (MCE) in the spin supersolid phase, and achieved a minimum refrigeration temperature of 94 mK by manipulating the magnetic field adiabatically, paving a new avenue for extremely low temperature cooling, as shown in Figure 1(c). A phase diagram for this compound including two spin supersolid phases (I and III), a spin solid phase (II), and a spin-polarized phase (IV), is depicted in Figure 1(d).

This work was published on January 11th 2024 in *Nature* entitled "Giant magnetocaloric effect in spin supersolid candidate $\text{Na}_2\text{BaCo}(\text{PO}_4)_2$ ". A *Nature* research briefing accompanying the paper highlighted that the giant MCE of the spin supersolid state "*promises a new route to extreme cooling*" and praised the work as "*a magnetocaloric effect, potentially useful for applications in sub-kelvin refrigeration, arises from this fundamental physics observation, with both advances reported in one paper.*"

The findings were covered by international scientific media such as *Physics World* and *Chemistry World*, etc. G. Modugno, an expert in the field of supersolid and superfluid from the University of Florence, remarked, "*It is exciting that the once hypothetical supersolid is becoming a real fundamental phase of matter showing up in more and more physical systems.*" He is further enthusiastic about "*practical applications like the enhanced cooling capabilities.*"

This work has garnered widespread attention and follow-up research worldwide. The research team has been invited to deliver talks at major events, including 2024 American Physical Society March Meeting.

Independent research groups from Switzerland and the United States have also reported experimental evidence of spin supersolids in another cobalt-based triangular lattice material. This paper was also selected as an ESI Highly Cited Paper.

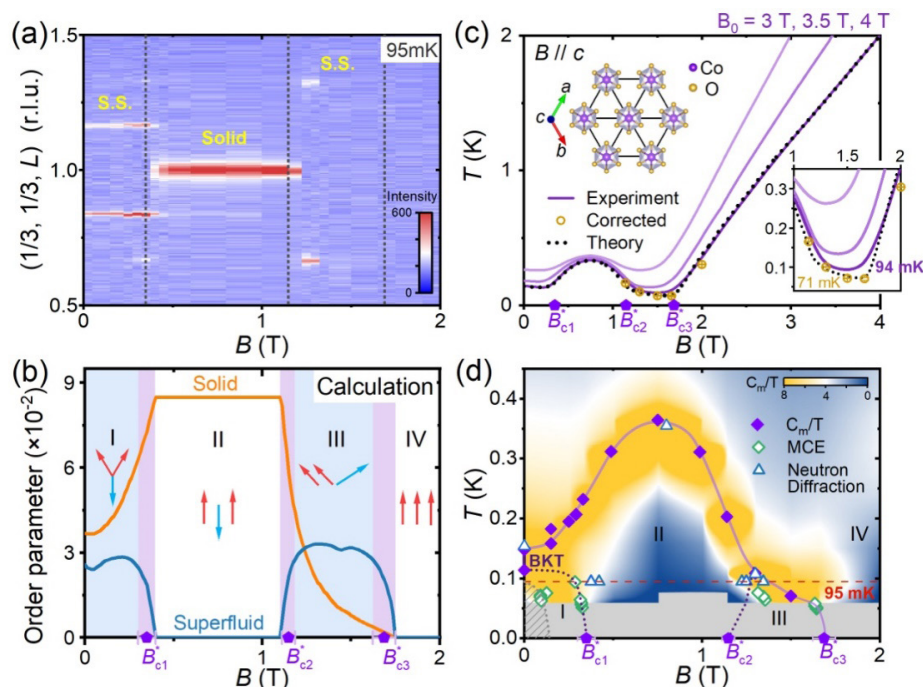


Figure 3-1-6 (a) Single-crystal neutron diffraction data of $\text{Na}_2\text{BaCo}(\text{PO}_4)_2$ at 95 mK, SS denotes the supersolid phase; (b) Calculated solid and superfluid order parameters versus magnetic fields; (c) Adiabatic demagnetization cooling curve, with the inset zooming into the regime near supersolid transition; (d) A comprehensive temperature-field phase diagram determined from various measurements in the experiment.

A Study of the Structure of Atomic Nuclei in Relativistic Heavy-ion Collisions

Atomic nuclei, composed of protons and neutrons, are microscopic quantum many-body quantum systems. Their shapes are explored via traditional nuclear reaction or structure measurements at low energies on long-time scales. High-energy heavy-ion collisions, as an important key to probing the properties of strongly interacting matter, offer a frontier intersection for studying nuclear structure across energy scales. High-energy heavy-ion collisions are on the order of a yoctosecond ($\sim 10^{-24}$ s) timescale, significantly shorter than the quantum fluctuations in nuclei in zeptosecond ($\sim 10^{-21}$ s) scale in the laboratory frame, which are six orders of magnitude shorter than the attosecond pulses used in studying electron dynamics of matter honored by the 2023 Nobel Prize in Physics. Structural information of colliding nuclei is effectively imprinted onto the initial conditions of the quark-gluon plasma (QGP) in an ultrashort timescale and subsequently mapped onto the momentum distributions of final-state particles through hydrodynamic evolution. Such nuclear collisions are analogous to the camera's fast snapshot, capture the instantaneous shape of the nucleus, and serve as a practical tool to explore nuclear structure (Figure 3-1-7).

Under the financial support of NSFC funding (Grants No. 11890710, 12147101, 12025501), Professor Yugang Ma's group at Fudan University, participating in the RHIC-STAR international collaboration based on large-scale scientific facilities, has achieved a breakthrough in imaging nuclear structures using high-energy heavy-ion collision experiments. This marks a pioneering advancement in nuclear structure research

across energy scales, providing a novel tool for quantitatively constraining nuclear structure information. This study confirms that the ground-state uranium-238 nuclei exhibit a significant elongated, axial-symmetric quadrupole deformation and highlights a possibly slight triaxial deformation deviation from axial symmetry. These findings are aligned with conclusions from previous low-energy experimental and theoretical studies (Figure 3-1-8). The above research, titled “Imaging Shapes of Atomic Nuclei in High-Energy Nuclear Collisions,” was published in *Nature* on November 7, 2024.

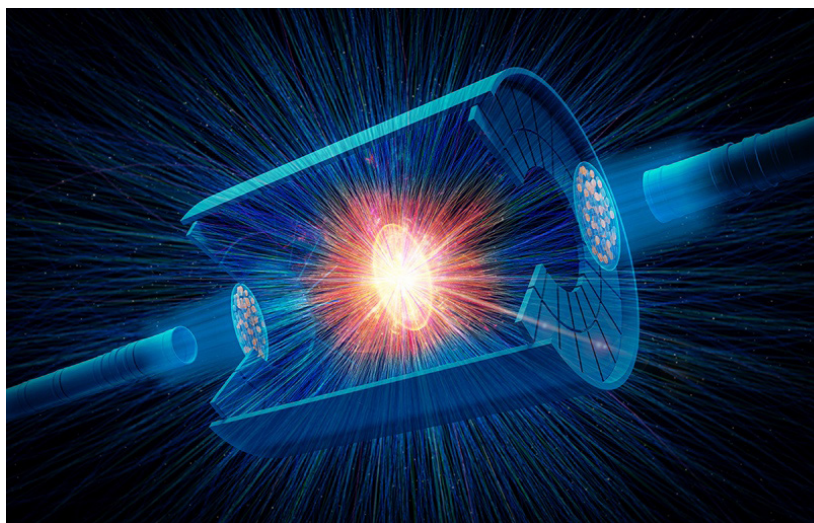


Figure 3-1-7 Sketch of uranium-238 nucleus collisions at relativistic heavy ion collider (RHIC)

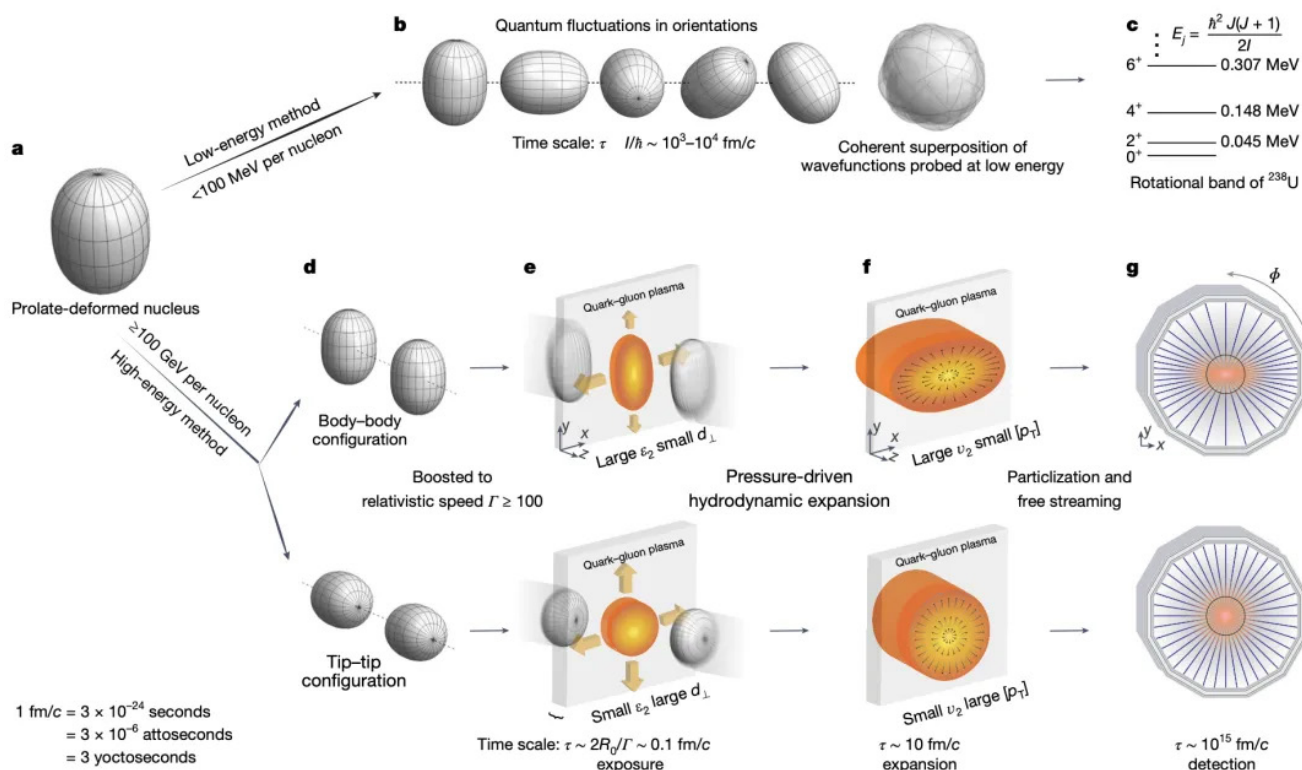


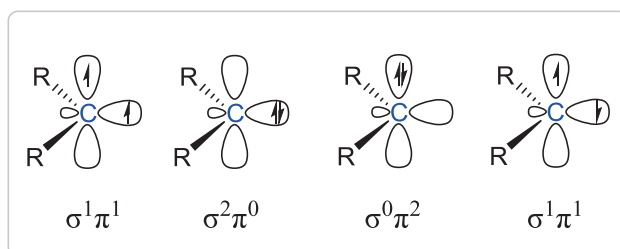
Figure 3-1-8 Schematic diagram of methods for determining nuclear structures in low-energy measurements and high-energy collisions.

This study facilitates a better constraint of QGP initial conditions and contributes to addressing fundamental scientific issues such as nucleosynthesis, nuclear fission, and neutrinoless double-beta decay. It also provides a critical reference for refining and improving the precision of nuclear theoretical models and their calculations. The innovative method proposed in this article holds the potential to help understand core challenges in low-energy nuclear physics, including higher-order nuclear deformations, shape coexistence, neutron skins, and cluster structures. It can be further extended to investigations at large-scale scientific facilities such as the European Organization for Nuclear Research (CERN), the next-generation Electron-Ion Collider (EIC) in the United States, and China's High-Intensity Heavy-Ion Accelerator Facility (HIAF). Future research will strengthen international collaborations, broaden the frontier of nuclear structure physics across energy scales, and enhance China's global influence in cutting-edge nuclear physics study.

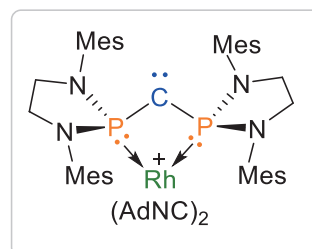
2. Department of Chemical Sciences

Synthesis and Characterization of Carbene with a $\sigma^0\pi^2$ Electronic Configuration

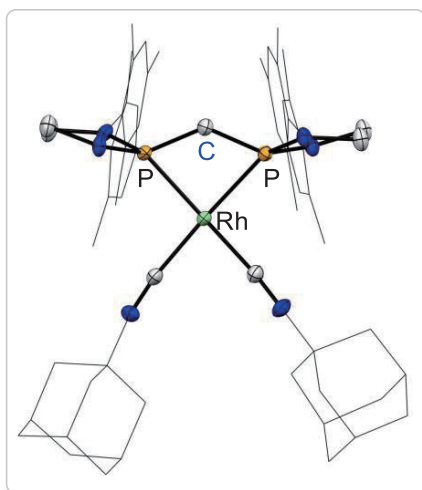
Carbon typically abides by the octet rule, but notable exceptions exist, such as six-electron carbene molecules ($R_2C:$). As a critical class of low-valent carbon species, carbenes find extensive applications in synthetic chemistry, materials science, and related fields. Carbenes can exhibit four distinct electronic configurations (Figure 3-2-1a), yet all previously synthesized singlet carbenes possess the $\sigma^2\pi^0$ electronic configuration. The synthesis and investigation of carbenes with a $\sigma^0\pi^2$ electronic configuration could expand the understanding of carbon chemistry and foster advancements in synthetic chemistry and related fields.



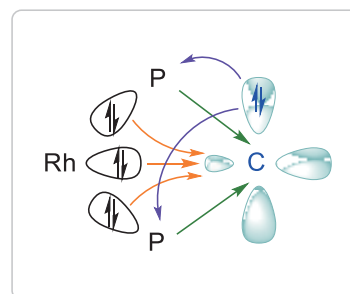
(a) Primary electronic configurations of carbenes



(b) Molecular structure of s^0p^2 carbene



(c) Solid-state structures of s^0p^2 carbene



(d) The essence stabilization of s^0p^2 carbene

Figure 3-2-1 The electronic configurations of carbenes and the structure and stabilization of a $\sigma^0\pi^2$ carbene.

Supported by the National Natural Science Foundation of China (Grants No. 22350004, 22271132, and 22301122), the research team led by Liu Leo Liu at the Southern University of Science and Technology has synthesized an ambiphilic carbene with a $\sigma^0\pi^2$ electronic configuration (Figure 3-2-1b). Utilizing the principle of electroneutrality and an innovative “coordination-fixation” strategy, the study achieved the following major breakthroughs:

(1) Synthesis and characterization of $\sigma^0\pi^2$ carbene for the first time: The carbene was stabilized by coordinating the phosphino substituents with a rhodium complex. The structure and properties of this

carbene were comprehensively analyzed using nuclear magnetic resonance, X-ray crystallography (Fig. 3-2-1c), high-resolution mass spectrometry, and theoretical calculations.

(2) Stabilization via the in-plane electron push effect and out-of-plane electron pull effect: The thermodynamic stability of the $\sigma^0\pi^2$ carbene was significantly enhanced through the in-plane σ -electron donation by the lone pairs of phosphino substituents and the rhodium d-electrons, coupled with the out-of-plane electron acceptance by the σ^* antibonding orbitals of the phosphino substituents (Figure 3-2-1d).

The findings, published in *Science* on January 5, 2024, under the title “A stable rhodium-coordinated carbene with a $\sigma^0\pi^2$ electronic configuration,” represent a seminal advancement in the field of carbene chemistry. This study details the first synthesis and characterization of the $\sigma^0\pi^2$ carbene, marking a significant departure from traditional carbene research paradigms. It establishes a foundation for future exploration into novel ambiphilic main-group molecules, heralding a new era of chemical innovation.

Dynamically ultrastable confined single-atom catalyst for dehydrogenation of light alkanes

Light olefins are strategic basic raw materials for bulk chemical products, such as synthetic fibers, rubber, and plastics, with an annual global demand of more than 300 million tons. In industry, direct dehydrogenation of alkanes is an important way to produce olefins, but the current commercial technology is mainly monopolized by foreign companies. Due to the harsh reaction conditions, the current commercial catalysts have drawbacks such as easy sintering, easy carbon deposition, and frequent regeneration, leading to carbon emissions. Therefore, it is of great significance to create ultra-high stability catalysts with independent intellectual property rights, develop a new generation of alkane direct dehydrogenation technology, and promote its industrialization.

With the support of the National Natural Science Foundation of China (Innovation Group Grant No. 22121001) and others, Prof. Wang Ye and Prof. Fu Gang of Xiamen University and collaborators from many domestic institutions have made important breakthroughs in the field of direct dehydrogenation of light alkanes to olefins. The research team employed the dynamic migration characteristics of indium (In) and the efficient C–H bond activation ability of single-atom rhodium (Rh) atoms to create an ultra-high stability In/Rh@Silicalite-1 (S-1) catalyst with a lifespan of more than 5,500 hours, which can directly dehydrogenate light alkanes such as propane to produce corresponding olefins (Figure 3-2-2). The results were published in *Science* on March 1, 2024, with the title “Stable anchoring of single rhodium atoms by indium in zeolite alkane dehydrogenation catalysts”.

In response to the major challenge of catalyst stability under high temperatures and harsh reaction conditions, the research team proposed the concept of “in situ dynamic construction of active sites”. Using the oxygen affinity and dynamic migration characteristics of indium, the In/Rh@S-1 catalyst with dynamic formation of active sites under reaction conditions and high stability was designed. In this catalyst, the single rhodium atom is located in the pores of the S-1 zeolite. The indium species spontaneously migrate to the pores to stabilize the single rhodium atom with the In-Rh bond, forming active RhIn_x centers confined in the zeolite. This method provides a new idea for the design and synthesis of ultra-stable and efficient single-atom catalysts.

The novel catalyst effectively avoids the formation of carbon deposits without the requirement of adding hydrogen and frequent regeneration, making the process greener and simpler. Under near-industrial reaction conditions of 550 °C, using pure propane as raw material, the catalyst was evaluated continuously for 5500 hours. Both activity and selectivity remained stable. At a high propane conversion rate of >60% at 600 °C, the In/Rh@S-1 catalyst can operate continuously and stably for more than 1200 hours. Single-atom

rhodium exhibits excellent C-H bond activation performance, and the propylene production rate is 1-2 orders of magnitude higher than that of current Pt-based catalysts. This work is expected to develop into a new alkane dehydrogenation technology with independent intellectual property rights, helping to achieve the goal of carbon neutrality.

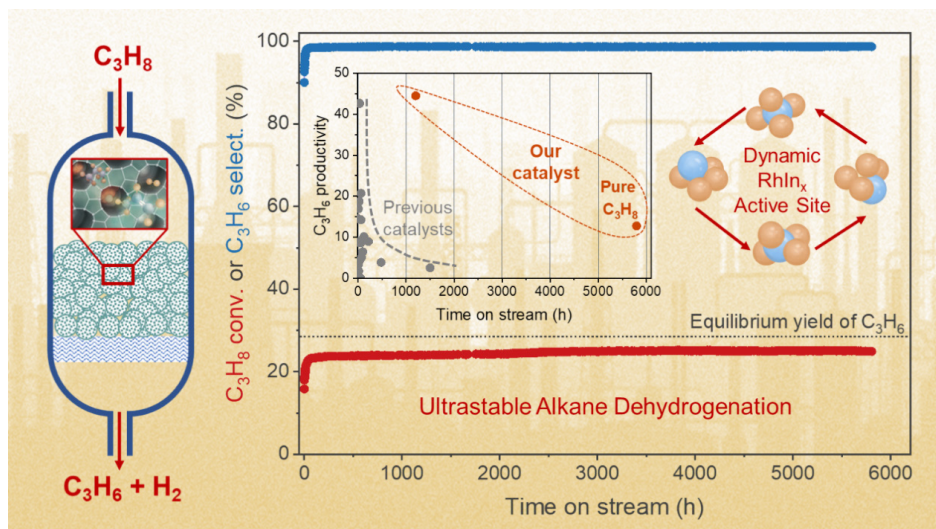


Figure 3-2-2 Ultra-stable single Rh atom catalyst for alkane dehydrogenation

Chiral Mass Spectrometry Analysis

Chirality refers to the property that an object cannot completely overlap with its mirror image, similar to our left and right hands. Chiral molecules are widely present in biological systems and play a crucial role on biological functions. In living organisms, the basic units that make up proteins, sugars, DNA, and RNA, such as amino acids, monosaccharides, and nucleotides, typically exist in a single chiral form (Figure 3-2-3). Due to the inherent chiral environment of biological systems, chiral enantiomer molecules also exhibit different physiological functions and pharmacological activities. Therefore, accurately distinguishing chiral enantiomers of molecules is crucial for life science and drug development. Mass spectrometry has the advantages of high sensitivity and high specificity, but it cannot distinguish chiral enantiomers. It usually needs to be combined with gas chromatography or high-performance liquid chromatography, together with chiral stationary phases for enantiomer analysis.

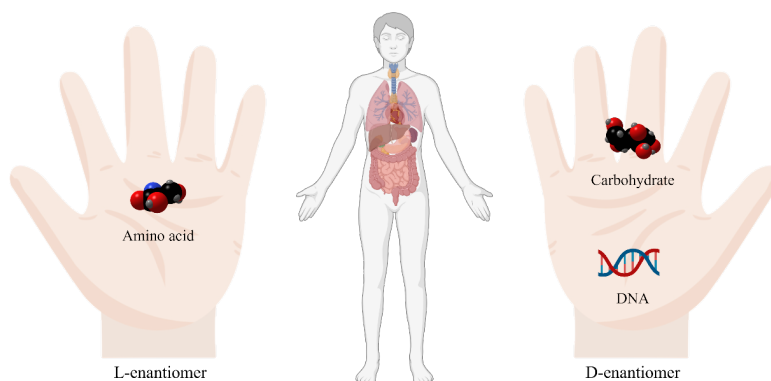
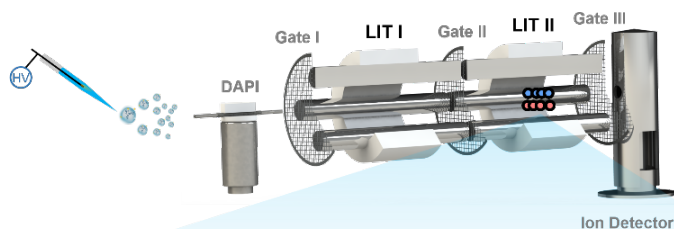


Figure 3-2-3 Chiral molecules in biological systems typically prefer a single chiral form.

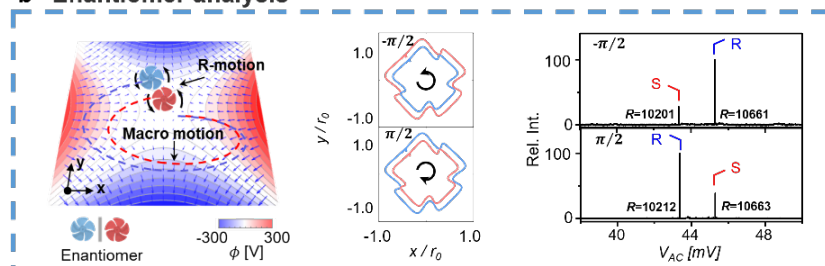
With the support of National Natural Science Foundation of China (Special Fund for Research on National Major Research Instruments Grants No. 21627807, 22227807; Key Program Grant No. 21934003), the group of Professor Ouyang Zheng and Associate Professor Zhou Xiaoyu from Tsinghua University used a miniature ion trap mass spectrometry system (Figure 3-2-4a) to achieve efficient separation and structural analysis of chiral molecules by inducing directional rotations of gas-phase ions using a dual AC (alternative current) excitation. A dual AC excitation electric field is used to induce directional rotation of enantiomer ions, which collides with neutral gas molecules to form differences in ion trajectories.

Adjusting the rotation direction of enantiomeric ions can modulate their emission sequence (Figure 3-2-4b). Ionic directional rotation technology demonstrates universality for chiral compounds. It can separate various chiral molecules such as drugs, metabolic biomarkers, sugars, and amino acids, and demonstrate the potential for relative quantitative analysis. In addition, this technology can be used for asymmetric catalysis to optimize the reaction conditions for enantioselective synthesis. Taking asymmetric hydrogenation reaction as an example, for analysis of enantiomeric excess under different ligand conditions, compared with the chiral chromatographic method (1 mg, several hours/time), the chiral mass spectrometry method using ion directional rotation requires less sample volume (<10 nanograms), and the analysis efficiency (<1 minute) is significantly improved (Figure 3-2-4c).

a Dual-LIT Mini MS



b Enantiomer analysis



c Analytical procedures

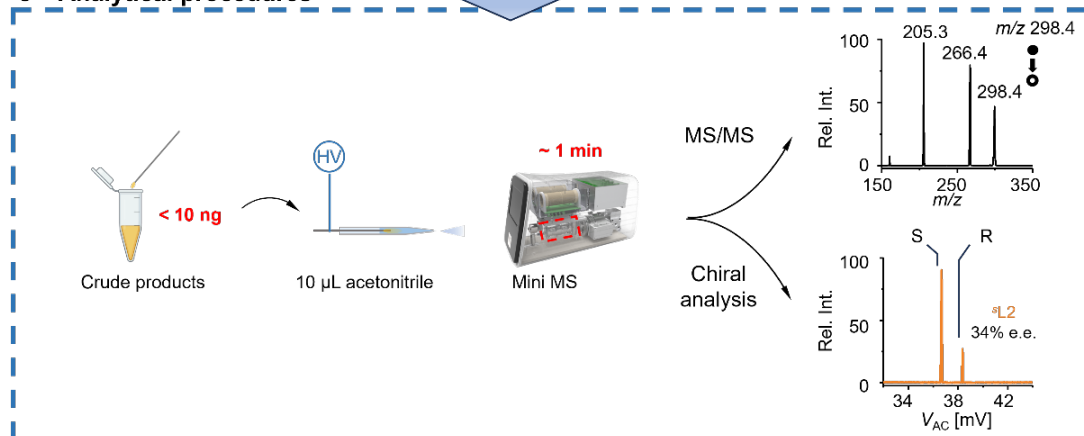


Figure 3-2-4 Workflow of the chiral mass spectrometry method using ion directional rotation.



The related results were published in *Science* on February 9, 2024, with a title of “Differentiating Enantiomers by Directional Rotation of Ions in a Mass Spectrometer”. This study has demonstrated for the first time that the separation of enantiomers can be achieved using physical methods that does not rely on high purity chemical environment. The *Science* reviewer commented that “this is a fascinating study because chirality and chirality analysis are so important.” *Science* and *Nature* reported this work with titles of “Enantioselective Mass Spec, Of All Things” and “Mirror-image Molecules Separated Using Workhorse of Chemistry”, respectively.

Covalent Targeted Radioligands Bring New Breakthroughs in Cancer Diagnosis and Treatment

Targeted Radionuclide Therapy (TRT) is a revolutionary treatment method for cancer that delivers radioactive nuclides to tumour cells for molecular-level therapy. However, improving tumour targeting, extending the retention time of nuclides in tumours to enhance efficacy, and accelerating their excretion from normal organs to reduce side effects are the main challenges faced by TRT. Solving all these simultaneously is even more daunting.

Under the support of the National Science Fund for Distinguished Young Scholars (Grant No.: 22225603), a team led by Liu Zhibo from Peking University and Changping Laboratory has developed a new type of drugs, namely Covalent Targeted Radioligands (CTR), based on modern covalent drug molecular engineering. This breakthrough addresses the long-standing challenge in traditional radiopharmaceuticals where “fast clearance” and “prolong retention” could not be achieved simultaneously (Figure3-2-5).

CTR has been validated at the molecular, cellular, animal model, and patient levels, showing excellent tumour targeting and retention time, while being rapidly cleared from normal tissues. Researchers found that in a mouse model with high expression of FAP (Fibroblast Activation Protein, a pan-cancer target), the PET diagnostic nuclide Ga-68 labeled CTR-FAPI showed more than double the tumour uptake compared to the unmodified drug, with rapid reduction in healthy tissue uptake. The CTR technology also enhances the efficacy of targeted radionuclide therapy by improving retention. Researchers used β^- (Lu-177) and α -radioactive therapeutic nuclides (Ac-225) to label CTR-FAPI, which almost completely inhibited the growth of FAP-high expressing subcutaneous tumours in mice. In preliminary clinical studies of medullary thyroid carcinoma patients, Ga-68 labeled CTR-FAPI showed a significantly higher lesion detection rate than [18F] FDG PET-CT (98% vs. 66%), with 32% of patients changing their treatment plans and 66.7% changing their surgical plans.

This technology enhances the tumour uptake and retention of the ligands while ensuring low uptake in the bloodstream or healthy tissues, potentially overcoming the long-standing dilemma of safety and efficacy in traditional radiopharmaceuticals. CTR-FAPI has been used for more precise diagnosis in over a hundred patients with medullary thyroid carcinoma, identifying minute lesions that existing methods cannot discern, guiding surgical treatment, and achieving significant clinical benefits. At the 2024 American Society of Clinical Oncology (ASCO) annual meeting, clinical experts pointed out that covalent FAPI will change the clinical guidelines for medullary thyroid carcinoma.

The CTR works by installing a “latent warhead” based on Sulfur (VI)-Fluoride Exchange (SuFEx) reaction on the ligand. When CTR reaches the tumour, it first non-covalently binds to the target and then, through the proximity effect, accelerates irreversible covalent connection to minimize tumour clearance, while free CTRs that do not bind to the target are rapidly excreted. This technology has been validated at the molecular, cellular, animal model, and patient levels.

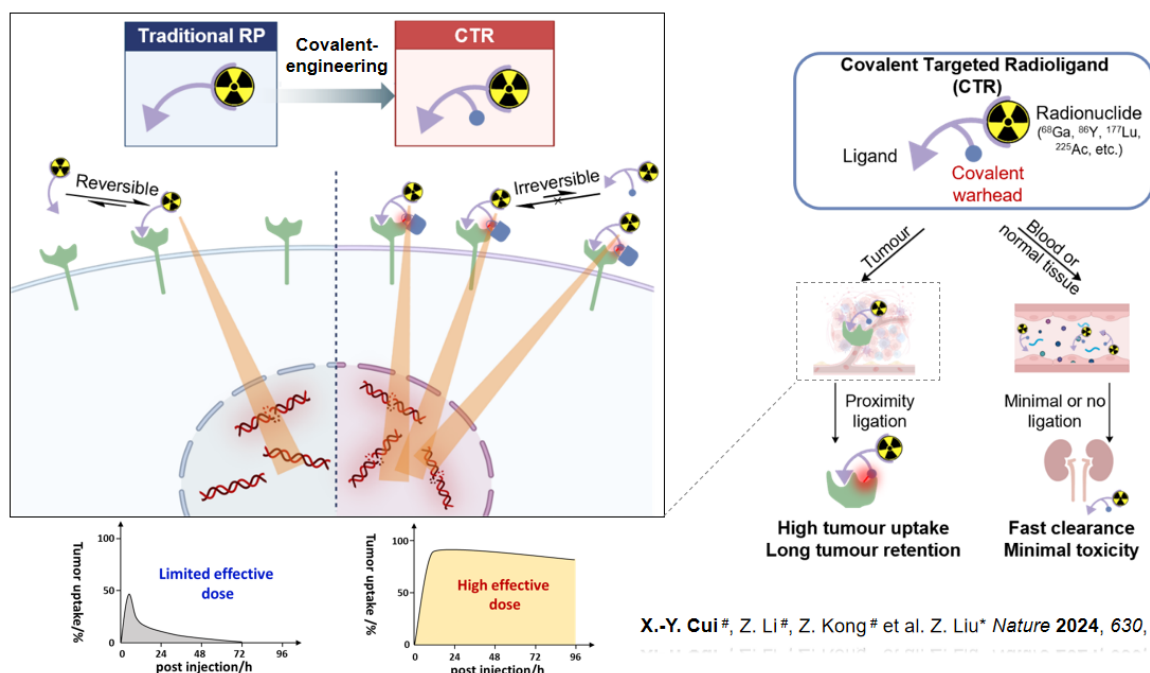


Figure3-2-5 The Advantages of Covalent Targeted Radioligands

3D printable elastomers with exceptional strength and toughness

Funded by National Natural Science Foundation of China (Grants No. U23A2098, 22288102, 52033009, 22375176), a research team led by Prof. Tao Xie and Dr. Jingjun Wu from Zhejiang University has achieved a major success in 3D printing of elastomers with superior mechanical properties. This work with the title of "3D Printable Elastomers with Exceptional Strength and Toughness" was published online in *Nature* on July 3, 2024. 3D printing, particularly light-curing based DLP printing, is uniquely suited for fabricating geometrically complex and highly integrated structures with high precision. Despite its potential for future manufacturing, the low strength and toughness of the printed materials remains a bottleneck for large scale manufacturing of end-use products. The underlying issue lies in the conflict between the molecular design towards high performance materials and the unique processing requirements of the DLP printing, making it difficult to simultaneously achieve rapid photo-polymerization and superior material mechanical properties.

The team from Zhejiang University applied the concept of Topology Isomerization Network (TIN) they previously developed to decouple the printing process from the regulation of material properties. The polyurethane acrylate monomer they designed, which contains dynamic hindered urea bonds, exhibits excellent printability (Figure 3-2-6). Upon post-printing thermal treatment, the dynamic bond exchange was triggered and the network structure underwent evolution via the topological isomerization mechanism. This allows introducing multiple toughening mechanisms such as interpenetrating networks, multiple hydrogen bonds, and micro-phase separation. Synergistically, these mechanisms significantly enhance the material's mechanical performance. The elastomeric materials designed based on this principle not only enable high-precision light-cured 3D printing but also achieve strength and toughness of 94.6 MPa and 310.4 MJ/m³, respectively, far exceeding any commercial products and those reported in scientific literature.

This work demonstrates a highly effective approach to overcome the conflict between material processing and performance. It opens up a new venue for molecular/network design of mechanically superior materials in photopolymer 3D printing. High-performance 3D printable elastomers have already

been validated for use in consumer products such as high-performance bicycle saddles and protective helmets. The researchers believe that this design concept can also be applied to develop other high-performance 3D materials, such as high-strength and tough engineering plastics, which would further unleash the freedom for future manufacturing.

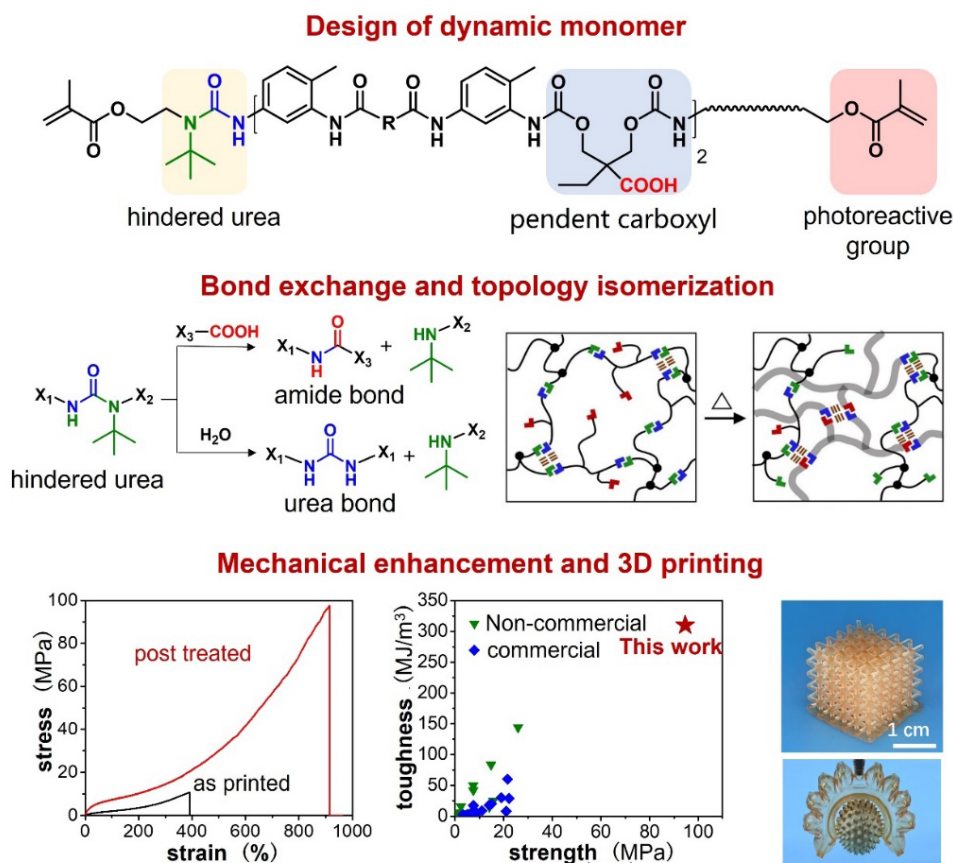


Figure 3-2-6 Elastomers with Exceptional Strength and Toughness: Molecular Design, Network Topology Isomerization, and Mechanical Enhancement.

Molecular Mechanisms of Cholestatic Pruritus and New Approaches for Liver Disease Treatment

Bile acids are the end products of cholesterol metabolism in the liver and participate in the digestion and absorption of fats as well as the regulation of cholesterol metabolism through the enterohepatic circulation, playing crucial physiological roles. However, when bile flow is obstructed, leading to cholestasis, bile acids cannot be properly metabolized and accumulate in the body. Up to 80% of cholestasis patients experience severe systemic chronic pruritus, significantly affecting their quality of life. Despite this, the molecular mechanisms underlying cholestatic pruritus remain unclear, and no effective therapeutic drugs are available, far from meeting clinical needs.

With support from the National Natural Science Foundation of China (Major Project Grant No. 22337002, Major Research Plan Integrated Project 92253305, Major Project 22193073, General Project 22177006), Professor Lei Xiaoguang's team at Peking University collaborated with Professor Li Yulong's team at Peking

University, and Professor Chen Yu's team at Beijing You'an Hospital, Capital Medical University. Through a close integration of basic research and clinical medicine, they were the first to discover that 3-sulfated bile acids enhance their affinity to the itch receptor MRGPRX4, thereby inducing cholestatic pruritus. Using cryo-electron microscopy (Cryo-EM), they determined the structure of the bile acid derivative DCA-3P bound with MRGPRX4, revealing the molecular mechanism by which bile acids activate this receptor and the critical role of the 3-hydroxyl group of bile acids in receptor activation.

Guided by this mechanistic study, they further chemically modified obeticholic acid (OCA), a clinical treatment known for its severe pruritus side effects, to obtain a novel candidate drug molecule (Figure 3-2-7). This new compound C7 was shown to retain its liver disease treatment properties while no longer activating the itch receptor, thus preventing pruritus. This study represents a complete research cycle—from addressing a clinical problem to conducting in-depth disease mechanism studies, identifying new drug targets, developing candidate drug molecules, and ultimately returning to clinical treatment, providing new insights for the treatment of liver and biliary diseases.

The related findings were published in *Cell* on October 29, 2024, under the title “Structure-guided discovery of bile acid derivatives for treating liver diseases without causing itch.”

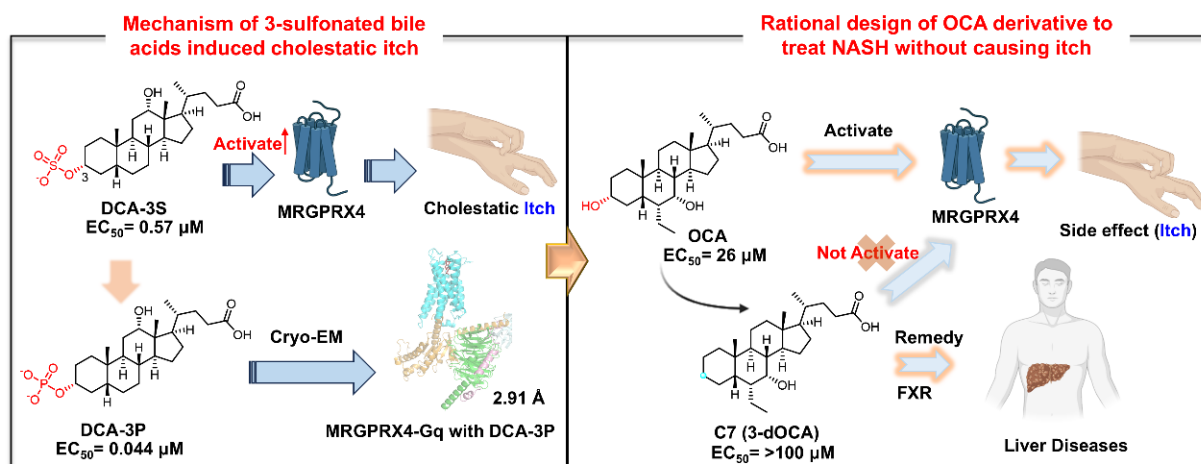


Figure 3-2-7 Molecular Mechanism of Bile Acid Activation of MRGPRX4 Leading to Pruritus and Development of Lead Compounds for Liver Disease Treatment without Pruritus Side Effects

3. Department of Life Sciences

Study on the Molecular Mechanisms by which the Floral Structure is Modified for Self-pollination in Tomato

Approximately 90% of plants on Earth reproduce through flowering and fertilization, producing fruits and seeds. Pollination of plants is one of the most important techniques in modern agricultural breeding. In nature, plants have two forms of pollination: self-pollination and cross-pollination. Self-pollination enhances the genetic stability of plant populations, preserving desirable traits and facilitating the development of new varieties in domesticated crops; many common crops are self-pollinating. Closed flower pollination (cleistogamy) is the most stringent form of self-pollination, isolating against contact and contamination by external pollens. Its high pollination efficiency often leads to increased fruit set rates and yields. Additionally, cleistogamy can help control the “gene pollution” associated with transgenic crops. Therefore, understanding the mechanisms underlying cleistogamy formation in plants is of great importance.

Recently, a team led by Shuang Wu from Fujian Agriculture and Forestry University, funded by the National Natural Science Foundation (General Program Grant No. 32370354), has uncovered, for the first time, the molecular mechanism by which tomato plants modify their floral structure through the formation of interlocking trichomes to change the way of pollination during evolution and domestication. This study reveals that specialized interlocking trichomes, forming at the edges of the anthers in modern cultivated tomatoes, are essential for the formation of closed anther cones, a key structure in cleistogamy. They further identified three homeodomain-leucine zipper (HD-Zip IV) transcription factors that coordinately regulate the formation of the anther cones. These key HD-Zip IV factors also control the style length by coordinating the cell division and endoreduplication. In the last part, the study elucidates how regulation mediated by the HD-Zip IV factors has evolved, contributing to the transition from open flower pollination in wild tomatoes to the cleistogamy observed in all modern cultivated tomatoes (Figure 3-3-1).

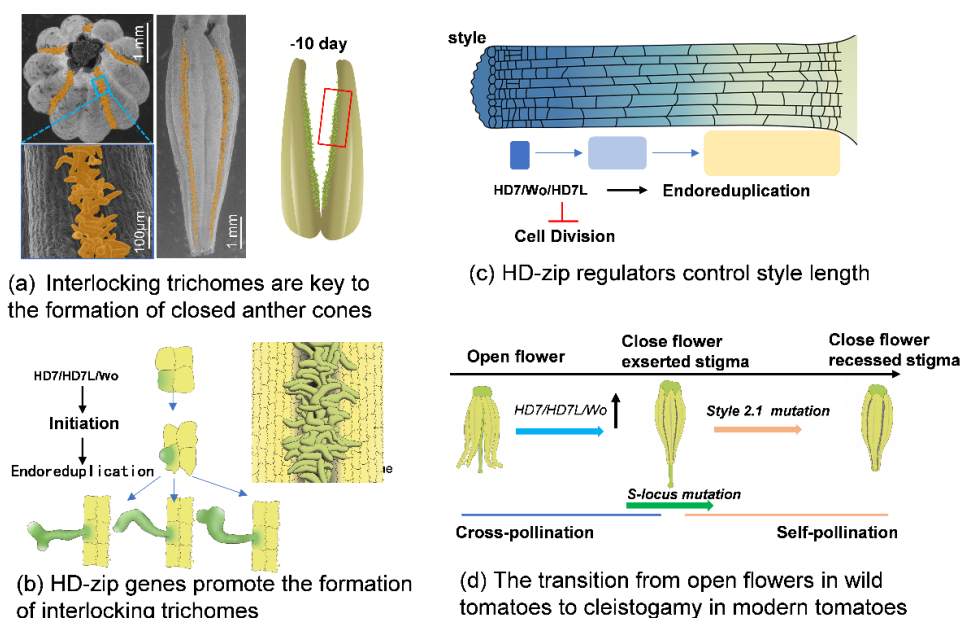


Figure 3-3-1 Schematic Diagram of the Evolution of Floral Organ Structures in Tomato Leading to Cleistogamy.

This work not only reveals the key molecular mechanisms of cleistogamy formation in plants but also provides new strategies for molecular breeding in crops. The results, titled “HD-Zip proteins modify floral structures for self-pollination in tomato” were published in *Science* on April 5, 2024. Following the publication, the findings attracted widespread attention in the plant science community, and highlight articles discussing this discovery were published in renowned journals such as *Trends in Plant Science*.

Research on National Yield Stability and Crop Diversity across Countries

Global environmental changes, particularly the intensification of climate fluctuations, have posed significant challenges to global food security. Compared to traditional agricultural management practices, crop diversification has been considered as a greener pathway to enhancing national yield stability (Figure 3-3-2). However, due to regional differences in crop varieties and higher economic costs, the stabilizing benefits of crop diversity have remained a subject of debate in agricultural management.

Funded by the National Natural Science Foundation of China (Grants No. 32122053, 31988102, 32201301), the research team led by Shaopeng Wang from the School of Urban and Environmental Sciences, Peking University, has made significant progress in the study of crop diversity and national food yield stability. Based on the multiscale stability theory of ecosystems and by incorporating data from the Food and Agriculture Organization of the United Nations (FAOSTAT), as well as global agricultural remote sensing and socioeconomic datasets, the team revealed the spatial scale dependency of the relationship between crop diversity and national yield stability. Specifically, as the total cultivated area increases, the stability of national yield also improves. Crop diversity enhances national yield stability, but this stabilizing effect is scale-dependent and strengthens as the national area increases (Figure 3-3-3). This is because given the limited total arable land in small countries, increasing crop diversity reduces the average planting area, thereby decreasing the average stability of crops. This study offers important insights for agricultural system management: when designing diversified agricultural production systems, the scale dependency of crop diversity effects and the economic costs of crop diversification should be taken into account. While crop and environmental diversification play important roles in buffering extreme weather events and reducing national food risks, these benefits could be weak in small countries. Strengthening irrigation or implementing crop rotation may be more effective approaches to improving food security in such countries.

These findings were published under the title “Larger nations benefit more than smaller nations from the stabilizing effects of crop diversity” in *Nature Food* on May 24, 2024. Concurrently, a commentary article by Professor David Tilman, a member of the National Academy of Sciences, was published, praising the paper for “innovatively introducing spatial ecological theory into agricultural research.” He noted that the study, by revealing the spatial scale dependency of the crop diversity-stability relationship, provides important insights for formulating management strategies for different countries.



Figure 3-3-2 Crop diversification in agricultural landscapes

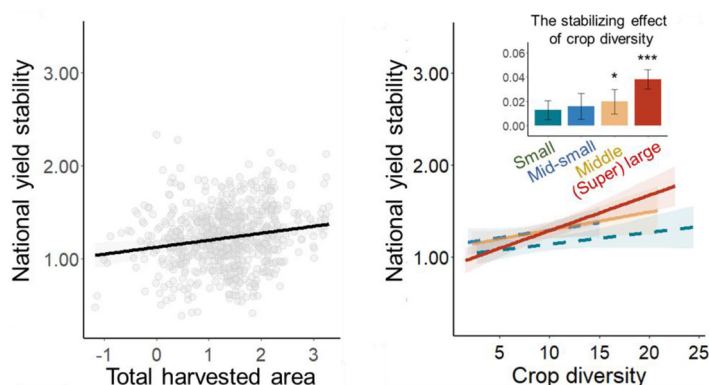


Figure 3-3-3 Effects of Crop Diversity on National Yield Stability and Their Scale Dependence

The Exploration and Utilization of the Smart-canopy-like Plant Architecture Gene in Maize

The essence of crop yield is the yield of the population, and the continuous increase in planting density is the main factor promoting the continuous improvement of crop yield per unit harvested area. However, increasing the planting density of crops often triggers canopy shade, induces shade avoidance syndrome and consequently results in decreased grain yield. An optimal plant architecture is a prerequisite for crops to adapt to dense planting. An ideal plant architecture for dense planting should have differentially oriented leaves at different canopy levels to make full use of the different light and temperature resources at each canopy level for photosynthesis, thereby improving the photosynthetic efficiency of the population and ultimately increasing the high-density yields. Identifying “smart” genes that can adapt intelligently to changing light and temperature under dense planting is a cutting-edge field.

Supported by the National Natural Science Foundation (Grants No. 32025027 and 32330077), Professor Feng Tian's team at China Agricultural University conducted a series of studies on mining gene controlling high-density-tolerant plant architecture in maize. The team for the first time discovered *lac1*, a gene controlling smart-canopy-like plant architecture, and revealed that *lac1* responds to light signals to dynamically regulate maize plant architecture as the plant density increases (Figure 3-3-4). *lac1* confers upright upper leaves, less erect middle leaves and relatively flat lower leaves, which optimizes light distribution within the dense canopy, significantly increases light penetration into the lower canopy, enhances the population photosynthetic efficiency, attenuates the shade avoidance responses, and ultimately increases grain yield under dense planting conditions (Figure 3-3-4). By integrating the gene editing and haploid induction technologies, Professor Feng Tian's team developed a haploid induction editing technology that enables gene editing directly in commercial varieties with a single cross. Using this novel technology, maize commercial varieties rapidly and precisely acquired smart-canopy-like plant architecture. This research is another breakthrough for the laboratory after identifying *UPA2/ZmRAVL1* that controls maize compact plant architecture in 2019 (Science 2019). The established molecular regulatory network for maize plant architecture and the developed haploid induction editing technology provide an important theoretical basis and technical support for the molecular design of ideal maize plant architecture and the breeding of dense-tolerant and high-yielding varieties.

The related research results, entitled “Maize smart-canopy architecture enhances yield at high densities” were published in *Nature* on June 12, 2024, in an “accelerated article preview” mode due to the potential importance. After the formal publication, *Nature* published a research briefing, in which Professor Sarah Hake, a renowned plant developmental biologist and member of the U.S. National Academy of

Sciences, commented that “This remarkable paper involves impressive use of technologies and has many layers, from gene discovery and understanding the mechanism of action to high-density field trials and moving the trait into multiple maize lines seamlessly.” International journals such as *Nature Plants* and *Science China-Life Sciences* have published research highlights, commenting that this pioneering research will greatly help promote the development of “smart crops” and “smart agriculture.”

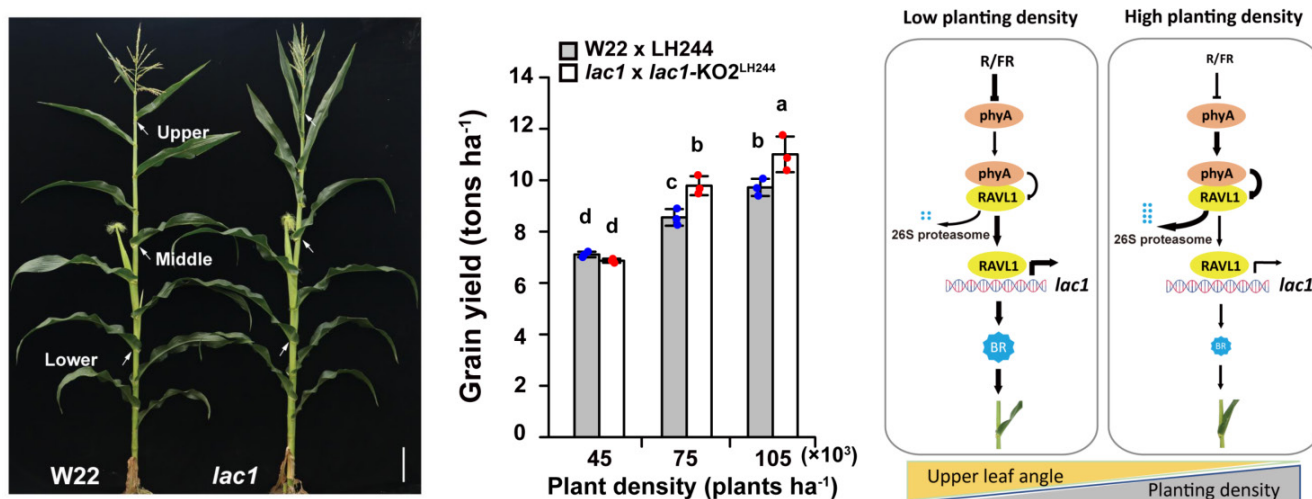


Figure 3-3-4 The lac1 Mutant Maize Plants Display Smart-canopy-like Plant Architecture and Increased Grain Yield at High Density

Developing DNA-Based Force Chrono Probes to Decipher Single-Molecule Force Dynamics in Living Cells

Electrical, chemical, and mechanical signaling constitute the three main signaling systems within cells, collaborating to maintain cellular activities. Compared to electrical and chemical signals, mechanical signals in cells have been less understood due to the lack of effective visualization technologies. Recent studies indicate that cells not only compete for living space by pushing against each other but are also regulated by mechanical forces such as compression, stretching, bending, and pulling from the extracellular matrix (ECM). Although the mechanical forces transmitted by each receptor on the cell membrane are incredibly small—ranging from a few piconewtons to several tens of piconewtons—these signals profoundly influence various processes such as cell migration, differentiation, and immune recognition. Therefore, accurately visualizing cellular mechanical forces in both space and time is key to understanding how cells utilize and modulate biochemical signals through mechanical signaling.

With funding from the National Natural Science Foundation of China (Original Exploration Plan Project “Future Biotechnology” Grant No. 32150016), a joint team from Wuhan University led by Liu Zheng and Zhang Xinghua has developed a single molecule force imaging technique based on DNA nanostructures (Force Chrono probe). This method introduces a force-tiered system using a double-hairpin tandem strategy, and when combined with single-molecule fluorescence imaging, enables precise measurement of force duration, loading rates, and magnitude on a single integrin in living cells. This research represents a significant advancement in the field and was published in *Cell* on June 20, 2024, under the title “DNA-based ForceChrono probes for deciphering single-molecule force dynamics in living cells”

By employing the ForceChrono probe, the researchers uncovered the relationship between the

magnitude and duration of integrin-mediated forces at the single-molecule level. The study demonstrated that intracellular proteins, such as myosin, and physical factors, including extracellular ligand density, tightly regulate the force dynamics of integrins. Additionally, by knocking out vinculin and reintroducing various full-length mutants into the knockout cells, the study systematically investigated the roles of vinculin and its functional domains in integrin-mediated force transmission (Figure 3-3-5). In summary, this study introduces a novel probe that serves as a single-molecule force spectroscopy tool, providing a powerful method for uncovering the functions of specific proteins and their domains within the complex networks of cellular mechanotransduction. Moreover, it offers valuable insights into the link between cellular mechanical sensing and downstream signaling cascades, including immune recognition, stem cell differentiation, and tumor metastasis.

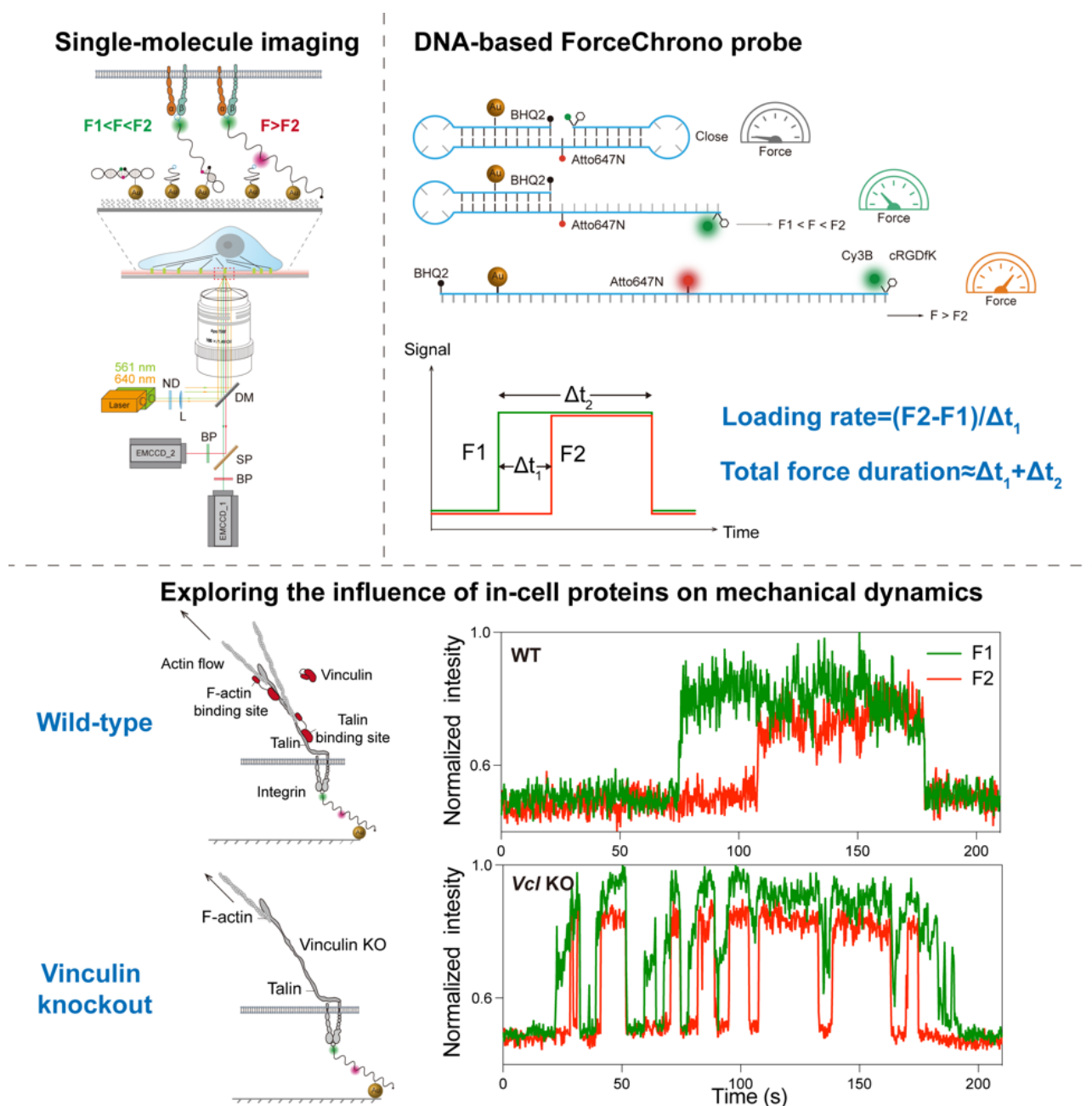


Figure 3-3-5 ForceChrono Probe Decodes the Force Dynamics at the Single-molecule Level.

Molecular Mechanism Research on Plant Cell Osmosensing Mediated by Phase Separable Protein

Water moves spontaneously across the plasma membrane according to intra-and extracellular osmotic gradient, a process known as osmosis. To maintain their shape and appropriate water content, cells must be able to sense and adapt to changes in environmental osmotic pressure, a capability particularly important for plant cells. Sessile plants are frequently challenged by osmotic stress caused by drought, flooding, high salinity, and extreme temperatures. Globally, more than one half of the crop production each year was lost due to natural disasters related to osmotic stress. Therefore, understanding the molecular mechanisms by which plant cells sense and adapt to environmental osmotic stress is of great theoretical and practical significance.

With support from the National Natural Science Foundation (Grants No. 32261160572, and 31870254), Professor Guo Hongwei's team at Southern University of Science and Technology has uncovered a novel mechanism of osmosensing and osmotic adaptation mediated by phase separation protein DCP5 in plant cells. Their findings, titled "A cytoplasmic osmosensing mechanism mediated by molecular crowding-sensitive DCP5," was published online in *Science* on Nov. 1, 2024.

It is generally believed that cells achieved osmosensing through plasma membrane-localized mechanosensitive ion channels which respond to osmotic membrane tension alterations through conformational changes. Recent studies suggest that cells may also perceive osmotic stress through different mechanisms in other cellular regions. Guo's team found that in an isosmotic environment, DCP5 proteins are uniformly dispersed in the cytoplasm. When cells are exposed to a hyperosmotic environment, DCP5 proteins respond to molecular crowding caused by changes in cell volume and undergo liquid-liquid phase separation to form condensates. Further research confirmed that during the condensation, DCP5 recruits RNA-binding proteins, translation initiation factors, and a large number of mRNAs, giving rise to the assembly of DCP5-enriched osmotic stress granules (DOSGs), which then reprogram both the transcriptome and translome, facilitating plants to adapt to osmotic stress (Figure 3-3-6). As a multifunctional osmosensor molecule, DCP5 allows both osmosensing and stress adaptation through phase separation and DOSG assembly. In compared to canonical stress signal transduction pathways, this mechanism does not require signal molecules and signaling processes, thus enabling a more rapid response to environmental changes. This study also provides significant experimental evidence supporting that protein phase separation is a general mechanism for cellular environmental sensing. This achievement has received high praise from domestic and international experts in the field, including Academician Chong Kang from the Chinese Academy of Sciences and Academician Yu Hao from the Singapore National Academy of Sciences. They said the discovery "provides a new perspective for a deeper understanding of cellular environmental sensing."

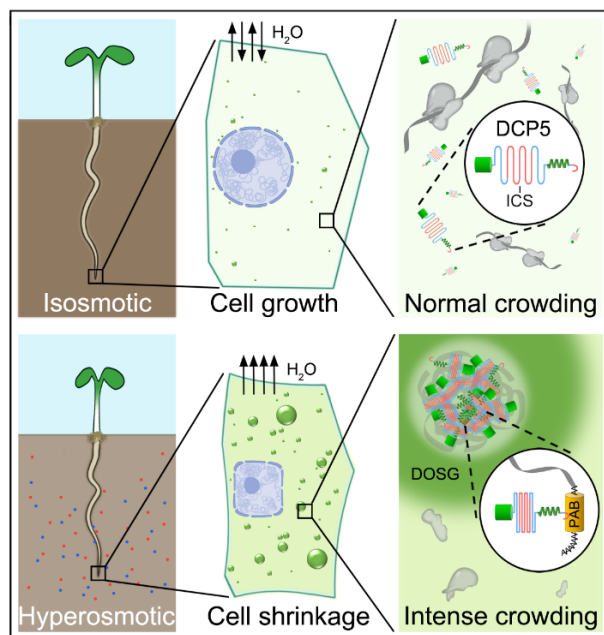


Figure 3-3-6 A Cytoplasmic Osmosensing Mechanism Mediated by Molecular Crowding-Sensitive DCP5.

The Molecular Mechanism of How Arabidopsis Blue-light Photoreceptor CRY2 Function in Darkness

Light is not only the energy source for plant photosynthesis, but also an important environmental signal for regulating plant development. Seedlings grown in the dark have long hypocotyls but very short roots, while seedlings grown under light have short hypocotyls but long roots. Plants develop completely differently under light and in the dark, as plant photoreceptor proteins act as the “eyes” of plants, sensing light signals and regulating plant growth and development. Plants have a series of different photoreceptors that sense different wavelengths of light. The blue light receptor cryptochrome (CRYs) mediate blue light regulation of plant hypocotyl elongation, flowering, circadian clock, and other developmental processes. Previous research on CRYs all focus on the “blue light excitation” mechanism of CRYs and their “blue light dependent” functional activity. Whether and how non-photoexcited CRYs function in darkness or non-blue-light conditions is unknown.

Supported by the National Natural Science Foundation of China (Grants No. 31825004, 32330006, 32150007), the research team led by Professor Hongtao Liu at Shenzhen University elucidated the molecular mechanism of how Arabidopsis blue-light photoreceptor CRY2 inhibits root cell in darkness. They show that CRY2 affects the Arabidopsis transcriptome even in darkness, revealing a non-canonical function. CRY2 suppresses cell division in the root apical meristem to down-regulate root elongation in darkness. Blue light oligomerizes CRY2 to de-repress root elongation. CRY2 physically interacts with FL1 and FL3 and these interactions are inhibited by blue light, with only monomeric, but not dimeric CRY2, able to interact. FL1 and FL3 associate with chromatin of cell-division genes to facilitate their transcription. This pro-growth activity is inhibited by CRY2's physical interaction with FLs in darkness. Plants have evolved to perceive both blue-light and dark cues to co-ordinate activation and repression of competing developmental processes in above- and below-ground organs through economical and dichotomous use of ancient light receptors (Figure 3-3-7).

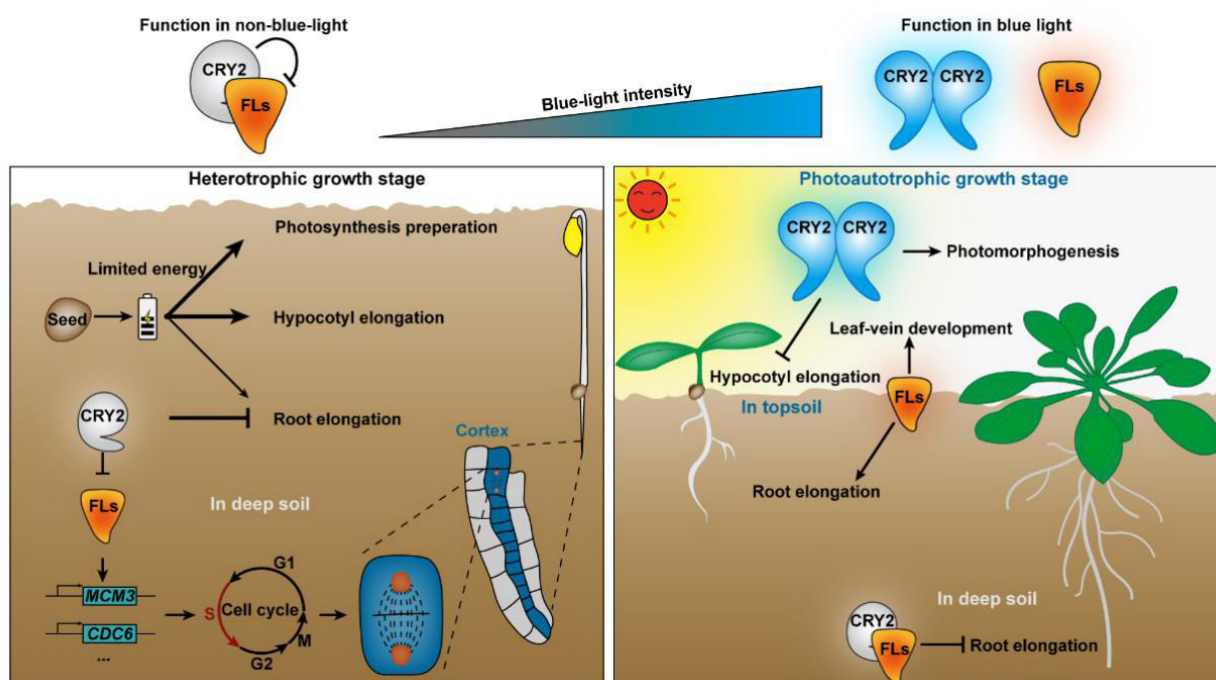


Figure 3-3-7 CRY2 Coordinates Plant Growth and Development in Different Growth Stages, Lighting Environments, and Tissues

The paper of the above findings, entitled “The Arabidopsis blue-light photoreceptor CRY2 is active in darkness to inhibit root growth”, was published in *Cell* on November 15th, 2024. Several internationally well-known journals such as *Nature Plants* and *Science China (Life Sciences)* have also published Research Highlight papers to introduce the discovery. It is believed that this discovery opens a new direction for light signal transduction research.

4. Department of Earth Sciences

Discovery of the earliest multicellular eukaryotes in Yanshan area is selected as one of the ten “2024 Breakthrough of the Year” by Science

All complex life on Earth, including animals, land plants and macroscopic fungi, are multicellular eukaryotes. Multicellularity is the key to acquire organismal complexity and large size for eukaryotes, thus often regarded as one of the major transitions in the evolutionary history of life. However, it remains poorly understood when multicellularity evolved in eukaryotes.

With support from the National Natural Science Foundation of China (Grant No. 2022YFF0800100, 41888101, 41921002 & 41972204), a research team led by Professor Maoyan Zhu at the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, in collaboration with Professor Andrew Knoll at the Harvard University, discovered the currently oldest multicellular eukaryotic fossil *Qingshania magnifica* Yan, 1989 from ~1.64 billion-year-old rocks of the Chuanlinggou Formation in the Yanshan area, North China (Figure 3-4-1). *Qingshania* consists of uniseriate filaments made up of two to more twenty large cylindrical or barrel-shaped cells, with diameter up to 194 μm and incomplete length up to 860 μm , and showing a certain degree of complexity in both overall shape and cell morphology. Some cells even contain a round intracellular structure (diameter 15-20 μm) which is interpreted to be reproductive structure (Figure 3-4-1). Based on their large cell size, morphological complexity, intracellular spores, and spectral characteristics of organic matter revealed by Raman analysis, researchers believe that *Qingshania* is not only multicellular eukaryotes, but also most likely extinct stems of crown-group eukaryotes. As *Qingshania* appeared only slightly later than the oldest eukaryotic fossils (single cells), the new finding indicates that eukaryotes acquired simple multicellularity far earlier than previously thought. Comparing with their widely accepted oldest records in ~1 billion-year-old rocks, the discovery of *Qingshania* suggests multicellular eukaryotes arose about 600 million years earlier (Figure 3-4-2). Moreover, this discovery provides new insights into the Earth-life system evolution during the mid-Proterozoic Eon.

The discovery was published in the journal *Science Advances* on January 24, 2024. In the meantime, a commentary entitled “Tiny fossils upend timeline of multicellular life” was published in *Science*. In this commentary, international colleagues said: “This gives us a better idea of the grand vision of life”, “There was this perception that multicellularity was hard [to evolve]”, “If the recent findings hold up, they are “remarkable” and transformative”. The achievement was selected as one of the ten “2024 Breakthrough of the Year”, announced by the journal *Science* on December 13, 2024.

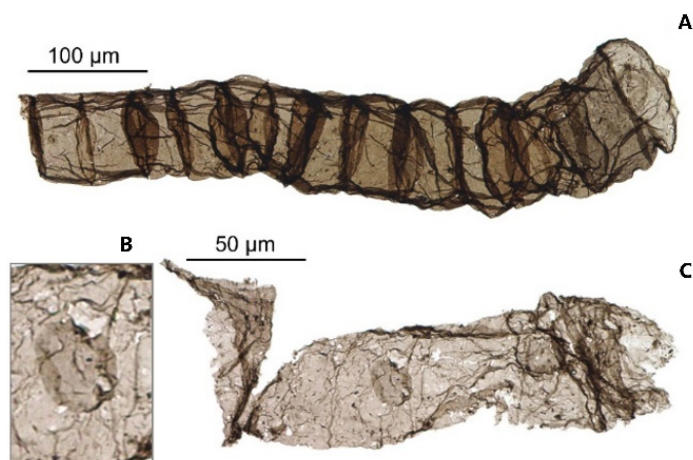


Figure 3-4-1 Multicellular fossil *Qingshania magnifica* (A, C), showing the exquisitely preserved cells and round intracellular structure (B).

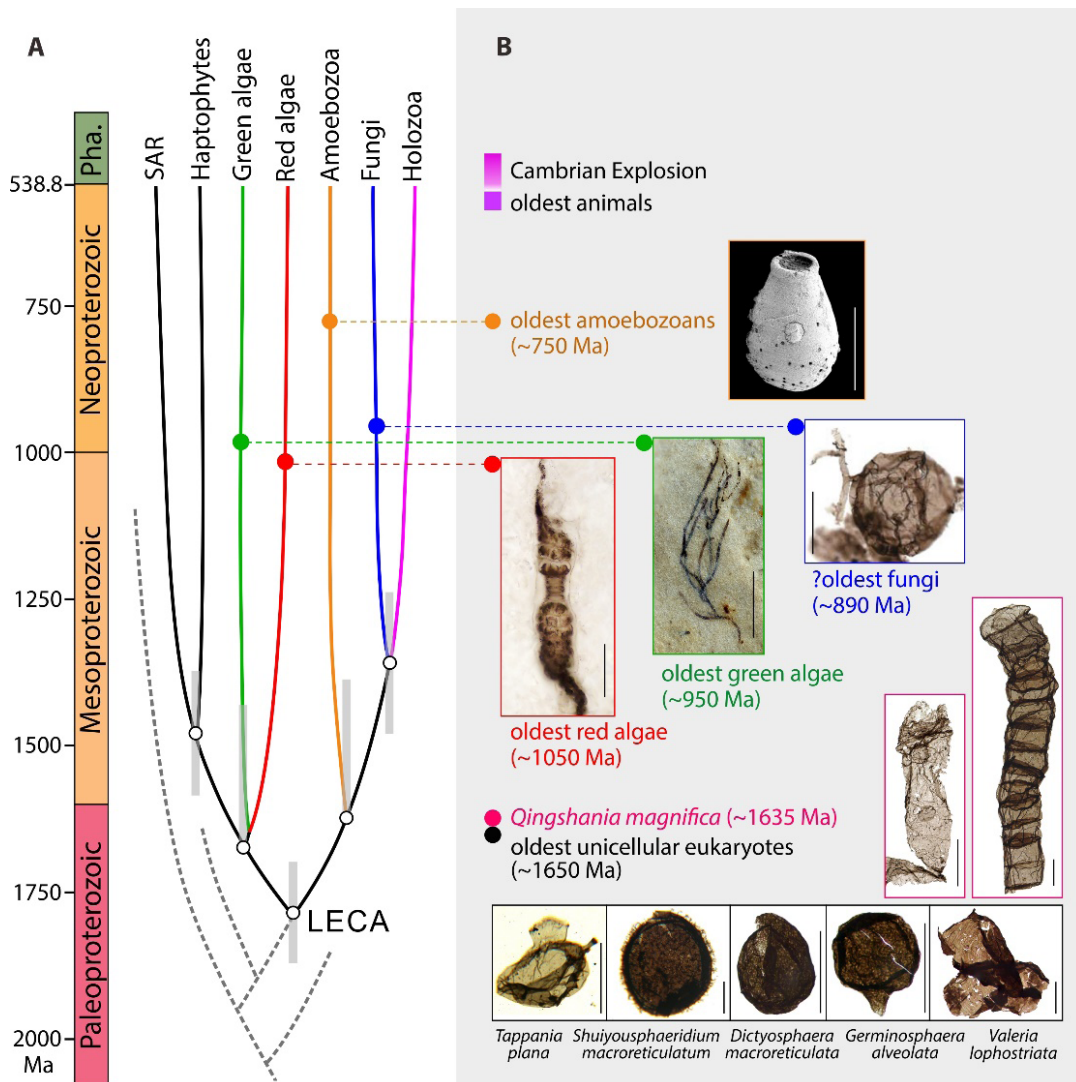


Figure 3-4-2 Simplified eukaryotic tree (A) and representative early eukaryotic fossils (B). In eukaryotic tree, grey dash lines represent stem group eukaryotes. Solid lines denote crown group eukaryotes (LECA plus its descendants). Grey bars at nodes display the estimated age range of divergence of major branches from a molecular clock study (Parfrey et al., 2011, PNAS).

Study on the Extinction Effects of Super El Niño during Greenhouse Periods

Since the Industrial Revolution, human activities have released large amounts of carbon dioxide into the atmosphere, leading to a continuous rise in global temperatures and sparking concerns about the Sixth Mass Extinction. Prior to the Industrial Revolution, the release of carbon dioxide was mainly caused by large volcanic activities; over the past 540 million years since the emergence of complex life, several super-volcanic events have occurred, of which only a few triggered short-term greenhouse climate events, and even fewer were associated with extinction events. However, the volcanic activity at the end of the Permian (around 250 million years ago) led to the largest extinction event in geological history. This rare phenomenon challenges the scientific understanding of the Earth's climate system tipping points.

With support from National Natural Science Foundation projects (Creative Research Groups Grant No. 41821001, General Program Grant No. 42272022), Professor Yadong Sun of China University of Geosciences (Wuhan), along with international collaborators, has established a unified theory on the initiation and extinction mechanisms of the end-Permian mass extinction by combining geochemical proxies, sedimentology, and Earth system modelling. The research suggests that the Pangaea supercontinent was more susceptible to prolonged strong El Niño events (Figure3-4-3), which, with only a slight increase in atmospheric CO₂ concentration, could drive the Earth system to a state of extinction. The study reveals that during the increase of atmospheric CO₂ partial pressure from ~410 ppm to ~860 ppm at the end of the Permian, the collapse of ocean meridional overturning circulation, the contraction of the Hadley circulation, and the intensification of the El Niño occurred. This was followed by forest degradation, coral reef extinction, and a crisis in plankton populations, marking the beginning of a series of ecological disasters. The reduction in carbon sequestration in both terrestrial and marine environments triggered positive feedbacks, resulting in warmer climates and stronger El Niño events.

The related findings were published in *Science* on September 12, 2024, under the title "Mega El Niño Instigated the End-Permian Mass Extinction," with an interpretation of the article in the "Science News" section. The long-term ecological effects of short-term climate variability are often overlooked in current society, and its ecological impacts under warming scenarios remain to be fully assessed. Modern strong El Niño events frequently cause sea temperature anomalies and extreme drought-flood climates, leading to coral bleaching, massive deaths of fish and birds, and subsequently affecting human society. Many international experts have highly praised this research, calling the perspective that short-term climate changes amplify extinction effects "refreshing" and "an important step forward in our understanding of Earth's climate evolution processes."

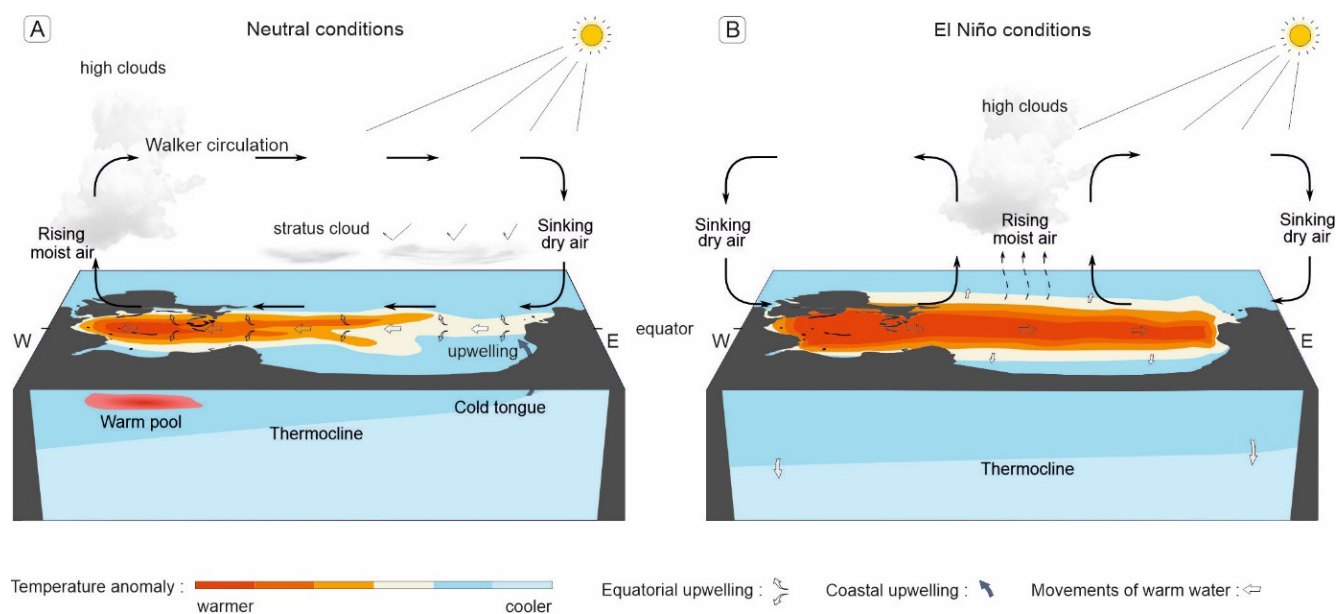


Figure3-4-3 Simplified and Idealized Ocean-atmosphere Interactions along the Paleoequator before (A) and during (B) the Onset of El Niño Conditions.

In neutral conditions, trade winds pushed warm surface waters westward along both sides of the equator, generating a western warm pool and eastern cold tongues. Homogeneous SSTs along the equator during the El Niño weakened easterlies by reducing near-surface pressure gradients, allowing eastward retreat of warm surface water and leveling the thermocline. Planetary albedo decreased with rarer occurrences of reflective stratus clouds during El Niño conditions.

Research on a Novel Mechanism of Ice Sheet Melting

Over the past fifty years, the Greenland ice sheet (GrIS) has been melting at an accelerated rate, making it the largest single contributor to global mass-induced sea-level rise. If it were to melt entirely, it could result in a global sea-level rise of approximately 7 meters. It will present significant social and economic challenges for coastal regions worldwide. Despite decades of research into the melting mechanisms of the GrIS, the critical scientific question of how meltwater behaves within the ice sheet remains unresolved.

Supported by the National Natural Science Foundation of China (Basic Science Center Program Grant No. 42388102, Excellent Young Scientists Fund Project Grant No. 42322403, and General Project Grant No. 42174096), Dr. Jiangjun Ran from the Southern University of Science and Technology, in collaboration with Prof. Jiancheng Li from Central South University and other international collaborators successfully tackled this challenging problem using the Global Navigation Satellite System. The research team innovatively developed a functional model linking the meltwater within and beneath the GrIS to the vertical displacement of bedrock and revealed the evolution mechanism of meltwater inside and at the bottom of the ice sheet for the first time (Figure 3-4-4). In addition, the study revealed that the amount of meltwater temporarily stored within the ice sheet is substantial, leading to significant bedrock subsidence of up to approximately 5 mm near the GNSS stations. This finding poses a challenge to the establishment and maintenance of a millimeter-level global vertical reference system.

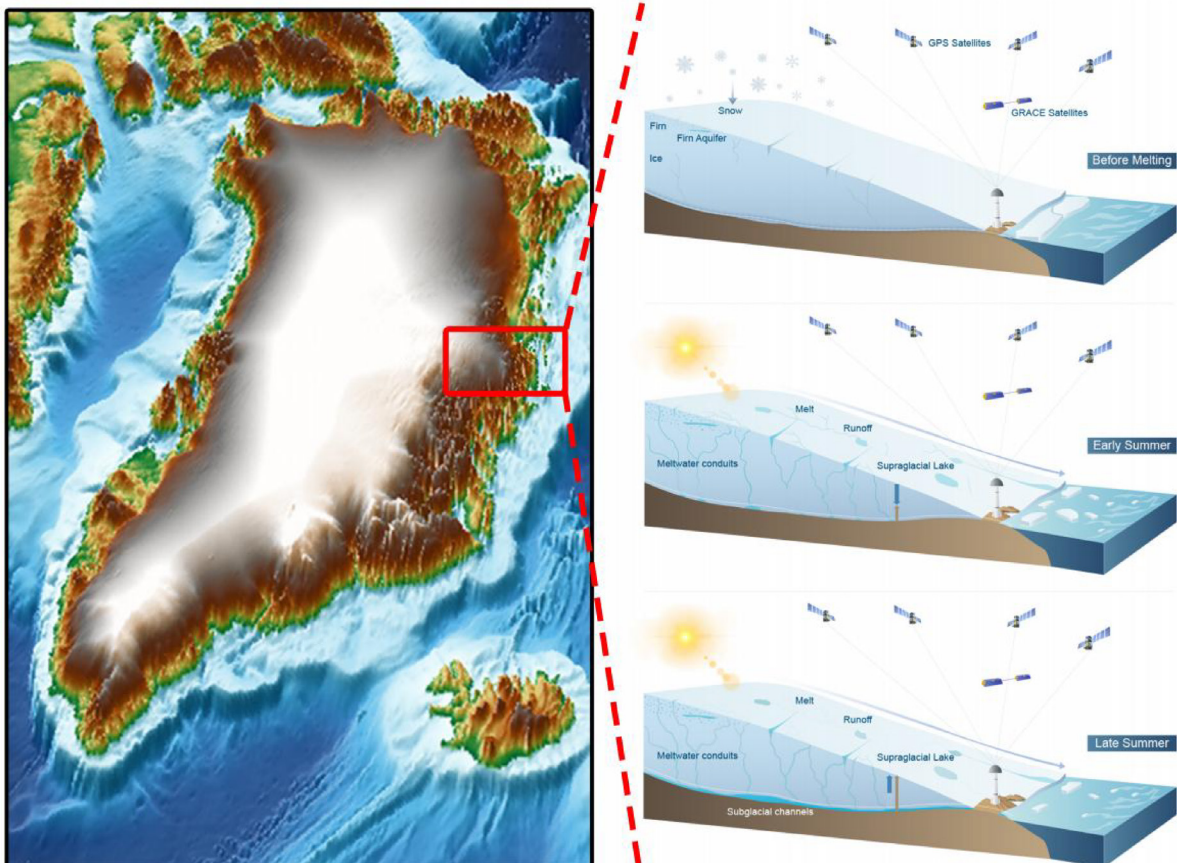


Figure3-4-4 Evolution of Water Storage and Associated Bedrock Displacements within the Greenland ice Sheet at Different Stages of the Melt Season



The findings were published in *Nature* on October 30, 2024, under the title “Vertical bedrock shifts reveal summer water storage in Greenland ice sheet”. This study marks a groundbreaking intersection of geodesy and glaciology, providing an unprecedented perspective on monitoring the evolution of meltwater within and beneath the ice sheet. It challenges the reliability of contemporary ice sheet modeling, influencing the prediction of ice sheet evolution in the context of global warming.

Study on Human-induced Amplification of Precipitation Variability

Global warming is intensifying the hydrological cycle, with increases in mean and extreme precipitation over a large part of global regions. How precipitation is delivered in time matters enormously. Larger variabilities mean bigger fluctuations in time, with intensified wet and dry periods and greater swings between them (Figure 3-4-5). Amplified precipitation variability can have far-reaching impacts on the climate resilience of human society and ecosystems. Although precipitation variability is projected to increase under future warming by climate models, it remains unclear whether it has already been on the rise in observations.

Supported by the National Natural Science Foundation of China (Grants No. 41988101, 42275038), a research team led by Prof. Tianjun Zhou at the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Sciences (CAS), in collaboration with scientists at the UK Met Office, has provided systematic evidence that human-induced climate warming has already amplified precipitation variability over the past century.

Using a wide range of observational data, the team identified a systematic amplification of precipitation variability since the 1900s from global to regional scales. The amplification has occurred over ~75% of land area with sufficient data, and is particularly prominent over Europe, Australia, and eastern North America (Figure 3-4-6). Precipitation variability has increased across a range of timescales from daily to intra-seasonal, with daily variability increased by 1.2% per 10 years globally.

To understand the underlying physics, the team conducted the moisture budget diagnostic in combination with the optimal fingerprinting detection and attribution analyses. The amplified precipitation variability can be attributed to anthropogenic greenhouse gas emissions since the pre-industrial era via the burning of fossil fuels, etc. Physically, the greenhouse gas emissions have acted as the main thermodynamic driver of amplified precipitation variability, by leading to atmospheric warming and moistening. That is, even if atmospheric circulation remains unchanged, the increased atmospheric moisture alone will enable larger precipitation anomalies when it precipitates, hence leading to greater fluctuations in precipitation. Such thermodynamic amplification is further modulated at decadal timescales by atmospheric circulation changes, which is region-specific and more complicated.

Over China, precipitation variability has amplified over most regions since the 1960s, in spite of notable decadal variations and regional differences. This is related to the complicated regional atmospheric circulation changes.

This study was published in *Science* on July 26th 2024, entitled “*Anthropogenic amplification of precipitation variability over the past century*”. This study has extended our understanding of water cycle changes from mean precipitation and extreme events to multi-timescale variability. Thus, it has provided a new perspective and strong evidence for anthropogenic hydrological change. Wide and rapid swings between precipitation extremes not only challenge existing capabilities of weather and climate prediction systems, but also have cascading impacts on human society, including climate resilience of infrastructures, water management, agriculture, and ecosystem functioning. These new challenges must be taken into account in climate change adaptation planning.

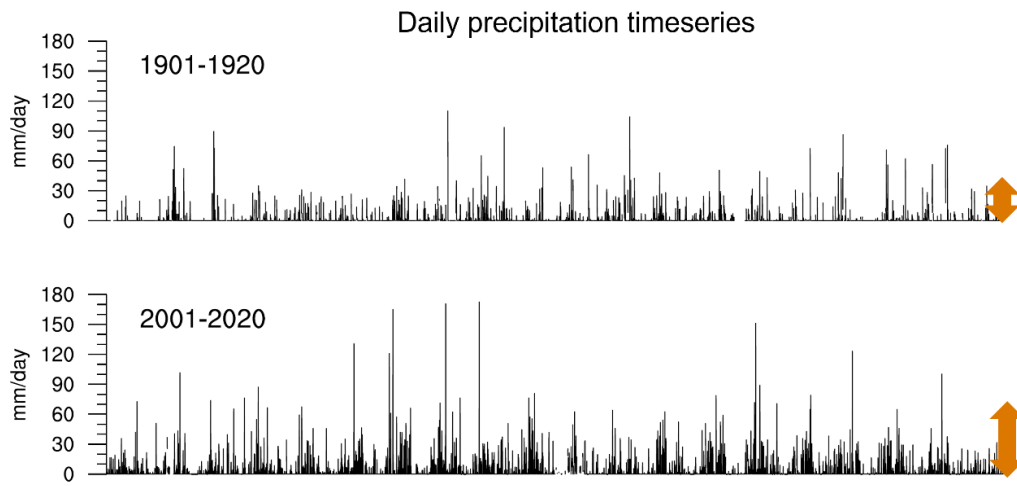


Figure 3-4-5 Illustration of Amplified Precipitation Variability

The upper and lower panels show daily precipitation time series in 1901-1920 and 2001-2020, respectively, at a station in North America. Compared to the earlier period, precipitation in the later period exhibited greater fluctuations from time to time, manifesting amplified variability.

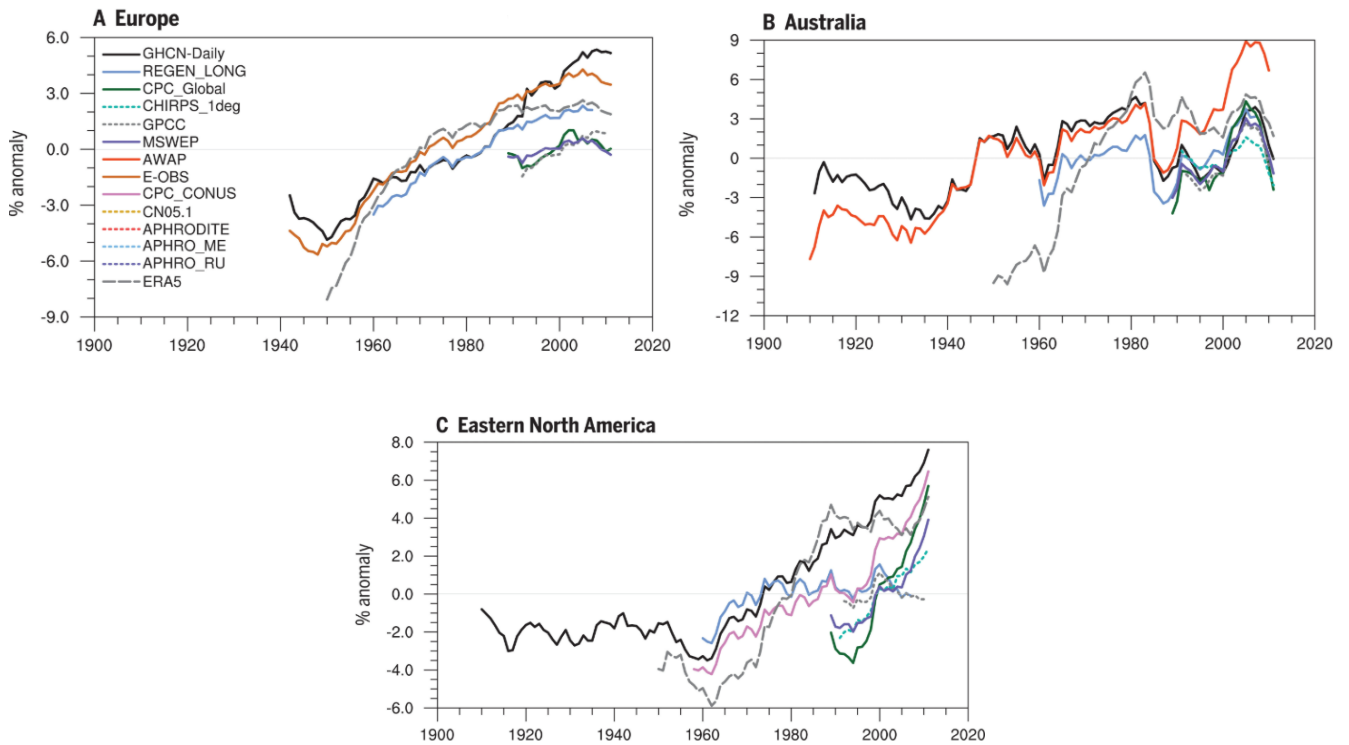


Figure 3-4-6 Linear Trend in Day-to-day Precipitation Variability over 1900-2020 Based on the GHCN-Daily Observational Data.



Researchers Reveal the Key Drivers of Subsurface Marine Heatwaves and Cold Spells.

Marine heatwaves (MHWs) and cold spells (MCSs) are of great concern to scientific and public attention, as they have the potential to cause severe damage to marine habitats and result in catastrophic ecological and socioeconomic consequences. The majority of previous studies on MHWs and MCSs have concentrated on surface signals, largely due to the wide availability of satellite observations of sea-surface temperature. However, extreme temperature events below the sea surface are of greater ecological concern, given that these regions are home to the majority of marine organisms. Despite a growing recognition of their importance, our understanding of temperature extremes below the ocean surface remains very limited due to the sparsity of long-term continuous subsurface temperature observations.

Supported by the Natural Science Foundation of China (General Program Grants No. 42276027 and 42276186, Key Program Grant No. 42130404), the research team led by Haigang Zhan from the South China Sea Institute of Oceanography (SCSIO), Chinese Academy of Sciences (CAS), in collaboration with overseas researchers, put forth a methodology for analyzing extreme temperatures based on discrete temperature observations, with a particular focus on quantifying the influence of mesoscale eddies by comparing the occurrence of temperature extremes in eddies versus their absence. Based on this method, the research team conducted a global assessment of subsurface MHWs and MCSs through a comprehensive analysis of data from 8 long-term mooring sites in different ocean basins and over 2 million global historical temperature profile measurements. In combination with co-located satellite-based eddy observations, they revealed that most of the measured subsurface MHWs and MCSs (100-1,000 m) do not concur with surface events, but rather occur during the passage of anticyclonic and cyclonic eddies, respectively. The contribution of eddies to surface MHWs and MCSs is only about 10% globally, whereas their contribution to subsurface MHWs and MCSs is more than 30%, and up to more than 50% in subtropical gyres and mid-latitude main current systems. Furthermore, the greater the intensity of the eddies, the greater the likelihood of their causing temperature extremes (Figure3-4-7). Additionally, it was also found that, the eddy-associated temperature extremes have intensified at rates greater than background level in recent decades, suggesting a growing impact of ocean eddies on subsurface MHWs and MCSs with ongoing global warming.

The results were published in *Nature* on 16 October 2024 under the title 'Common occurrences of subsurface heatwaves and cold spells in ocean eddies'. The study overcomes the limitations of the severe shortage of continuous subsurface observations, and for the first time, reveals the critical role of ocean eddies in driving subsurface MHWs and MCSs globally. This discovery paves the way for a new paradigm of detection, assessment, and prediction of subsurface extreme temperature events. A number of experts offered high praise for the results, stating that 'they represent a significant advancement in the remote sensing monitoring of subsurface MHWs and MCSs and constitute a breakthrough in the remote sensing of extreme environments in the subsurface ocean'.

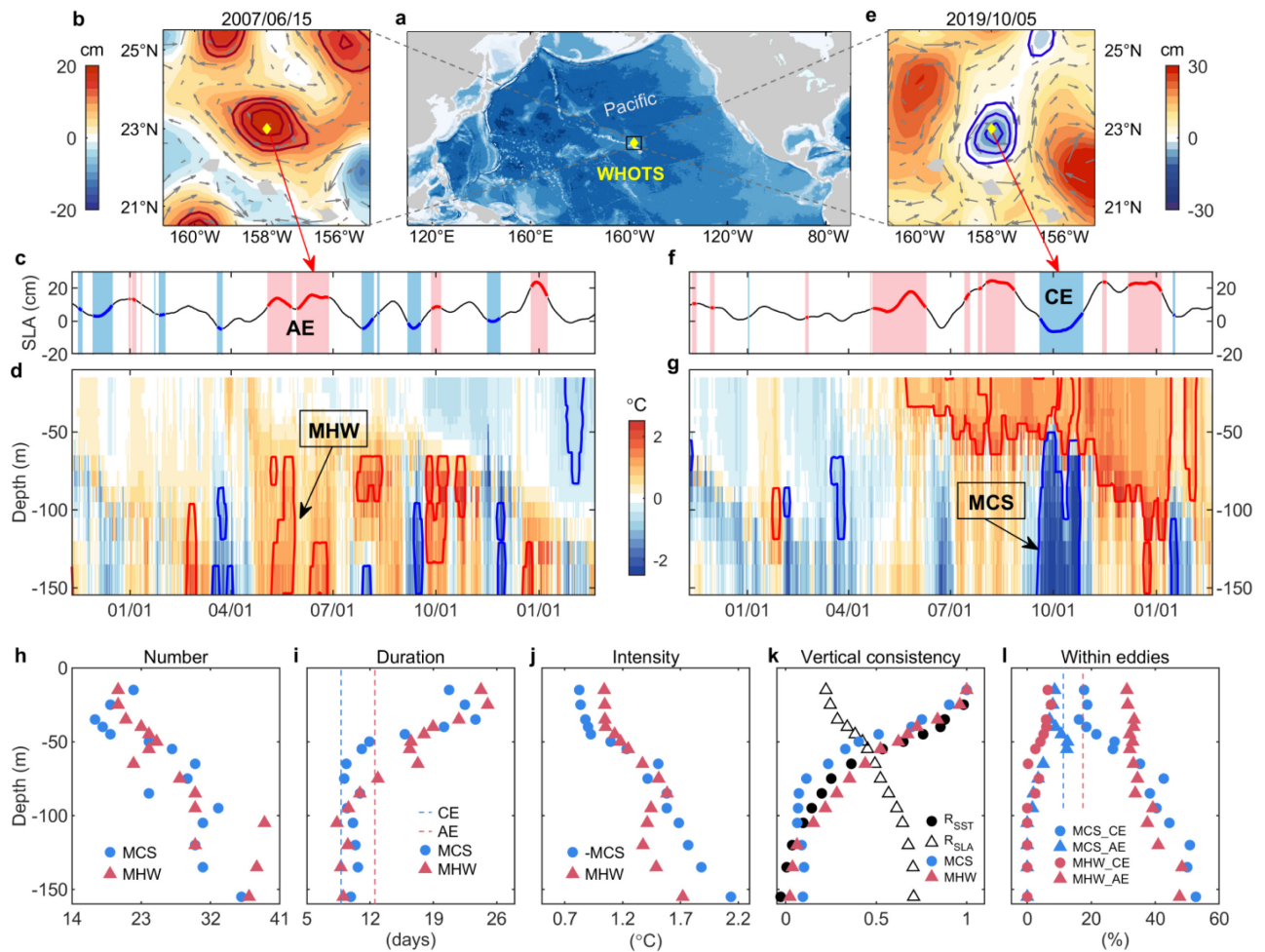


Figure3-4-7 Thresholds for Extremely-high-temperature Anomaly (EHTA) and Extremely-low-temperature Anomaly (ELTA) and the Corresponding Percentages of Extreme Temperature Measurements Observed within Anticyclonic Eddies (AEs) and Cyclonic Eddies (CEs), respectively, at a Depth of 200 m.

Harnessing Water Photovoltaic and Piezoelectric Energy to Drive Microbial Growth, Metabolism and Biogeochemical Cycles

The core of life lies in the acquisition and utilization of energy, fundamentally driven by the transfer and uptake of electrons. Within Earth's systems, various energy fields exist, with light and chemical energy being the most widely utilized forms by microorganisms. Phototrophic microorganisms can grow by transferring photoelectrons (solar energy $\rightarrow$ electrical energy), while chemotrophic microorganisms complete metabolism by utilizing elemental valence electrons (chemical energy stored in organic/inorganic matter $\rightarrow$ electrical energy). In recent years, a groundbreaking discovery revealed that certain microorganisms can grow and metabolize by directly utilizing extracellular electrons (e.g., direct current from electrodes). This phenomenon has been termed the third type of microbial energy utilization—electrotrophy. Various natural energy fields can be converted into electrical energy (electrons), indicating life's potential to exploit a wider array of energy types.

Supported by the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars Grant No. 41925028 and National Science Fund for Excellent Young Scholars

Grant No. 42322706), Professor Zhou Shungui and his team at Fujian Agriculture and Forestry University discovered the “heat energy $\rightarrow$ electric energy” conversion process (hydrovoltaic electrons) under the evaporation of plant leaves and a new form of microbial energy utilization based on the intake of hydrovoltaic electrons (hydrovoltaic energy). Further research demonstrated that hydrovoltaic electrons can be produced in various evaporation environments; the hydrovoltaic electrons produced by the evaporation of water in the biofilm can be used by purple non-sulfur bacteria to achieve reductive CO_2 fixation. In addition, the team found that denitrifying microorganisms in soil can use the electrons (piezoelectric energy) generated by mineral compression (piezoelectric energy) to fuel their denitrification metabolism. This led to the proposal of a new microbial energy utilization pathway: “piezoelectrophy”. Based on this discovery, the team developed an innovative wastewater treatment technology of “piezoelectric denitrification” (Figure 3-4-8), by growing piezoelectric minerals on the surface of denitrifying bacteria and using mechanical force to oscillate the reactor, to achieve the first mechanically driven biological nitrogen removal process.

The series of findings has been published in *Nature Water* and *Nature communications*. These studies have broken through the traditional knowledges on the types of energy that can be used by life, suggesting that any energy convertible into “electrons” could potentially power microorganisms. This offers a new perspective on understanding the diversity and complexity of microbial ecosystems and exploring metabolic strategies of life in extreme Earth systems.

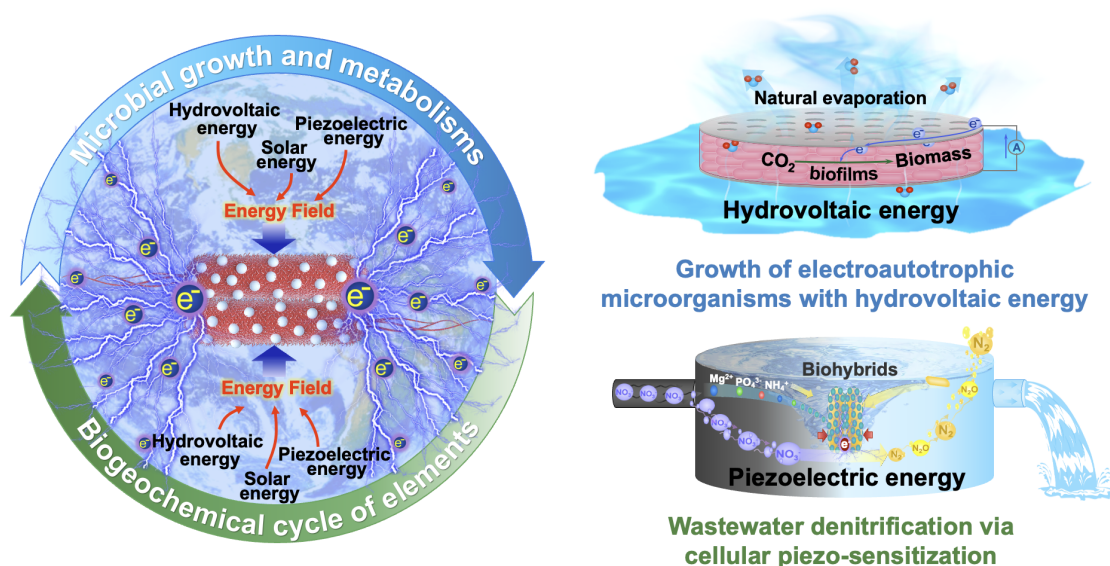


Figure 3-4-8 Harnessing Water Photovoltaic and Piezoelectric Energy to Drive Microbial Growth, Metabolism and Innovative Wastewater Treatment Technology of “Piezoelectric Denitrification”

5. Department of Engineering and Material Sciences

Power System Defense and Recovery Theory against Extreme Events

Power systems are critical national infrastructure. The frequency of large-scale power outages, triggered by both natural disasters and man-made malicious attacks, has alarmingly increased in recent years. These events have features of low-probability but vast in impact by causing huge damage, making them hard to identify, and it is difficult for power systems to defend against and recover from them. Traditional reliability theories are inadequate to capture these events, and the security risks they pose are often overwhelmed by high-probability, low-risk events, so that the principles of event evolving characteristics and their impacts to power systems are not fully understood. Consequently, developing robust defense and swift recovery strategies has become imperative to maintain national energy security and to support the sustainable development of our economy and society. The urgency and severity of solving these challenges has been highly emphasized, and decisive actions are required.

Supported by the National Natural Science Foundation (Key Project Grant No. 51637008, Joint Project Grant No. U22B20103, and General Project Grant No. 51577147), Prof. Zhaohong Bie's team at Xi'an Jiaotong University has established a theoretical framework for extreme event defense and recovery in power systems, focusing on precise modeling and mechanism discovery, encompassing risk identification, proactive defense, and rapid recovery. The laws governing the evolution of multi-dimensional characteristic parameters that describe the features of these extreme events have been successfully uncovered. A novel subset simulation sampling algorithm has been proposed, adeptly converting low-probability events into a series of nested high-probability scenarios, so that the challenge of precise risk identification has been overcome. A probabilistic ranking method for vulnerability identification, considering impact of stochastic power flow, has been developed. The synergistic and complementary mechanisms of electricity-gas system co-planning to enhance proactive defense capabilities have been revealed, opening up a new research area in proactive defense through multi-energy coordination. Additionally, a rapid recovery method for extreme events, based on the coordination of multi-type distributed resources, has been proposed. The mitigation mechanism of loop-current through master-slave control strategy for network reconfiguration has been uncovered. Furthermore, the service restoration method involving grid topology reconfiguration, dynamic microgrid partitioning, and coordination of mobile emergency resources has been proposed, enabling rapid post-event load restoration and recovery (Figure 3-5-1).

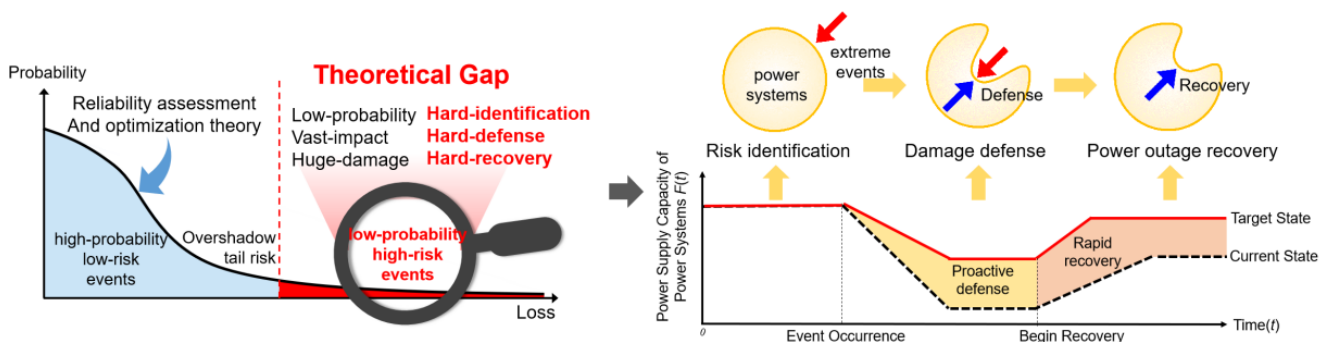


Figure 3-5-1 Basic Concept of Power System Defense and Recovery against Extreme Events



Prof. Zhaohong Bie's team has developed a comprehensive theoretical framework for proactive defense and recovery of power systems against extreme events, bridging a critical gap in the existing theory and pioneering a new research frontier in power system resilience. The team's work has been highly praised by scholars worldwide. Building on these achievements, three international standards have been developed, and the first decision support system worldwide for extreme event defense and recovery in power systems has been established. This system has been deployed at several power system dispatch centers, including those in Zhejiang Province and the Guangdong-Hong Kong-Macao Greater Bay Area, where it has become a vital tool for predicting extreme natural disaster risks and supporting emergency decision-making. The related research work won the second prize of the State Natural Science Award of P. R. China, and the first prize of the Natural Science Award of the Ministry of Education and the China Electric Power Science and Technology Award.

Design and Clinical Translation of Polymeric Drug Delivery Systems

The enhanced permeability and retention (EPR) effect has historically been regarded as the foundation for tumor-targeted drug delivery. This phenomenon, primarily observed in murine tumors, is characterized by the presence of numerous nanoscale gaps or pores in tumor capillaries, as compared to the tightly structured capillaries in normal tissues. These gaps facilitate the extravasation of drug delivery systems (DDSs) into tumor tissues. However, DDSs developed based on this mechanism have consistently failed to demonstrate enhanced efficacy in clinical applications. The fundamental limitation lies in the minimal gap coverage in human tumors, which obstructs the extravasation of DDSs from blood vessels and their subsequent infiltration into tumor tissues, thereby significantly diminishing delivery efficiency.

Supported by the National Natural Science Foundation of China (Key Program Grant No. 51833008 and National Key Research and Development Program of China Grants No. 2021YFA1201200), Professor Youqing Shen's research group at Zhejiang University has achieved pioneering advancements in the theoretical framework of tumor-targeted drug delivery, innovative methods for the facile synthesis of monodispersed dendrimers, and the clinical translation of DDSs (Figure 3-5-2). The team has identified the phenomenon of cationic polymers facilitating efficient tumor extravasation and penetration, elucidating the underlying mechanism of this transcytosis-mediated process. This discovery effectively addresses the intrinsic limitations of tumor extravasation and penetration observed in conventional DDSs, leading to the establishment of a novel theory of active tumor drug delivery based on transcytosis. This theoretical innovation overcomes the constraints of the traditional EPR paradigm and has generated a profound academic impact. Furthermore, the research group developed an innovative methodology for the concise, efficient, and scalable synthesis of dendrimers through successive click reactions of kinetically and thermodynamically selective monomer pairs. By leveraging the isothiocyanate-amine reaction and thiol-Michael addition, the team greatly simplified the synthetic process and significantly enhanced the precision and yield of the final product, achieving a world-record efficiency in dendrimer synthesis. Additionally, the team delineated the CAPIR cascade processes, i.e., circulation-accumulation-penetration-internalization-release, involved in tumor-targeted drug delivery and clarified the relationships between key carrier properties—such as charge, particle size, and stability—and overall delivery efficiency. On this basis, they established principles for function integration and synchronization in the design of efficient DDSs, alongside corresponding strategies for function tuning.

To date, these research achievements have led to the development of polymeric DDSs that have received four clinical trial approvals and two FDA orphan drug designations. Clinical trials are currently being conducted in China, the United States, and South Korea, marking a critical milestone for China's

innovation in drug delivery systems. These achievements have been recognized with the Second Prize of State Natural Science Award (2023) and the First Prize of Zhejiang Provincial Natural Science Award.

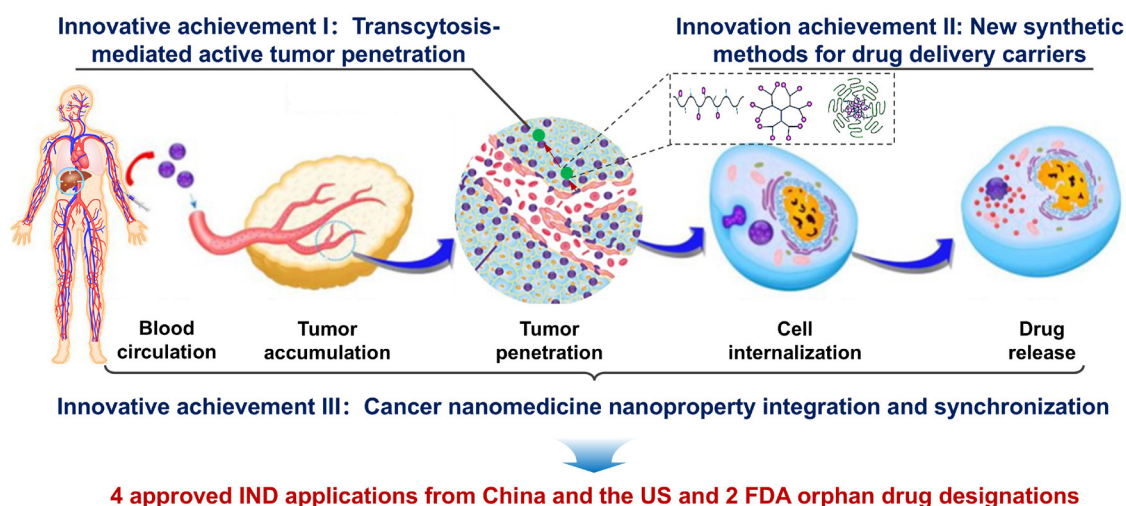


Figure 3-5-2 Summary of Research Achievements

Research on High-Performance Multilayer Ceramic Capacitors

High-performance multilayer ceramic capacitors (MLCCs) are critical components in electrical and electronic systems. Compared to batteries and electrochemical capacitors, MLCCs play a vital role in high-power pulse technology due to their ultrahigh power density (ultrafast charge/discharge rate) and long lifetime. However, the energy storage density and efficiency of MLCCs are relatively low, requiring larger volumes to increase energy storage, which not only increases size and cost but may also lead to more complex layouts and connections, thereby affecting the overall integration and efficiency of the equipment. Developing MLCCs with higher energy storage density and efficiency has become a key issue that needs to be addressed, and is at the forefront of materials science research.

Funded by the National Natural Science Foundation of China (Fundamental Research Center for Basic Sciences Project Grant No. 52388201, National Science Fund for Distinguished Young Scholars Project Grant No. 52025025, Excellent Young Scientists Fund Project Grant No. 52322212), etc., the team led by Professor Yuanhua Lin and Academician Cewen Nan of Tsinghua University and domestic and foreign collaborators have made important progress in the research of multilayer ceramic capacitors. The relevant research results were published online in *Science* on April 11, 2024, titled "Ultrahigh energy-storage in high-entropy ceramic capacitors with polymorphic relaxor phase". The team also won the second prize in the National Natural Science Award in 2024 for their outstanding contributions in related fields.

The research team has collaborated with domestic and foreign researchers and proposed a strategy combining polymorphic relaxor phase with high entropy to effectively reduce hysteresis loss by lowering domain-switching barriers and enhancing the breakdown strength through lattice distortion and grain refinement resulting from the high-entropy effect. Benefiting from the synergistic effects, the BaTiO₃-based MLCCs presented in this study achieved comprehensive improvements in energy storage performance, obtaining an ultra-high energy storage density of 20.8 J cm⁻³ and an ultra-high energy storage efficiency of 97.5% (Figure 3-5-3). Compared to existing MLCCs, these BaTiO₃-based MLCCs exhibit significant advantages such as simple preparation processes and superior overall performance.

The synergistic strategy of polymorphic relaxor phase and high entropy in this research has important

guiding significance for the development of high-energy-storage dielectric materials and devices. Science also published an article commenting on this work by Professor Zibin Chen of the Hong Kong Polytechnic University. The article points out that high-entropy design provides greater freedom for enhancing material performance compared to materials characterized by a single element, a single phase, a simple structure, and long-range order. Guided by the principles of combining polymorphic relaxor behavior with high-entropy composition, compatible ionic radii, and balanced valence states, this strategy should be universally applicable for designing high-performance dielectric capacitors, promoting the development of energy storage and other related functional materials.

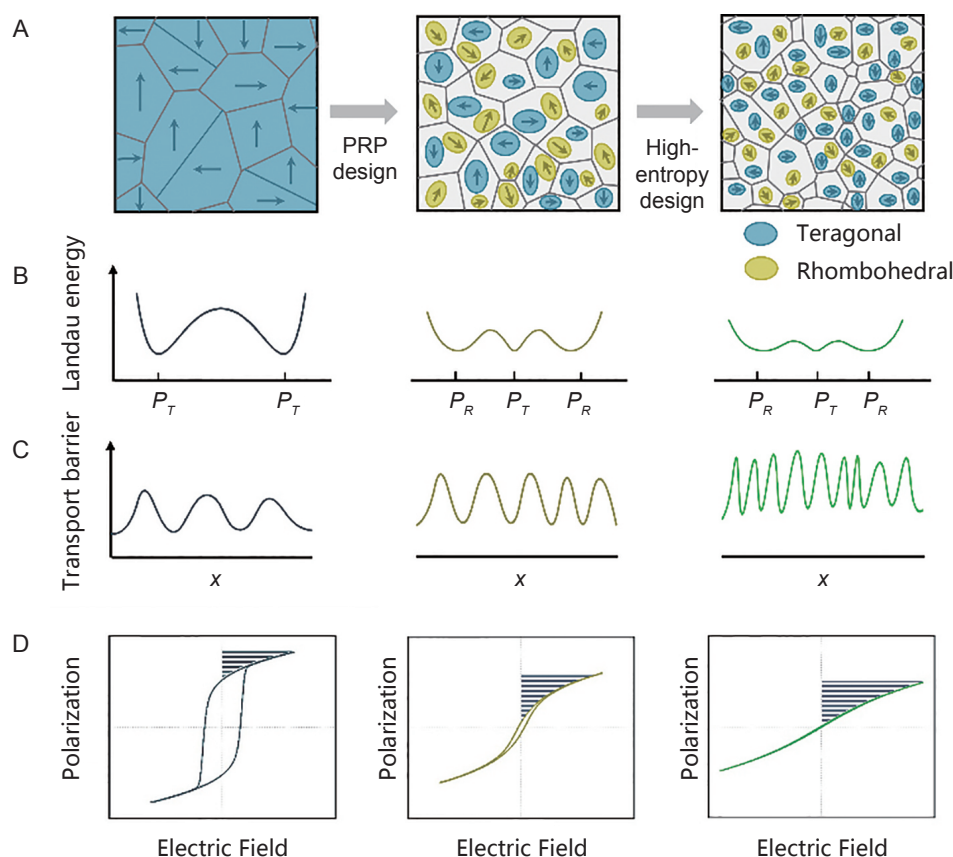


Figure 3-5-3 High-entropy Design Strategy for Ultrahigh Energy Storage with Polymorphic Relaxor Phase (PRP)

Research on Near-Atomic-Scale Polishing Theory, Technology, and Equipment for Chemical Mechanical Polishing in Integrated Circuit

Chemical mechanical polishing (also known as chemical mechanical planarization, CMP), is one of the five critical technologies in integrated circuit manufacturing. It is the most effective technique for flattening wafers through the dynamic coupling of chemical and mechanical actions, ensuring that processes such as photolithography proceed normally. CMP supports the continuous scaling down to technology nodes of 3 nanometers and below, in line with Moore's Law. The mechanism of CMP is complex, the critical technologies and equipment related to CMP have long been monopolized by foreign entities, and export

restrictions have been imposed on China at technology nodes of 14 nanometers and below, which presents significant barriers that severely restrict China's ability to achieve independent control over integrated circuit manufacturing technology. Facing the major strategic needs of the national IC industry, supported by the National Natural Science Foundation of China (National Science Foundation for Distinguished Young Scholars Grant No.50825501, Major Research Plan Grant No.91323302, Major Program Grant No.51991370), Professor Lu Xinchun's team at Tsinghua University has conducted in-depth fundamental research into near-atomic-level polishing. Significant progress has been made regarding polishing mechanisms and equipment intelligent regulation.

The team has undertaken a series of original studies aimed at addressing the technical objectives of ultra-smoothness, high flatness, and low defects in wafer polishing. A molecular dynamics model was constructed to elucidate two core mechanisms underlying material removal at an atomic scale during the CMP process (Figure 3-5-4). The team proposed the mechanism governing fluid flow field motion patterns alongside global pressure regulation on wafers, addressing the challenge of coordinated control of polishing pressures across various zones under the combined influence of hydrodynamic pressure and external pressure, achieving an within-wafer uniformity better than 98%. Additionally, models for airflow distribution across surfaces during wafer rotation as well as theoretical models concerning vertical drying liquid film detachment under organic vapor influence were established. These models analyzed the dynamics of water film stripping driven by the Marangoni effect under surface/interface interactions, enabling particle residue of <30 particles above 26 nm on 12-inch wafers. Furthermore, the team developed technology for sub-nanometer film thickness measurement and "normalized" friction end-point detection, enabling real-time measurement and regulation of global film thickness. The invention of the "multi-parallel" modular flexible layout for the entire polishing system significantly enhanced polishing quality, efficiency, and process adaptability (Figure 3-5-5). An intelligent control theory system integrating physical models of

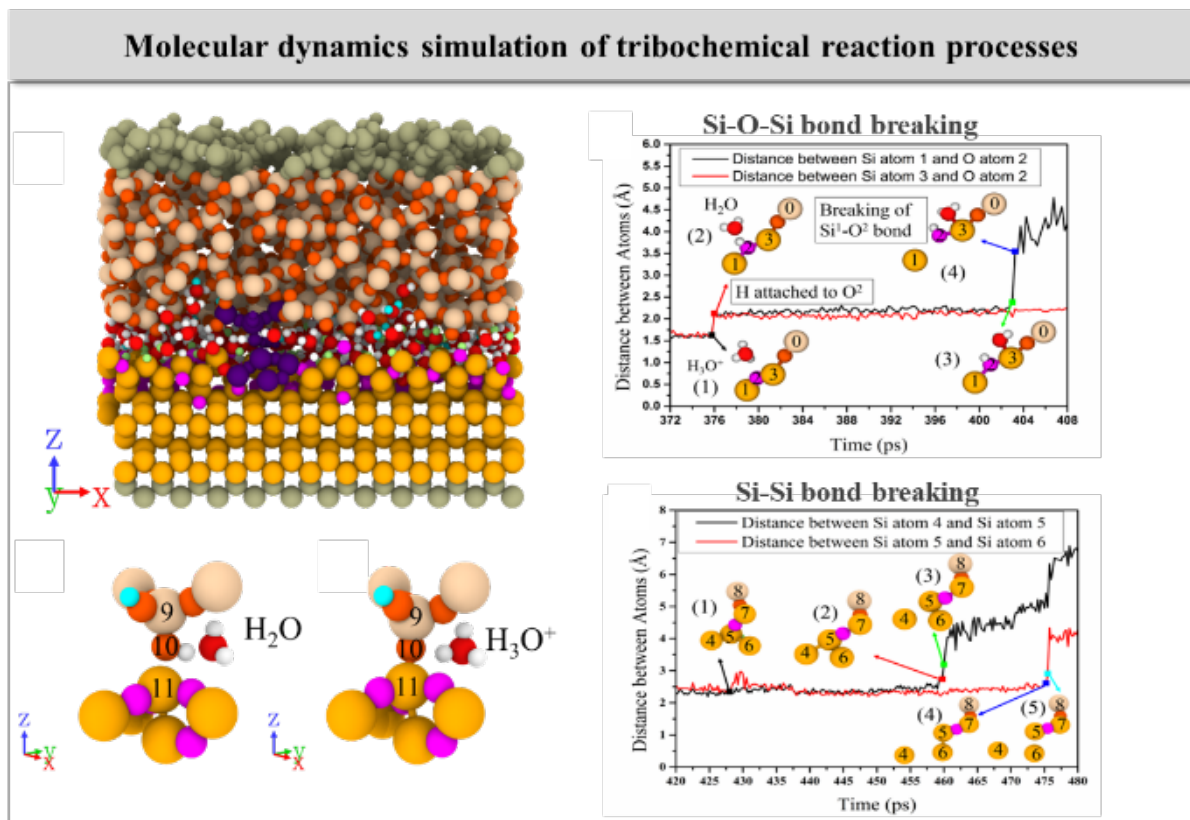


Figure 3-5-4 Atomic Scale Based Study of the Material Removal Mechanism during Planarization Process

planarization with data-driven approaches was established, facilitating online real-time monitoring of nano-scale film thicknesses and dynamic morphology regulation. This series of research provides robust theoretical and technical support for high precision wafer planarization in IC mass production. The achievements have broken through foreign patent barriers, providing a full range of CMP equipment for China's chip manufacturing industry. With over 600 sets deployed in major production lines, domestic market share has surged from zero to over 50%. It plays an important supporting role in the independent and controllable of high-end chip manufacturing.

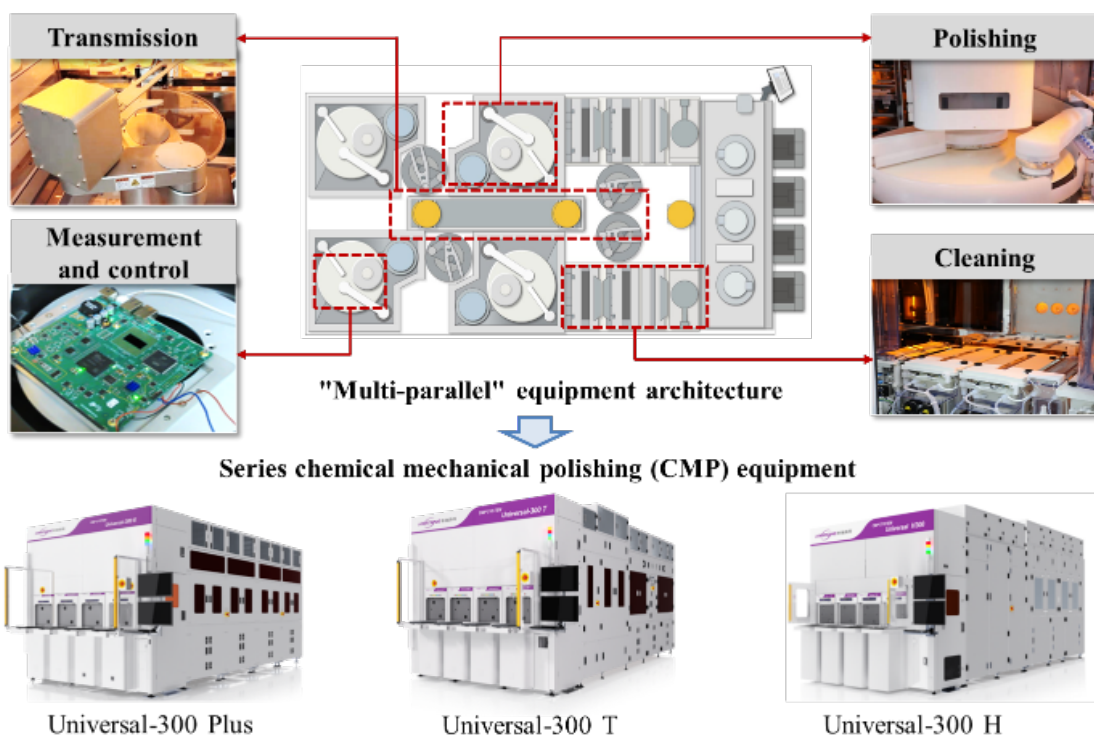
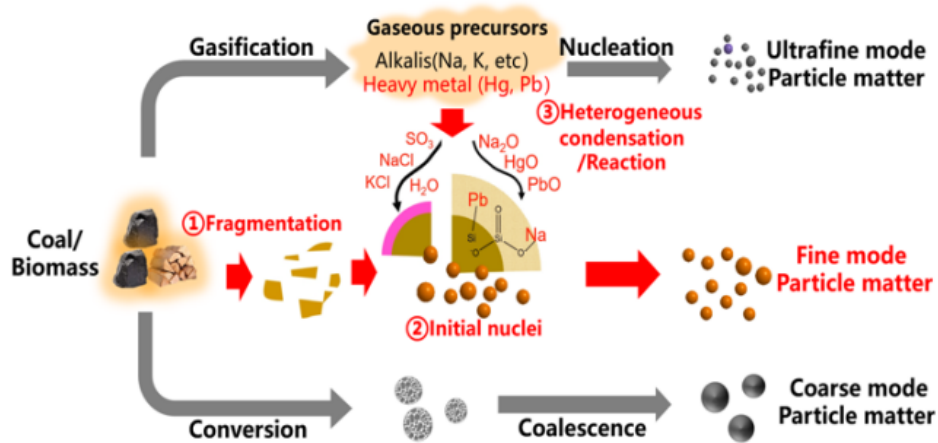
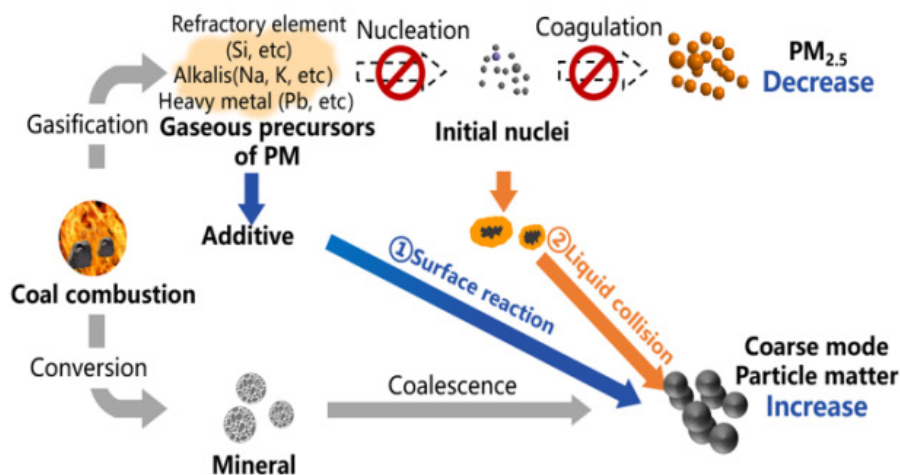


Figure 3-5-5 Series of CMP Equipment Developed Using a "Multi-parallel" Machine Architecture

Formation and Regulation of PM_{2.5} during Coal and Biomass Combustion

Coal is the primary energy source in China, while biomass is an important carbon neutral fuel. Fine particulate matter (PM_{2.5}) and the enriched toxic heavy metals from coal/biomass combustion are important causes of atmospheric haze, carcinogenesis, teratogenesis and even premature death. The theory of PM_{2.5} generation and regulation is the scientific foundation for environmental health assessment, formulation of environmental regulation, and development of control technologies. Since the 1970s, the investigation of the formation mechanisms of combustion-derived PM_{2.5} and the corresponding control technologies has become the hotspot in energy research. With the stricter environmental regulations, the control of fine particulate matter (PM_{2.5}) has become the focus of public attention. Therefore, clean and efficient use of coal was significantly emphasized in the Report to the 20th National Congress of the Communist Party of China. The emission control of the combustion-derived PM has become one of the country's major needs.

With over 20 years of continuous financial supports from the National Natural Science Foundation of China (The National Science Fund for Distinguished Young Scholars Grant No. 50325621, Science Fund for Creative Research Groups Grant No. 50721005, Key International (Regional) Joint Research Program Grants No. 50720145604 and 51520105008). Professor Minghou Xu's team at Huazhong University of Science and Technology has conducted in-depth research on the generation and regulation of PM_{2.5} during coal/biomass combustion. The main scientific discoveries include: (1) Creating a particle mode identification method based on chemical composition-particle size distribution, discovering new generation modes of PM_{2.5} and revealing their formation mechanisms, and establishing a complete PM_{2.5} generation theory (Figure 3-5-6); (2) Constructing a full-size/full process particle generation prediction models, achieving accurate characterization and prediction of particle generation; (3) Establishing a regulation method based on mineral surface chemical reactions and liquid-phase physical capture to reduce the generation of fine particles (Figure 3-5-7), inhibiting PM_{2.5} formation. The project results have been demonstrated and applied in large-scale coal-fired power generation units, achieving efficient synergistic removal of particulate matter and toxic trace elements. The achievements have played an important role in promoting the development of engineering thermophysics discipline and meeting the needs of national clean energy development. The achievement won the second prize of National Natural Science Award for "Formation and regulation of PM_{2.5} during coal and biomass combustion" (completed by Minghou Xu, Hong Yao, Dunxi Yu, Xiaowei Liu, Changdong Sheng).

Figure 3-5-6 PM_{2.5} Formation MechanismsFigure 3-5-7 PM_{2.5} Regulation Method

New Energy Dissipation Technology of Permanent Magnet Eddy Current Damping for Vibration Reduction and Shock Buffering

Energy dissipation technology for vibration reduction and shock buffering is a generic key technology in the broad field of structural dynamics to ensure the safety and longevity of structures and heavy equipment under the dynamic actions of vibration, earthquake, and shock. In these circumstances the requirement of energy dissipation devices is extremely stringent: for example, the accumulative movement of longitudinal dampers for the girder of the Jiangyin Yangtze River Bridge exceed 250km during the past 10-years period of service and the seismic load under strong earthquakes may exceed 10,000 tons; the instantaneous peak acceleration of the recoil of a heavy artillery reaches 350g. The commonly-used hydraulic oil damping devices relies on the mechanism of friction for energy dissipation. When subjected to above ultra-long and ultra-strong dynamic disturbances, oil dampers will inevitably wear, leak oil and finally fail within only a fraction of service life of a structure. Eddy current damping (ECD) does not rely on friction to dissipate the energy and has many advantages of non-contact and oil-free. However due to its low energy-dissipation-density and performance degradation after a critical speed of operation, ECD has not been successfully used for vibration reduction of engineering structures since its discovery about 100-years ago.

With funding mainly from the National Natural Science Foundation of China (Grant No. 50738002), the research group led by Academician Chen Zhengqing and Professor Hua Xugang at Hunan University overcomes the major technical bottlenecks of traditional eddy current damping, achieving main breakthroughs as follows: (1) development of the basic theory for high energy-dissipation-density and high critical-speed permanent magnet eddy current damping (PMECD) and the corresponding testing platform; (2) invention of the tuned-mass-based damping technology based on planar PMECD; (3) invention of large-tonnage axial PMECD technology; (4) invention of external recoil buffer and integrated coaxial buffer for heavy artillery based on tubular PMECD. The research outcome has formed a complete innovative PMECD energy dissipation technology for vibration reduction and shock buffering. Various kinds of eddy current dampers have been developed and commercialized, and have been applied to more than 120 large-scale projects in civil engineering, electric power, engineering machinery, among others in China as well as foreign countries such as Morocco and Malaysia. The results have significant social and economic benefits and broad application prospects, such as Jiangyin Yangtze River Bridge (Figure 3-5-8) and Morocco Noor III Solar Tower(Figure 3-5-9).



Figure 3-5-8 Large-tonnage Eddy Current Damper Application Case - Jiangyin Yangtze River Bridge



Figure 3-5-9 Eddy Current Tuned Mass Damper Application Case - Morocco Noor III Solar Tower

For the first time the PMECD has been applied to real, large engineering structures for vibration reduction in the world, and has fundamentally changed the traditional point of view that eddy current damping was difficult to be used for vibration reduction of large structures. It provides a new universal, long-lasting and efficient damping technology for vibration reduction in multiple fields of military and civilian use. The research won the first prize of the National Technological Invention Award in 2023.

6. Department of Information Sciences

A Three-dimensional Liquid Diode for Wearable Integrated Electronics

Wearable electronic devices based on flexible intelligent sensing technology are widely used in fields such as biomedicine, healthcare, and sensing. However, existing wearable devices still face grand challenges in terms of breathability and integration. Limited breathability and sweat permeability often lead to sweat accumulation at the device-skin interface, causing not only thermal discomfort for users but also damage to the device-skin interface, significantly reducing the accuracy of flexible sensors. Therefore, achieving high breathability and high integration in wearable electronic devices, and enhancing their long-term monitoring capabilities, has been a critical challenge in the field of flexible intelligent sensing.

Supported by the National Natural Science Foundation of China (Excellent Young Scientists Fund, Grant No. 62122002), Professor Xinge Yu's team at City University of Hong Kong conducted research on wearable electronic devices with high breathability and high integration. To address the challenges of balancing high breathability and integration, as well as the lack of highly integrated flexible substrates, the team proposed a novel structure called 3D liquid diode that enables spontaneous and directional liquid transport in three dimensions (Figure 3-6-1). By applying selectively superhydrophobic treatments to the fiber surfaces, the team created an anisotropic gradient hydrophobic interface, allowing rapid sweat transport from the skin to the device. Additionally, a horizontal gradient hydrophilic structure is constructed based on the gradient arrangement of hydrophilic micro-pillars, enabling efficient sweat transport within the device. Through the orderly integration of in-plane and out-of-plane sweat transport structures, the 3D liquid diode achieved a liquid transport rate over 4,000 times faster than the human body's natural sweat rate. Meanwhile, as a universal breathable and sweat-permeable substrate material, the 3D liquid diode can be directly integrated with high-performance flexible circuits through traditional processing techniques, which enables the development of wearable electronics with both high breathability and high integration. Based on this technology, the research team has developed a set of highly breathable and sweat-permeable flexible integrated electronic devices, achieving continuous and precise ECG monitoring for up to seven

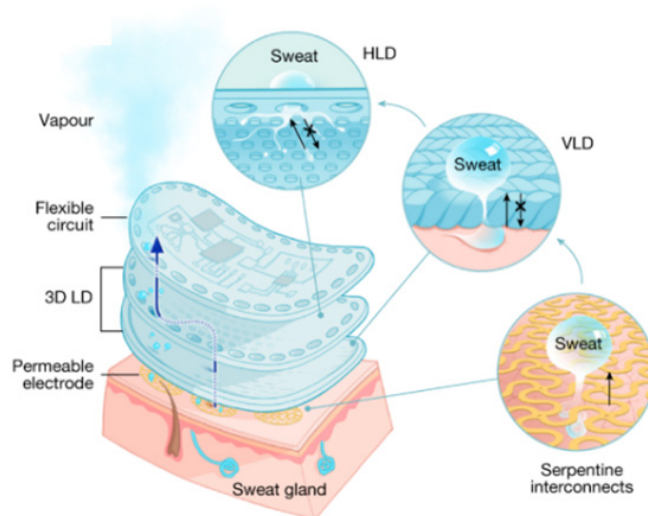


Figure 3-6-1 Three-dimensional Liquid Diode for Rapid Liquid Transportation

days during daily activities and exercise. Furthermore, they applied this technology into textile-integrated electronics, designing an electronic textile for multifunctional wireless environmental monitoring (Figure 3-6-2).

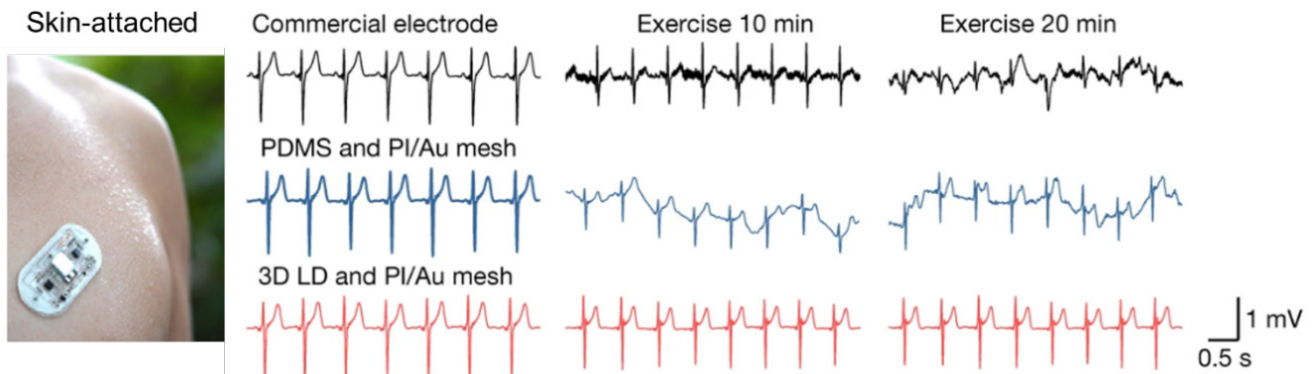


Figure 3-6-2 Sweat-guiding Structure Significantly Enhances Humidity Stability and Accuracy of Flexible Sensors in ECG Signal Monitoring

The research findings, titled “A three-dimensional liquid diode for soft, integrated permeable electronics,” were published online in *Nature* on March 27, 2024. This study addresses the bottleneck issue in flexible intelligent sensing technology — balancing the high mechanical and electrical performance of wearable electronic devices with breathability, which is often limited by integration processes. The breakthrough holds promise for the development of medical-grade wearable devices capable of long-term continuous physiological signal monitoring, with significant application prospects in chronic disease management, early disease diagnosis, personalized medicine, and clinical research. The study has received widespread recognition and follow-up research.

The Low Latency Key Technologies for Cloud Computing

With the maturity of CPU virtualization technology and breakthroughs in elastic computing, global computing models began transitioning to cloud computing in 2010. The business and user base supported by cloud data centers rapidly grew from the tens of millions to the hundreds of millions and even billions. To cope with this surge in business and users, the only solution was to scale up the system capacity. However, existing technologies were insufficient to effectively organize and utilize such vast computing resources (with the number of servers in a single cloud data center expanding from thousands to hundreds of thousands). The core challenge that emerged was the latency issue in cloud computing systems. There are three primary approaches widely agreed upon for reducing latency in cloud computing systems: first, using faster hardware to accelerate processing speeds; second, eliminating or reducing redundant latency in the software stack of cloud systems; and third, reducing the collaboration latency that arises when applications are deployed across multiple cloud nodes.

With support from the National Natural Science Foundation of China (NSFC) (National Fund of Distinguished Young Scholars, Grant No. 61525204 and Key Research Program, Grant No. 61732010), a series of technological breakthroughs have been achieved in reducing latency in cloud computing systems, resulting in a new research framework for low-latency technologies in cloud computing (Figure 3-6-3). Latency has been reduced from the hundreds of milliseconds to just tens of milliseconds. To address

hardware latency, a decoupling mechanism between resource authorization and resource usage has been proposed, along with hot migration technologies for GPU virtual machines and SGX virtual machines. Additionally, virtualization technologies for seven types of heterogeneous hardware have been developed. These solutions address the challenge of effectively utilizing new heterogeneous hardware in cloud systems, which had previously been underutilized. Technologies such as GPU virtualization and NVMe virtualization have been adopted by the Linux kernel, providing support for the virtualization of GPUs and other hardware devices. Regarding node latency, a cross-layer virtualization architecture, virtual machine collaboration technologies with separate authorization and authentication, and virtual machine scaling techniques with concurrent startup and on-demand synchronization have been introduced. These innovations have reduced vertical, horizontal, and amplification latency within the software stack by one to two orders of magnitude. To tackle system latency, feature-driven differentiated data partitioning and storage techniques, a low-latency virtual RDMA resource pool, and virtual machine hot backup technologies based on output consistency have been proposed. These advancements have resulted in a 58% reduction in average latency and a 90% reduction in tail latency. The low-latency dual virtual machine hot backup software developed has been adopted by the Linux kernel and remains the world's only open-source dual virtual machine hot backup technology.

These innovations have been recognized by the second prize of the State Technological Innovation Award released in June 2024, and have been integrated into open-source software releases such as Xen, KVM, Linux, and OpenEuler, introducing new functionalities to these platforms. As a result, these technologies have been indirectly applied to all cloud service providers worldwide that use these open-source software solutions.

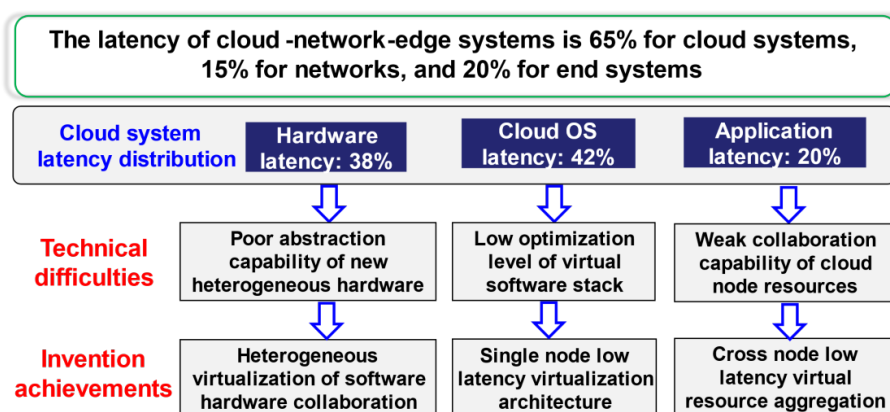


Figure 3-6-3 Research Framework for Key Low-Latency Technologies in Cloud Computing Systems

Theory and Method for Visual Computing by Leveraging Diversified Information

The exponential growth of visual data is astounding, occupying over 90% Internet traffic. Such growth demands techniques that can perform automated understanding of visual data effectively so as to understand scenes, objects, activities and interactions. This is one of the most fundamental problems in artificial intelligence and has wide applications. Existing approaches struggle with challenges like significant variations in viewpoint, high-dimensional multimodal features with implicit correlations, and the presence of confusing classes to be recognized. Inspired by human visual systems that integrate multi-sensory information in a hierarchical manner, we argue that a comprehensive collection of diversified clues embedded in visual

data should be fully explored for visual computing.

Funded by National Natural Science Foundation of China (Grant No. 61572134, 60873178), Prof. Yu-Gang Jiang's team from Fudan University discovered that there are helpful clues at varying levels of visual computing. For each level, the team designed a principled strategy which fully exploits the diversified information encoded therein (Figure 3-6-4).

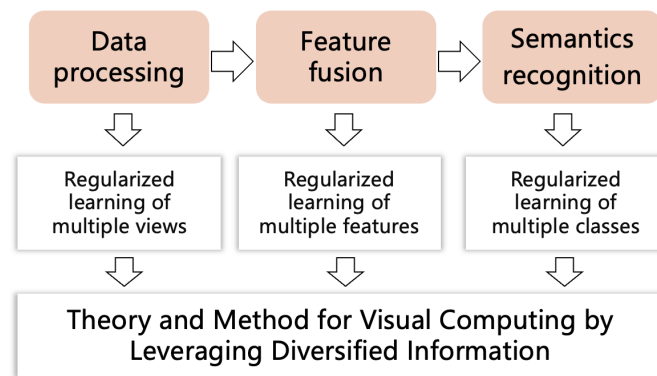


Figure 3-6-4 An Overview of the Research Framework

The research achievements have been widely recognized by scholars both domestically and internationally, sparking numerous follow-up studies and driving new developments in research and applications within related disciplines. More importantly, the research has been recognized by the second prize of State Natural Science Award released in June 2024. A significant number of citing papers explicitly state that the outcomes are “best-performing”, “state-of-the-art”, “pioneering”, etc. The systems developed by the team, grounded in the theoretical outcomes of the project, have been utilized multiple times to serve major national needs.

Over the years, these research outcomes have been used in winning solutions for many international benchmark competitions. In addition, the datasets constructed by the team in collaboration with researchers from Columbia University, Google, and INRIA in France, such as THUMOS and FCVID, have been widely adopted in both academia and industry. Due to these exceptional contributions in visual computing, the project lead has been elected as a Fellow of IEEE and IAPR.

Mosaic Integration Technology for Single-Cell Multi-Omics Data

Single-cell sequencing technology has emerged as a groundbreaking innovation in the field of life sciences in recent years. It enables the detection of various genetic materials and functional molecules (such as RNA, proteins, chromatin accessibility, etc.) within individual cells, revealing cellular heterogeneity and cross-omics associations at different molecular levels. This technology facilitates a deeper understanding of cellular functions and the mechanisms underlying processes such as development and disease progression. However, with the advancement of sequencing technologies and the exponential growth of sequencing data, integrating “mosaic” single-cell data—comprising different omics combinations, sequencing technologies, and experimental samples—has become an immense challenge.

Supported by the National Natural Science Foundation of China (Young Scientists Fund, Grant No. 62303488), the research teams of Professors Xiaomin Ying and Xiaochen Bo from the Academy of Military Medical Sciences have conducted studies on mosaic integration and knowledge transfer in single-cell multi-omics data. The teams proposed a novel method, MIDAS, based on generative artificial intelligence

(Figure 3-6-5). MIDAS assumes that the multimodal observations of each cell are generated by a deep neural network from two modality-agnostic and disentangled latent variables: one representing the biological state of cellular heterogeneity, and the other capturing technical noise introduced by single-cell experiments. Its input consists of expression matrices and batch ID vectors derived from different single-cell samples (batches), which may originate from various experiments or sequencing technologies (e.g., CITE-seq and ASAP-seq) and exhibit distinct technical noise, modality combinations, and observed features. The outputs of MIDAS include two low-dimensional representation matrices for biological states and technical noise, as well as an expression matrix with missing modalities and features imputed and batch effects removed. These outputs can be used for downstream analyses such as clustering, cell typing, and trajectory inference. UMAP visualizations and quantitative evaluations have demonstrated that MIDAS effectively removes batch effects while preserving biological signals. It performs robustly across various mosaic tasks and significantly outperforms state-of-the-art algorithms (Figure 3-6-6). Furthermore, MIDAS efficiently and flexibly transfers knowledge from reference datasets to query datasets, enabling seamless handling of new single-cell multi-omics data. The latent variables derived through MIDAS-based dimensionality reduction also allow for pseudotime analysis of mosaic data with missing modalities. In cross-tissue knowledge transfer tasks, MIDAS exhibits exceptional performance in aligning heterogeneous datasets, identifying known cell types, and discovering novel cell types.

This research, titled “Mosaic integration and knowledge transfer of single-cell multimodal data with MIDAS”, was published in *Nature Biotechnology* on January 23, 2024. The study holds significant implications for uncovering cellular functions and molecular regulatory mechanisms, as well as for understanding the processes of disease onset and progression. It is anticipated to provide robust technical support for applications such as disease diagnosis and precision therapy.

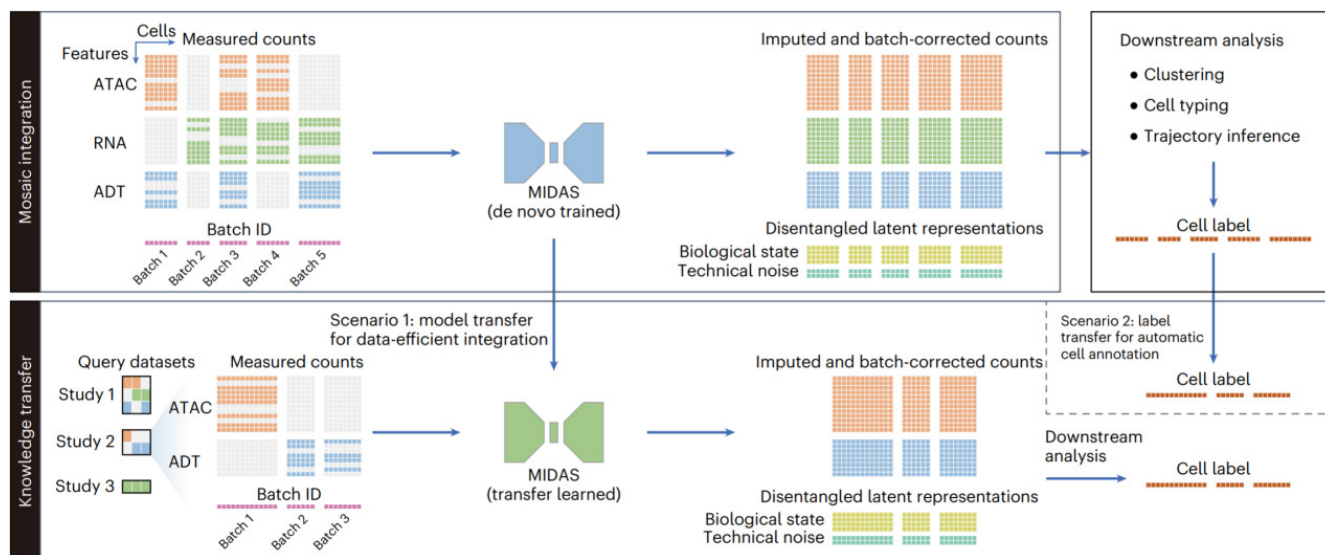


Figure 3-6-5 Overview of MIDAS Functionality

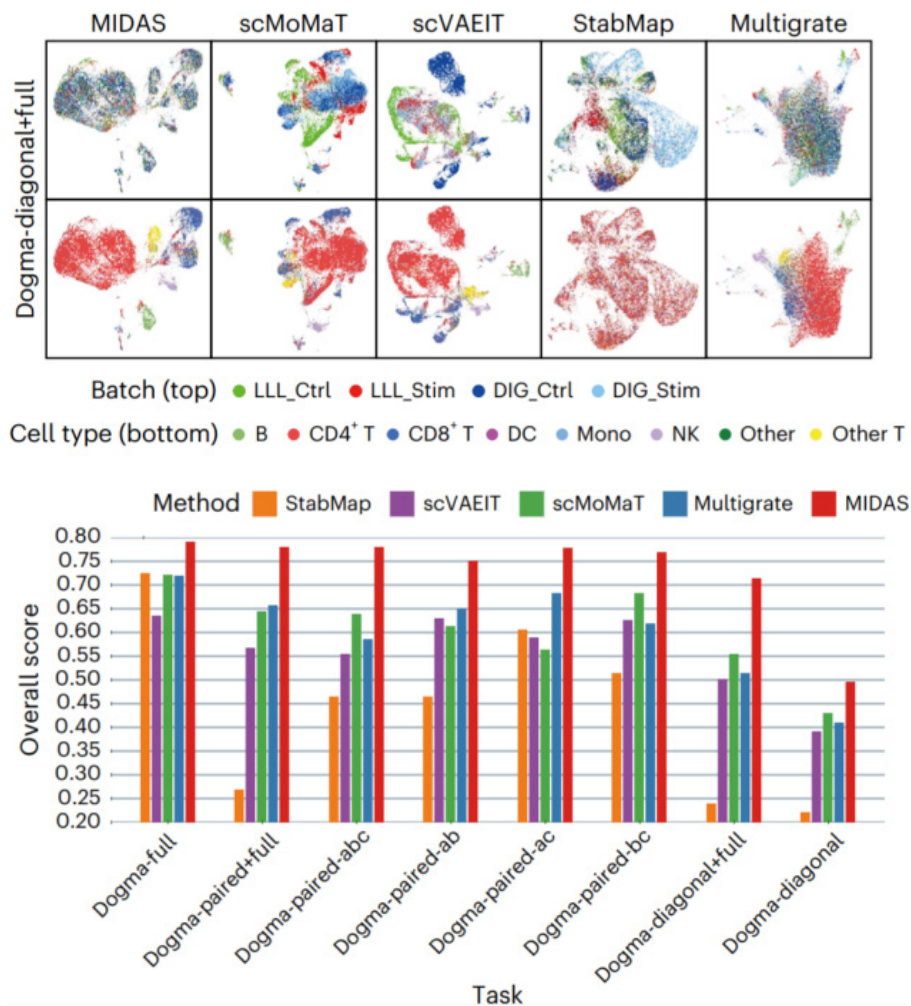


Figure 3-6-6 Performance Evaluation of MIDAS

Research on On-Chip Optics

Advancements in detection techniques are driving the development of intelligent and lightweight systems, which highlights an urgent need for compact and multidimensional optical imaging solutions. Existing multidimensional imaging techniques typically rely on complex systems assembled from discrete optical components. These systems are often constrained by limitations in payload capacity, computational power, bandwidth, etc. On the other hand, the study on multidimensional imaging devices faces three key challenges originated from the intrinsic limitations of photoelectric conversion mechanism, including single detection dimension, restricted information throughput, and low imaging accuracy. These challenges have become focal points in worldwide research.

With the support of the National Natural Science Foundation of China (Excellent Young Scientists Fund, Grant No.62322502, Major Scientific Research Instrument Development Program 61827901, Basic Science Center Program, Grant No. 62088101, General Program, Grant No. 61971045), the research group led by Prof. Zhang Jun (an Academician of Chinese Academy of Engineering) at Beijing Institute of Technology, has made significant progress in the field of on-chip optics. The group funded the basic theory of on-chip

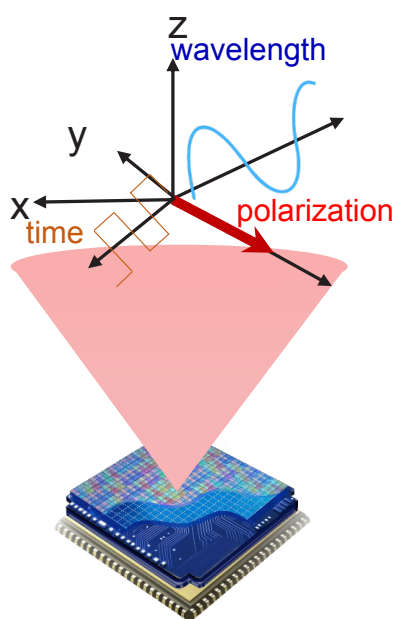


Figure 3-6-7 The Photon Multiplexing Theory

photon multiplexing (Figure 3-6-7), and reported a series innovative methods including on-chip modulation, broadband multiplexed sensing, and joint computational optimization. These breakthroughs fundamentally redefine traditional techniques such as geometric spectroscopy, narrowband sensing, and physical signal output. They effectively address the long-standing bottlenecks of photoelectric devices, including single-dimensional detection, limited data throughput, and poor imaging accuracy in complex environments.

The research group also made key technological achievements, including photolithography fabrication of on-chip spectral modulation arrays, precise integration of multidimensional imaging sensors, and computing chip design. These efforts led to the development of the world's first real-time hyperspectral imaging sensor with hundred spectral channels and megapixel resolution, weighing only a few dozen grams. The sensor has a wide spectral response range from visible to near-infrared, with leading spatial, temporal, and spectral resolution. Its light throughput increased from conventional less than 25% to a record-breaking 74.8%. Building on the above key techniques, the group has developed six types of hyperspectral sensing systems (Figure 3-6-8) that have been deployed in major national projects, including the Sharp

Eyes Public Security Project, the National Next-Generation Remote Sensing Project, the Future Advanced Equipment, and the National Intelligent Transportation Project. This study has established a new research field on on-chip optics, with promising applications in remote sensing, deep-space exploration, and next-generation equipment. It provides a groundbreaking framework for the development of next-generation intelligent imaging sensors, fostering interdisciplinary collaboration across integrated circuits, electronics, computing, physics, and materials science. These innovations are set to elevate China's capabilities in intelligent equipment development to unprecedented levels.

This landmark research, titled "A Broadband Hyperspectral Image Sensor with High Spatio-Temporal Resolution", was published in *Nature* on November 7, 2024.



Figure 3-6-8 The Hyperspectral Image Sensor and Multidimensional Fusion Detection Devices

Research on Mass-Producible Lithium Tantalate Photonic Integrated Circuits for Volume Manufacturing

In the post-Moore era, the performance of integrated circuits is increasingly constrained by physical limits. Integrated photonic technologies, represented by silicon photonics and thin-film lithium niobate photonics, have emerged as disruptive solutions to overcome these bottlenecks. While lithium niobate has garnered significant attention due to its exceptional electro-optic properties, its high production costs, strong birefringence, and photorefractive effects remain significant barriers to industrialization.

Under the support of the National Natural Science Foundation of China (Grant No. 62293521), Prof. Xin Ou's team from the Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, has pioneered a novel approach by introducing lithium tantalate photonics, combining superior electro-optic properties with scalable manufacturing. The research spans wafer fabrication, micro-nano processing, and chip performance validation (Figure 3-6-9), resulting in several key innovations:

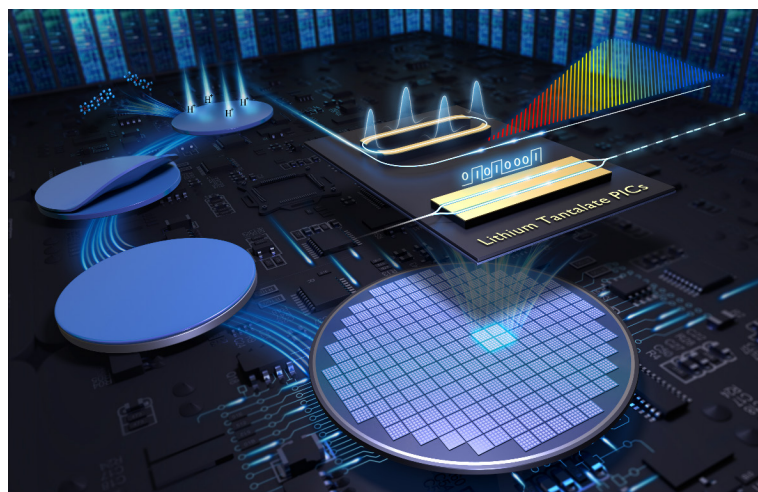


Figure 3-6-9 Schematic of Heterogeneous Lithium Tantalate Wafer and High-Performance Photonic Chip

1. A ion-cutting method was developed to fabricate optical-grade silicon-based lithium tantalate single-crystal thin-film wafers for the first time (Figure 3-6-10a). This process is akin to the silicon-on-insulator (SOI) platform and tailored for 5G RF applications, enabling low-cost, scalable production of lithium tantalate thin films.

2. A wafer-level fabrication process for lithium tantalate photonic devices was established (Figure 3-6-10b), achieving an ultra-low optical loss of 5.6 dB/m—significantly lower than the minimum losses reported for wafer-scale lithium niobate chips.

3. The study explored lithium tantalate's potential as an electro-optic modulation platform, leveraging its weaker birefringence, reduced photorefractive effects, and suppressed Raman scattering. Microcavity devices demonstrated no mode-crossing interference across the entire communication wavelength band, while the platform also enabled chip-scale generation of soliton optical frequency combs in X-cut structures (Figure 3-6-10c, Figure 3-6-10d).

These findings, published in *Nature* on May 8, 2024, under the title *Lithium Tantalate Photonic Integrated Circuits for Volume Manufacturing*, were also featured in a *Nature Research Briefing*. The study highlights the

potential of lithium tantalate thin films to achieve ultra-low optical loss, efficient electro-optic conversion, and soliton frequency comb generation. This breakthrough offers promising solutions to key challenges in communications, including speed, power consumption, frequency, and bandwidth limitations, while paving the way for transformative applications in quantum technologies, optical computing, and optical communications.

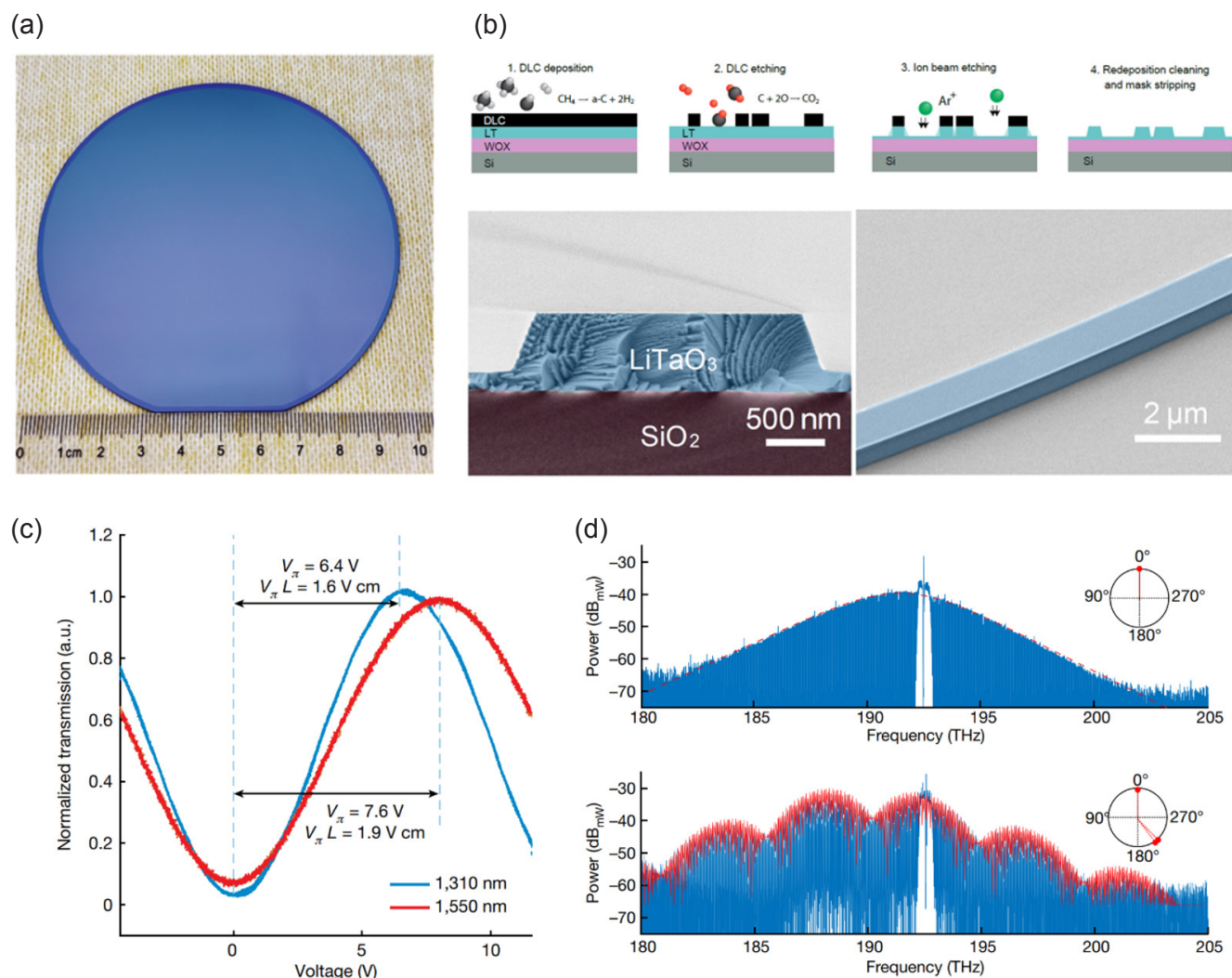


Figure 3-6-10 (a) Optical-grade Silicon-based Lithium Tantalate Single-crystal Thin-film Wafer; (b) Wafer-scale Lithium Tantalate Processing; (c) High-performance Electro-optic Modulator; (d) Soliton Frequency Comb Generation.

7. Department of Management Sciences

Nuclear Norm Computation of High-Dimensional Tensors and Its Applications

As a foundational resource of our national strategy, big data has gradually become a key driver of economic and social development. The Party Central Committee and the State Council attach great importance to the development of the big data industry and are actively promoting the implementation of the national big data strategy. To fully unlock and harness the potential value of big data resources, there is an urgent need to develop more powerful decision-making tools and theoretical methods that can transform multidimensional big data into valuable information and process it effectively.

The decomposition and optimization algorithms of high-dimensional tensors (also known as high-dimensional arrays) have emerged in recent years as theoretical tools for processing high-dimensional data. A critical aspect of achieving tensor decomposition and optimization lies in the effective calculation of tensor nuclear norms. Therefore, the computation of nuclear norms for high-dimensional tensors holds significant importance for uncovering the application value of big data resources, fostering innovation and value addition in China's big data industry, and enhancing the quality of management decision-making.

Supported by the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars, Grant No. 71825003, and Major Program Grant No. 72394360), Professor He, Simai of Shanghai Jiao Tong University, Professor Jiang, Bo of Shanghai University of Finance and Economics, and their collaborators conducted research on the approximation of high-order tensor p -mode nuclear norms, achieving the following key results:

(1) Utilizing theoretical tools such as robust optimization and second-order cone programming, they proposed, for the first time, a polynomial-time algorithm with a theoretically guaranteed constant approximation ratio for the computation of the nuclear p -norm of matrices (i.e., two-dimensional tensors). This result paves a way for the application of the matrix nuclear p -norm model.

(2) They developed the so-called "hitting sets" of different scales and covering rates to achieve l_p ball coverage approximation. These coverage methods effectively balance the number of points required for ball approximation and the resulting approximation error, providing a basis for balancing algorithmic efficiency and accuracy in tensor nuclear p -norm computation.

(3) Based on the above results, they proposed multiple deterministic approximation algorithms and one randomized algorithm for computing the p -mode nuclear norm of high-dimensional tensors. They further proved that the approximation ratio of the randomized algorithm matches the best-known approximation ratio of the associated dual norm (i.e., the spectral p -norm).

These research findings were published online in December 2024 under the title " l_p Sphere Covering and Approximating Nuclear p -Norm" in *Mathematics of Operations Research*.

This study has promoted the theoretical development of high-dimensional tensor decomposition and optimization, with potential applications in related fields. The ideas and methods of spherical covering can be extended to optimization problems with other set constraints (such as high-dimensional box constraints and non-negative spherical constraints), finding broad applications in graph theory, neural networks, non-convex matrix decomposition, and other areas. In particular, when p tends to infinity, the corresponding infinity-norm ball $\{-1, +1\}^n$ represents the most common integer constraint set in integer programming.

Tensor nuclear norm optimization is closely related to tensor decomposition, and efficient spherical covering methods provide new insights and foundations for designing tensor decomposition algorithms.



Additionally, based on approximation algorithms for computing tensor nuclear norms, further research can be conducted on efficient algorithms for tensor nuclear norm minimization problems, with applications in revenue management, machine learning, and related fields.

Chinese Scholars Make Progress in Research on Price Interpretability in Prediction Markets

Prediction markets, also known as information markets, are mechanisms that reflect public expectations about uncertain future events through the trading of contracts. These markets are characterized by strong information aggregation capabilities and high predictive accuracy, making them applicable in a wide range of fields. For example, in the real estate market, public expectations of housing prices can provide valuable reference points for government macroeconomic policy formulation. In agriculture, weather prediction markets help farmers anticipate and mitigate risks from extreme weather events, thereby ensuring crop yields. In such markets, trading prices play a critical role as the key medium for information transmission and sharing. Understanding the evolution of market prices and the mechanisms by which final convergent prices form is essential for improving the effectiveness and credibility of prediction markets across various applications.

Supported by the National Natural Science Foundation of China (Grant No: 71971132, 72150002), Associate Professor Jianjun Gao of Shanghai University of Finance and Economics, Professor Zizhuo Wang of The Chinese University of Hong Kong, Shenzhen, Associate Professor Weiping Wu of Fuzhou University, and Dr. Dian Yu of Industrial Bank have collaborated to investigate the interpretability and convergence properties of prices in prediction markets. Their research has yielded the following key results:

1) They conducted a systematic study on the basic properties of prediction markets, including market efficiency and the dynamic evolution of prices. In a general prediction market, they proposed a novel multi-agent utility-based price formation mechanism, which unifies several existing automated market-making mechanisms, such as the Logarithmic Market Scoring Rule (LMSR), into a common framework.

2) Based on the multi-agent utility mechanism, they established price convergence results in a general prediction market consisting of a finite number of risk-averse traders with heterogeneous beliefs and a market maker. They proved that, under repeated interactions, traders' wealth processes converge to a limiting wealth distribution. This limit lies on the Pareto-efficient frontier defined by the utility functions of all market participants, offering a new perspective on interpreting prediction market prices.

3) Under various market models—including those using exponential utility functions and risk-measure-based approaches—they conducted analytical and numerical analyses to demonstrate how different modeling assumptions affect the convergent price.

These findings are published under the title *"Price Interpretability of Prediction Markets: A Convergence Analysis"* in *Operations Research*, online on June 10, 2024.

This research provides effective guidance for the design of market-making mechanisms in prediction markets, helping to improve the efficiency of information aggregation. It also has important policy implications for enhancing macroeconomic regulation, promoting agricultural development, and maintaining financial market stability in China.

Research on the Value-Enhancing Effects of Human-Machine Collaboration in Complex Information Processing

With the rapid growth of data volumes and advancements in artificial intelligence (AI) technologies, collaboration between humans and advanced algorithms has become increasingly close. However, this collaboration also brings a series of challenges, such as managing the expanded scale of information. Although machines outperform human decision-makers in information processing, the value of human-machine collaboration and its underlying mechanisms still require deeper exploration. Existing research has sought to uncover the “black box” of machine learning algorithms to reduce friction between humans and machines and improve efficiency, but progress in this area remains insufficient.

Supported by the National Natural Science Foundation of China (Grant No. 72272003), Prof. Yingjie Zhang from Peking University and her collaborator have made significant strides in the field of human-machine collaboration. Their related work, titled “*1+1>2? Information, humans, and machines*”, was published in *Information Systems Research* in May 2024. The study systematically investigates the value and driving factors of human-machine collaboration by examining the effects of information complexity and algorithmic explanations.

Partnering with an online lending platform, the research team designed a two-stage field experiment and conducted empirical analyses (Figure3-7-1). Multiple experimental conditions were set based on different levels of information complexity, status of human-machine collaboration, and the availability of algorithmic explanations. The study found that when the information volume is small, algorithmic explanations alone make it difficult for human decision-makers to add extra value to the final collaborative

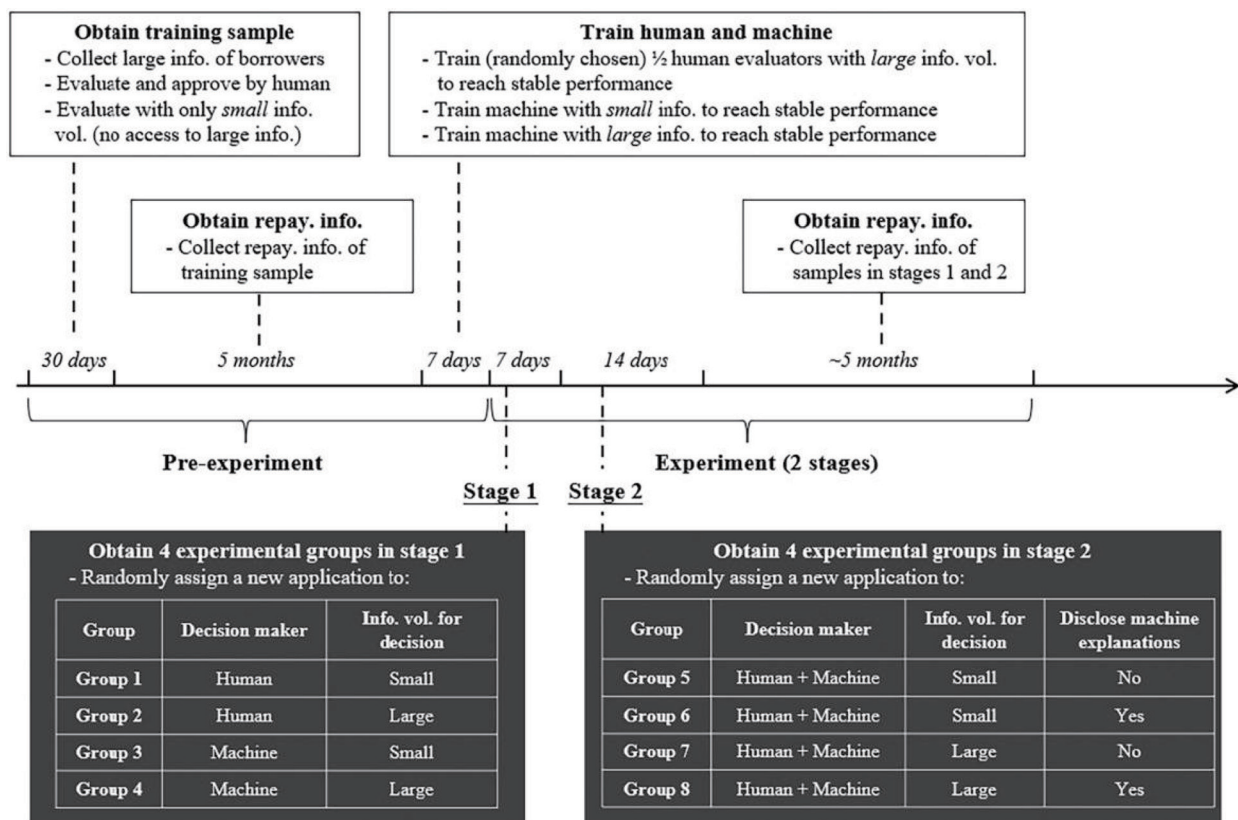


Figure3-7-1 Two-stage Experiment Design on Human-Machine Collaboration



outcomes. However, when large amounts of information are paired with algorithmic explanations, human involvement significantly enhances decision outcomes and effectively reduces default rates compared to decisions made solely by algorithms. Further mechanism analysis revealed that the combination of abundant information and algorithmic explanations can stimulate human reflective thinking, narrow gender gaps, and improve prediction accuracy. Notably, human decision-makers are capable of proactively linking new features with previously overlooked attributes that could potentially correct algorithmic errors. This ability not only highlights the importance of human-machine collaboration but also offers a new perspective for optimizing related systems.

Although the availability of vast information attracts the attention of human decision-makers, it does not guarantee their effective assistance to machines. To guide humans in actively reflecting on complex information and addressing uncertainty, additional cues are particularly crucial — helping achieve better decision outcomes. Against the backdrop of rising information costs, machine training costs, and human resource expenses, this study moves beyond surface-level quantitative analysis of human-machine collaboration outcomes and delves into the specific conditions and mechanisms for realizing the value of such collaboration. As a result, its conclusions hold considerable potential for practical application.

Partitioning-Based Econometric Analysis

Supported by the National Natural Science Foundation of China (Young Scientists Fund, Grant No. 72203122), Associate Professor Yingjie Feng at Tsinghua University, in collaboration with Professor Matias Cattaneo at Princeton University, Associate Professor Max Farrell at the University of California, Santa Barbara, and Richard Crump at the Federal Reserve Bank of New York, conducted original research on partitioning-based econometric methods in economics. Their findings, titled "On Binscatter", were published in May 2024 in the *American Economic Review*, one of the top five journals in economics.

With the advent of larger datasets, classical scatter plots become overly dense when visualizing bivariate relationships, making it difficult to uncover underlying data patterns. Moreover, as data privacy requirements grow more stringent, displaying raw data is often not permitted. To address these challenges, the partition-based econometric method Binscatter ("binned scatter plots") has become a popular alternative tool in empirical economic studies. By dividing the support of the independent variable into multiple bins and displaying the sample mean of the dependent variable within each bin, Binscatter enables a clearer visualization of the relationship between two variables. However, there are some critical issues in the application of Binscatter, particularly regarding covariate adjustment and uncertainty quantification, which can potentially lead to misleading conclusions. This study establishes a formal econometric framework to correct and extend existing Binscatter methods and examines the statistical properties of the resulting estimators, providing both theoretical and practical guidance for empirical researchers. The main contributions and innovations of this paper are as follows:

First, this study provides a comprehensive Binscatter toolkit, including conditional mean estimation with optimal binning, variance visualization, uncertainty quantification, as well as model specification and shape restriction tests, enabling researchers to conduct more in-depth analyses of their data. Second, through theoretical investigation, the study highlights a potential problem in existing Binscatter practice related to covariate adjustment that can yield incorrect conclusions. A corresponding remedy is proposed. Third, this research greatly relaxes the restrictions on smoothing parameters previously imposed in the related literature and takes the randomness of binning into account, thereby establishing a rigorous theoretical foundation for the Binscatter method. Finally, companion software packages in Python, R, and Stata are provided, making it easier for empirical researchers to apply the findings of this paper in practice.

Mental Accounting and Investment Decisions

With support from the National Natural Science Foundation of China (Excellent Young Scientists Fund, Grant No. 72322004 and Special Project, Grant No. 72342020), Li An from Tsinghua University (collaborated with Joseph Engelberg from the University of California, San Diego, Matthew Henriksson from the University of Tennessee, Baolian Wang from the University of Florida, and Jared Williams from the University of South Florida) conducted original research on the impact of mental accounting on investment decisions. Their findings, titled “The Portfolio Driven Disposition Effect”, were published in August 2024 in the *Journal of Finance*, the best journal in this area.

The concept of “mental accounting,” introduced by Nobel laureate Richard Thaler, successfully explains many real-world instances of bounded rationality. Mental accounting refers to the cognitive process by which decision-makers break down complex financial situations into smaller, more manageable parts. Results grouped within the same account are evaluated jointly, while those in separate accounts are assessed independently. *“The idea that households use systems of mental accounting is widely seen as plausible, but has proven hard to study: we lack a fully-developed model of mental accounting, and the data that would be needed to test such a model are not easy to come by.”* noted by Nick Barberis, a leading behavioral economist at Yale University. These obstacles, coupled with significant causal identification challenges, have left the specific mechanisms and dynamics of mental accounting largely unexplored in empirical research.

To address these challenges, the study leverages detailed investor holding and trading data and explores the role of outcome similarity in the formation of mental accounts. By comparing financially identical but perceptually distinct investment events, the researchers provide compelling evidence for multiple frames in investors’ mental accounts. These findings offer fresh insights into how mental accounting operates.

Building on the classic disposition effect, the study uncovers a new phenomenon: the “portfolio-driven disposition effect.” This effect reveals that an investor’s overall portfolio gains or losses significantly influence their tendency to exhibit the disposition effect. Specifically, when the portfolio is profitable, the disposition effect for individual stocks weakens, whereas it becomes more pronounced during portfolio losses. The study identifies the primary driver of this phenomenon as multiple frames in investors’ mental accounting. Investors employ at least two mental frames when making trading decisions—one at the individual stock level and another at the portfolio level. The interaction between these mental frames leads to the portfolio-driven disposition effect. This discovery has important implications for understanding investor behavior and its broader impact on market equilibrium.

Research on Sustainable Nitrogen Management in the Food System of Urban Agglomerations

With the support of the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars, Grant No. 71825006), the research group led by Professor Zongguo Wen from Tsinghua University has made progress in collaboration with the Macau University of Science and Technology. Based on the resource metabolism theory and long-term time series datasets, they developed an integrated approach that combines substance flow analysis, trade-embedded pollution transfer models, and spatial econometric analysis, to reveal the dynamic patterns of nitrogen metabolism within the food

system of an urban agglomeration and the underlying mechanisms of spatial interactions among cities. The findings provide scientific references for promoting coordinated nitrogen pollution control and facilitating the transition to sustainable nitrogen management in urban agglomerations. This research, titled "Uneven agricultural contraction within fast-urbanizing urban agglomeration decreases the nitrogen use efficiency of crop production," was published in *Nature Food* on May 14, 2024.

In the context of urban agglomeration development, the diverse development paths and significant differences in industrial divisions among cities within an urban agglomeration can lead to uneven changes in their agricultural production scales, which reshape the inter-city food supply patterns and the spatiotemporal characteristics of nitrogen pollution in the food system. To mitigate the overall nitrogen pollution in the urban agglomerations, it is necessary to clarify the mechanisms of nitrogen metabolism within the food system and avoid exacerbating spatial spillover of nitrogen pollution under localized management models. It is essential to fully leverage the synergies between cities to enhance nitrogen use efficiency and system sustainability. Using the Guangdong-Hong Kong-Macao Greater Bay Area of China as a case, this research revealed that as the unevenness in agricultural production scale within the urban agglomeration increased, there was a significant rise in the transfer of nitrogen pollution embedded in food trade from highly developed cities to less developed ones (Figure 3-7-2), exhibiting reduced nitrogen use efficiency in crop production and decreased sustainability of the food system. This research enhances the understanding of key challenges and opportunities in sustainable nitrogen management amid urbanization, providing scientific evidence for developing socio-economic policies aimed at coordinated nitrogen pollution reduction across multiple cities. It also offers important insights for achieving sustainable development goals in the food system through nitrogen management.

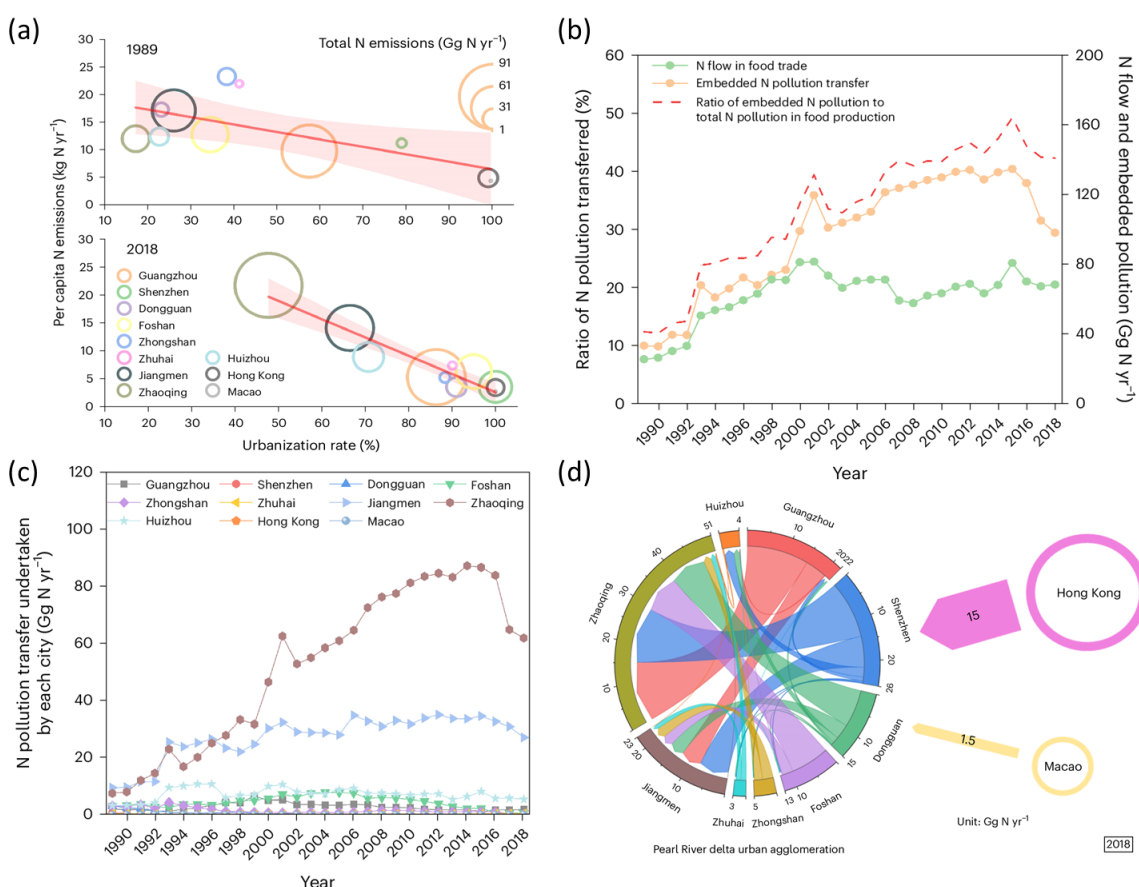


Figure 3-7-2 Nitrogen Emissions in the Food System of the Guangdong-Hong Kong-Macao Greater Bay Area and the Embedded Nitrogen Pollution in Inter-city Food Trade

8. Department of Health Sciences

A Brain-to-Gut Signal Controls Intestinal Fat Absorption

Approximately 50% of Chinese adults are overweight or obese, posing a critical threat to public health today. Over the past forty years, the proportion of fat in the diets of Chinese residents has increased from 22% to 32.9%. The excessive intake of high-calorie foods, particularly fats, has become a key contributor to the obesity epidemic. Fat absorption in the small intestine is prevailingly understood to occur primarily through “simple or facilitated diffusion,” and there is currently no evidence indicating whether the central nervous system is involved in this process.

Supported by funding from the National Natural Science Foundation of China (Grant No. 82088102, 91957124, 82250901, and 82100905), Dr. Wang Weiqing and Dr. Wang Jiqui from Ruijin Hospital, Shanghai Jiao Tong University School of Medicine, have made significant progress in understanding the mechanisms underlying obesity.

This study revealed that fat absorption in the jejunum is directly regulated by the dorsal motor nucleus of the vagus (DMV) in the brainstem. Utilizing a chemogenetic strategy to control the excitability of DMV neurons, the researchers found that inactivation of these neurons reduces intestinal fat absorption and subsequently leads to weight loss, while activation of the DMV enhances fat absorption and causes weight gain. Notably, inactivation of a specific subpopulation of DMV neurons projecting to the jejunum resulted in shorter microvilli, thereby reducing fat absorption (Figure 3-8-1). Moreover, they identified a natural compound, puerarin, which mimics the suppression of the DMV–vagus pathway, resulting in decreased fat absorption. Photoaffinity chemical methods and cryogenic electron microscopy of the structure of a GABAA receptor–puerarin complex reveal that puerarin binds to an allosteric modulatory site. Notably, conditional knockout of *Gabra1* in the DMV largely abolished puerarin-induced intestinal fat loss. In summary, this study discovered that suppression of the DMV–vagus–jejunum axis regulates intestinal fat absorption by shortening microvilli and highlights the therapeutic potential of puerarin binding to GABRA1 for promoting fat loss.

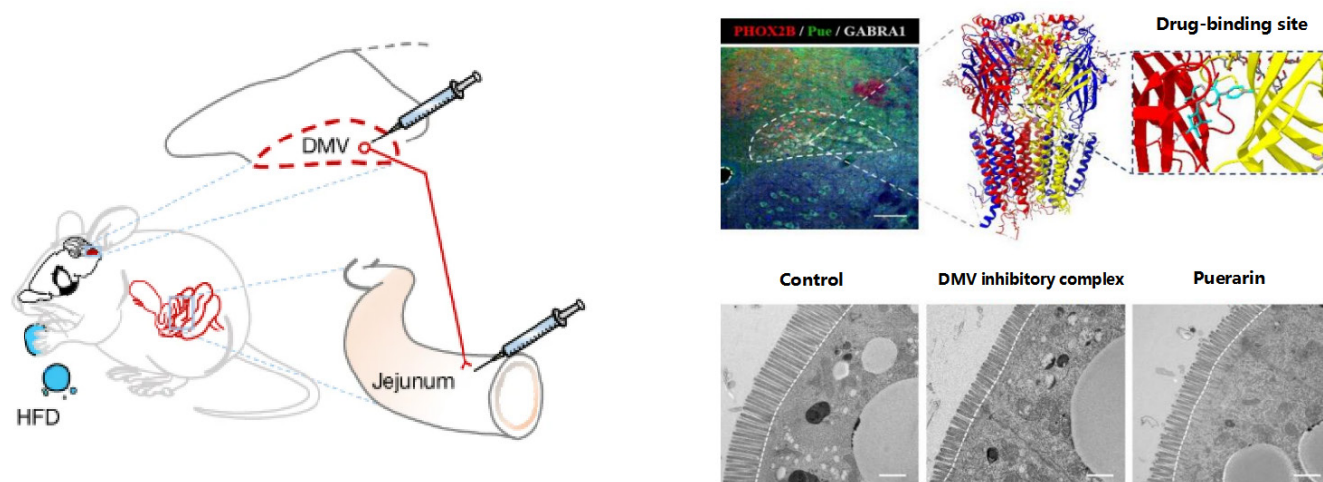


Figure 3-8-1 A brain-to-gut signal controls intestinal fat absorption.



These findings were published under the title “A Brain-to-Gut Signal Controls Intestinal Fat Absorption” in *Nature* on October 24, 2024. The study received commendation from Nature Research Briefing, which noted, “This is a great study that spans metabolism, physiology, neuroscience, and structural biology.” Frank Duca from the University of Arizona commented, “The authors demonstrate an extremely novel brain–gut signal that regulates fat absorption in the intestine, opening up numerous new research avenues.” The findings were also featured as a “Research Highlight” in *Nature Reviews Endocrinology*.

Spatiotemporal Modulation of Aging and Interventions

Aging is a complex, heterogeneous, asynchronous, and nonlinear systemic process that leads to the progressive decline of multiple organ functions, resulting in the loss of physiological integrity and an increased risk of chronic diseases such as neurodegenerative disorders, cardiovascular diseases, and diabetes. Over time, aging induces uneven changes in tissue structure and cellular characteristics, disrupting intracellular molecular regulatory networks and profoundly affecting the spatial distribution and interactions of cells within organs. Our understanding of how aging leads to tissue and cellular degeneration in the spatial dimension remains limited. Unveiling the key drivers of aging and developing safe and effective interventions within the complex spatiotemporal context is a significant challenge in gerontological research.

Supported by the National Natural Science Foundation of China (Grant No. 81921006, 82125011, 92149301, 92168201), collaborations between the Guang-Hui Liu team from the Institute of Zoology, Chinese Academy of Sciences, the Weiqi Zhang team from the Beijing Institute of Genomics, Chinese Academy of Sciences (China National Center for Bioinformation), and the Jing Qu team from the Institute of Zoology, Chinese Academy of Sciences, have made new strides in research on immunoglobulin-driven aging and metformin interventions.

The research team, through precise analysis of millions of spatial spots, constructed a high-precision pan-organ aging spatial navigation map (Gerontological Geography, GG), revealing the distribution characteristics of over 70 cell types and identifying tissue structure disorder and loss of cellular identity as universal features of multi-organ aging. The study not only accurately located the core areas of aging in multiple organs but also found that the accumulation of immunoglobulin G (IgG) is a key characteristic and driver of aging (Figure 3-8-2). These findings provide a new scientific basis for understanding the mechanisms of aging, early warning, and intervention. The concept of Immunoglobulin-associated Senescence Phenotype (IASP) expands the field of aging science and opens new avenues for delaying aging and preventing and treating related diseases.

Furthermore, the team discovered that metformin exerts geroprotective effects in multiple tissues of aged primates. Based on their self-developed human cell aging research system, they revealed that metformin activates the NFE2-like bZIP transcription factor 2 (Nrf2)-mediated antioxidant gene expression network and enhances cellular antioxidant capacity. Utilizing over 60 physiological parameters, including physiological function assessment, medical imaging, and blood tests, combined with multidimensional omics and histopathological analysis techniques, they confirmed that metformin has a rejuvenating effect on dozens of tissues and can significantly delay cortical atrophy in aged primates, enhancing their cognitive abilities (Figure 3-8-3). This study paves new avenues for delaying aging and preventing and treating related diseases, laying the foundation for translational medicine in human aging intervention and marking a shift in geriatric medicine research from single disease treatment to comprehensive systemic intervention in aging.

The aforementioned achievements, titled “Spatial transcriptomic landscape unveils immunoglobulin-associated senescence as a hallmark of aging” and “Metformin decelerates aging clock in male monkeys,”

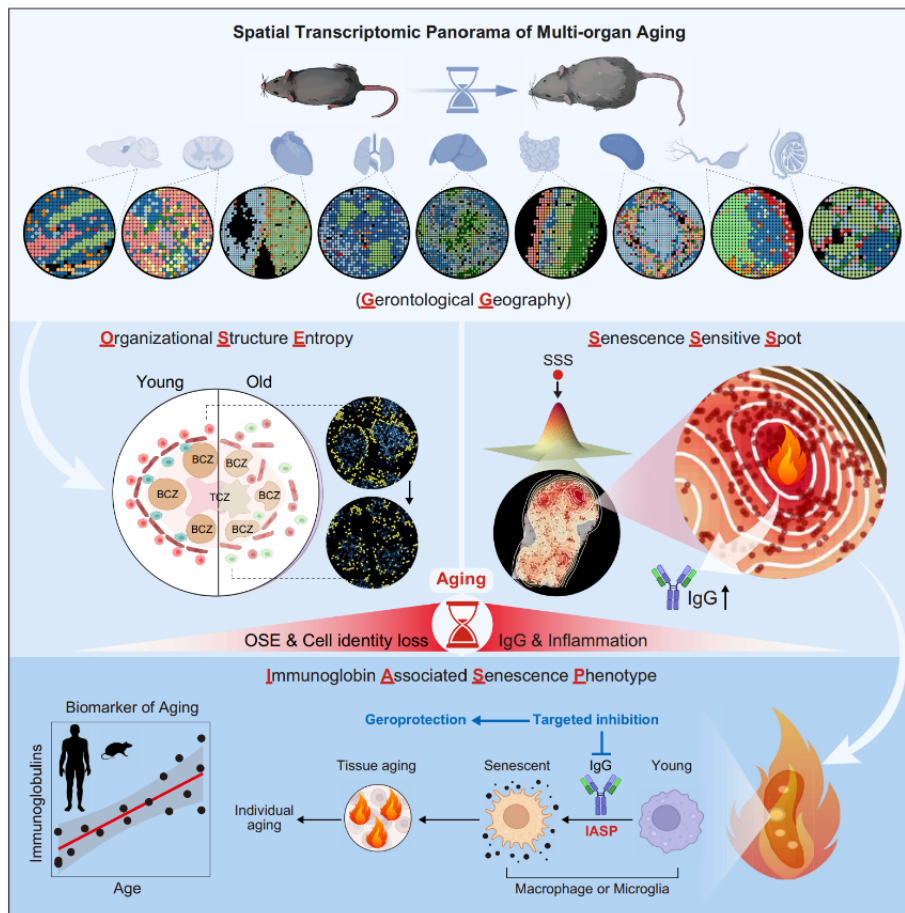


Figure 3-8-2 Spatial Transcriptomic Landscape Reveals Immunoglobulin-associated Senescence Phenotype.

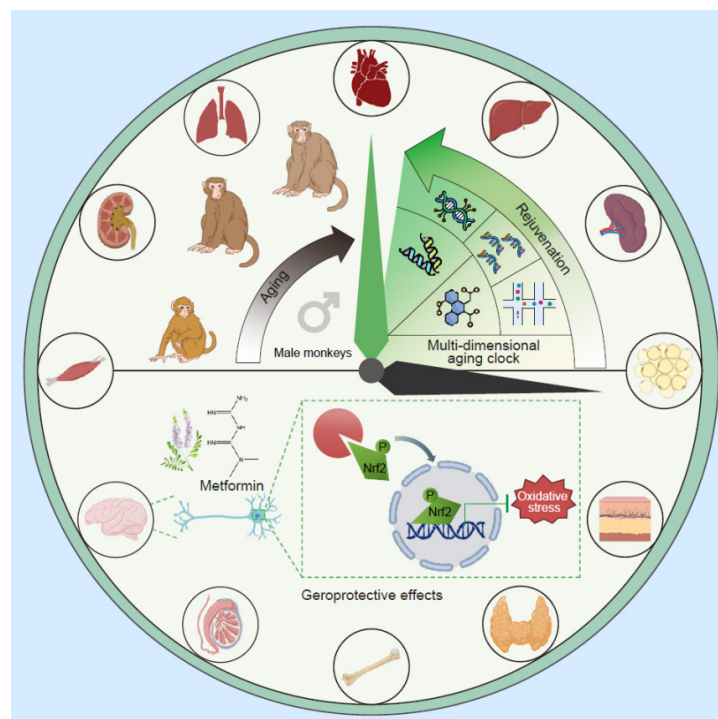


Figure 3-8-3 Metformin Decelerates Multidimensional Aging Clocks in Primates.

were published in *Cell*, and were featured as Featured Articles, receiving highlight reviews from *Nature*, *Science*, and *Nature Aging*.

Mechanisms of Spindle Assembly in Human Oocytes

Correct spindle assembly is essential for the successful mitosis and meiosis, ensuring accurate chromosome segregation and normal cell and embryo development. Spindle assembly primarily involves microtubule nucleation and spindle bipolarization. However, the process and mechanisms of spindle formation in human oocytes remain unclear.

Under the support of the National Natural Science Foundation of China (Grant No. 82271685, 82325021, 82101737, 82171643 and 82288102), Prof. Lei Wang and Qing Sang from Fudan University, and Dr. Wen Li from Shanghai Jiao Tong University, have made significant advancements in understanding the mechanisms of spindle bipolarization in human oocytes. Their research was published online in *Science* on August 23, 2024 (Figure 1), under the title "Mechanisms of Minor Pole-Mediated Spindle Bipolarization in Human Oocytes".

The research team previously discovered a novel submicroscopic structure responsible for polymerizing microtubules in human oocytes, named Human Oocyte Microtubule Organization Center (huoMTOC). When it's disrupted, spindle microtubule polymerization is blocked, preventing spindle formation (Science, 2022). Further studies revealed that upon the initiation of spindle microtubules polymerization, human oocyte experienced a completely different process of spindle bipolarization from mitosis and other mammalian oocytes. It takes a long time for the multipolar spindle state to form a bipolar spindle. Furthermore, HAUS6, KIF11 and KIF18A were key proteins in regulating spindle bipolarization. Mutations in the genes encoding key proteins have been identified in patients with reproductive disorders. These mutations could cause different degrees of abnormal spindle polarization, leading to oocyte maturation disorder, fertilization failure, and early embryo developmental arrest (Figure 3-8-4).

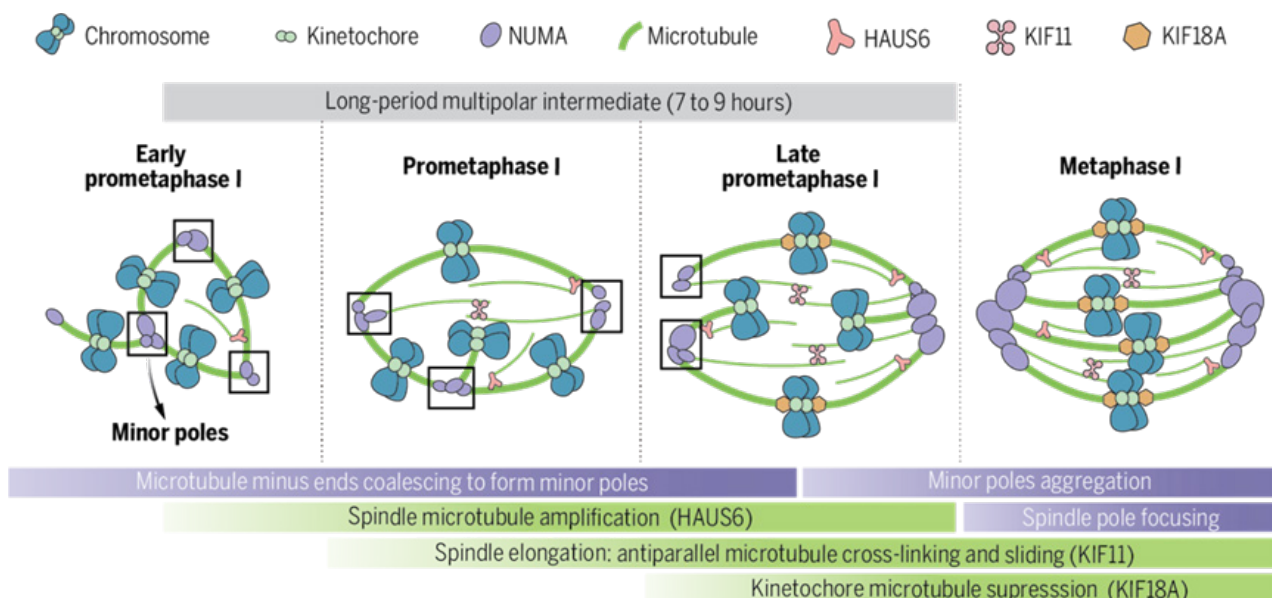


Figure 3-8-4 Mechanisms of Bipolar Spindle Assembly in Human Oocytes

These series of studies discovered for the first time a new sub-microscopic structure—huoMTOC, for initiating spindle microtubule polymerization in human oocytes, accurately depicted the process of

bipolar spindle formation, and found that the “multipolar spindle” is an essential physiological state in the process of spindle bipolarization in human oocytes. And it also revealed the unique physiological and pathophysiological mechanisms of spindle bipolarization in human oocytes. This finding deepens our understanding of the spindle assembly process in human oocytes and provides scientific basis for the diagnosis and treatment of clinical reproductive disorders.

Study on the Mechanism of Action of Anti-tuberculosis Drug Bedaquiline and its Derivatives

Tuberculosis (TB) is an infectious disease caused by *Mycobacterium tuberculosis*. According to the World Health Organization (WHO)'s Global Tuberculosis Report 2024, it is estimated that there are nearly 2 billion people with latent tuberculosis infection worldwide, with 10.8 million new cases of tuberculosis and 400,000 cases of multidrug-resistant or rifampicin-resistant tuberculosis. In China, there are 741,000 new cases of tuberculosis. Tuberculosis caused by multidrug-resistant and extensively drug-resistant *Mycobacterium tuberculosis* poses a serious threat to global health. Therefore, the development of new anti-tuberculosis drugs has become an urgent need to control the spread of tuberculosis.

Bedaquiline (BDQ) is an inhibitor that targets the ATP synthase of *Mycobacterium tuberculosis*, effectively inhibiting the growth of the bacteria. As the first new anti-tuberculosis drug developed globally and launched in nearly 50 years, BDQ has been listed by the World Health Organization as the first-choice drug in the long-term treatment of tuberculosis resistant to rifampicin or multiple drugs. However, studies have found that BDQ increases the risk of cardiac arrhythmias in patients due to its interaction with the hERG potassium ion channel, in addition to having potential cross-inhibitory activity on human ATP synthase. Therefore, it is of great significance to reveal the mechanism of action of BDQ as well as the molecular mechanism to inhibit the ATP synthase in humans in the development of novel inhibitors for ATP synthase of *Mycobacterium tuberculosis*, thus reducing the side effects of tuberculosis treatment.

Supported by the National Natural Science Foundation of China (Excellent Young Scientist Fund, Grant No. 82222042), Prof. Hongri Gong and Academician Zihao Rao from Nankai University, Assoc. Prof. Fengjiang Liu from Guangzhou Laboratory, and Assoc. Prof. Yan Gao from ShanghaiTech University cooperated and made progress in the molecular mechanism by which BDQ and its analogue TBAJ-587 inhibit the ATP synthase of *Mycobacterium tuberculosis* and human.

The research team innovatively used the gene knock-in/knock-out & gene overexpression strategy in combination with affinity chromatography and gel filtration chromatography to obtain a uniform, stable and active protein sample of *Mycobacterium tuberculosis* ATP synthase. They determined the high-resolution cryo-electron microscopy structure of *Mycobacterium tuberculosis* ATP synthase bound to BDQ and its analogue TBAJ-587. The structures revealed that BDQ and TBAJ-587 interact strongly with the leading site, c-only sites, and lagging site formed by the a subunit and c-ring of *Mycobacterium tuberculosis* ATP synthase through their quinoliny (A unit) and dimethylamino (D unit) groups, preventing the rotation of the c-ring in the transmembrane region of the ATP synthase and the transport of protons, thereby halting the synthesis of the energy currency (ATP), ultimately achieving the goal of *Mycobacterium tuberculosis* starved to death (Figure 3-8-5). The study also found that both BDQ and TBAJ-587 affect the activity of human ATP synthase, with BDQ binding to the binding pocket in the human ATP synthase that corresponds to the leading site in *Mycobacterium tuberculosis* ATP synthase (Figure 3-8-6). Researchers analyzed and found that the redesigned TBAJ-587 which has optimization on the B and C units in BDQ only reduces the risk of cardiac arrhythmias caused by the interaction with hERG protein. Optimizing the A unit may reduce the interaction with human ATP synthase, thereby avoiding potential health risks in clinical treatment.

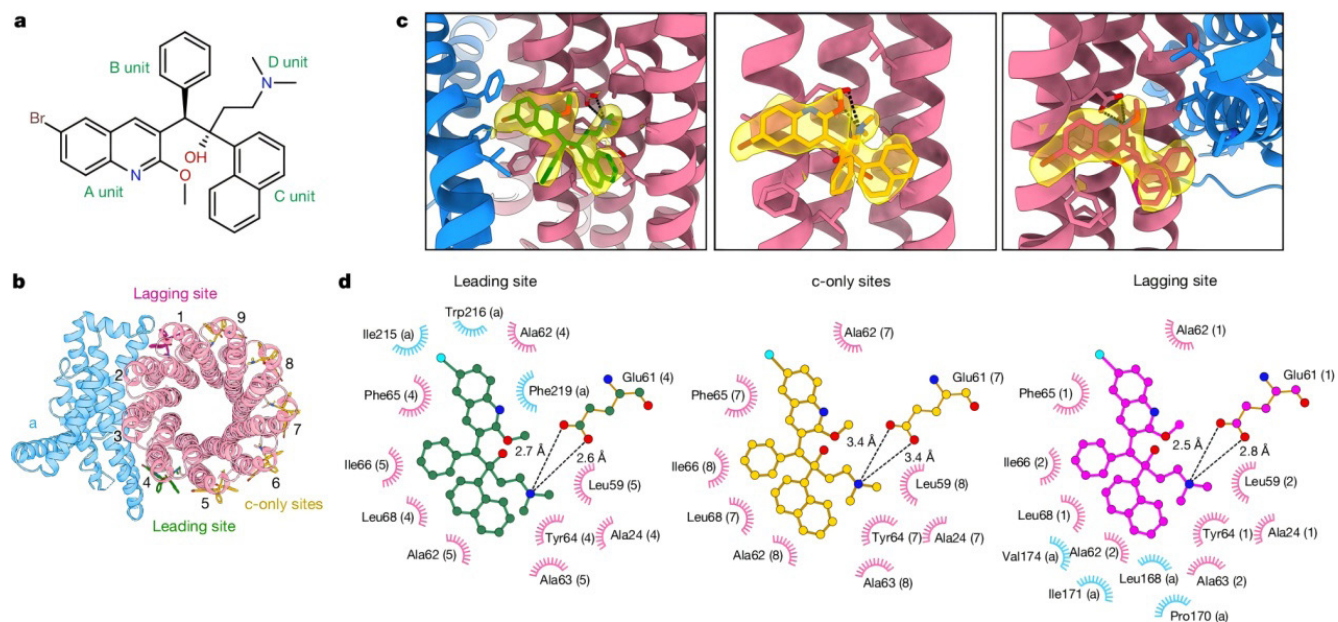


Figure 3-8-5 Three-dimensional Structure and Interaction Analysis of Mycobacterium Tuberculosis ATP Synthase Bound to BDQ

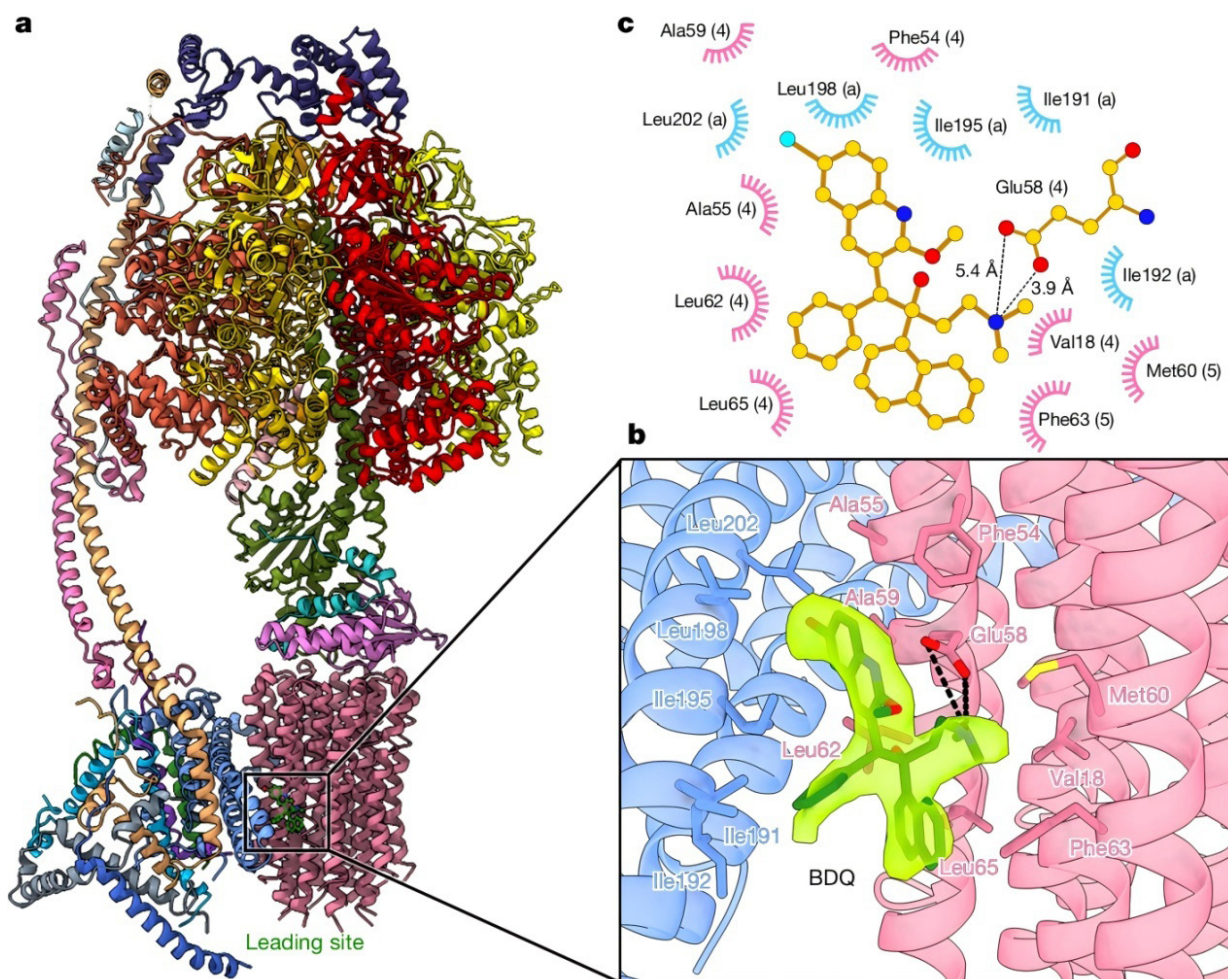


Figure 3-8-6 Three-dimensional Structure and Interaction Analysis of Human ATP Synthase Bound to BDQ

The relevant research achievements were published in *Nature* with the title “Inhibition of *M. tuberculosis* and human ATP synthase by BDQ and TBAJ-587”. In the same issue, *Nature* invited Prof. Gregory M. Cook, a fellow of the Royal Society of New Zealand, and his colleagues to publish a brilliant review commentary, in which they pointed out that by utilizing the structural biology information of the ATP synthesis machinery of *M. tuberculosis* and integrating computational chemistry with artificial intelligence drug design methods, it is possible to further design compounds that specifically target the ATP synthase of *M. tuberculosis*, consolidating the position of this class of drugs as a key component of anti-tuberculosis treatment regimens. Prof. Nanshan Zhong, an academician of the Chinese Academy of Engineering and director of the Guangzhou National Laboratory, stated that this achievement not only strengthens the theoretical research foundation in the field of tuberculosis but also provides more possibilities for the design of anti-tuberculosis drugs with higher selectivity.

Deciphering the Tumor Microenvironment to Promote Precision Therapy for Cancer

Cancer poses a severe threat to the health of the Chinese people. Surgical resection remains the preferred treatment for solid tumors, but the high rate of recurrence and metastasis is the main factor restricting patients' long-term survival after surgery. After decades of development, combination therapies based on immunotherapy have been applied throughout the treatment of malignant tumors, greatly improving patient prognosis. However, immunotherapy alone, immunotherapy combined with targeted therapy or dual immunotherapy, the overall response rate for solid tumors is still less than 50%. Additionally, the highly complex characteristics of the microenvironment presents a significant challenge to precision therapy for solid tumor. Deciphering the tumor microenvironment and identifying new immune therapy sensitizing targets are key to improving the response rate of solid tumor treatments and improving patient prognosis.

In response to these urgent clinical and scientific issues, the team led by Academician Fan Jia of Zhongshan Hospital Affiliated to Fudan University, carried out a series of fundamental studies to comprehensively analyze the characteristics of liver cancer microenvironment cell subpopulations and their cancer-promoting/anti-cancer mechanisms: (1) A Pan-cancer single-cell neutrophil transcriptome analysis of 17 solid tumors, with a total of 225 samples from various cancers, including HCC, CCA, and gallbladder cancer, found that LA-DR+CD74+ neutrophils trigger antigen presentation through leucine metabolism and histone H3K27 acetylation modification, thereby inducing T-cell antigen-specific reactions and promoting the formation of a “hot tumor” microenvironment to exert anti-cancer effects. A leucine-rich diet or the delivery of LA-DR+CD74+ neutrophils can reshape the immune microenvironment and enhance the therapeutic effect of anti-PD-1 treatment (Figure 3-8-7, *Cell* 2024); (2) A single-cell transcriptome analysis of B cells from a total of 477 solid tumor samples across 20 cancer types systematically revealed the phenotypic and functional heterogeneity, dynamic differentiation, and epigenetic regulatory mechanisms of B cells in the tumor microenvironment. It was found that a subset of DUSP4+ atypical memory B cells differentiate into plasma cells through the extrafollicular response pathway, capable of secreting antibodies that recognize self-antigens and suppressing T-cell function, leading to an immunosuppressive state in the tumor microenvironment, which is not conducive to patient prognosis and anti-cancer immunotherapy. This discovery provides important clues for the future precision control of B cells, identification of new immunotherapy targets, and the development of new immunotherapy combination regimens (Figure 3-8-8, *Science* 2024).

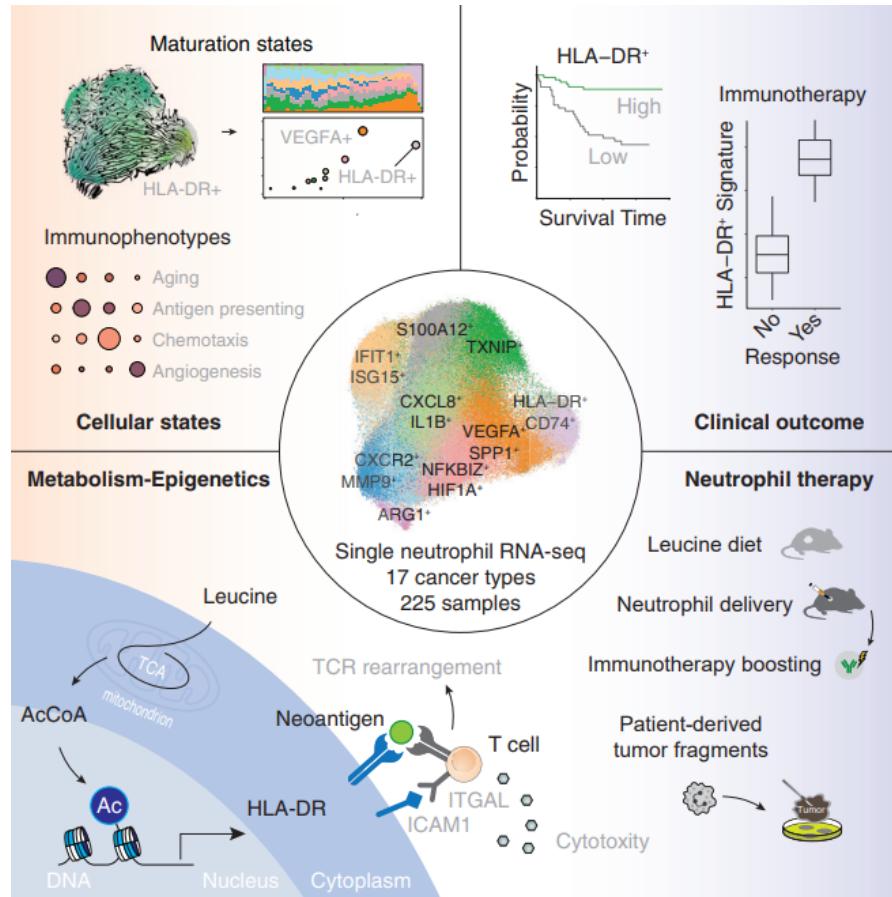


Figure 3-8-7 Neutrophil Profiling Illuminates Anti-tumor Antigen Presenting Potency

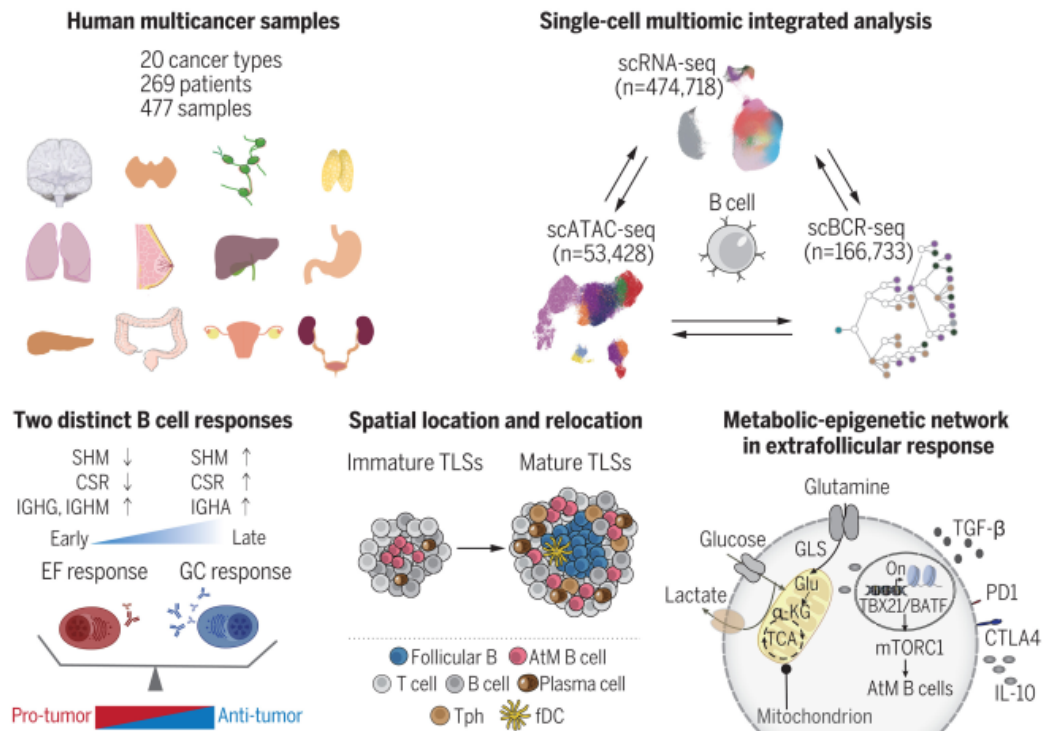


Figure 3-8-8 A Blueprint for Tumor-infiltrating B Cells across Human Cancers

The series of research achievements mentioned above were accomplished with the support of projects such as the National Natural Science Foundation of China (Grant No. 82130077, 81961128025, 82121002, 82341008, 82394450, U23A6010), laying an important foundation for the development of precise clinical treatment of cancer.

Research on the Novel Immune Checkpoint CD3L1: Mechanism and Drug Development

Malignant tumors pose a severe threat to human health and life, and advanced-stage tumors lack effective treatment options. Currently, despite the remarkable clinical success of tumor immune checkpoint inhibitors represented by programmed death receptor-1/programmed death-ligand 1 (PD-1/PD-L1) antibodies, a substantial number of patients exhibit poor responses to immunotherapy, prompting the exploration of novel immunotherapy targets.

Supported by grants from the Natural Science Foundation of China (Key Project No. 82030104; General Projects No. 81874050, 81572326), Professor Xu Jie's research team at Fudan University has successfully identified a novel immune regulatory checkpoint, CD3 ligand 1 (CD3L1, also known as ITPRIPL1), conducted an in-depth analysis of its mechanism of action, and developed therapeutic antibodies targeting this checkpoint. The study revealed that CD3L1 is highly expressed in immunologically privileged organs and tumor tissues lacking PD-L1 expression, suggesting its potential role in promoting tumor immune evasion.

Utilizing high-throughput technologies such as single-cell sequencing and mass spectrometry analysis, combined with a series of binding experiments and functional validations, the team revealed that CD3L1 acts as a natural ligand for CD3 ϵ , effectively inhibiting T-cell activation. This discovery not only elucidates the central role of CD3L1 in the mechanism of tumor immune evasion but also confirms, for the first time, the existence of a natural inhibitory ligand for CD3, which has the potential to alter the traditional "master-slave" regulatory model of the T-cell antigen receptor (TCR)/CD3 complex and establish a new "bipolar" regulatory mechanism where both TCR and CD3 receive signals from natural ligands (Figure 3-8-9).

Based on these findings,

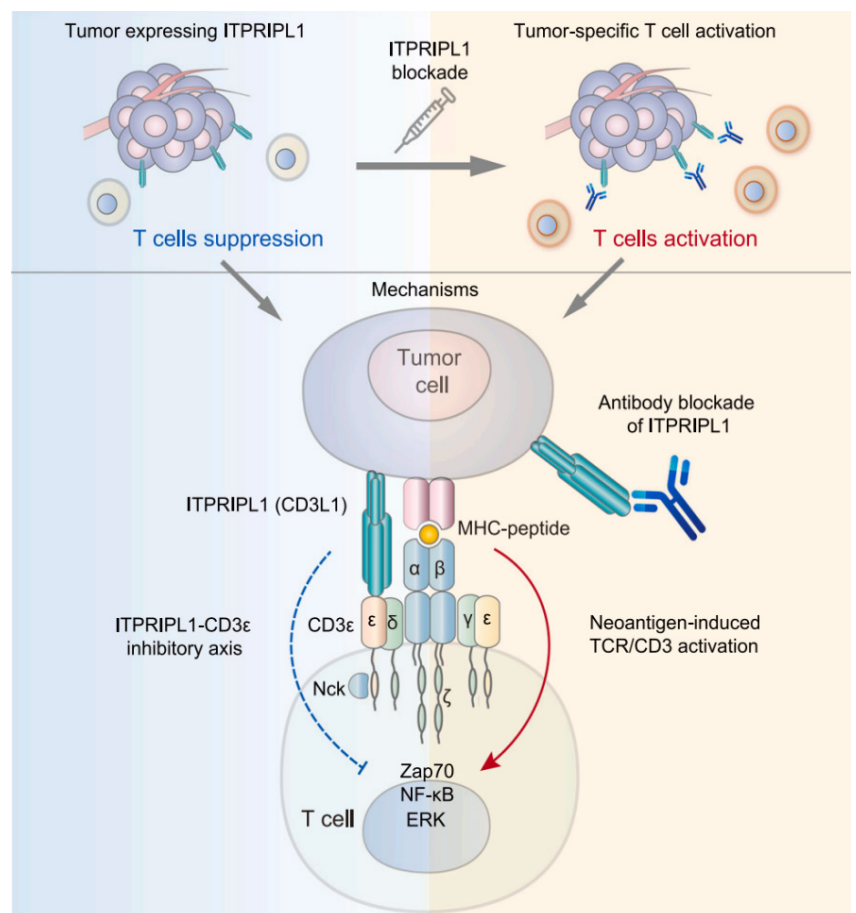


Figure 3-8-9 Mechanism of Action of CD3L1 and Anti-CD3L1 Antibodies



the team developed specific therapeutic antibodies targeting CD3L1, which demonstrated significant therapeutic potential in tumor models and natural tumors in pets. Currently, the antibody (BT02 monoclonal antibody injection) has received Investigational New Drug (IND) approval from both the U.S. Food and Drug Administration (FDA) and the National Medical Products Administration (NMPA) of China and is in Phase I clinical trials. Preliminary clinical observations have shown good safety and significant efficacy of the CD3L1 antibody in some patients with advanced tumors, indicating that this original target has been clinically validated.

Professor Xu Jie's team has achieved an original exploration from the discovery of a new mechanism, validation of a new target, to the development of a candidate drug, bringing new hope for the development of tumor immunotherapy. The research findings, titled "ITPRIPL1 binds CD3 ϵ to impede T cell activation and enable tumor immune evasion," were published in the international top-tier journal *Cell* on April 25, 2024.

9. Department of Interdisciplinary Sciences

A Study on the 100,000-Year Evolution of Rice from Wild to Domesticated at the Shangshan Cultural Sites

As one of the world's major staple crops, rice not only feeds one-third of the global population but also provides a crucial material and cultural foundation for the flourishing of Chinese civilization. For over a century, the domestication of rice and the origins of rice agriculture have been focal points of research across multiple disciplines, including archaeology, biology, agronomy, genetics, and anthropology.

Supported by funding from the Natural Science Foundation of China (T2192950), a research team led by Professor Houyuan Lyu at the Institute of Geology and Geophysics, Chinese Academy of Sciences, in close collaboration with experts from the Zhejiang Provincial Institute of Cultural Relics and Archaeology, Linyi University, and 13 other institutions nationwide, employed phytolith analysis to study the origins of domesticated rice, revealing the continuous history from wild rice collection to domestication in East Asia. The relevant findings, titled "Rice's trajectory from wild to domesticated in East Asia," were formally published in *Science* on May 24, 2024.

Based on years of systematic research on phytoliths in modern wild and domesticated rice plants and soils, the research team established a method for distinguishing wild and domesticated rice by using the number of fish-scale facets on bulliform phytoliths in rice leaves as a criterion. They determined that the threshold proportion of bulliform phytoliths with nine or more fish-scale facets for domesticated rice is 40% or higher. Furthermore, they clarified the relationship between the increasing number of fish-scale facets on bulliform phytoliths and the enhanced physiological and agronomic traits linked to rice domestication.

Building on this, they conducted sampling and analysis of archaeological and natural profiles at representative Shangshan cultural sites, i.e. the Shangshan site in Pujiang County and the Hehuashan site in Longyou County, Zhejiang Province. Based on Bayesian modeling of 38 OSL ages and phytolith ¹⁴C dates from the Shangshan and Hehuashan sites, they established a high-precision chronological stratigraphy for the past 100,000 years.

The results indicate that as early as 100,000 years ago, wild rice was already present in the lower reaches of the Yangtze River. Around 24,000 years ago, humans began gathering and utilizing wild rice. Around 13,000 years ago, the proportion of domesticated-type bulliform phytoliths in rice began to gradually increase, marking the pre-domestication cultivation process of wild rice. Around 11,000 years ago, the proportion of domesticated-type phytoliths increased rapidly, reaching the domestication threshold, which marks the beginning of rice agriculture in East Asia. This discovery not only reveals the complete and prolonged process of wild rice collection to domestication in East Asia, establishing a clear evolutionary framework for the study of rice agricultural origins (Figure 3-9-1), but also further confirms that China is the cradle of domesticated rice.

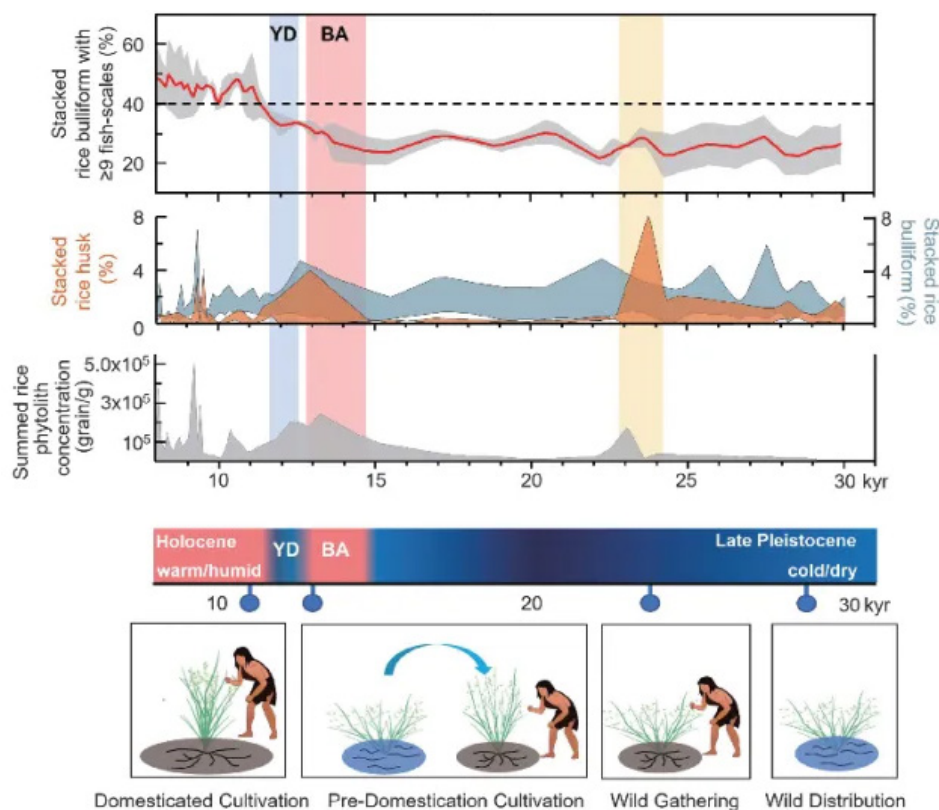


Figure 3-9-1 Combined records of rice exploitation towards domestication over the past 100 kyr in the lower Yangtze region

Encoding signal propagation on topology-programmed DNA origami

Supported by the National Natural Science Foundation of China (Project No. T2188102), Professor Chunhai Fan from Shanghai Jiao Tong University and Professor Hao Pei from East China Normal University have collaboratively developed a topology-programmed DNA origami system. This topologically allosteric DNA origami can form dynamic scaffolds, encoding the connectivity and connection modes of signal nodes at the nanoscale, establishing a new model for topological graphical computation. The research findings were published in *Nature Chemistry* on June 17, 2024, under the title "Encoding signal propagation on topology-programmed DNA origami", and selected as the cover article (Figure 3-9-2).

How to dynamically configure the connections between nodes using topological transformations and establish adaptive computational functional connections through topological patterns is a forefront direction in graphical computation. In recent years, the development of structural DNA nanotechnology has provided new opportunities for constructing biomimetic topological isomeric nanostructures. However, building artificial structures with complex topological control functions and achieving complex topological transformations remains a significant challenge.

To address this challenge, the research team first proposed a strategy for achieving topological operations (pasting and cutting) at the molecular level, which can induce global conformational changes in DNA origami structures (Figure 3-9-3). Based on this strategy, they successfully designed and constructed three types of reconfigurable DNA origami systems, achieving continuous topological transformations through molecular topological operations and characterizing these transformations using topological invariants. These topology-programmed DNA origami can serve as dynamic scaffolds for spatiotemporally

controlled molecular signal propagation. Topological transitions can alter the positions, connection modes, and connectivity of nodes, establishing a direct correlation between topological properties and the architecture of computational networks, thereby enabling the regulation of computational functions through changes in topological properties and making the network topology adaptable to functional connections to perform various logical computations.

Based on the mechanism of continuous molecular topological transformations, this study provides a programmable dynamic scaffold for exploring topological graphical computation at the nanoscale, achieving continuous topological transformations in DNA origami structures and demonstrating a signal transmission network scale of up to 77 molecular nodes in experiments. By realizing the transformation of connection modes among computational network nodes through topological allosterism, the research showcases the extremely high topological programmability of nucleic acid molecules at the nanoscale. Through more than 100 strand displacement reactions and hybridization reactions at the molecular level, efficient topological operations were achieved. By arranging active DNA hairpins in space, signal transmission was enabled along pathways of varying



Figure 3-9-2 The research finding was published in Nature Chemistry and selected as the cover article.

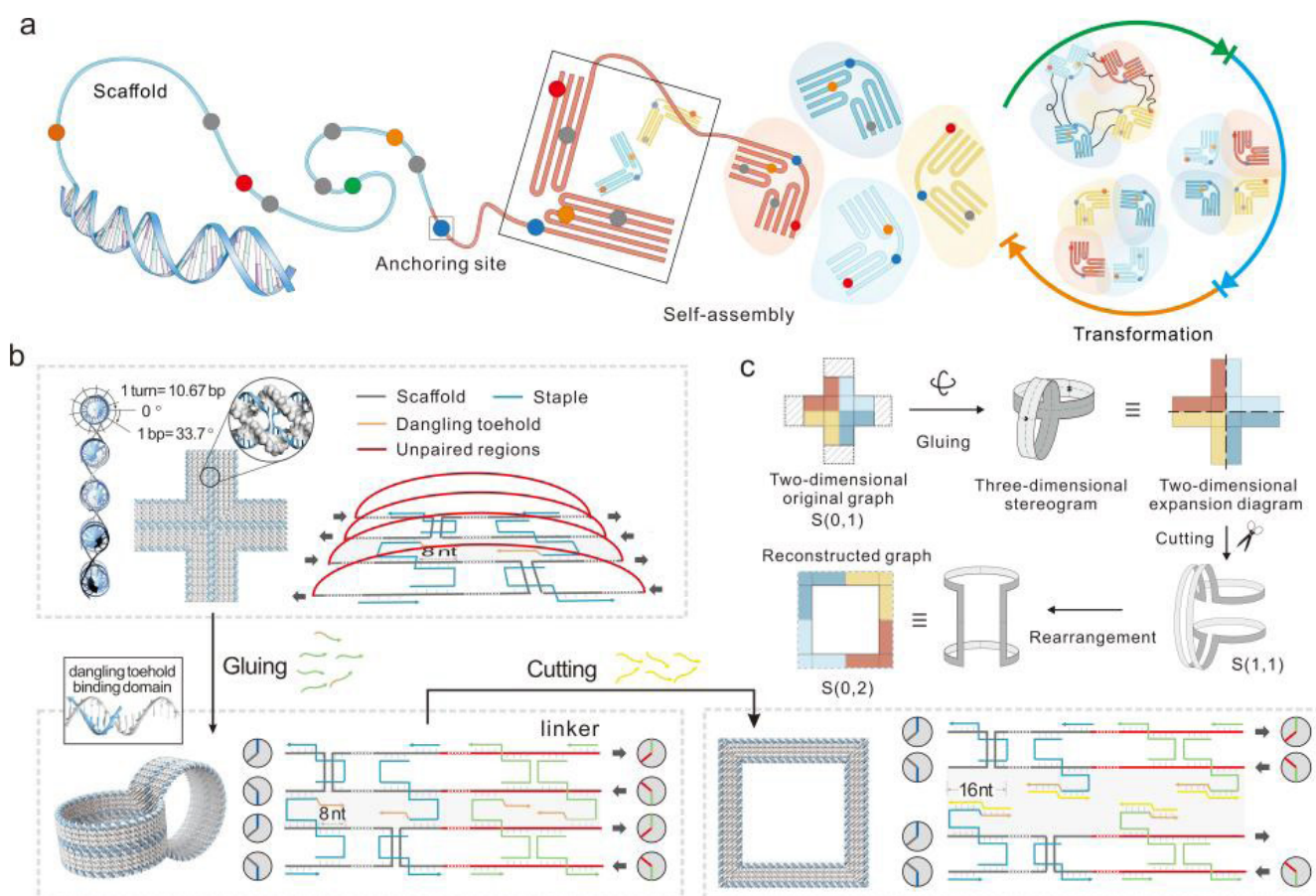


Figure 3-9-3 Topological transitions and computation based on DNA origami systems.



lengths (exceeding 300 nm), directions, and curvatures (concave or convex) on 3D origami surfaces. The topological operation strategy proposed in this study provides a general approach for the fabrication of dynamic DNA self-assembly and offers new insights for advancing topological graphical computation.

Design and discovery of cell membrane and DNA dual targeting peptide mimics against drug-resistant fungi

Fungal infections pose a significant threat to human health. Due to the highly adaptable genomes of fungi and the rapid spread of antifungal-resistance genes, fungi are prone to develop resistance to conventional single-targeting antifungal drugs. The dual-targeting drugs are expected to significantly reduce the likelihood of antifungal resistance by simultaneously acting on multiple pathways of microorganisms, holding great promise in antifungal drug development. The current dual-target antifungal design dominantly uses a combination of two drugs to achieve a synergistic effect to treat drug-resistant fungal infections. However, the therapeutic effect is limited by the distinct in vivo distribution and pharmacokinetics of two different drugs, making it challenging to achieve the desired synergistic effects in the body. Additionally, as both fungal and mammalian cells are eukaryotic, it is challenging to identify specific antifungal molecular targets. Consequently, dual-targeting drugs have yet to achieve breakthroughs in antifungal research.

Under the support of the National Science Fund for Distinguished Young Scholars (T2325010), the Professor Runhui Liu group from East China University of Science and Technology has made significant progress in dual-target antifungal research. The findings, titled "A dual-targeting antifungal is effective against multi-drug resistant human fungal pathogens", were published in *Nature Microbiology* on April 8, 2024.

Liu group successfully designed dual-targeting compound against drug-resistant fungi by employing poly(2-oxazoline) as the mimic of natural host defense peptides (HDPs), while introducing DNA-binding functional groups. This is the first time that dual-target antifungal compound targeting both cell membranes and DNA have been developed, and the dual-target antifungal mechanisms are also comprehensively elucidated in conjunction with microscopic imaging (Figure 3-9-4). The dual-targeting compound demonstrated superior antifungal activity and selectivity against clinically multidrug-resistant fungi. Moreover, the compound exhibited outstanding therapeutic efficacy in multiple preclinical mouse models of drug-resistant fungal infections, such as keratitis, abrasion infections, and systemic infections. Compared to clinical available antifungal drugs with single-targeting mechanisms, the dual-targeting compound are less likely to induce resistance, showing considerable potential for clinical antifungal drug development.

This work introduces a novel design strategy for dual-targeting antifungal peptide mimics, provides a new perspective for the development of drugs to combat drug-resistant fungal infections, and explores the potential application value of dual-targeting antifungal compounds.

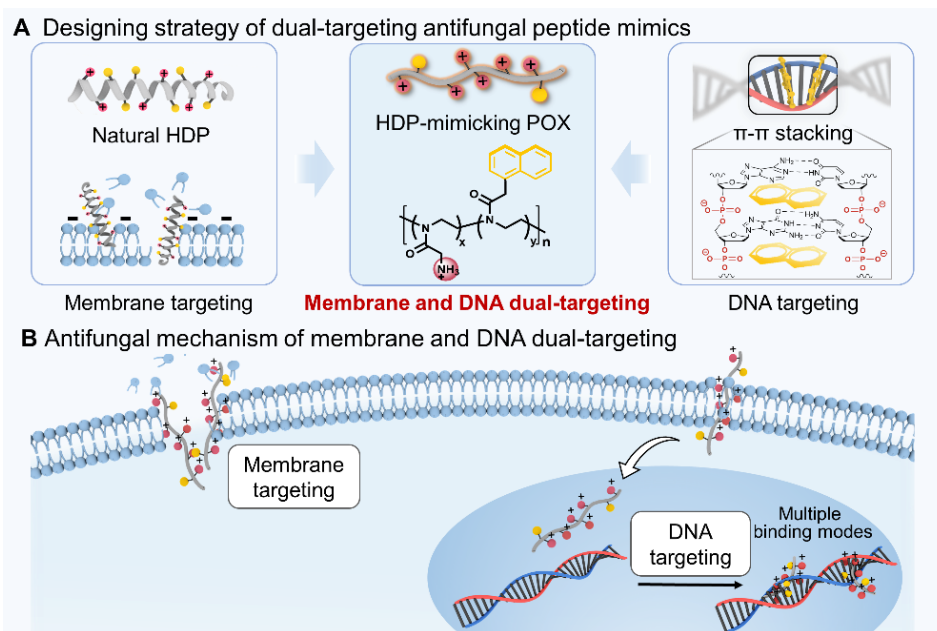


Figure 3-9-4 Design strategy of antifungal peptide mimics with dual targets of membrane and DNA.

Hybrid Diffusion and Spread Models of Chinese Dialects

As one of the key carriers of Chinese culture, Chinese dialects are spoken by over 1.4 billion native speakers globally. The mechanisms of their spread and evolution have long been a focus of interest in both anthropology and population genetics.

Supporting by the National Natural Science Foundation of China (The Excellent Young Scientists Fund, No. T2122007), the research team led by Menghan Zhang at Fudan University, in collaboration with Prof. Shuhua Xu's and Prof. Li Jin's teams, has systematically integrated theories and methods from linguistics, population genetics, and ecology. This research has analyzed the distribution patterns and diffusion history of Chinese dialects. The results were published as a cover article (Figure 3-9-5) in *Nature Human Behaviour* on May 13, 2024, under the title "Large-scale lexical and genetic alignment supports a hybrid model of Han Chinese demic and cultural diffusions."

Through quantitative analysis and spatial projection of 1,018 lexical traits from 926 dialect varieties, the team found that the diversity of Chinese dialects is closely related to their geographical distribution. The lexical differences exhibit a clear north-south gradient, with large mountains and rivers acting as geographical barriers that further promote the differentiation of dialect groups. The Yangtze River serves as the geographical boundary between northern and southern dialects, while the Qinling-Huaihe Line further distinguishes northern Mandarin from southern Mandarin. To further uncover the historical interactions between Han population movements and dialect admixture, the team applied Bayesian



Figure 3-9-5 Cover image of *Nature Human Behaviour*

ancestry composition inference and diffusion pattern reconstruction. They found that dialect admixture is most prominent in central China, forming a “dialect melting pot” (Figure 3-9-6). The direction of this mixing corresponds well with major historical Han migrations from north to south, such as the “Jiangxi fills Huguang, Huguang fills Sichuan” migration.

By integrating public genetic data, this study further compared the relationship between the linguistic structure of Chinese Han populations and their population genetic structure. It concluded that the demic diffusion model is the key driving force behind the spread and differentiation of Chinese dialects, while cultural diffusion and language assimilation also play important roles in regional dialect evolution.

This research systematically analyzes the potential driving forces behind the formation of Chinese cultural diversity from both linguistic and genetic perspectives. It emphasizes the key role of social and cultural factors in the evolution of Chinese languages, beyond the demic diffusion model. These findings provide crucial interdisciplinary insights into understanding the historical activities of the Han people and offer valuable references for further studies on language evolution and the co-evolution of language, genetics, and culture.

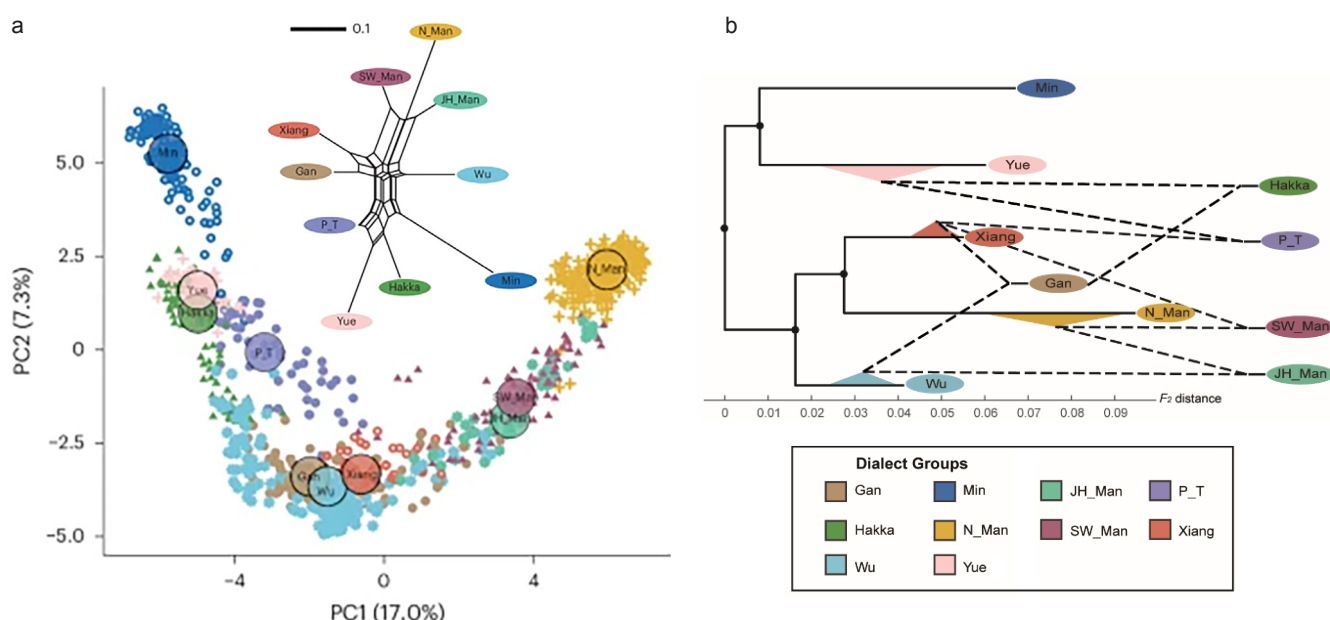


Figure 3-9-6 Admixture patterns of Chinese dialects

Analysis and Modeling of Regional Labor Mobility Using Internet Search Data

Funded by the National Natural Science Foundation of China (Grant No. 92370204) and others, Prof. Hui Xiong's team from the Hong Kong University of Science and Technology (Guangzhou) proposed a real-time labor market analysis framework based on internet search. The research findings were published in *Nature Cities* on January 16, 2024, titled “Large-scale online job search behaviors reveal labor market shifts amid COVID-19”.

Social sciences, a vital component of scientific inquiry, seek to understand complex societal phenomena, uncover patterns in social dynamics, and inform policymaking for social development. While traditional social science research has relied on census and survey data—which are costly and time-

consuming—the internet era offers rich online search data that reveals human intentions and activities. Therefore, Prof. Hui Xiong's team developed an intelligent search data-based social pattern analysis method, advancing the integration of AI with social sciences.

This work establishes an automated analysis method for tracking spatiotemporal patterns through unstructured search semantic awareness. It features a location-aware multi-pattern matching algorithm that precisely identifies individual job transfer patterns. It introduces an innovative dynamic graph-based regional labor mobility modeling framework, alongside a hyperlink-induced topic search-based city attractiveness measurement, thus effectively handling both long-tail characteristics and temporal changes in searching behaviors.

This research overcomes key challenges in complex search-implied intent analysis and modeling, significantly demonstrating how search patterns can illuminate social dynamics. The resulting frameworks and tools have broad applications across social sciences. In particular, for labor economics, by enabling detailed, real-time analysis of labor market dynamics, it provides valuable support for government policymaking on labor migration and macroeconomic planning.

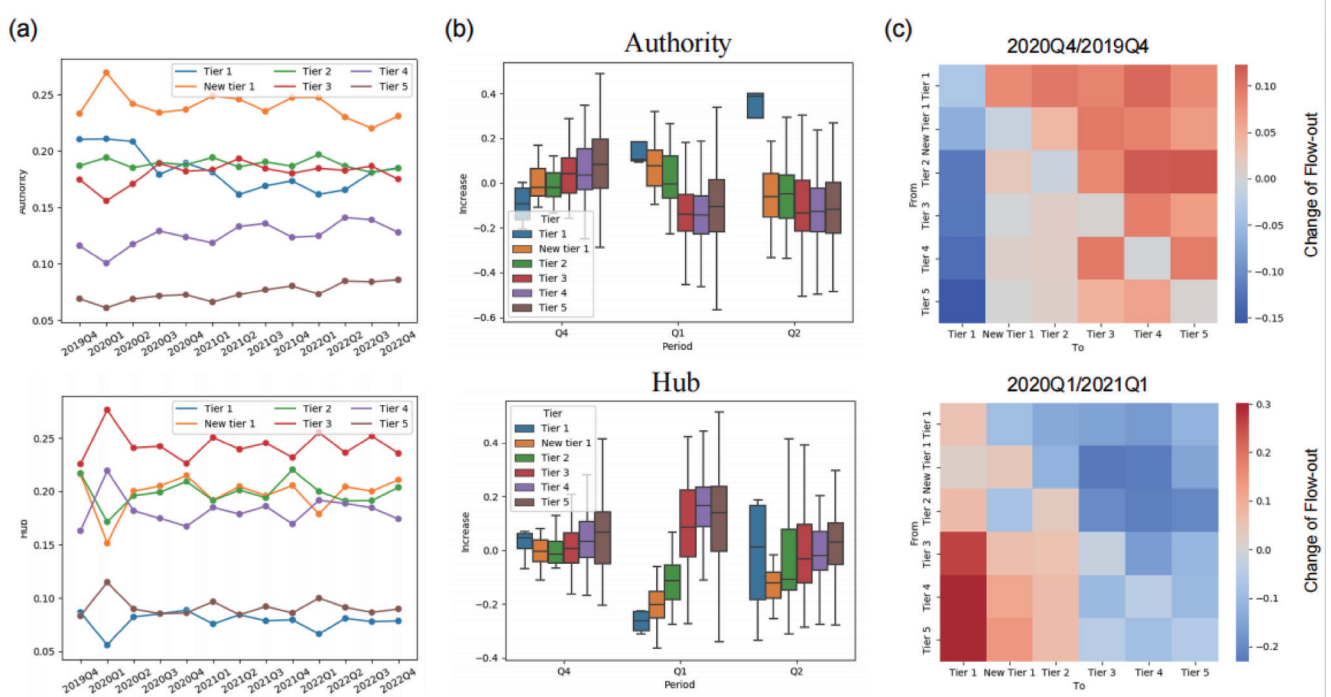


Figure 3-9-7 Internet job search data-based regional labor force mobility mining. Nodes represent cities, edges represent inter-city mobility intentions identified from job searches, and node sizes indicate labor force attraction intensity.

Data-driven development of engineered probiotic therapeutic for ulcerative colitis treatment

Supported by the National Natural Science Foundation of China (Approval No. T2225021 and other grants), Researchers Wei Wei and Guanghui Ma, from the Institute of Process Engineering (IPE) of the Chinese Academy of Sciences, have collaborated with Professor Yimin Cui from Peking University First Hospital and have made progress in developing an engineered probiotic therapy for treating ulcerative colitis (UC). The

study, entitled 'Engineered probiotic ameliorates ulcerative colitis by restoring gut microbiota and redox homeostasis', was published as the cover story in *Cell Host & Microbe* (Figure 3-9-8).

Probiotics are potential treatments for alleviating UC symptoms and restoring gut microbiota, but their efficacy is frequently compromised by gastrointestinal conditions that limit adhesion and viability. Moreover, the complicated pathological environment of inflamed tissue also implies the presence of other pathogenic factors. To address these issues, researchers employed data mining and clinical samples to reveal the importance of synergistically restoring intestinal redox and microbiota homeostasis for UC treatment. Based on this, researchers functionalized *Lactobacillus casei* (Lac) with ultrasmall but highly active selenium dots (Se-fLac). The resulting Se-fLac endowed Lac cells with enhanced gastric acid resistance and intestinal mucoadhesion after oral administration. At the lesion site, Se-fLac efficiently scavenged reactive oxygen species and modulated the gut microbiota (Figure 3-9-9). In multiple mouse models and non-human primates, Se-fLac effectively relieved inflammation and reduced colonic damage, outperforming clinical drugs such as 5-aminosalicylic acid and dexamethasone. Considering the strong translational potential of Se-fLac, researchers are currently collaborating with Peking University School of Stomatology to conduct an Investigator Initiated Trial.



Figure 3-9-8 Delivery of the engineered probiotic to the UC lesion site for synergistic treatment (Cover illustration)

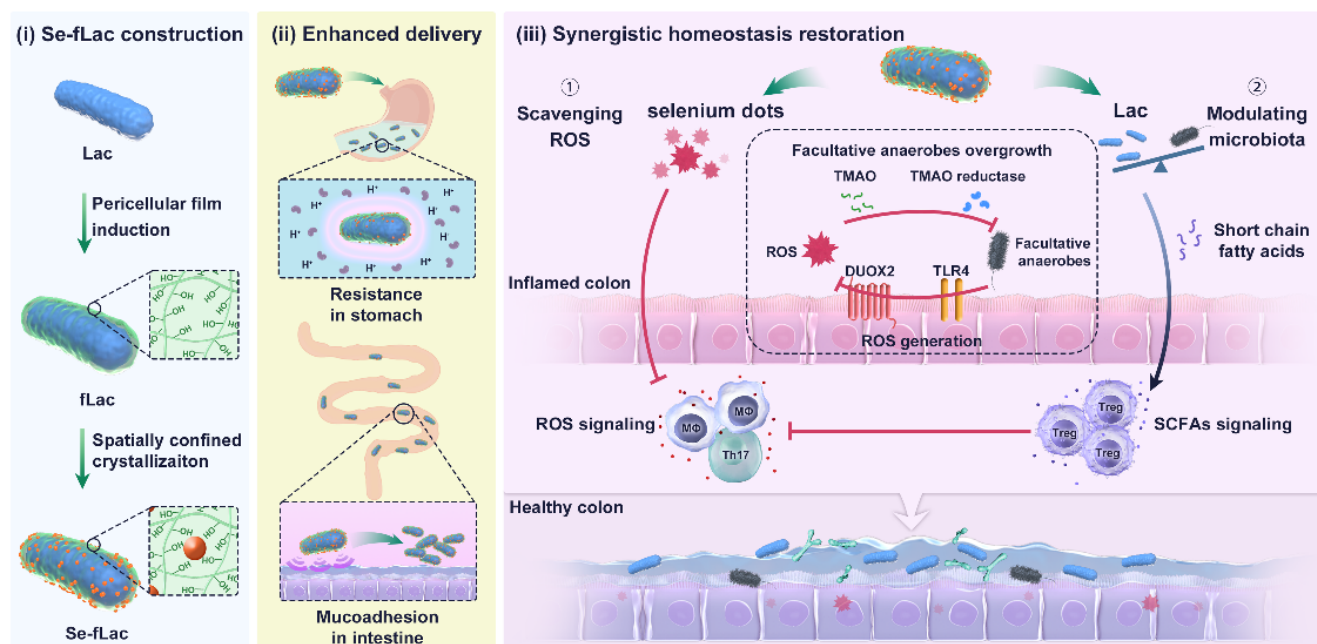


Figure 3-9-9 Schematic illustration of the preparation, enhanced oral delivery, and synergistic homeostasis restoration of Se-fLac for UC treatment

10. The Administrative Center for China's Agenda 21

Research on Conservation and Restoration Techniques for Rare and Endangered Flagship Species and Small Populations

With funding from National Key Program of Research and Development (Protection and Restoration of Typical Fragile Ecological Systems Program, No. 2022YFC1301500), a research team led by the Institute of Zoology, Chinese Academy of Sciences, in collaboration with researchers from eight institutions, including Sun Yat-sen University, Peking University, Guangdong Academy of Forestry Sciences, and others, explored the environmental responses and adaptive mechanisms of rare and endangered species, advanced key theories on the conservation and restoration of flagship and small populations, and developed techniques for the artificial rescue and breeding of endangered animals.

The project group systematically revealed the environmental adaptation and response mechanisms of endangered species from the perspectives of behavioral adaptation and gut microbiota. The evidence of foraging planning ability was firstly found in wild gibbons. A combined analysis of viromes and metagenomes was proposed to fully recover both lytic and temperate phage genomes in the gut, addressing the challenge of previous studies that could not simultaneously reconstruct phage genomes inside and outside bacterial cells.

The first reported cases of *E. fergusonii* infection in pangolins and infantile hemangiomas were documented. A systematic study was conducted on key viruses threatening pangolins, such as respiratory syncytial virus and rotavirus D, leading to the development of a comprehensive disease prevention and control system. A specialized feed for the weaning transition period was developed. The first-ever male pangolin breeding performance evaluation standard was established. Based on these advancements, the success rate of pangolin artificial rescue has increased to over 80%. The largest artificial breeding foundation population of pangolins in China was established. The Guangdong Provincial Local Standard "Technical Regulation for the Husbandry of the Chinese pangolin" was promulgated, and two technical regulations for pangolin rescue and breeding were drafted. Four invention patents were successfully granted.

The human-like ability for future planning was first confirmed in wild gibbons, with the research subsequently reported by *New Scientist* and *China Science Daily*. The Gaoligong Hoolock gibbon, an extremely endangered species with fewer than 200 individuals remaining, is listed on the IUCN Red List. This series of research provides a scientific basis for the planting of food tree species and the formulation of conservation policies for Gaoligong Hoolock gibbon. The developed rescue and breeding techniques have been applied in over 20 conservation institutions, including the Guangdong Provincial Wildlife Rescue Center (Figure 3-10-1). More than 150 pangolins have been rescued, and 19 Chinese pangolins (including one second-generation) have been successfully bred, establishing an artificial population of 41 Chinese pangolins. The twenty-five Malayan pangolins have been bred, establishing an artificial population of 80 individuals. This technical system lays the foundation for rewilding and population restoration efforts. These achievements have significantly enhanced China's international influence in pangolin conservation, with former IUCN Pangolin Specialist Group Chair Dan Challender praising the project's outcomes.



Figure 3-10-1 Artificial breeding of Chinese pangolin and Malayan pangolin offspring. (a) Artificial rearing techniques for pangolins, (b) Artificially bred Chinese pangolins, (c) Artificially bred Malayan pangolins, (d) Artificially bred pangolins feeding on artificial diet.

AI-enabled Hazard Assessment and Green Alternative Design Technologies for Plastic Additives

Plastic additives are diverse, easily released, and harmful to the environment, making them a central issue in global plastic pollution. Accurately assessing their risks is essential for China to tackle plastic pollution, manage new pollutants, and promote a circular economy and sustainable development. However, the large data gap in chemical hazards, challenges in hazard screening and prediction, and the lack of rational design technologies for green alternatives severely constrain national environmental governance capacity, limiting its influence in plastic treaty negotiations and in addressing green trade barriers from developed countries.

Under the financial support from the national key R&D program “Key Technologies and Equipment for Circular Economy,” Dalian University of Technology leads the project “Key Technologies for Hazard Screening and Prediction of Typical Plastic Additives” (2022YFC3902100), with joint participation from the South China Institute of Environmental Sciences, Ministry of Ecology and Environment, and the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The project has made significant progress in three areas this year: (i) elucidation of the inventory of plastic additives, their release, and environmental exposure behavior; (ii) toxicity pathway analysis and prediction; and (iii) development of hazard databases and screening software. By using *ab initio* molecular dynamics simulations, the research team has accurately modelled the degradation behavior of chemicals at the environmental air-water interface for the first time. They also developed “end-to-end” artificial intelligence (AI) algorithms, such as graph attention neural networks, to integrate toxicological multi-omics and high-content imaging data. This led to the development of an AI-based screening model for chemical hazards (Figure 3-10-2A) and a generative AI model for designing molecular structures of green alternative chemicals (Figure 3-10-2B). The

team proposed, for the first time, the weighted molecular similarity density and weighted inconsistency of activities, as two novel metrics to accurately characterize the application domains of deep learning models developed from multi-source, multi-modal high-dimensional data (Figure 3-10-2C). These results have been published this year in prestigious journals such as the Journal of the American Chemical Society and Environmental Science & Technology.

The generative model has been used to design over 100,000 novel surfactant structures with high functionality and low toxicity, and is currently being co-developed with leading fine chemical companies both domestically and internationally. The prediction models achieve an average accuracy of over 80%, covering more than 50,000 chemicals across 31 hazard endpoints, with performances higher or comparable than the state-of-the-art models. By integrating the hazard database and prediction models, a chemical prediction toxicology software platform (CPTP, Figure 2, Registration No.: 2024SR1038601) has been developed, enabling efficient prediction of chemical hazards. This software has been applied in the Solid Waste and Chemicals Management Center, Ministry of Ecology and Environment, to predict and fill-up over 200,000 data points for 6,500 plastic additives, aiding in the formulation of prioritized additives list. This achievement lays technological foundation to support national strategies for plastic pollution and new pollutant management.

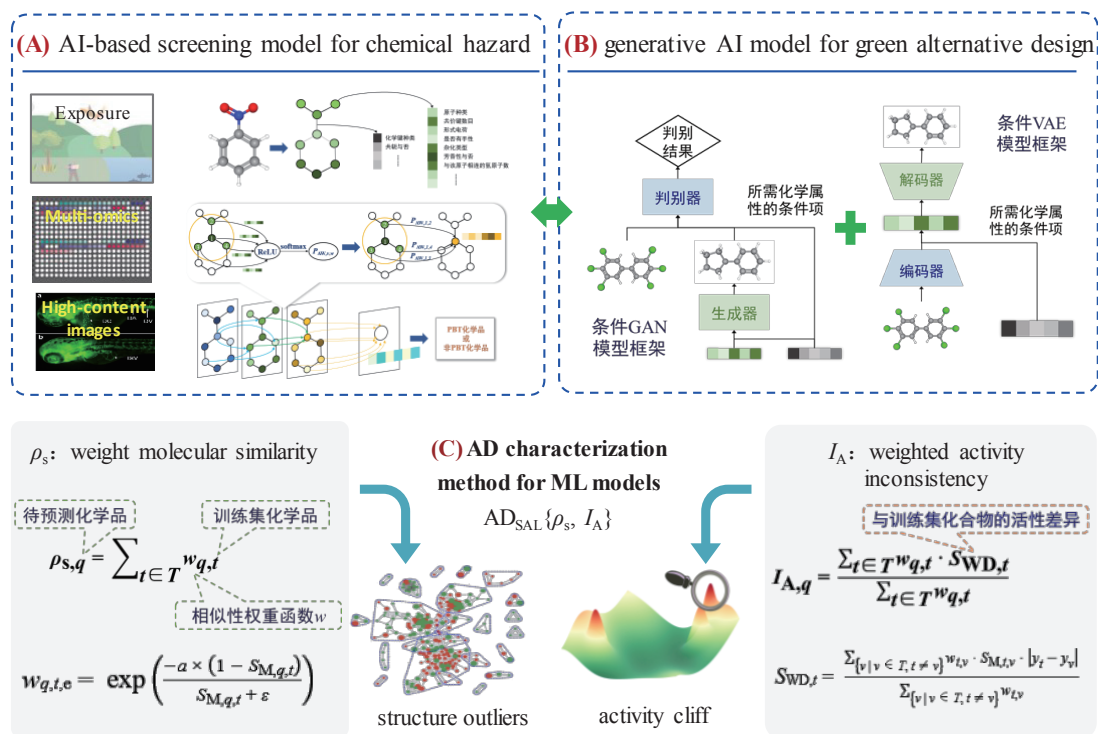


Figure 3-10-2 AI-powered Framework for Hazard Screening and Green Design Technologies of Plastic Additives

Research and Demonstration of a Chinese-developed Full-Ocean-Depth Optical-Electrical Cable Winch System

The optical-electrical cable winch system is an essential piece of equipment for deployment, recovery, and towing in large-scale systems such as deep-sea towed systems and remotely operated vehicles (ROVs). It plays a crucial role in deep-sea resource exploration and development. Currently, China imports all deep-sea optical-electrical cable winch systems from European and American countries, leaving us reliant on

foreign technology. Therefore, it is imperative to initiate the independent domestic development of full-depth optical-electrical cable winch systems to safeguard our maritime rights and interests.

Under the support of the National Key Research and Development Program (Key Technologies and Equipment for Deep Sea and Polar Regions 2023YFC2809600), Dalian Maritime University, Nantong Liwei Machinery Co., Ltd., and Jiangsu Hengtong Huahai Technology Co., Ltd., among other organizations, jointly undertook the project "Development and Demonstration of Full-Ocean-Depth Optical-Electrical Cable Winch System and Full-Ocean-Depth CTD Winch System" (2023YFC2809600). This project addresses critical challenges in deep-sea scientific research operations, such as the excessive self-weight of traditional metallic armored cables and cable winding irregularities with ultra-large capacity cables. It overcomes scientific issues like the stress deformation of multi-layer stacked non-metallic armored cables, efficiency improvement under load, heat accumulation effects limiting transmission capacity, dynamic fatigue control of optical fiber transmission, and the electromagnetic-thermal multi-field coupling characteristics of ultra-long optical-electrical cables. Key breakthroughs include design optimization technologies for full-ocean-depth winch systems, torque-balanced design for multi-fiber armored cables, efficiency improvement in fiber layer armoring and braiding, and adaptive technologies for complex environments and load compatibility in full-ocean-depth winch systems. The project successfully developed a full-ocean-depth optical-electrical cable winch system, the "Haiwei GD11000." (Figure 3-10-3)

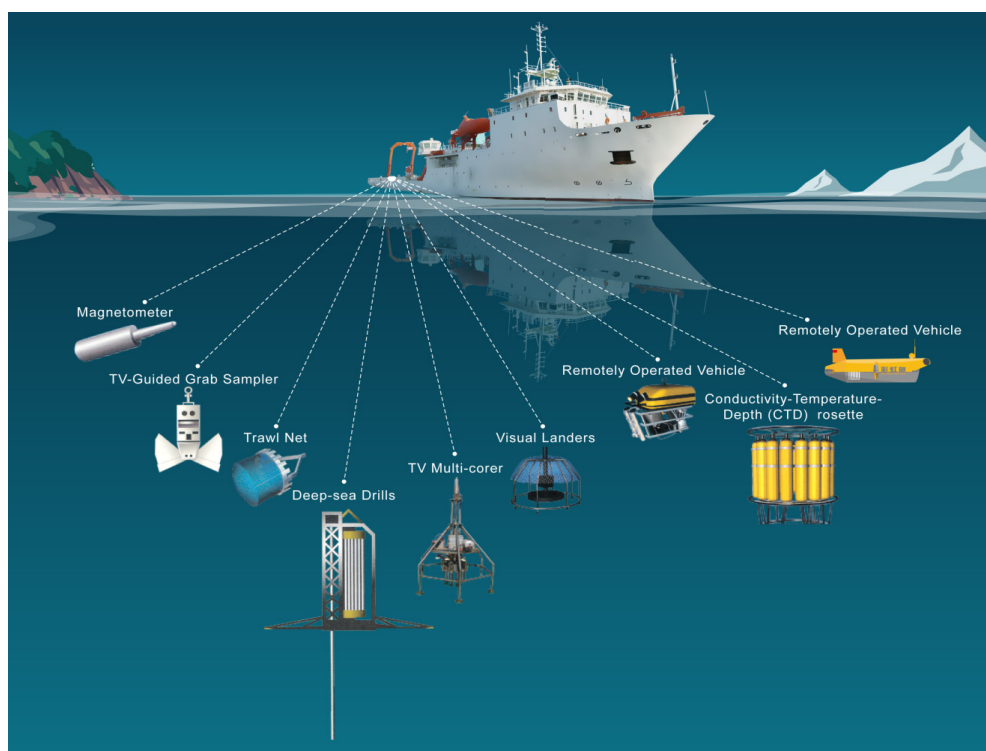


Figure 3-10-3 The "Haiyang Dizhi II" vessel

"Haiwei GD11000" is the world's only full-ocean-depth optical-electrical cable winch system, and is entirely domestically developed and has strong control over the key links of the industrial and supply chains, breaking the monopoly of foreign technology. It enables scientific research operations at the greatest depths of any ocean worldwide. In October 2024, the "Haiwei GD11000" accompanied the Guangzhou Marine Geological Survey Bureau's vessel Marine Geology No. 2 on its first deep-sea survey mission in the South China Sea. During this mission (Figure 3-10-4), the system performed two deep-sea towing operations in waters over 4,000 meters deep, with cable lengths exceeding 11,000 meters on each occasion and a maximum cable length of 11,228.7 meters. Additionally, the system successfully completed two ROV-

based seafloor observation operations, including marker deployment and sample collection demonstration applications. These operations fully validated the stability and operational capability of China's domestically produced deep-sea winch system, which has been widely featured in national mainstream media such as Xinhua News Agency, People's Daily, Science and Technology Daily, and Guangming Daily. The developed system provides technological support for the country's deep-sea resource development, as well as the strategic goals of becoming a strong maritime and transportation power.



Figure 3-10-4 Demonstration applications of "Haiwei GD11000"

Research on Common Supporting Technologies for the Digital Brain of Smart Justice

Funded by the National Key Research and Development Program (2021FYC3340100)□this project addresses significant theoretical and technical challenges in the development of a unified judicial artificial intelligence infrastructure, including automatic judicial knowledge generation and the construction of reasoning engines that integrate Large Language Models (LLMs) and Domain-Specific Legal Models (DLMs). Led by the Information Technology Service Center of the Supreme People's Court, the project collaborates with the China Judicial Big Data Research Institute, iFLYTEK, Taiji Computer Corporation Limited, China University of Political Science and Law, and Peking University. The goal is to establish mechanisms for automatic knowledge generation and a unified judicial knowledge base, creating a judicial intelligent reasoning engine and digital court brain system capable of providing standardized intelligent services to courts nationwide. The system has been integrated and implemented with 129 business systems at the four levels of courts nationwide.

The key technological achievements of the project are as follows: 1) The pioneering development of a Digital Court Brain System, integrating four core components—data, knowledge, intelligent engine, and applications—has filled a gap in the judicial field, achieving international leading standards. This marks a breakthrough in the theory and application of unified AI infrastructure for vertical industries. 2) Judicial Data Switching Service Network Technology: Based on historical data, the Judicial Data Switching Service Network technology has been developed and implemented, achieving real-time network connectivity for large-capacity data of case dossier and archive across 182 nodes nationwide. This improved the cross-level remote retrieval rate of case dossier and archive from less than 50% to over 99%(Figure 3-10-5). 3) Development of a Legal LLM: Using over 3 million high-quality judicial corpus entries, specific training and fine-tuning of a general LLM was conducted, resulting in the first domestic creation of the Legal LLM with 175 billion parameters. 4) Intelligent Agent Orchestration for LLMs and DLMs: Advanced technologies have been developed for integrating DLMs (e.g., dossier images, trial audio-visuals, document texts) with general LLMs. This unified intelligent engine reduced the average time for trial transcript preparation from 1.5 hours

to 30 minutes, improved petition registration efficiency by 60%, enhanced voice recognition model tuning efficiency by 53.3%. 5) Integration of Domain-Specific Knowledge with general LLMs: A novel governance method has been developed for combining domain-specific and general knowledge. The unified judicial knowledge repository now contains 1.14 billion pieces of knowledge, representing a 115% increase from the historical data□with over 81.58% of the knowledge being automatically generated. The average accuracy of dossier OCR recognition has been improved from 91.5% to 94.6%, with the processing speed increasing by 3–5 times, compared to traditional models.

These outcomes have been successfully demonstrated in courts in Beijing, Henan, Zhejiang, Jiangsu. It has supported the Supreme People's Court in releasing 25 national knowledge service catalogs, delivering 4.32 billion services. These achievements provide critical support for addressing the challenges of imbalanced and insufficient development in the intelligent construction of courts nationwide and promoting the modernization of adjudication.



Figure 3-10-5 Operation Status of the Smart Justice Digital Brain System

Research and Demonstration of Key Technologies for Operation Monitoring, Early Warning, and Intelligent Operation and Maintenance of Super High-Rise Buildings

With the accelerated pace of urbanization and advancements in construction technology, the number of high-rise buildings has steadily increased. According to statistics from the Council on Tall Buildings and Urban Habitat (CTBUH), there are about 30,000 super high-rise buildings with a height of more than 100 meters in the world by 2023, and nearly 50% are located in China. Due to the large volume, various types, long service life, and complex service environment, super high-rise buildings face various challenges and difficulties in safe operation and maintenance. Therefore, comprehensively enhancing the intelligent

monitoring, early warning, and full life-cycle intelligent operation and maintenance of super high-rise buildings has become a critical national need.

Funded by the Key Special Project for “Key Technologies and Equipment for Sustainable Urban Development” of the National Key R&D Program, Shenzhen Technology Institute of Urban Public Safety undertook the “Research and Demonstration of Key Technologies for Operation Monitoring, Early Warning, and Intelligent Operation and Maintenance of Super High-Rise Buildings” project (2022YFC3801200). Following a technical path of “data aggregation - technology R&D - platform integration - demonstration application,” the project team focused on two key scientific issues: lightweight massive data integration and multimodal feature fusion application. The essential data and operation and maintenance safety data of 1,061 super high-rise buildings were collected; a knowledge graph containing 34,839 nodes for intelligent operation and maintenance decision support was established; a satellite-borne radar remote sensing deformation intelligent monitoring technology was developed, with a deformation monitoring accuracy of higher than 5mm; a “free-flying + wall-walking” inspection drone with a maximum wind resistance of over 10 m/s and a continuous working time more than 4 hours was prototyped; a super high-rise building operation safety evaluation and early warning technology was developed, with a safety events alarm accuracy of higher than 97%.

Based on the super high-rise building database (Figure 3-10-6), the project combined technology innovation and equipment development and developed a “sensing – identification – evaluation – warning – decision – control” integrated platform with intelligent identification, security defense, and data visualization for super high-rise building monitoring, early warning, and intelligent operation and maintenance (Figure 3-10-7). An all-time, all-space and all-scenario space-air-ground integrated demonstration of multi-disciplinary applications was carried out. The super high-rise building database and the monitoring and early warning and intelligent operation and maintenance integrated platform broke through the key technical issues of the “information silo” effect, lightweight integration of massive data, and multimodal feature fusion, which can effectively enhance the capabilities in monitoring and early warning, safe operation, and intelligent operation and maintenance of super high-rise buildings in China, supporting the safe, green, low-carbon, and intelligent operation of super high-rise buildings.



Figure 3-10-6 Super high-rise building operation and maintenance database platform



Figure 3-10-7 Super high-rise building structural safety, intelligent operation and maintenance, monitoring and early warning platform

High Power Battery Intelligent Precision Test Technology Research and Instrument Development

Power batteries are the cornerstone of large-scale development of electric vehicles and new energy storage, and have become a new track for major country competition. The test instrument is the “pioneer” of battery research and the “protector” of application, which is an indispensable national instrument throughout the whole life cycle of the battery, and the demand is wide. However, China's market has been monopolized by European and American companies for a long time, and it has become a major urgent need to break through the battery test neck technology and realize localization.

Funded by the Major Research Instrument Development Project(NSFC) and National Key R&D Program of China, researchers of Shandong University made an innovative breakthrough, aiming at the extreme conditions such as large impact of charging and discharging current transient switching unique to the test process, revealing the mechanism of the excitation current on the dynamic characteristics of the battery, and created an integrated battery test method of “fast and accurate excitation-intelligent modeling and estimation”(Figure 3-10-8), which solved the recognized problem of fast and accurate evaluation of battery performance parameters such as state of health and remaining useful life, and realized the intelligent testing. The invention of high-power, high-frequency, high-efficiency excitation power supply and fast control technology have overcome the problem of fast charging and discharging switching control of thousand-ampere-level excitation current without overshoot, and realized the precision of testing. The first intelligent precision testing instrument for high-power and high-frequency batteries in the world has been successfully developed, and the tests of the international authoritative testing organization Shanghai Testing & Inspection Institute have shown that the main performance indicators such as charging/discharging switching time, current ripple, system efficiency and test accuracy are international advanced, and the performance evaluation function fills the international gap, leading the cutting-edge technological change and development trend of international battery testing.

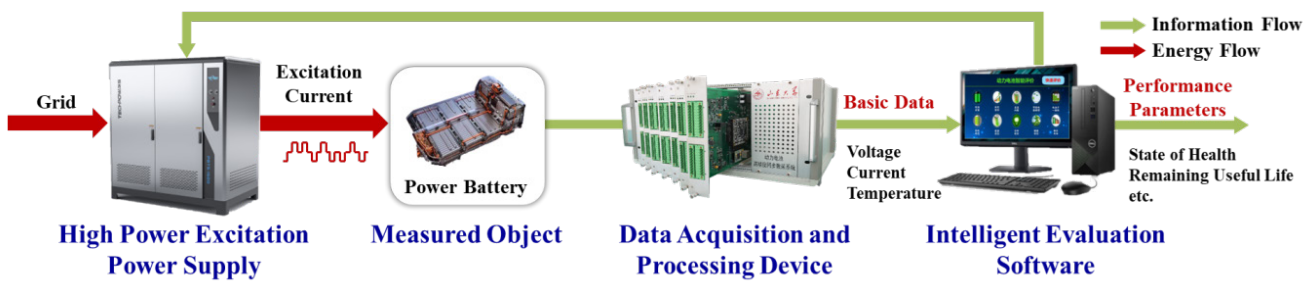


Figure 3-10-8 Flow chart of power battery test principle

The achievements have been transferred to Techpow Electric Co., LTD, etc, which are leading enterprises. A series of new battery testing instruments have been developed, which have been sold to more than 30 provinces and cities, and exported to the United States, Germany, India, Mexico and other countries, which have been recognized and praised. For example, BYD, a leading power battery company, purchased 300 sets within a year for battery research, manufacturing and application(Figure 3-10-9), which was hailed as “an important milestone in the field of battery testing”. After the application of China Inspection and Certification Group and other authoritative testing institutions at home and abroad, it is evaluated as “set a new benchmark in the battery evaluation industry.” The achievements have realized a major leap in China's battery testing technology and equipment from following to leading, from introduction to export, and have driven the breakthrough and high-quality development of the power battery industry chain cluster. Won the second prize of the 2023 National Science and Technology Progress Award.

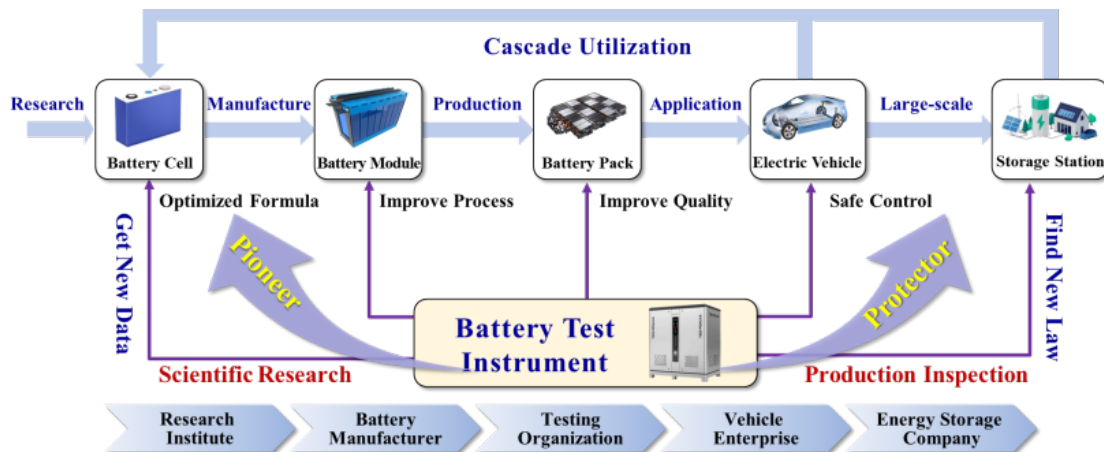


Figure 3-10-9 Schematic and application diagram of instrument supporting the whole industrial chain of the power battery

11. High Technology Research and Development Center

Development of twist-phase-matching theory for optical crystal design and fabrication of novel optical crystals

Optical crystals lie at the heart of laser technology, serving as the core components for functions such as laser frequency conversion, pulse compression, data encryption, and information processing. In 1962, Giordmaine of Harvard University and Nobel laureate Bloembergen, proposed two phase-matching theories in nonlinear parametric processes: birefringence-phase-matching and quasi-phase-matching. These two theories directly guided the research and development of optical crystals for the next 60 years and spurred the rapid advancement of technologies such as deep ultraviolet, ultrafast, and high-power lasers. However, traditional crystals are increasingly unable to meet the new demands of laser miniaturization, high integration, and functionality. The development of next-generation laser technology urgently requires breakthroughs in the theory and materials of optical crystals.

With the support from the National Natural Science Foundation of China (National Distinguished Young Scientist Fund Project 52025023, National Key R&D Program 2022YFA1403500), Peking University has made a significant breakthrough in the field of optical crystals, the research team introduced a novel phase matching concept — the twist-phase-matching theory (Figure 3-11-1)— and developed a new type of optical crystal — twisted rhombohedral boron nitride (rBN) optical crystal. This breakthrough opens up new design theories and material systems in the field of optical crystals. The crystal is only micrometer-thick, “as thin as a cicada's wing,” making it the thinnest known optical crystal in the world, with energy efficiency increased by 100 to 10,000 times compared to traditional crystals. The theoretical breakthrough and material fabrication of two-dimensional materials for optical crystals are highly innovative. The development of atomically layered material optical crystals will greatly promote the advancement of next-generation integrated laser technology in China, and is expected to play a key role in areas such as deep ultraviolet lasers, micro-nano processing technology, miniature laser communication systems, and integrated quantum optical chips.

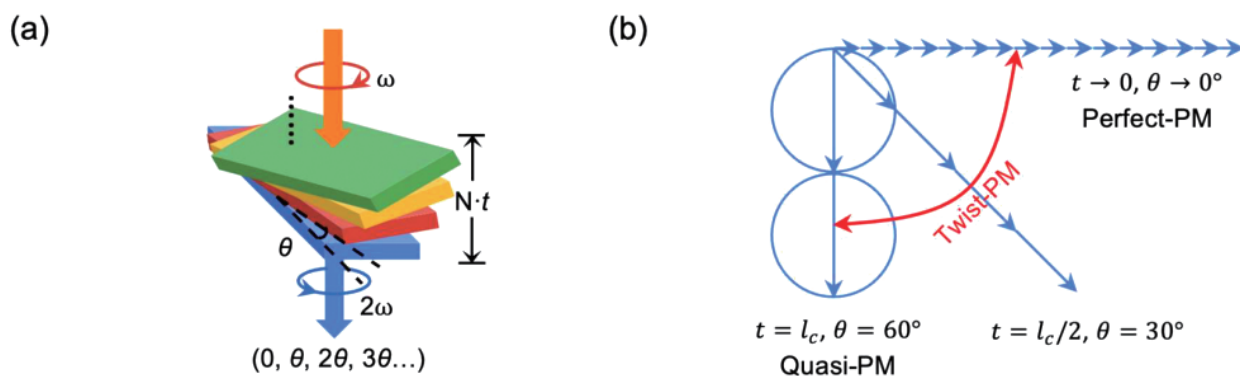


Figure 3-11-1 Twist-phase-matching theory and the design of twisted optical crystals.

At the 2024 Zhongguancun Forum Annual Conference, the top ten major scientific and technological achievements included “The Laser Masterpiece — Original Theory and Materials of Twisted Boron Nitride Optical Crystal,” marking a “major breakthrough in nonlinear optical theory in 60 years.”

Research on Strengthening and Toughening of Metal Materials

Metal structural materials with both high strength and high toughness are important guarantees for strategic equipment such as national major projects, aerospace, and ocean engineering. However, metal materials generally have an inverted contradiction between strength and toughness, which severely limits their industrial applications. In recent years, researchers have proposed body centered cubic insoluble multi principal component alloys, which exhibit ultra-high strength in a wide temperature range from room temperature to high temperature. It is a kind of metal structural material with great potential for engineering applications, but there is still a fatal flaw of poor room temperature tensile plasticity. Researchers have improved the tensile plasticity of the alloy through microstructure design, but at the cost of reducing its yield strength, the “strength toughness inversion contradiction” has not been fundamentally broken. The most critical issue is that current multi principal component alloy designs mostly rely on trial and error methods, lacking scientific and effective alloy design criteria to provide theoretical guarantees for designing alloys with both high strength and high tensile plasticity.

Under the funding of the National Key Research and Development Program “Nano Frontier”, Professor Han Xiaodong's team of Beijing University of Technology have proposed a new academic idea of “negative enthalpy alloying” (Figure 3-11-2) and successfully applied it to the design of high-performance alloys. The new academic idea of reducing the mixing enthalpy of the solid solution to increase the bonding force between atoms and introduce the difference in chemical affinity, thereby improving the strength and toughness of the alloy is proposed and the mechanism is revealed: The atoms with negative mixing enthalpy form cross-scale heterostructures in the grain, which hinder the movement of dislocation and promote the movement of multi-system slip and cross-slip, so that the strain strengthening rate is maintained at a high level in a large strain range. The new concept makes up for the loss of toughness caused by the traditional fine grain strengthening, solves the problem that the strength and toughness of the material cannot be both, and has been proved in the multi-principal component alloys with different structures. Based on the “negative enthalpy alloying” design criteria, the project team successfully developed a new alloy with high yield strength (~1390 MPa) and high toughness (uniform elongation up to ~20%), and its strength and toughness synergies are far superior to similar alloys.

The results were published in Nature under the title “Negative mixing enthalpy solid solutions deliver high strength and ductility.” A new academic thought and theoretical basis for the design of alloys with both high strength and high toughness is proposed, and this breakthrough also provides a new idea for

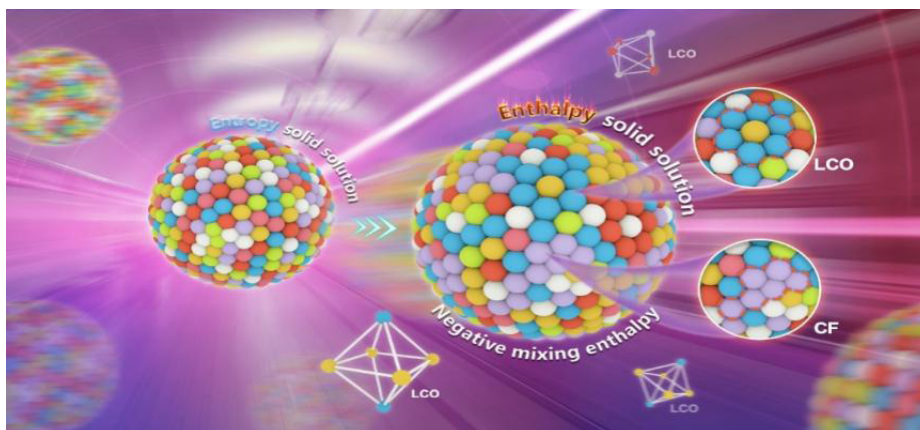


Figure 3-11-2 Local chemical composition fluctuation and ordered structure induced by negative mixing enthalpy alloying.

breaking the “strength-toughness inversion contradiction” of metal materials(Figure 3-11-3), and is expected to promote the development of high strength and toughness alloys in China.

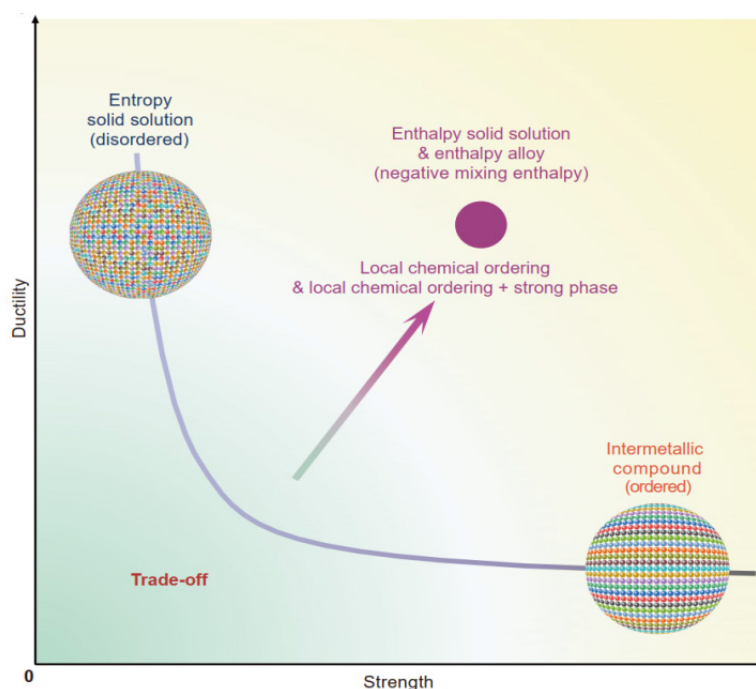


Figure 3-11-3 Strength and toughening strategy of negative mixing enthalpy solid solution/alloy to obtain synergistic effect of high strength and toughness.

Key Technologies and Applications of Cognitive Foundation Models

As the core technology of generative artificial intelligence products such as ChatGPT, foundation models are rapidly affecting the industrial landscape and even become a new way of user interaction, forming asymmetric advantages in public opinion guidance, social governance, and information services.

With the funding of the National Science and Technology Major Project of New Generation Artificial Intelligence, Tsinghua University undertook the “Key Technology of Cognitive Foundation Models” project (2022ZD0118600) working together with Zhipu AI and other units. The project made efforts in developing the original GLM series foundation models. It took a unique approach in developing the core technologies of foundation models such as the original large language model training architecture, cognitive-based multimodal understanding and generation, as well as autonomous agent, and carried out research from theoretical technology to application, establishing a new generation of integrated cognitive foundation models technologies(Figure 3-11-4).

Based on GLM—the self-developed autoregressive fill-in-the-blank pre-training architecture, the models can be trained with domestic chips and achieve lossless quantization, which are adapted to more than 40 domestic chips. The project developed GLM-4, the first agent model based on mixed instruction fine-tuning in China, achieving autonomous understanding of complex tasks, instruction planning, and tools invoking. It developed CogVLM, the first Chinese-English bilingual multimodal understanding models, which ranked first in 10 international cross-modality benchmark evaluations. It released CogAgent, a multimodal agent model based on high-resolution cross-attention, which scored first in 9 international evaluation tasks.

GLM models products have been applied in more than 10,000 enterprises and institutions, supporting more than 20 industries such as finance and education. Based on those models, the generative artificial intelligence assistant “Zhipu Qingyan” serves nearly 20 million users (Figure 3-11-5). More than 20 GLM models were open sourced, which have accumulated more than 70,000 GitHub stars and more than 17 million downloads worldwide. It has been reported by Nature as a representative of excellent Chinese foundation models. The GLM team was selected as one of the top five liked AI institutions by Hugging Face, the international open source community.

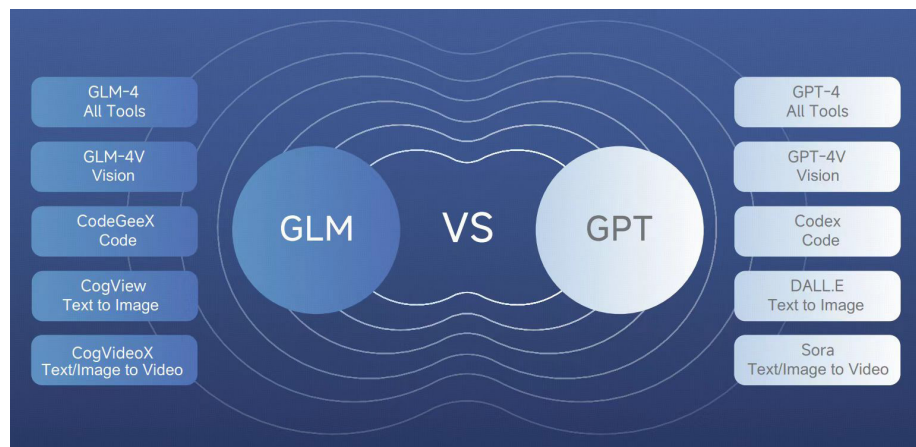


Figure 3-11-4 GLM vs GPT.

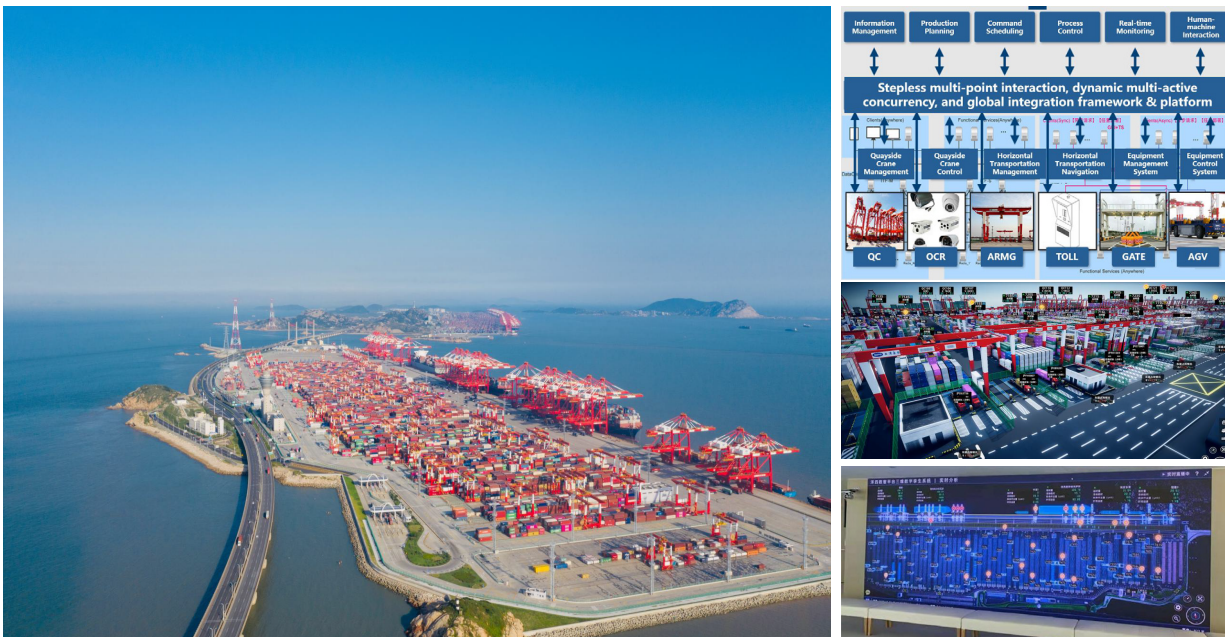
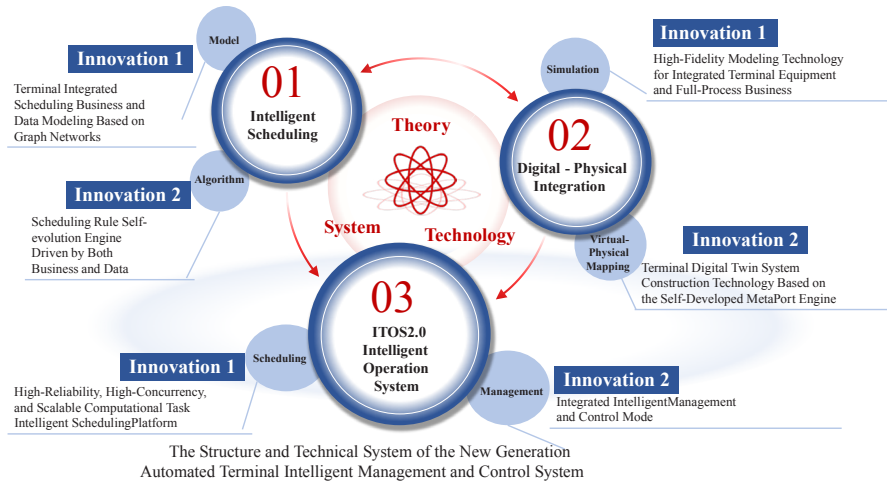


Figure 3-11-5 “Zhipu Qingyan” and functional interface

Intelligent Operation and Control Technology for Ultra-Large Container Terminal Based on Big Data Driven

Ports are critical infrastructure for national economic and social development as well as for participating in global competition and cooperation. Efficient and resilient world-class ports are essential for the implementation of national strategies such as the “Belt and Road Initiative” and building China into a strong transportation nation. The highly intelligent operation control system, known as the “brain” of automated terminals, represents the forefront of cutting-edge technology in the port sector. With the support of the National Key Research and Development Program project “Intelligent Operation and Control Technology for Ultra-Large Container Terminal Based on Big Data Driven”, the Shanghai International Port

Group (SIPG), in collaboration with multiple organizations, has undertaken key technological advancements in algorithm models and system development. This effort addresses the central challenge of collaborative optimization and intelligent decision-making for ultra-large container terminal operations, achieving numerous world-leading outcomes(Figure 3-11-6).



Next-generation intelligent operation system for ultra-large automated container terminals

Figure 3-11-6 Outstanding achievements of the new generation of automated terminal intelligent control system.

Knowledge-Data Dual-Driven Intelligent Scheduling Method: The project has developed a knowledge-data dual-driven intelligent scheduling method, establishing a spatiotemporal dynamic evolution network model for integrated scheduling at ultra-large automated container terminals. It has designed a self-evolving mechanism for scheduling rules driven by both knowledge and data and created over 20 fundamental scheduling rules with a global perspective. Scheduling algorithms covering all operational scenarios of the terminal have been developed.

Cyber-Physical Fusion Technology for Intelligent Control of Ultra-Large Container Terminals: In the domain of cyber-physical fusion technology for intelligent control, the project has achieved high-fidelity

digital twin modeling for full-terminal equipment and business integration, as well as seamless data interaction engine technology. It has designed a replaceable and pluggable fusion mechanism for intelligent algorithms along with an evaluation system, developed a multidimensional full-process digital twin system, and enabled global evaluation of algorithm execution processes at different stages, supporting continuous iterative optimization and upgrades of the intelligent control system.

The Neo-Generation Intelligent Terminal Operation System for Automated Container Terminals: The neo-generation automated container terminal intelligent terminal operation system designed under this project includes a fully integrated architecture, a highly reliable, high-concurrency, and scalable foundational platform for intelligent scheduling of computational tasks, and an automated container terminal intelligent terminal operation system with fully independent intellectual property rights, surpassing all core performance metrics of mainstream international products.

The project has significantly supported the efficient operation of the Yangshan Phase IV automated terminal, achieving an annual throughput of over 6.8 million TEUs (twenty-foot equivalent units), which is more than double the project's inception. Labor productivity has improved by 52.86%. The project effectively promotes the deep integration of big data and artificial intelligence with the port's physical economy, ensuring self-sufficiency in China's automated container terminal control technology and related industrial chains. This eliminates bottlenecks hindering the high-quality development of China's ports. Additionally, the project's application in the Haifa New Port in Israel marks a milestone in exporting China's advanced port technology to developed countries, serving as a core force in supporting national strategic implementations.

Key Technologies and Applications of Electrolytic Hydrogen Production by Renewable Energy coupled with Low-Temperature, Low-Pressure Ammonia Synthesis

The recent years have witnessed the soaring of renewable energy sources such as wind and solar, which highlight the urgent demand for "zero-carbon ammonia storage" system based on the technological pathway of "green electricity–green hydrogen–green ammonia" to achieve carbon neutrality and build a sustainable national energy system. The development of efficient ammonia synthesis catalysts operating at low-temperature and low-pressure, as well as the comprehensive process technologies tailored to renewable energy power is pivotal for advancing green ammonia synthesis.

With the funding of the National Science and Technology Major Project of Hydrogen Energy Technology, a research team at Fuzhou University, together with collaborators, has made significant progress in low-temperature, low-pressure ammonia synthesis catalysts and green ammonia synthesis technologies. They have pioneered a comprehensive innovation across the entire chain of green ammonia synthesis, encompassing "mechanisms–catalysts–process packages."

To solve the problem of the restrictive relationship between the adsorption-dissociation energy of N_2 and the adsorption energy of $N-H_x$ in low-temperature, low-pressure ammonia synthesis in the study of reaction mechanisms, the team designed and synthesize novel catalysts to decouple this limitation (Figure 3-11-7). This breakthrough enabled highly efficient ammonia synthesis at mild conditions, providing a vital theoretical foundation for the advancement of transformative ammonia synthesis technologies. This achievement promotes deeper understanding of ammonia synthesis process and provides valuable guidance for the development of efficient catalysts under mild conditions.

Based on the mechanistic insights, the research team has successfully developed a high-performance Ru-based ammonia synthesis catalyst and established a production line with an annual capacity

exceeding 100 tons(Figure 3-11-8). The batch-produced catalysts achieved an ammonia yield of 15.8% under conditions of 6.8 MPa, 390°C, and 10,000 h⁻¹ after thermal resistance testing, setting benchmarks at an internationally leading level. Further, the team has designed an industrial-scale process package for “renewable energy-based electrolytic hydrogen production coupled with low-temperature, low-pressure ammonia synthesis”(Figure 3-11-8). This system achieved operational parameters of ≤7.0 MPa pressure, ≤395°C outlet temperature, and ammonia net values of ≥15.0%, with an adjustable operational load ranging from 40% to 120%, enabling seamless integration and flexible regulation of hydrogen production and ammonia synthesis under mild conditions. Compared to the green ammonia process package developed by Swiss technology provider, this technology significantly reduced ammonia synthesis pressure by over 40% while maintaining equivalent ammonia yields, markedly decreasing energy consumption. Furthermore, it accommodated the intermittent and fluctuating nature of renewable energy power. The team plans to

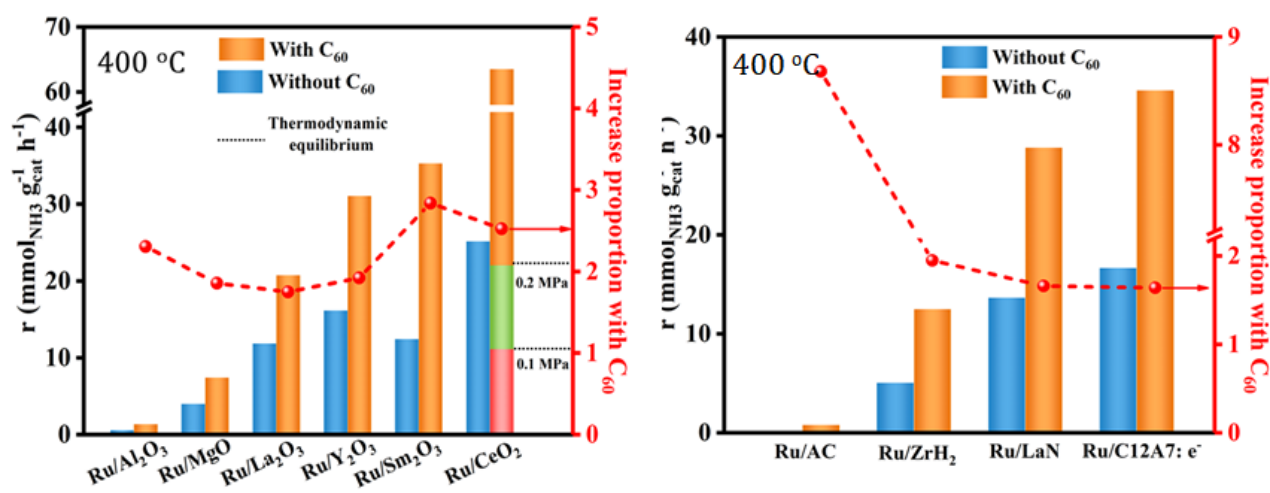


Figure 3-11-7 Catalytic performance. Ammonia production rate of C₆₀, Mo⁺ and Ru-based catalysts at 400°C and 1 MPa.

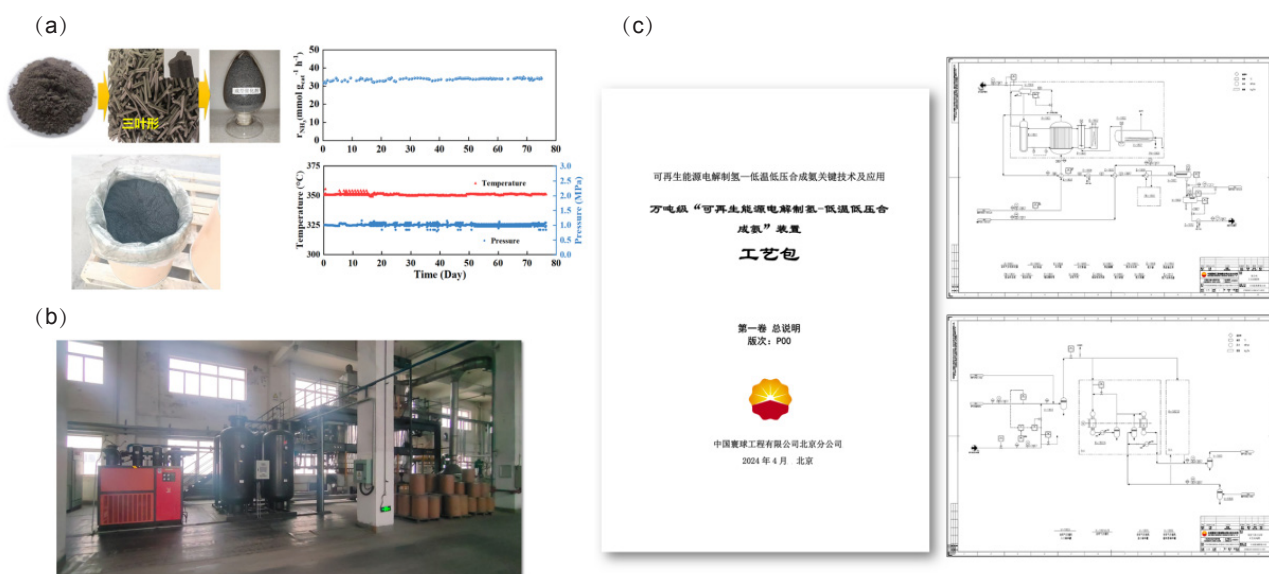


Figure 3-11-8 Construction of catalyst production line for low-temperature, low-pressure ammonia synthesis and design of the industrial-scale process package for “renewable energy-based electrolytic hydrogen production coupled with low-temperature, low-pressure ammonia synthesis”.

construct China's first 10,000-ton-scale "renewable energy-based electrolytic hydrogen production coupled with low-temperature, low-pressure ammonia synthesis" facility in 2025. This groundbreaking initiative aims to secure a strategic advantage in green ammonia energy storage technology, spearheading and driving the development of China's trillion-dollar "zero-carbon" ammonia-hydrogen circular economy.

Research on the Theory and Application of Service Performance Optimization of Complex System Based on Heterogeneous AI Agents

General Secretary Xi Jinping has placed great importance on the development of the modern service industry and has repeatedly emphasized the need to promote its growth and expansion. The modern service industry has become the largest industry in the national economy, giving rise to a large number of new productive forces and generated numerous service systems, which involve division of labor and collaboration among heterogeneous intelligent agents. These systems are characterized by large scale, intelligent heterogeneity, and complex cooperation. The operation of these service systems requires a comprehensive understanding of both the service supply side and demand side. From the perspective of service performance, it is important to explore the operating laws of these systems, ensuring high performance while preventing the entire system from falling into a cycle of ineffective output.

Under the support of the National Natural Science Foundation of China (National Key R&D Program "Cultural Technology and Modern Service Industry" Special Project 2021YFB3900700), a research team led by Shandong University, in collaboration with Tsinghua University, Tianjin University, Central University of Finance and Economics, and other institutions, tackled the challenges of measuring, evaluating, and optimizing service performance in large-scale heterogeneous intelligent service systems. They developed an entropy-fusion-based service performance measurement model and constructed a multidimensional indicator system integrating nonlinear value entropy, dynamic structural entropy, and heterogeneous intelligence entropy. Using a hybrid dynamic network structural equation approach, they established the complex relationship between intelligence levels and service performance, successfully uncovering collective intelligence emergence patterns such as "high intelligence but low efficiency" and "low intelligence but high efficiency." The team proposed a service performance factor analysis method integrating generative multi-agent experiments and simulations, effectively revealing the mechanisms of multi-agent network service performance influencing factors oriented towards the co-evolution of value entropy. They also developed a game-based regulation theory for service performance targeting heterogeneous intelligence and proposed optimization strategies and tools integrating inducement and regulation. This enabled integrated optimization of complex service systems, encompassing "interconnection-synchronization-diagnosis-tracking-optimization"(Figure 3-11-9). By integrating these innovative results, the team developed a service performance optimization platform tailored to customized scenarios, with application validation in fields such as 5G autonomous networks, HarmonyOS ecosystems, and data element circulation. This platform provides monitoring, simulation, and optimization assurance for service performance, laying a solid foundation for the healthy and rapid development of the modern service industry.

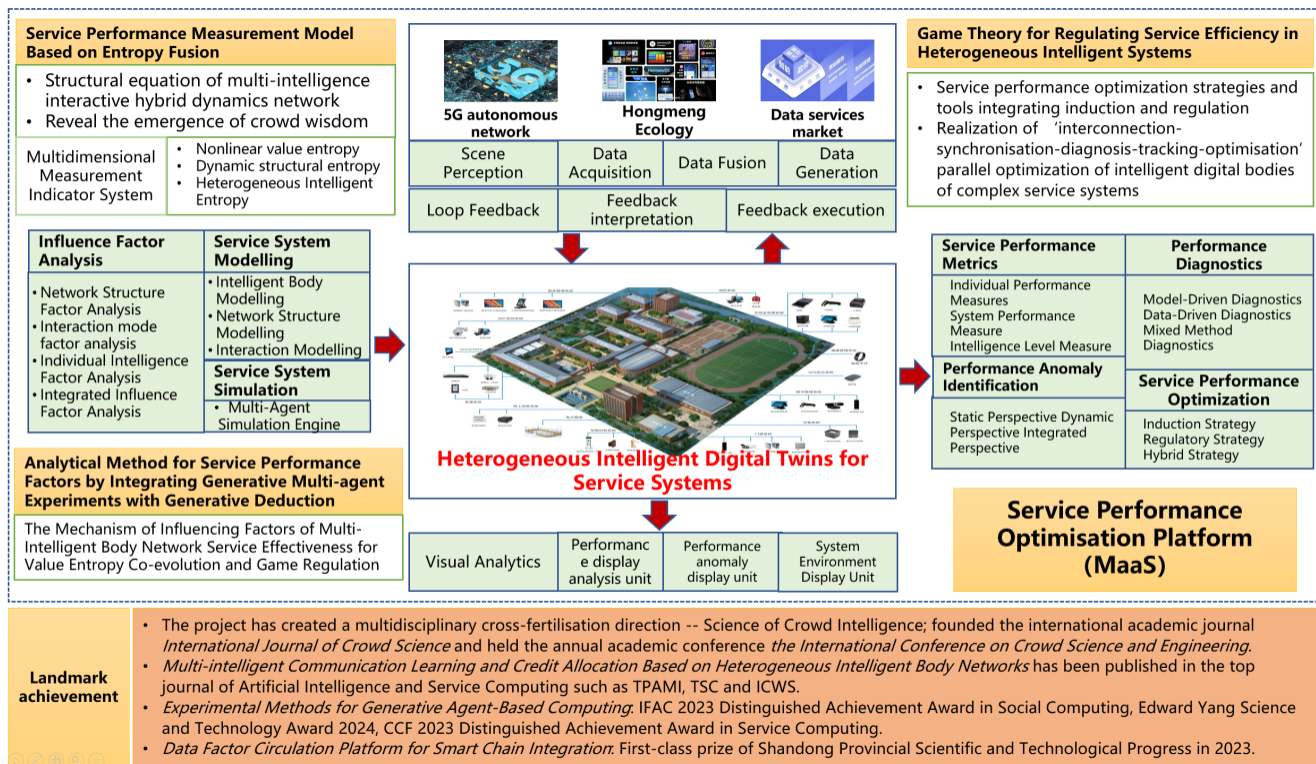
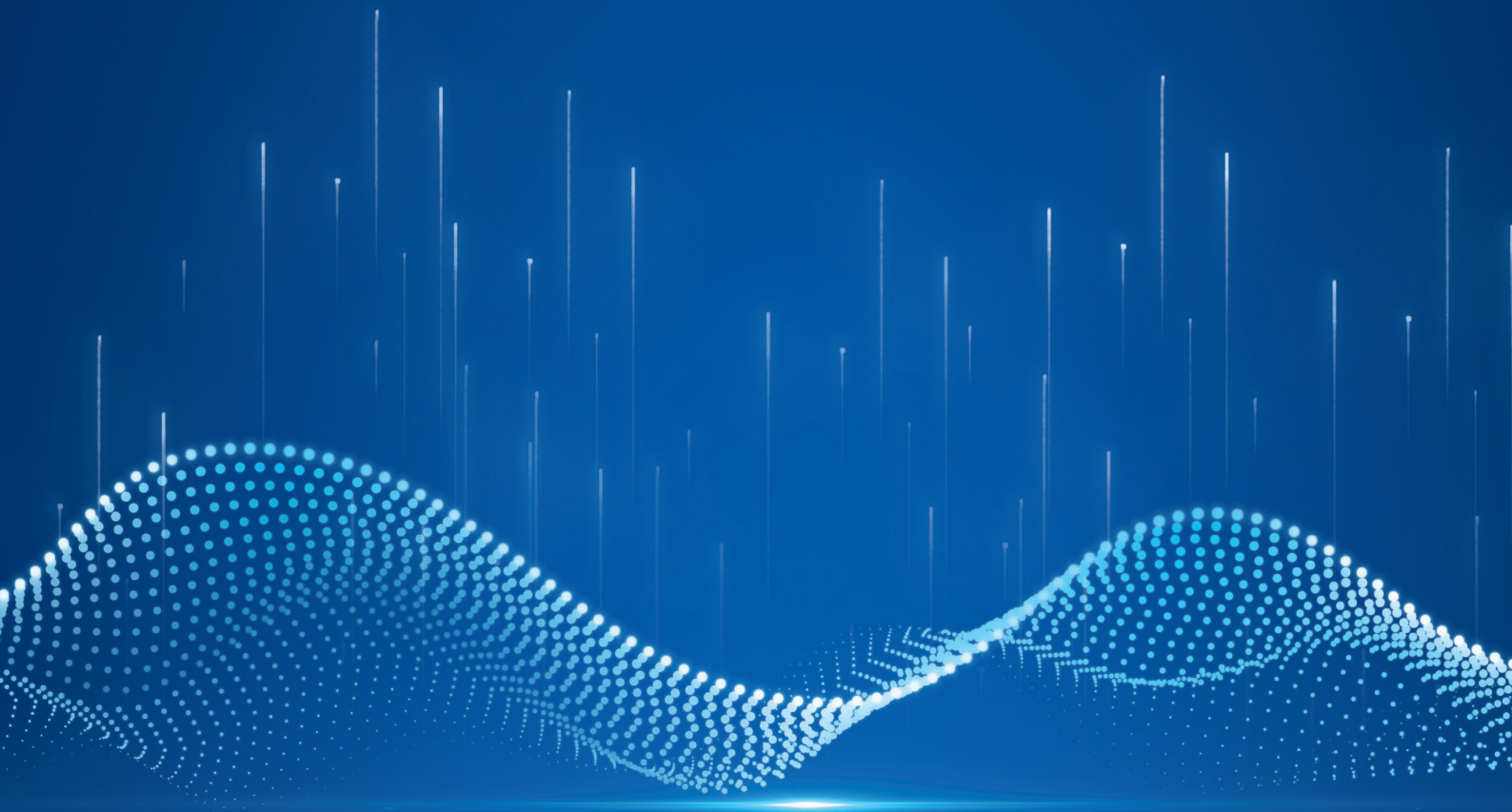


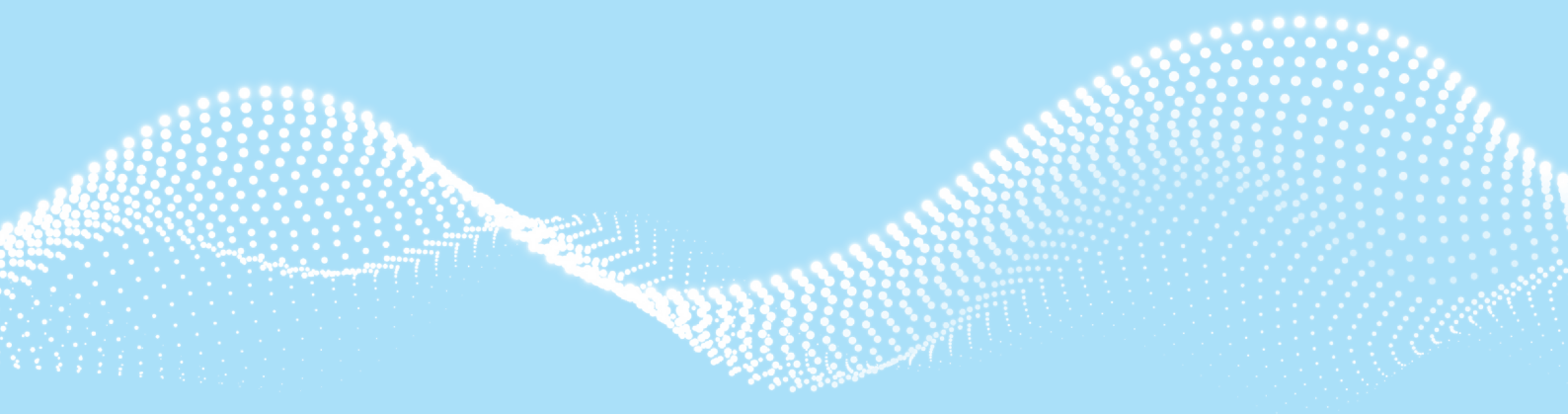
Figure 3-11-9 The theoretical framework of service performance optimization.

PART 4

International (Regional) Cooperation and Exchange



NSFC



1. Promoting International (Regional) Exchange and Cooperation

In 2024, NSFC continued to promote international (regional) exchange and cooperation based on globally accepted academic standards and operational mechanisms. We collaborated with 55 institutions outside China's mainland on joint funding programs, academic exchange activities, and high-level dialogues. During the year, 2 new bilateral MoUs were signed, 11 existing cooperation agreements renewed, and we joined e-Asia JRP as its member organization. By the end of 2024, NSFC has established partnerships with 106 funding agencies and international organizations in 54 countries and regions, further enhancing the influence of the National Natural Science Fund on the global stage.

(1) Integrating into the global innovation network with distinctive strengths

In terms of cooperation with the Americas and Oceania, NSFC implemented the important consensus reached between the Presidents of China and the United States, promoting exchanges and joint funding to support stable and long-term cooperation. With partner agencies in Australia and New Zealand, we achieved shared commitments to facilitate academic exchanges.

In terms of cooperation with Europe, a comprehensive framework is taking shape, with new progress achieved. Joint funding programs with certain European agencies are expected to resume. Cooperation with Italy, Belarus and Spain yielded productive outcomes and supported high-level diplomatic engagements of national leaders. NSFC, in partnership with Science Europe, co-hosted the 4th Sino-European Strategic Dialogue on Basic Science centered on talent development and data sharing. President Dou Xiankang accepted an interview by *Nature*, where he introduced the progress and outcomes of the Science Fund reforms, receiving positive recognition globally.

Cooperation with Asia and Africa was further strengthened. NSFC reinforced ties with Japan and South Korea through joint seminars and funding initiatives in synthetic biology, sustaining momentum for scientific collaboration in Northeast Asia. Exchanges with neighboring countries and Belt and Road partners were further deepened and broadened.

We leveraged multilateral platforms to catalyze and deepen bilateral cooperation. President Dou Xiankang led a delegation to the annual meeting of Global Research Council (GRC), engaging in substantive discussions with funding agencies from over 10 countries. The 2024 GRC Asia-Pacific Regional Meeting, held in Beijing by NSFC, brought together high-level representatives from 13 funding agencies across the region to discuss on "research management in the era of AI" and "working together in co-creation to address global challenges". Cooperation with International Institute for Applied Systems Analysis (IIASA), Belmont Forum, BRICS, and other platforms was also further deepened.

In terms of cooperation with Hong Kong, Macao and Taiwan, NSFC advances the integration of Hong Kong and Macao's scientific and technological strengths into the overall development of the country. NSFC leaders conducted visits to Hong Kong and Macao to promote the gradual opening of three categories of the Young Scientist Fund (Young Scientists, Excellent Young Scientists, and Distinguished Young Scientists) and Key R&D Program to the two regions. We expanded joint funding scales with Hong Kong Research Grants Council (RGC) and Macao Science and Technology Development Fund (FDCT), and established mechanisms for joint youth and frontier forums.

The functional transformation of the Sino-German Center for Research Promotion progressed steadily. We organized strategic exchange activities and selected outstanding doctoral and undergraduate students to attend the Lindau Nobel Laureate Meetings. The 27th Joint Committee Meeting of the Sino-German Center for Research Promotion was successfully convened to chart the future direction of the Center.

(2) Promoting high-level mutual visits to strengthen international consensus

In 2024, NSFC leaders led 11 delegations to visit 13 countries, including the United States, the Netherlands, Finland, Norway, Austria, Belgium, Poland, Russia, Serbia, Switzerland, South Korea, Australia, and New Zealand, as well as visits to UNEP and Hong Kong and Macao SARs. NSFC hosted 36 high-level visits



from institutions from various countries and regions, including the U.S., Brazil, Chile, Germany, the U.K., Spain, Sweden, and Hong Kong and Macao SARs. These high-level visits significantly advanced practical bilateral and multilateral cooperation, leading to the resumption of joint funding and academic exchange with over 10 overseas funding agencies.

(3) Building the platform for international basic research cooperation with global partners

In 2024, NSFC collaborated with 31 funding agencies and international organizations from 23 countries (regions), including the U.S., the U.K., France, Japan, South Korea, BRICS nations, and Hong Kong and Macao SARs, to implement joint funding programs. We also advanced the implementation of Sustainable Development International Cooperation Program (SDIC). During the year, NSFC received 4,932 applications for International (Regional) Cooperation Programs, a 31.8% increase from 2023, and funded 706 projects with a total of 479 million yuan. Over 100 young researchers and students were supported for overseas study and exchange in countries with advanced research capabilities. 87 projects of the Key International (Regional) Cooperation Program were funded, with a total of 206 million yuan.

2. Implementing the Science Fund for Global Challenges and Sustainability

Based on the pilot programs, NSFC further clarified SFGCS's strategic orientation and refined its funding mechanism by introducing three sub-categories, thereby establishing a new framework to support "individuals, teams, and organizations."

Firstly, NSFC set up a pilot program jointly with the Ministry of Education, to support outstanding international students pursuing doctoral studies in China, attracting global young scientific talent and building a hub for research innovation. Secondly, NSFC launched the International Collaboration Fund for Creative Research Teams (ICFCRT) to support pioneering scientists with foreign citizenship in building and leading research teams in China, to conduct innovative basic and applied basic research, strengthening scientific collaboration and cultivating world-class research teams. Thirdly, NSFC conducted cooperation and exchange based on major scientific plans and programs, large-scale facilities, and international organizations. Fourthly, NSFC expanded the scale of the Research Fund for International Scientists (RFIS), and implemented all-in-English application and review processes, further improving its accessibility for international researchers.

In 2024, the SFGCS funded 74 projects with a total direct cost of 193.63 million yuan, while the RFIS supported 315 projects with a total direct cost of 198.82 million yuan.

3. Deepening International Cooperation in Sustainable Development, Expanding and Strengthening the Collaboration

ACCA21 continues to lead the negotiations on technology-related issues under the UNFCCC framework while taking the role of coordinator for the "Group of 77 and China", while participating in the 61st Plenary Session of the Intergovernmental Panel on Climate Change (IPCC) and supporting the review and consultation of relevant report frameworks. Through in-depth consultations with the US Department of Energy on sustainable development and global challenges, ACCA21 successfully organized six Sino-US CCUS Technology Cooperation Seminars, culminated in the signing of the "Sino-US Carbon Management Cooperation Memorandum", thereby deepening the bilateral dialogue mechanism on climate change. ACCA21 has also been actively engaged in ministerial-level multilateral mechanisms emphasizing green and low-carbon technological innovation, including the 15th Clean Energy Ministerial (CEM) and the 9th Mission Innovation Ministerial Meeting (MI), facilitating China's accession to the MI Carbon Dioxide Removal (CDR) Mission. Besides, ACCA21 has been strengthening collaboration with global institutions, such as the

Global Carbon Capture and Storage Institute (GCCSI) and the International Energy Agency (IEA), while enhancing involvement in Asia-Pacific Global Change Research Network (APN) activities.

ACCA21 has been implementing the outcomes of the leadership summits, making progress in the establishment of the “Sino-French Carbon Neutrality Center” and the renewing of the China-EU cooperation flagship programs. ACCA21 has also been actively promoting the science and technology exchanges in marine and polar sectors by gaining the observer status for China at the International Seabed Authority and advancing the establishment of the “BRICS International Research Center on Deep-Sea Resources” alongside international cooperation in ocean drilling. Besides, ACCA21 has been developing the South-South cooperation platform for sustainable development through organizing the second Belt and Road Science and Technology Exchange Conference, implementing the specialized cooperation initiatives of the sustainable development technologies under the Belt and Road framework, and participating in the Asian and Pacific Centre for Transfer of Technology (APCTT) tasks as the national focal point.

4. Typical Achievements

Anthropogenic climate change has influenced global river flow seasonality

River flow, as a critical component of the water cycle, has significant impacts on human society and ecosystems. It not only provides freshwater resources and affects flood disasters but also plays a vital role in maintaining biodiversity. However, the mechanisms driving river flow changes are complex, as they are regulated by interactions among atmospheric, oceanic, and terrestrial factors. Coupled with the scarcity of long-term, high-quality observational data, a comprehensive understanding of the changes in global river flow seasonality and their driving mechanisms remains elusive. Consequently, there are still critical knowledge gaps regarding the overall impacts of global climate change on river flow.

Under the support of the national project “Impacts of climate change on the water-food-energy nexus in the Lancang-Mekong River Basin” (Project No.: 42361144001), researchers from Southern University of Science and Technology, North China University of Water Resources and Electric Power, the University of Leeds, and ETH Zurich collaborated to investigate the impacts of climate change on the seasonality of global river flow. Using monthly river flow data from 10,120 global hydrological stations spanning 1965–2014, the study employed allocation entropy to assess the spatial distribution and historical trends of river flow seasonality. The findings revealed that approximately 21% of the hydrological stations (2,134 stations) exhibited significant changes in seasonality, with a pronounced weakening trend observed in high-latitude regions of the Northern Hemisphere. Through Spearman correlation tests and optimal fingerprinting methods (Figure 4-1-1), the study further quantified the dominant role of anthropogenic climate change in driving changes in river flow seasonality in these regions. Global warming was identified as the primary driver, leading to environmental changes such as earlier snowmelt, glacier retreat, and permafrost degradation, which collectively altered the seasonal characteristics of river flow, while the influence of precipitation was relatively minor.

The study achieved several key breakthroughs. It was the first to reveal the spatial patterns and historical trends of global river flow seasonality, highlighting the significant weakening of seasonality in high-latitude regions of the Northern Hemisphere. It also innovatively quantified the contribution of anthropogenic climate change to these changes and completed the global picture of climate change impacts on river flow by providing a comprehensive view of seasonal variations. This work offers critical

support for the integrated study of river flow annual averages, extremes, and seasonality.

The findings provide essential theoretical support for water resource management and ecosystem conservation under the backdrop of climate change. As global warming persists, the weakening trend in river flow seasonality is expected to intensify, with far-reaching implications for ecosystems and water resource availability. This study not only aids in predicting the impacts of climate change on water resource distribution but also offers valuable guidance for developing scientific water management and ecosystem conservation strategies, ensuring their forward-looking and adaptive nature.

The study, titled “Anthropogenic climate change has influenced global river flow seasonality”, was published online in Science on March 1, 2024.

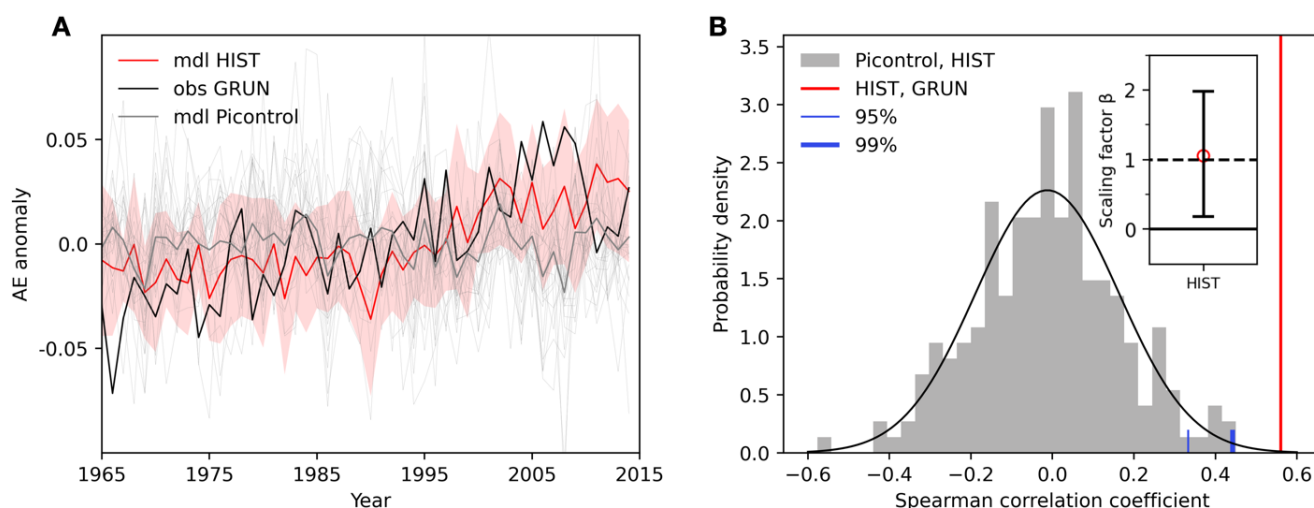


Figure4-1-1 Trends in river flow seasonality (1965–2014) expressed using allocation entropy.

The project of photon-phonon driven cascade catalysis for efficient methane oxidation to formaldehyde

With the support of the National Natural Science Foundation of China (Grant No. 22250710677, Research Fund for International Senior Scientists), the team led by Prof. Tang Junwang at Tsinghua University, China, in collaboration with Dr. Tianyu Zhang at Beijing Forestry University and Dr. Yang Lan at University College London, UK have realized a photon–phonon synergistic catalysis strategy. This breakthrough enables the oxidation of methane into formaldehyde under mild conditions, achieving unprecedented high yield and selectivity. The related research, titled “Efficient methane oxidation to formaldehyde via photon–phonon cascade catalysis”, was published in Nature Sustainability on July 18, 2024.

Methane, the main component of natural gas and methane hydrates, is abundant on Earth and serves as a key chemical feedstock. However, current industrial processes for converting methane into high-value chemicals (e.g., formaldehyde) typically require high-temperature and high-pressure conditions, being an energy-intensive process and facing challenges in the products’ selectivity and carbon economy. Developing a green, mild, and efficient approach for methane conversion is critical for improving the economic utilization of fossil resources, significantly reducing greenhouse gas emissions, and addressing the core scientific issue of low-carbon utilization of fossil fuels.

To tackle this challenge, the team have developed a cascade catalytic approach by means of a Ru single-atom-decorated zinc oxide catalyst, which acts as an efficient electron acceptor to promote the

reduction of oxygen (Figure 4-1-2). In the new approach developed, methane is first selectively converted into methyl hydroperoxide intermediates via photocatalysis with water; the intermediates are then further decomposed into the favourable product formaldehyde through phonon-driven thermocatalysis with a nearly 100% selectivity. The study has revealed, for the first time, the highly efficient synergistic mechanism of the photocatalysis and thermocatalysis cascade process, significantly reducing the reaction conditions (far below the condition used in the traditionally thermal catalytic process). This cascade pathway effectively avoids the generation of byproducts caused by excessive activation of C–H bonds under high-temperature and high-pressure conditions, demonstrating the potential of photon–phonon coupled catalysis for green chemical processes and efficient energy utilization.

This work not only provides a new scientific foundation for low-carbon chemical processes but also opens new directions for catalyst design and reaction pathway optimization. This novel approach, characterized by a high selectivity, low energy consumption, and environmentally friendly features, offers a sustainable approach to formaldehyde production with potentially industrial scaling-up. The efficient methane conversion achieved through this approach also helps reduce the carbon footprint of fossil fuel upgrading and provides a strong potential for the production of clean chemicals. Furthermore, it highlights the effectiveness of international collaboration in addressing scientific challenges and offers vital scientific support for promoting the transition of the petrochemical industry from grey to green processes.

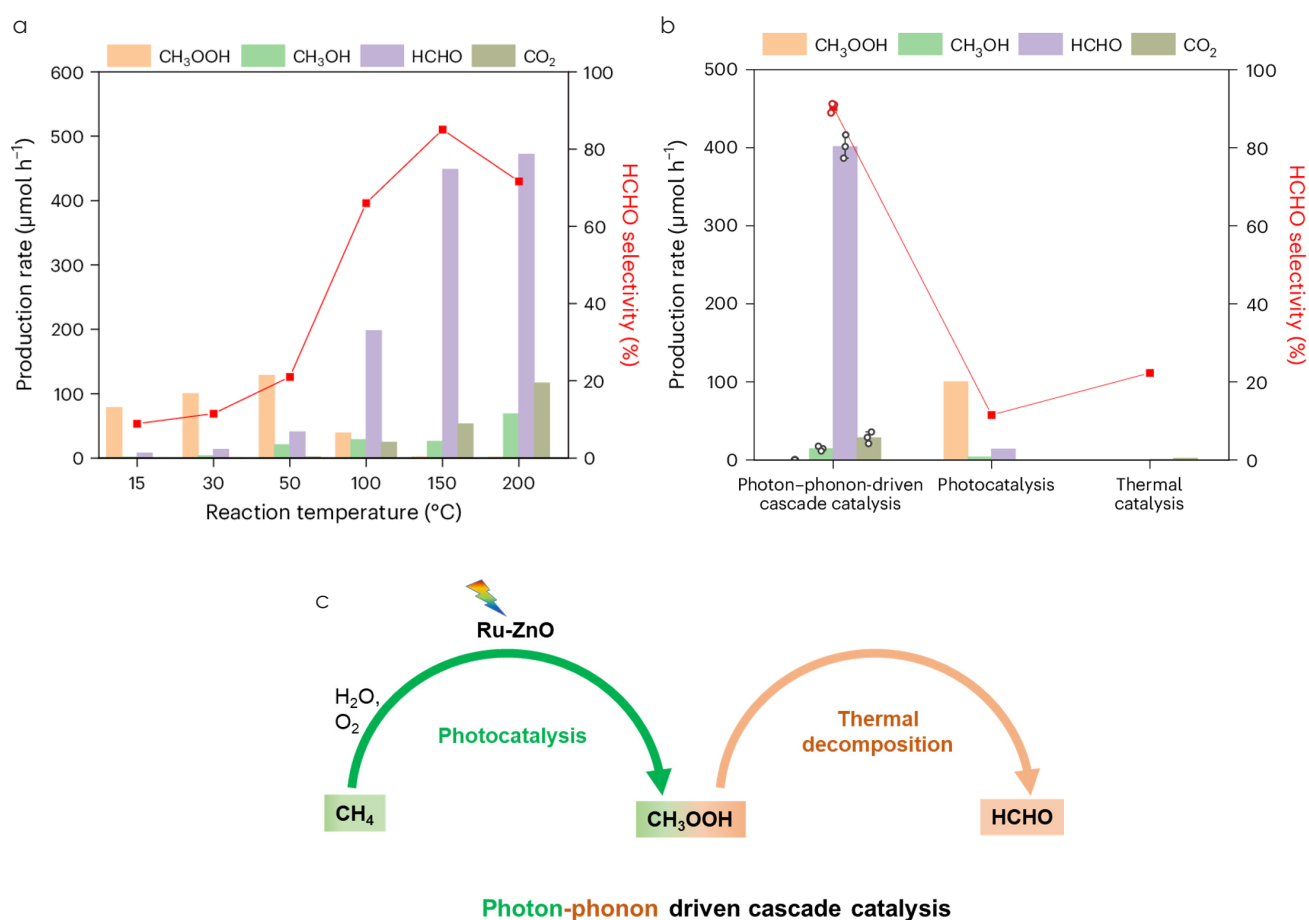


Figure 4-1-2 a. Photon–phonon coupled catalytic oxidation of methane to formaldehyde at different reaction temperatures; b. Significant advantages of photon–phonon coupled catalytic methane conversion compared to purely thermal or photocatalytic processes; c. Mechanism of highly efficient photon–phonon synergistic catalysis for methane oxidation to formaldehyde.



Studies on elastic films of single-crystal materials

Naturally occurring and synthetic materials are often polycrystalline. Typically, the higher the crystallinity, the brittle the polycrystalline materials are. Namely, there is a trade-off between the mechanical stability – which is desirable for practical applications – and high levels of long range crystal order due to the existence of grain boundaries, which can dominate properties of crystals. Meanwhile, similar to other materials, crystalline materials suffer from trade-off effects between mechanical rigidity and toughness. In contrast, crystals are often required to be processed into macroscopic films which are inevitably polycrystalline and contain numerous amounts of grain boundaries. Therefore, it remains challenging to obtain highly crystalline membranes with simultaneously enhanced mechanical rigidity and toughness.

To address the challenge, Supported by the National Natural Science Foundation of China (Grant No. 52061135103 and 51873236), Professor Zhikun Zheng from Sun Yat-sen University in collaboration with Professor Armin Götzhäuser from Bielefeld University, Professor Ute Kaiser from Universität Ulm, and Professor Stefan C. B. Mannsfeld from Dresden University of Technology, Germany, reported a breakthrough in constructing highly crystalline yet tough/elastic organic polymer membranes. The related research was titled "Elastic films of single-crystal two-dimensional covalent organic frameworks" and published in *Nature* on June 27, 2024.

Given that products can enhance mechanical rigidity and toughness through interwoven of their components and interwoven structures widely present in amorphous polymers, the research team introduced sacrificial amorphous polymer components, which act as "shuttles" to guide the interwoven of adjacent single-crystal domains of crystalline polymer membranes, and therefore created interwoven grain boundary structures (Figure 4-1-3). The obtained membranes use fully crystalline structure to provide mechanical rigidity, and energy dissipation offered by sliding of the interwoven structure at the grain boundaries to enhance mechanical toughness. The obtained membranes showed Young's moduli similar to that of aluminum alloy, while their fracture strength and elongation at break are better than aluminum alloy. When subjected to external impact and fractured, the fractured area was confined to the force concentration point (Figure 4-1-4). In contrast, once cracks are formed, they rapidly propagate, causing serious effects on mechanical properties of other highly crystalline materials. Moreover, the obtained membranes are resistant to rubbing, a property other highly crystalline material hard to achieve.

This work laid the foundation for the use of fully crystalline materials in flexible devices and separation membranes. Flexible materials of crystals can be used to produce flexible chips, flexible displays, flexible batteries, flexible sensors, etc. Membrane-based separation technology has been widely used in chemical engineering, environmental protection, energy, and biotechnology *et al.* In comparison with conventional separation membranes, fully crystalline polymer membranes are expected to gain high purity substances with higher efficiency due to their high regularity, especially in high value-added fields where traditional separation membranes are difficult to apply, such as precise separation of chemical intermediates, purification of high-purity electronic chemicals and pharmaceutical intermediates.

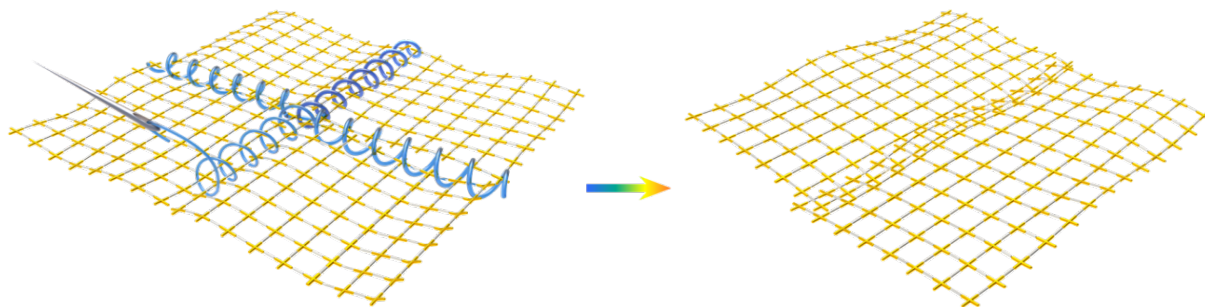
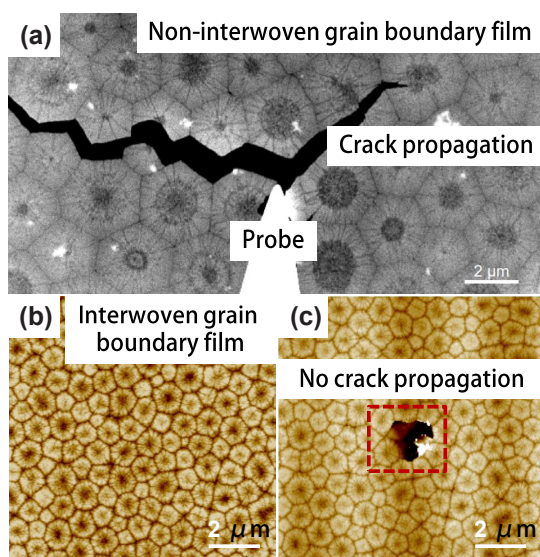


Figure 4-1-3 Schematic for the formation of interwoven grain boundary.



Note: (a) Fracture morphology of fully crystalline polymer film without interwoven grain boundary under stress. Morphology of polymer film containing interwoven grain boundary (b) before and (c) after fracture under stress.

Figure 4-1-4 Fracture morphologies of polymer film without and with interwoven grain boundary under stress.

Parental Histone Recycling during DNA Replication: Structural and Mechanistic Insights

In eukaryotes, DNA is organized into chromatin, with nucleosomes—comprising a histone octamer wrapped by DNA—serving as the basic units. During DNA replication, parental nucleosomes must be disassembled to allow DNA unwinding. The evicted histones are then recycled and reassembled onto daughter DNA strands to form new nucleosomes, ensuring epigenetic inheritance. Histone chaperones like FACT and the fork protection complex (FPC) are known to assist this process, but their precise mechanisms remain unclear.

Supported by the National Natural Science Foundation of China [International/Regional Collaboration Project 32321163647], a collaborative team led by Professors Ning Gao and Qing Li (Peking University), Yuanliang Zhai (University of Hong Kong), and Bik Tye (Cornell University) successfully captured a key intermediate state of nucleosome disassembly and parental histone recycling. Through in-depth structural and mechanistic analyses, the team elucidated a pivotal molecular mechanism underlying parental histone recycling. The findings, titled “Parental histone transfer caught at the replication fork”, were published in *Nature* in June 2024.

The research team purified endogenous replisomes from the eukaryotic model organism *Saccharomyces cerevisiae* and performed in-depth structural analysis using cryo-electron microscopy

(cryo-EM). They resolved the high-resolution structure of replisome associated with FACT, FPC, and an evicted histone hexamer $[(H3-H4)_2-(H2A-H2B)]$ (Figure 4-1-5). Structural analysis revealed this histone hexamer as a disassembly subcomplex derived from the parental nucleosome, where the parental DNA is fully displaced, and one H2A-H2B dimer is dissociated (Figure 4-1-6). The Spt16 subunit of FACT, the Mcm2 subunit of the replicative helicase, and the Tof1 subunit of the FPC act as molecular chaperones. They bind to histone interfaces exposed after DNA and H2A-H2B dissociation, stabilizing the histone hexamer (Figure 4-1-6 c-f). The structural data also revealed a previously uncharacterized interaction between the N-terminal extension (NTE) of Mcm2 and Tof1 (Figure 4-1-5). The strong interaction positions the histone hexamer at the front of the replication fork, near the lagging-strand DNA polymerase. Functional assays using eSPAN (enrichment and sequencing of protein-associated nascent DNA) demonstrated that disrupting Mcm2-Tof1 interactions significantly impairs parental histone recycling and its delivery to nascent lagging-strand DNA, highlighting the critical role of this interaction.

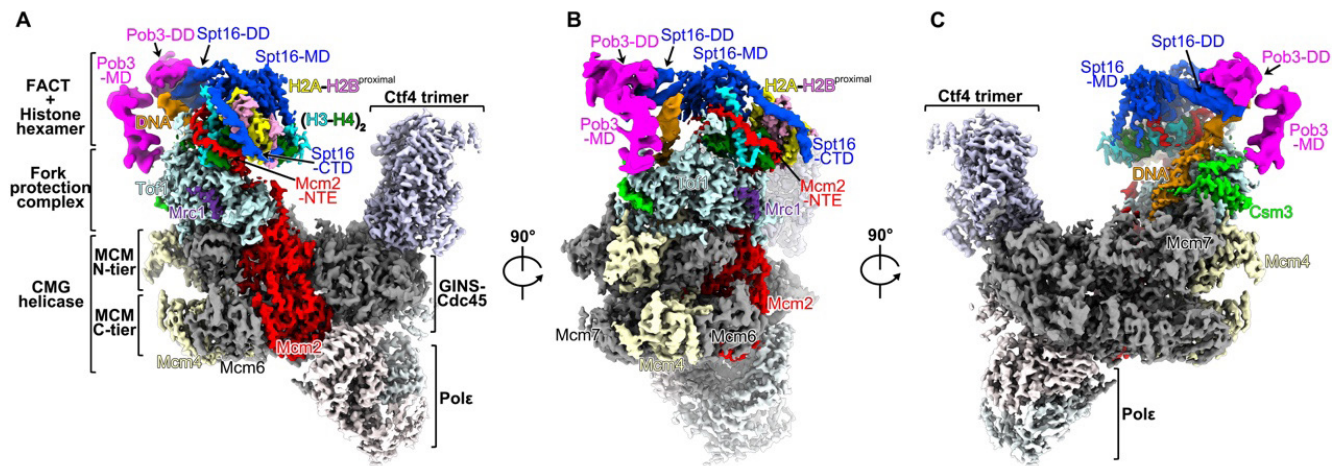


Figure 4-1-5 The overall structure of an endogenous replisome associated with FACT and a histone hexamer

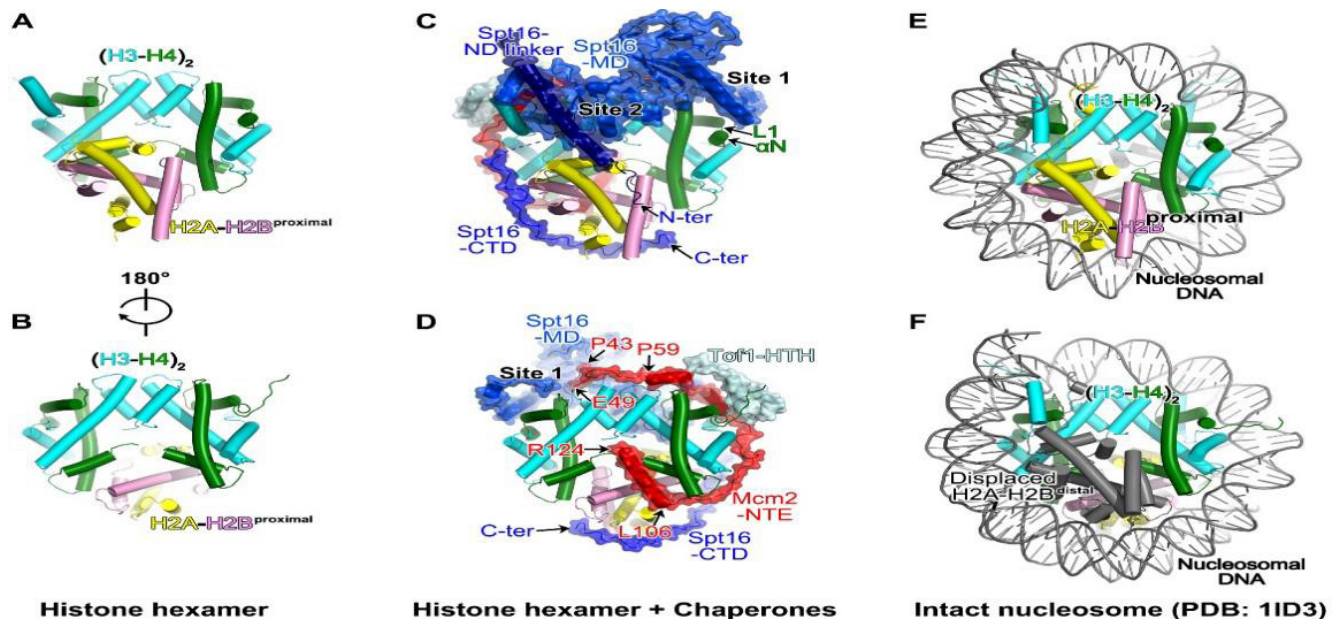


Figure 4-1-6 The evicted histone hexamer and its associated chaperones captured at the replication fork. (A-B) The atomic model of the evicted histones; (C-D) The atomic model of captured chaperone-histone complex; (E-F) The atomic model of the intact nucleosome

This work clearly illustrates the molecular details of a critical intermediate step during replication-coupled parental histone recycling. It elucidates the mechanisms by which FACT, Tof1, and Mcm2 coordinate to facilitate the recycling process, and indicates that the evicted histone hexamer might serve as a recycling unit. These findings significantly advanced our understanding of the mechanisms underlying DNA replication-coupled epigenetic inheritance maintenance.

Globally elevated greenhouse gas emissions from polluted urban rivers

Urban areas harbor the highest density of human production and consumption activities. Urban rivers are often characterized by disturbed element cycling as a result of strong hydrological control, point/non-point source pollution and heat island effect, leading to negative environmental effects such as eutrophication and further altered greenhouse gas (GHG) emissions. However, the global-scale quantitative evaluation and spatiotemporal pattern of the three main GHGs are still lacking, and the underlying mechanisms are poorly understood.

With the support of the NSFC [No. T2261129474], Professor Xinghui Xia from Beijing Normal University and Professor William H. McDowell from University of New Hampshire, USA, cooperatively accurately predicted the spatial pattern of GHG concentrations and fluxes in global urban rivers, identified the key control mechanisms, and made quantitative estimates of their magnitude for the first time. The relevant research were published in *Nature Sustainability* on May 27, 2024 with the title of "Globally elevated greenhouse gas emissions from polluted urban rivers".

The study deeply revealed the key environmental and socioeconomic controls of GHG concentrations and fluxes in global urban rivers (Figure 4-1-7). We found that the concentrations and fluxes of CH₄ and N₂O both increased with the increase of watershed population, population density and GDP, but significantly decreased with the increase of GDP per capita. In addition, the enhancement of primary productivity or soil respiration in urban areas can promote riverine CH₄ and CO₂ emissions, but it can intercept nitrogen from surface runoff and inhibit its transport to rivers, thereby reducing N₂O emissions.

Based on the machine learning predictions, the study found that the average fluxes of CH₄, CO₂ and N₂O in urban rivers were 6, 1.2 and 19 times that of global rivers, respectively. The concentrations and fluxes of the three GHGs showed the inverted U-shaped relationship with income levels, coinciding with the Environmental Kuznets Curve theory. This result indicated that stricter environmental regulations and higher water pollution control investment in high-income countries could effectively reduce urban river GHG emissions (Figure 4-1-8).

Global urban rivers annually emitted 1.1 Tg CH₄, 42.3 Tg CO₂ and 0.02 Tg N₂O into the atmosphere, totalling 78.1 Tg CO₂-equivalent emissions. Urban rivers in high-middle-income countries contributed 41.7% of global emissions, while Asian urban rivers accounted for 66.1%. Compared with global rivers, CH₄ and N₂O made a higher contribution to total GHG radiative forcing in urban rivers, increasing from 12.7% to 45.9%. Though covering a small percentage of the global river surface area (~0.8%), urban rivers contributed substantially higher fractions of CH₄ and N₂O to global riverine GHG emissions with 4.9% and 15.4%, respectively. The research results can provide scientific guidance for policy formulation and management practices for urban GHG emission reduction and water environmental pollution control.

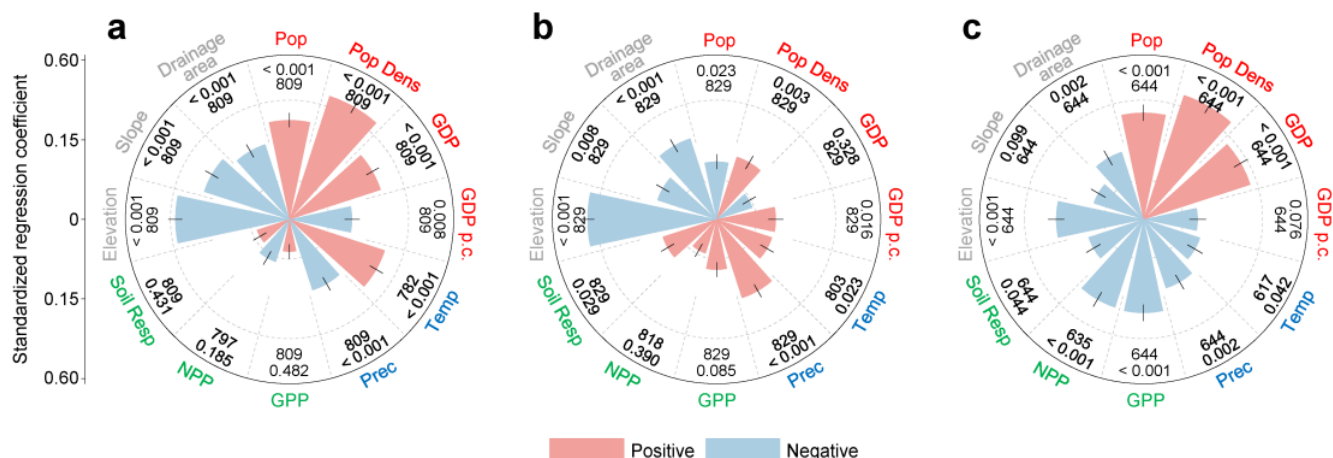


Figure 4-1-7 Standardized regression coefficients between GHG concentrations and fluxes in global urban rivers and watershed environmental and socioeconomic variables.

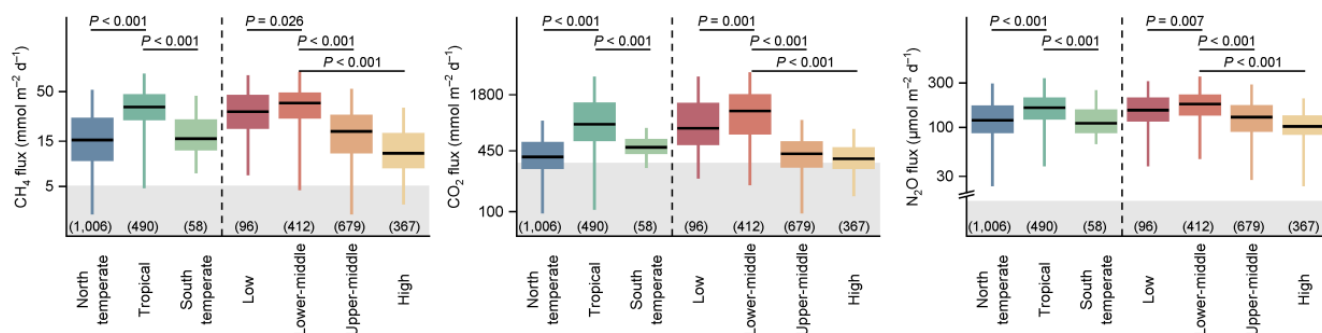


Figure 4-1-8 Spatial distribution pattern of GHG fluxes in global urban rivers.

China-Ethiopia/Sri Lanka Trilateral Cooperation Project on Renewable Energy

Under the current backdrop of profound adjustments in the international political and economic landscape, intensified geopolitical conflicts, and intertwined factors such as unilateralism and protectionism, the strategic significance of "South-South cooperation in science and technology" has become increasingly prominent. To fully leverage the supporting role of South-South cooperation in China's comprehensive opening-up and innovation-driven sustainable development under new historical conditions, the Administrative Center for China's Agenda 21 (ACCA21) and the United Nations Development Programme (UNDP) jointly designed and launched the "China-Ethiopia/Sri Lanka Trilateral Cooperation Project on Renewable Energy" in 2019, which has achieved positive outcomes.

Through preliminary research, the project analyzed Ethiopia's immense renewable energy potential, spanning hydropower, geothermal, wind and solar energy, as well as Sri Lanka's urgent demand for renewable energy and energy efficiency-enhancement technologies. Considering that Ethiopia's development ratio for renewable energy sources other than hydropower remains below 1% of its national potential, and recognizing the significant emission reduction potential in Sri Lanka's agro-industrial sector—the country's second-largest greenhouse gas emitter, the project established a new trilateral cooperation

model focused on technology transfer, while strengthening capacity building and knowledge sharing to ensure the sustained implementation.

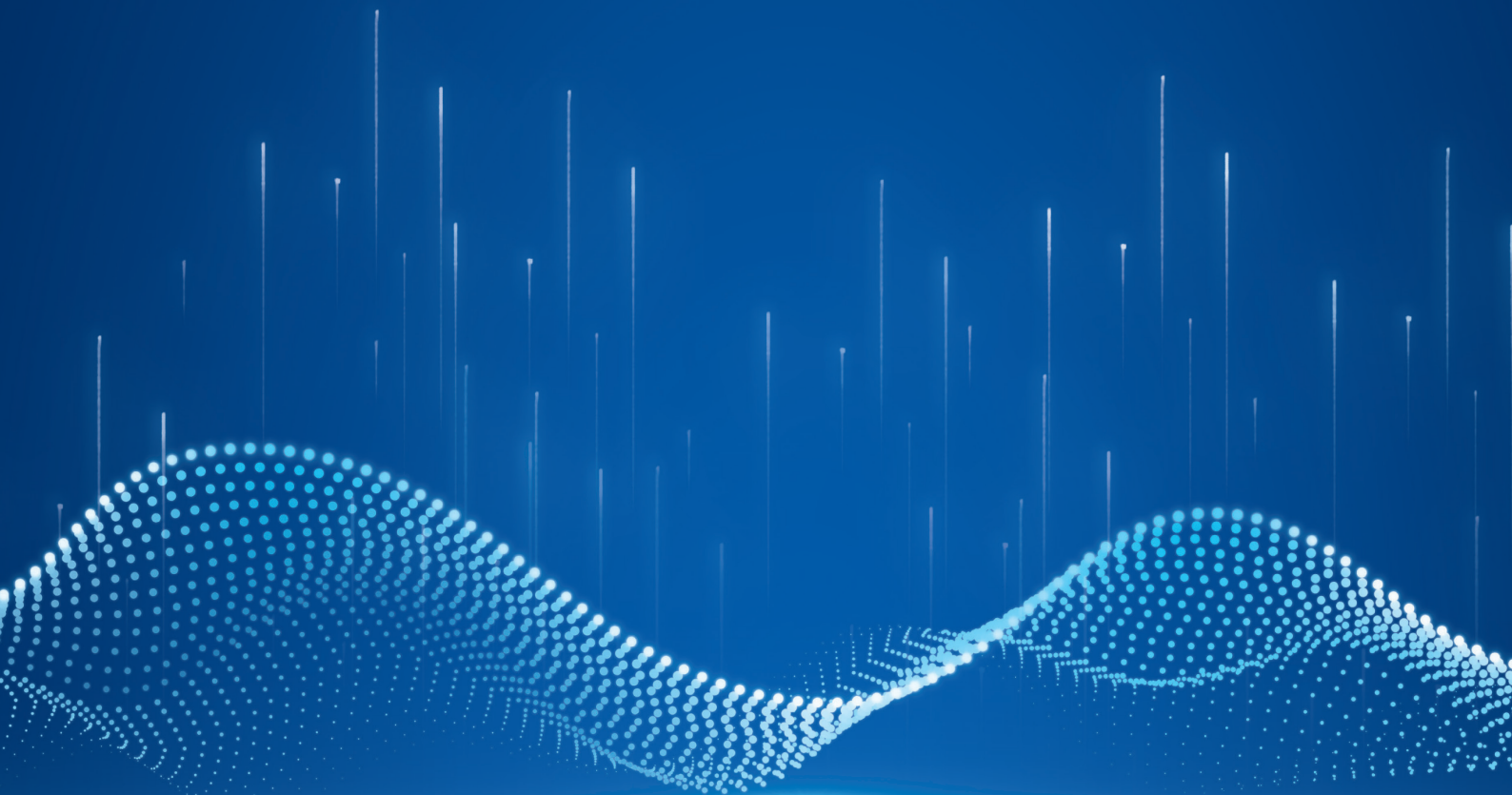
After nearly four years of steady implementation, the project successfully concluded in 2024. Since its inception, it has garnered widespread attention. In 2022, the project was listed in the United Nations “Good Practices in South-South and Triangular Cooperation in Least Developed Countries” (Figure 4-1-9). UNDP Administrator Achim Steiner highlighted this project as “a sample of the good practices contained in the report” during the launch. In 2023, the project was again recognized by the UN as a successful case in the joint publication “Technology and Nationally Determined Contributions: Summary for Policymakers” by the Climate Technology Centre & Network (CTCN) and the Technology Executive Committee (TEC) of the UNFCCC.



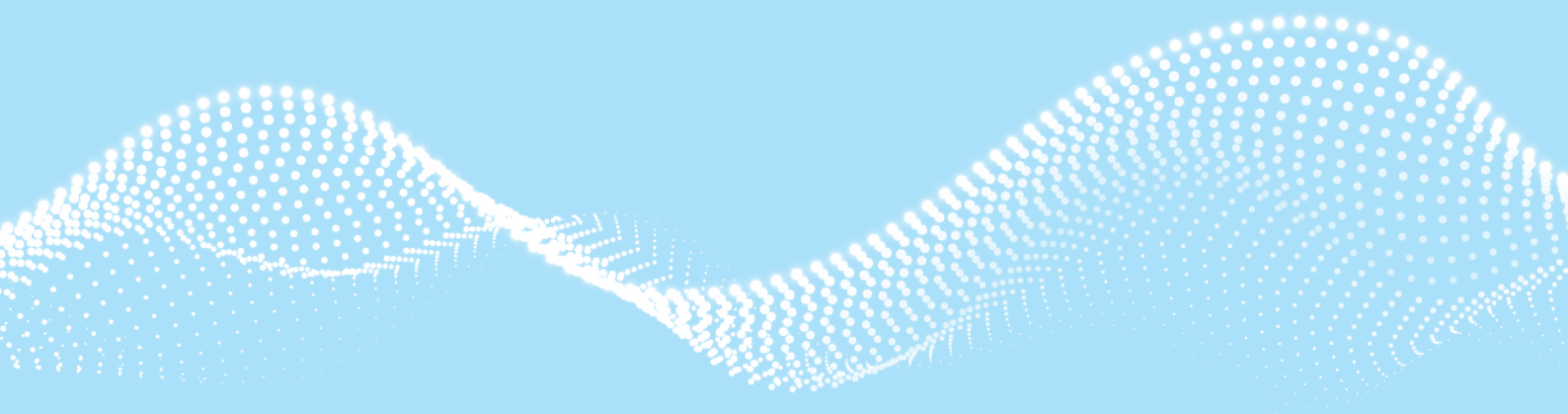
Figure 4-1-9 "China-Ethiopia/Sri Lanka Trilateral Cooperation Project on Renewable Energy" was listed in the United Nations "Good Practices in South-South and Triangular Cooperation in Least Developed Countries"

PART 5

Research Integrity



NSFC



NSFC has consolidated and deepened the achievements of the special rectification on the persistent issue of string-pulling in the process of peer review, has implemented an action plan in five aspects: education, motivation, regulation, supervision and punishment, and is committed to promote a clean and upright scientific research environment.

I. Consolidate and Deepen the Achievements of the Special Rectification of the Persistent Issue of String-pulling in the process of Peer Review

First, strengthen positive guidance as starting point. By utilizing various publicity methods such as the animated film *Resolutely resisting the behavior of jeopardizing the impartiality of peer reviewers and jointly creating a clean and upright evaluation environment* and the *Handbook of Scientific Research Integrity Standards*, a strong indication has been released to resolutely and seriously investigate and punish the misconduct of string-pulling in the process of peer review, which has received widespread attention and full recognition from all society, especially the technology sector. Second, take strict discipline and regulations as benchmark. Actively assist in the revision of the *Regulation of the National Natural Science Foundation of China* and clarify the legal responsibilities for misconduct behaviors; Revise the performance guidelines and commitment letter for correspondence review experts, and clarify the requirements for the special initiative; Revise the *Reminder Letter for the Performance of Duties and Responsibilities of Project Review Experts* and *Reminder Letter for Panel Review Respondents of Project of National Natural Science Foundation* to further strengthen and standardize the responsibilities and behaviors of respondents and peer review experts. Third, take extreme defense as the driving force. Increase the proportion of overseas experts and young experts, adopt batch assignments, shorten meeting review time, and reduce the possibility of “sea fishing” review experts; Improve the confidentiality measures for expert opinions and voting results in panel reviews, address the issue of computer screensaver in panel reviews, and no longer display vote information for projects that are not recommended for funding in some project reviews; Display the *List of Prohibited Behaviors for String-pulling in the Review of National Natural Science Foundation Projects* throughout the entire panel review, and play animated films alerting misconduct behaviors during the break. Strictly carry out on-site supervision of panel review, with a focus on on-site supervision of behaviors such as lobbying, canvassing, and pulling strings. Conduct impartial investigations to ensure fair and impartial project reviews. Fourth, take serious punishment as a warning point. Under the guidance of the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection and the National Supervisory Commission stationed in the Ministry of Science and Technology, the issue of reporting scientific research misconduct involving string-pulling in the process of peer review has been listed as a key case for investigation and handling. NSFC promoted supervision linkage and information sharing to improve the efficiency of problem verification. Serious punishment will be imposed on the relevant responsible individuals in accordance with the law and regulations for confirmed cases of misconduct behaviors, effectively exerting a deterrent effect.

II. Steady Progress in the Active Supervision of Key Aspects of Scientific Funding

First, fully implement the fairness commitment system. The project applicant, host institution, review expert, and staff of NSFC all signed Commitment Letter of Impartiality, covering more than 400,000 project applications, over 2000 host institutions, more than 90,000 evaluation experts and all staff of NSFC. Second,



continuously conduct similarity checks on project applications. Conduct an investigation into high similarity cases of application forms based on the results of similarity checks. In 2024, a total of 145 highly similar cases were investigated and serious measures were taken against those relevant people. Third, continuously carry out disciplinary reminders before the panel review. In the form of a handwritten letter from President Dou Xiankang, a *Reminder Letter for Defenders of National Natural Science Foundation Project Review Projects* and a *Reminder Letter for Expert Reviewing Performance of National Natural Science Foundation Project* will be sent before the panel review to remind the defenders and review experts to fulfill their scientific research integrity commitments. Fourth, further strengthen the on-site supervision during the conference review period. NSFC has completed on-site supervision work for 39 review meetings, covering 348 review groups. Fifth, seriously carry out joint disciplinary integrity audits for proposed funding projects. Before the approval of science fund projects, a joint disciplinary integrity audit shall be conducted on the applicants, participants, host institutions and cooperative research institutes of the proposed approved projects. Individuals and institutions found to have integrity issues and are within the punishment period shall be rejected with one vote to ensure that the responsible parties recorded in the database of serious research integrity breaches do not assume or participate in NSFC funded projects during the punishment period. Sixth, regularly conduct expert qualification reviews for scientific fund evaluations. We have conducted two joint disciplinary integrity audits of the expert review database to ensure that individuals with records of serious dishonest behavior such as illegal activities, plagiarism, forgery, and tampering are not allowed to participate in the evaluation of scientific fund projects.

III. Continuously Increase Efforts to Combat Research Misconduct

In 2024, three full committee meetings of the Supervisory Committee were held to review and propose solutions to various complaints and reports related to scientific misconduct. Following the Committee's approval, a total of 630 individuals and 11 host institutions were subject to disciplinary measures. Among the cases, 65 people liable received official criticism, and others were subject to internal criticism, warnings, and other treatments. The qualifications of over 200 individuals for reviewing and applying for NSFC projects were permanently revoked. The eligibility of several persons liable to apply for and participate in fund projects was canceled for different periods; 1 host institution was notified of public criticism, several were issued warnings or received criticism or education.

IV. Comprehensive Implementation of Research Integrity Education and Promotion

First, we organized the mobilization and deployment meeting for the NSFC project peer review process, and emphasize the requirements of the review. NSFC has thoroughly implemented the relevant requirements for consolidating and deepening the achievements of the special rectification of the persistent issue of string-pulling in the process of peer review, continue to carry out this special initiative work, strictly plug risk loopholes, innovate the organizational mode of evaluation, and effectively maintain the fairness of the peer review. Second, we took multiple measures to carry out education and promotion, covering four main stakeholders. NSFC conducted training of research integrity, scientific ethics, and use of funds for research management personnel of host institutions, new staff of NSFC, and researchers through training sessions at host institution training meetings, regional liaison network meetings, training sessions for NSFC new staff and lectures on academic conduct and research integrity at host institutions.

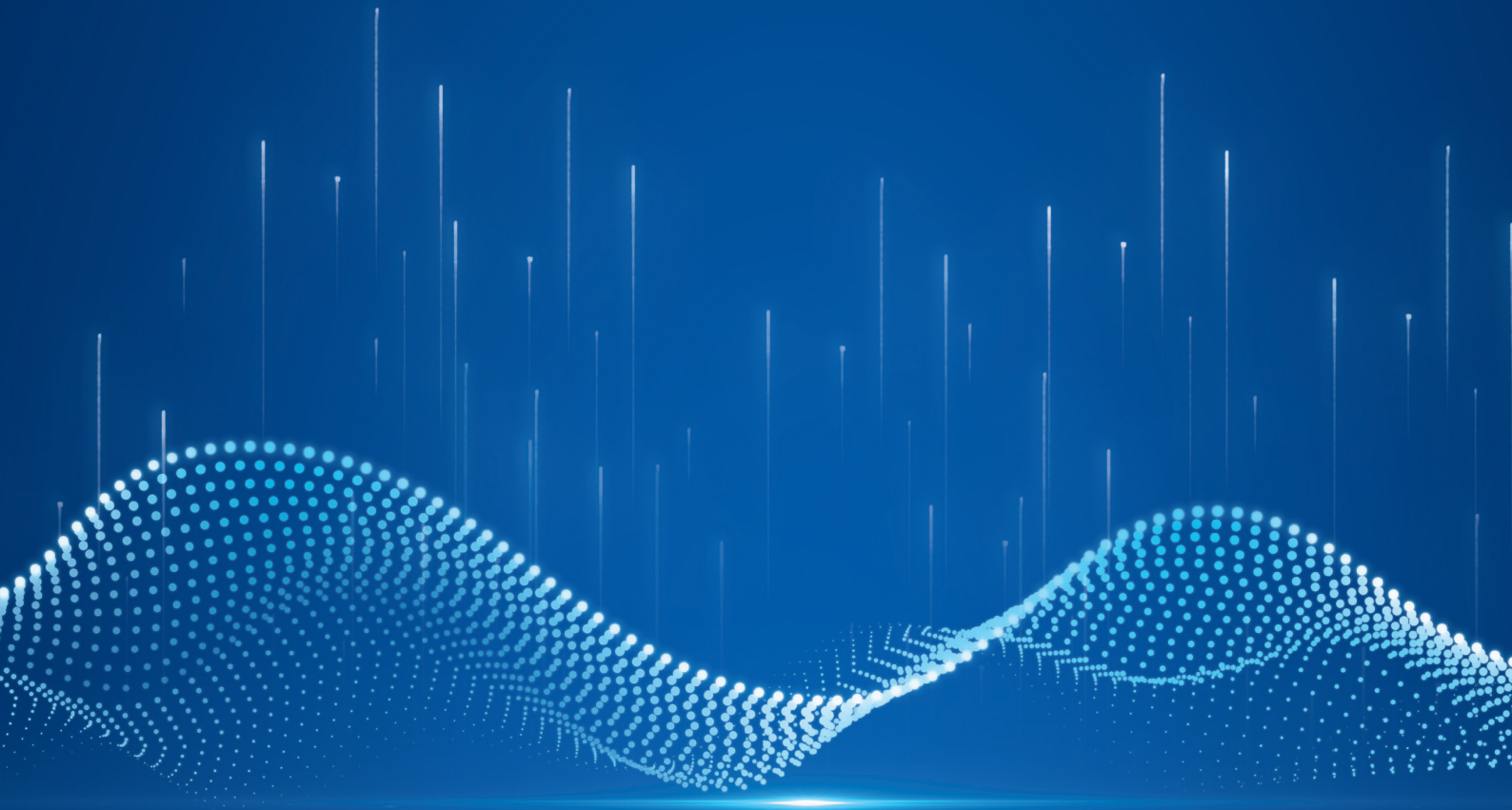
Third, we strengthened public guidance through multiple channels. New regulations regarding scientific research integrity and ethical construction in the newly revised Regulation of National Natural Science Foundation of China were interpreted in the media such as Guangming Daily, Economic Daily, and Xinhua Net; the special rectification was publicized and reported in publications such as China Science Journal and China Youth Daily, sending a strong signal of resolutely and seriously investigating and punishing the misconduct in the process of peer review. Fourth, we actively participated in scientific research integrity construction and exchange activities from home and abroad. At the 8th World Conference on Research Integrity, the China Switzerland Research Integrity Symposium, and the Ministry of Science and Technology's Science and Technology Supervision and Research Integrity Practice Training Course, NSFC promoted the innovative measures and achievements of its research integrity and technology ethics construction. Fifth, we released typical cases of scientific misconduct and strengthen warning education. In 2024, the results of typical cases of scientific misconduct were announced in two batches on the official website of NSFC. The negative list will be transformed into a warning textbook for positive education, guiding researchers to clarify their bottom line of integrity. Sixth, we strengthened the main responsibility of relying on the integrity construction of the host institutions and give full play to the management role of the institutions. In the Guide to Programs and the promotion of scientific research integrity, NSFC emphasized the main responsibility and key role of the host institutions in the construction of scientific research integrity, and built a credit evaluation mechanism for host institutions.

V. Thoroughly Conducting Supervision and Inspection of Project Funds

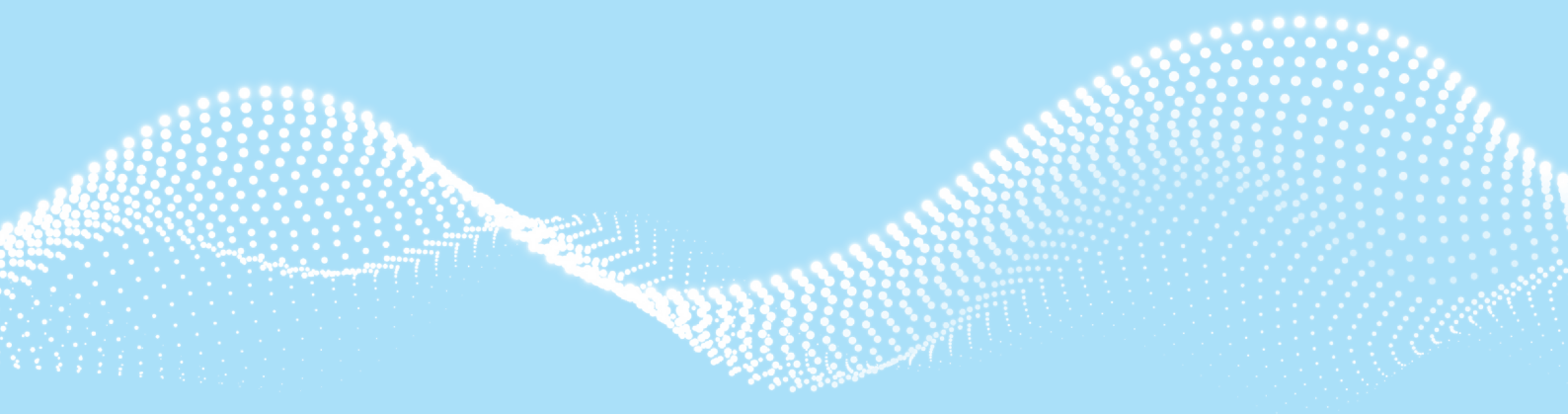
First, the supervision and inspection of project funds was planned as a whole. The supervision and inspection meeting of NSFC projects was held in Shaanxi Province, Xizang Autonomous Region, Heilongjiang Province, Liaoning Province and Jilin Province. Fund supervision and inspection on 1426 projects were randomly selected from 152 host institutions in these five provinces, involving a total amount of 998.874 million RMB. Second, the "second part" of the supervision and inspection of NSFC project funds was effectively carried out. Convene a summary meeting for the supervision and inspection of NSFC projects in Guangdong, Sichuan, and Hebei provinces through a combination of online and offline methods. With the goal of "finding and rectifying", responsibilities for rectification were enforced. 102 host institutions were issued letters of rectification opinions, specifying rectification requirements and deadlines. Approximately 15 million RMB of improperly used funds were recovered. Thirdly, reported issues and clues related to project funds were investigated and handled. In 2024, a total of 64 complaints and reports related to project funds were received. Through case investigation, more than 3 million RMB of improperly used funds were recovered, and one individual received internal criticism and his application and participation qualification was revoked for 5 years.

PART 6

Organizational Structure of NSFC

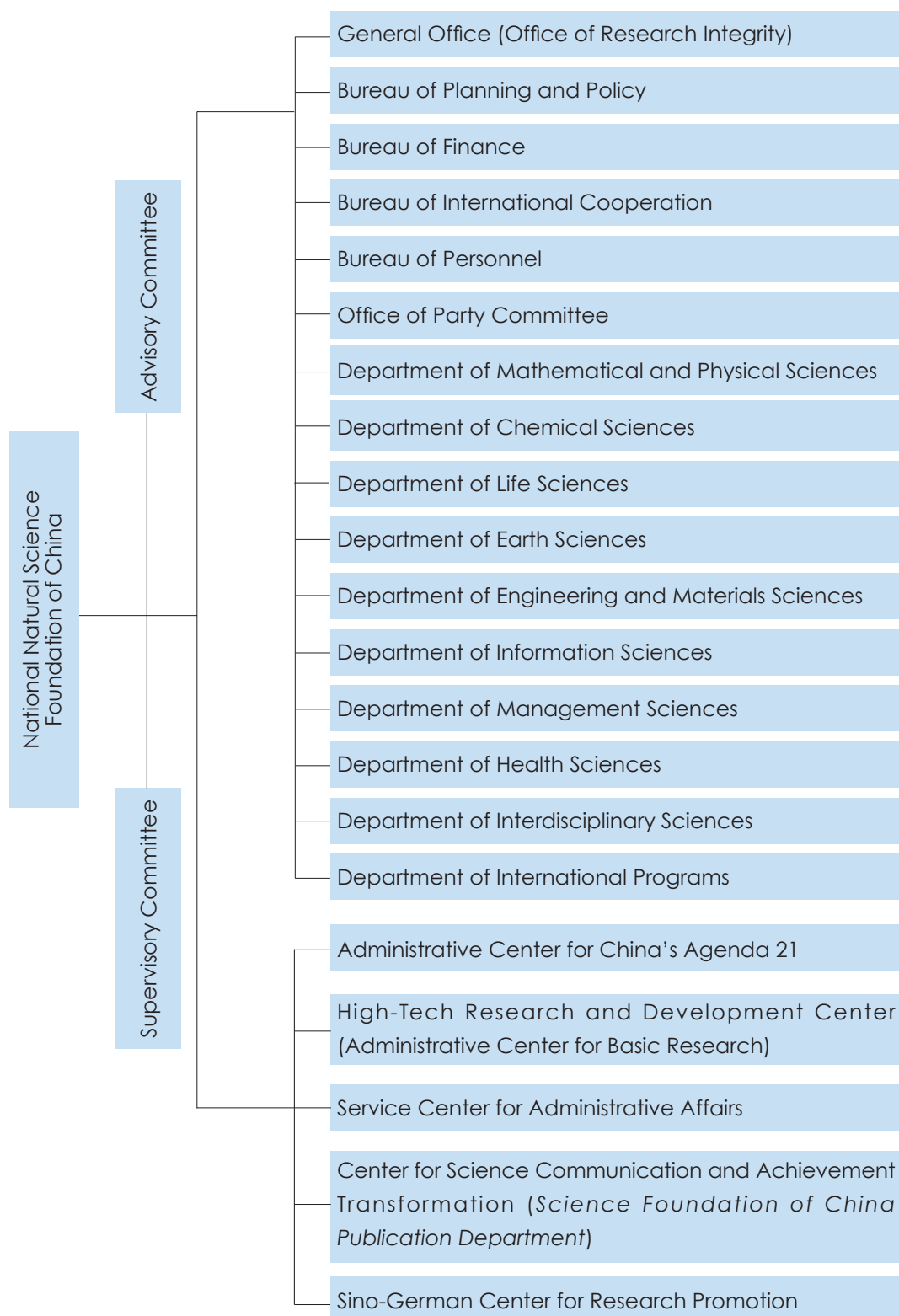


NSFC



Organizational Structure

1. Chart of Organization Structure





2.NSFC Staff

The budgeted staff quota at NSFC is 309. By December 31, 2024, NSFC has 259 permanent staff, of whom 153 are males and 106 are females; and 240 hold a professional technical position (title). The average age of the permanent staff is 42.7 years old. The distribution of their gender, age, 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.

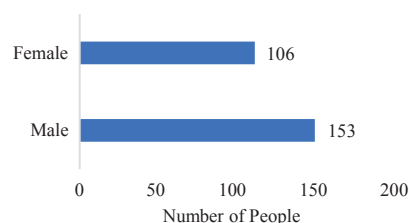


Figure 6-1-1 Gender distribution of NSFC staff

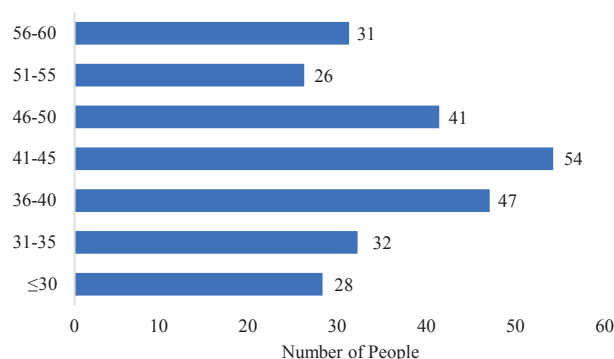


Figure 6-1-2 Age distribution of NSFC staff

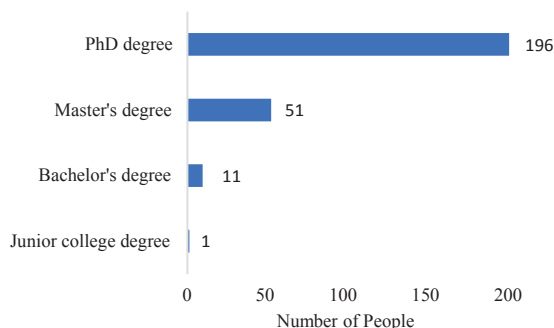


Figure 6-1-3 Academic degrees of NSFC staff

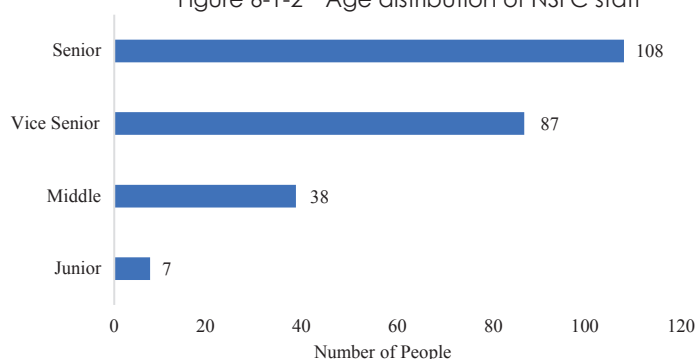


Figure 6-1-4 Professional titles of NSFC staff

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

Leaders of NSFC's Bureaus and Departments

(As of December 31, 2024)

Bureaus and Departments	Leaders
General Office (Office of Research Integrity)	Wang Cuixia (F), Guo Jianquan, Jing Yaxing, Zhang Fengzhu (F), Fan Li (F), Li Dong (F, Director of Information Center)
Bureau of Planning and Policy	Wang Yan (F), Yang Liexun, Yao Yupeng (concurrently)
Bureau of Finance	Wang Kun (F)
Bureau of International Cooperation	Fan Yingjie (F)
Bureau of Personnel	Lyu Shumei (F), Wang Wenzhe
Office of Party Committee	Yang Feng, Huang Baosheng

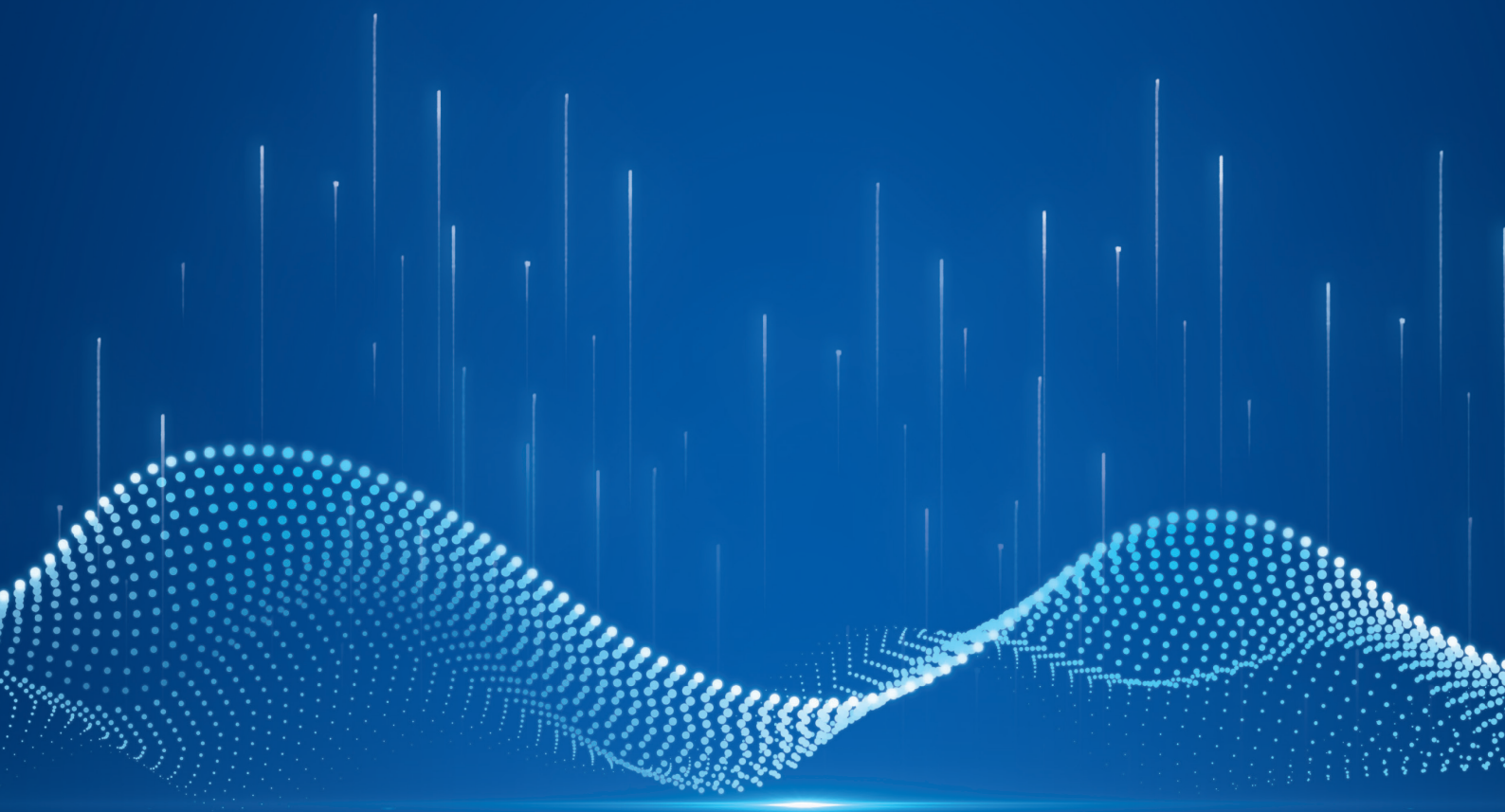
Bureaus and Departments	Leaders
Department of Mathematical and Physical Sciences	Chen Xianhui (concurrently), Ni Peigen
Department of Chemical Sciences	Yang Xueming (concurrently), Yang Junlin, Zhan Shige (F)
Department of Life Sciences	Zhong Kang (concurrently), Wang Puyue (F)
Department of Earth Sciences	Guo Zhengtang (concurrently), Yao Yupeng
Department of Engineering and Materials Sciences	Qu Jiuhui (concurrently), Lai Yinan (F), Miao Hongyan
Department of Information Sciences	Hao Yue (concurrently), Liu Ke
Department of Management Sciences	Ding Lieyun (concurrently), Liu Zuoyi, Wu Gang
Department of Health Sciences	Zhang Xuemin (concurrently), Hong Wei (F), Yan Zhangcai
Department of Interdisciplinary Sciences	Tang Chao (concurrently), Fu Xuefeng (F)
Department of International Programs	Yin Wenxuan (F), Lyu Qunyan (F)

Leaders of NSFC's Subordinate Units

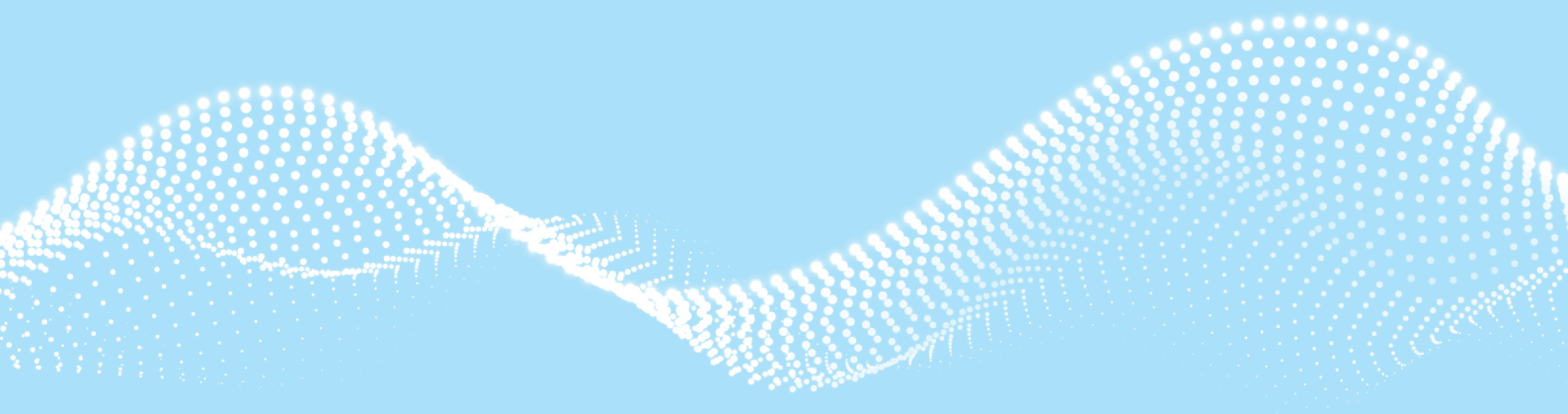
(As of December 31, 2024)

Unit	Leaders
Administrative Center for China's Agenda 21	Chen Qizhen, Zhang Yongtao
High-Tech Research and Development Center (Administrative Center for Basic Research)	Zhang Honggang, Wu Gen, Yan Jinding
Service Center for Administrative Affairs	Feng Wen'an
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



I. Important Activities of NSFC in 2024

January

On January 24, Vice President Lan Yujie met with the visiting delegation led by Xie Yongqiang, Chairman of the Administrative Committee of the Macao Science and Technology Development Fund (FDCT).



February

On February 29, NSFC released "China's Top 10 Science Advances in 2023". Vice President Lan Yujie attended the press conference.



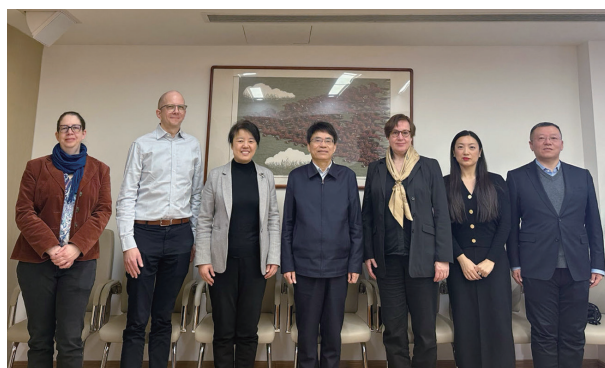
March

On March 1, the signing ceremony for a donation from Xiaomi Foundation to NSFC was held in Beijing. President Dou Xiankang and Lei Jun, Founder, Chairman and CEO of Xiaomi Group, attended the ceremony and delivered speeches. Vice President Wang Xiqin, along with Liu Wei, Director of President's Office of Xiaomi Group and Secretary General of Xiaomi Foundation, signed the donation agreement on behalf of the respective parties.





On March 1, Lan Yujie, Vice President and Co-Chair of the Joint Committee of the Sino-German Center for Research Promotion, met with the visiting delegation led by Ingrid Krüßmann, Director for the German side of the Center.



On March 12, President Dou Xiankang met with Mark Walport and Alison Noble, Vice Presidents of the Royal Society. Vice President Lan Yujie attended the meeting.



April

From April 10 to 11, the Sino-European Policy Workshop on Basic Science Cooperation, jointly organized by NSFC and Science Europe, was held via video conference. President Dou Xiankang attended and delivered a speech. More than 50 scientific administrators and experts from China and European countries, including Germany, the United Kingdom, the Netherlands, Belgium, Switzerland, Norway, Spain, and Serbia, participated in the event and engaged in extensive exchanges.



From April 14 to 21, Vice President Lan Yujie led a delegation to New Zealand and Australia, visiting 10 institutions including the Royal Society of New Zealand.



On April 15, NSFC and German Research Foundation (DFG) jointly held the Sino-German Workshop on AI and the Sustainable Development of Research Funding via video conference. The meeting was chaired by Han Yu, Vice President and Secretary General. Vice President Lan Yujie and Heide Ahrens, Secretary General of DFG, attended and delivered remarks.



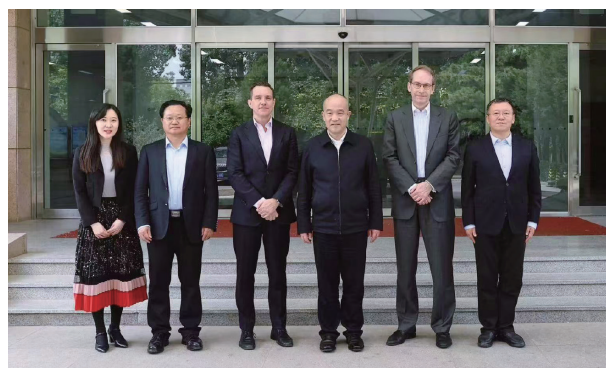
On April 24, President Dou Xiankang met with the delegation led by Jesse C. Wiley, Chairman of Wiley.



On April 24, President Dou Xiankang met with the delegation led by Annette Schmidtman, Head of Department of Scientific Affairs of the German Research Foundation (DFG).



On April 26, President Dou Xiankang met with the delegation led by Andreas Göthenberg, Executive Director of the Swedish Foundation for International Cooperation in Research and Higher Education (STINT). Vice President Lan Yujie attended the meeting.



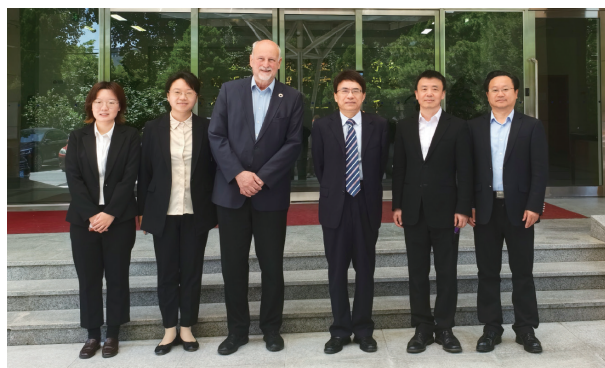


May

On May 6, Han Yu, Vice President and Secretary General, met with the delegation led by Stuart Whayman, President of Global Research Solutions of Elsevier.



On May 13, Vice President Lan Yujie met with Wolfgang Lutz, Acting Deputy Director of the International Institute for Applied Systems Analysis (IIASA), and Jiang Leiwen, Member of IIASA's Science Advisory Committee, along with their delegation.



On May 22, Han Yu, Vice President and Secretary General, met with the delegation led by Nandita Quaderi, Senior Vice President of Clarivate Analytics and Editor-in-Chief of Web of Science.



On May 22, President Dou Xiankang met with the delegation led by Sudip Parikh, Chief Executive Officer of the American Association for the Advancement of Science (AAAS). Vice President Lan Yujie attended the meeting.



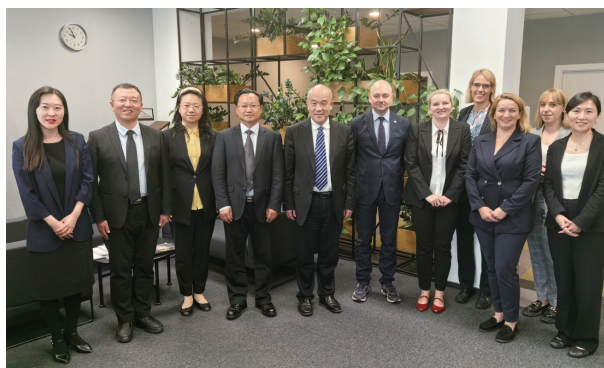
On May 27, Vice President Jiang Song met with the delegation led Alexander Kohls, Member of the Executive Committee of the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP³), and Stefan Hohenegger, Chair of the SCOAP³ Governing Council.



From May 27 to 30, President Dou Xiankang led a delegation to Interlaken, Switzerland, to attend the 12th Annual Meeting of the Global Research Council.



From May 31 to June 4, President Dou Xiankang led a delegation on official visits to Poland and Serbia.



June

On June 17, the signing ceremony for the Agreement on the Second Phase of the Joint Fund for Corporate Innovation and Development between China General Technology Group and NSFC was held in Beijing. President Dou Xiankang and Yu Xubo, Chairman of China General Technology Group, attended the ceremony and delivered speeches. Vice President Wang Xiqin, and Cui Zhicheng, General Manager of the General Technology Group, signed the agreement on behalf of the two parties.





On June 19, President Dou Xiankang met with Mark Suzman, Chief Executive Officer of the Bill & Melinda Gates Foundation.

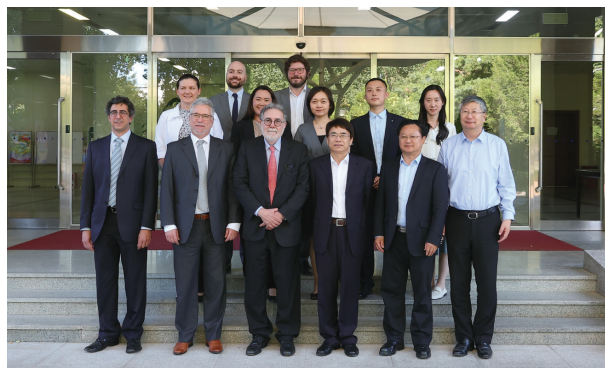


On June 21, the send-off ceremony and pre-departure training for the Chinese student delegation selected for the 2024 Lindau Program under the Sino-German Center for Research Promotion was held in Beijing. President Dou Xiankang attended the event and delivered remarks. Vice President Lan Yujie presided over the ceremony and presented certificates to the selected students.



On June 24, President Dou Xiankang met with Antoine Petit, President of the French National Center for Scientific Research (CNRS), to sign a renewed MoU on scientific cooperation.

On June 24, Vice President Lan Yujie met with the visiting delegation from the São Paulo Research Foundation (FAPESP) of Brazil.



July

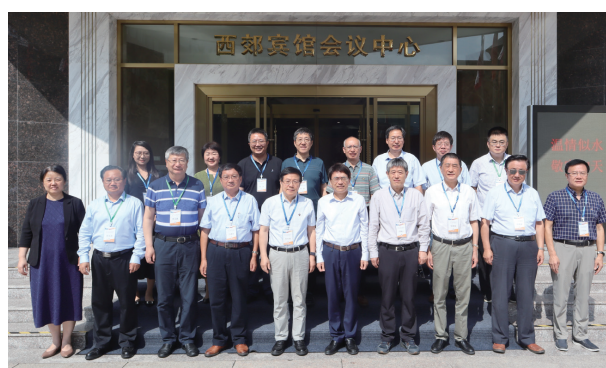
From July 8 to 12, Vice President Lan Yujie led a delegation to the United States, where meetings were held with agencies including the National Institutes of Health (NIH), the National Science Foundation (NSF), and the American Association for the Advancement of Science (AAAS).



From July 9 to 13, Vice President Lu Jianhua led a delegation to Seoul, South Korea, to attend the 28th Meeting of the China-Korea Joint Committee for Basic Scientific Research.



On July 31, the Scientific Expert Group Meeting of the NSFC International Science Program for Sustainable Development was held in Beijing. Lan Yujie, Member of the CPC Leading Group and Vice President of NSFC, attended the meeting and delivered a speech.



August

From August 15 to 23, Han Yu, Vice President and Secretary-General of NSFC, led a delegation to visit Kenya and Egypt, participating in the first "Africa-China-CIMMYT Science Forum" and visiting institutions such as the International Maize and Wheat Improvement Center (CIMMYT), the World Agroforestry Center (ICRAF), the United Nations Environment Programme (UNEP), and the Academy of Scientific Research and Technology (ASRT) in Egypt.



September

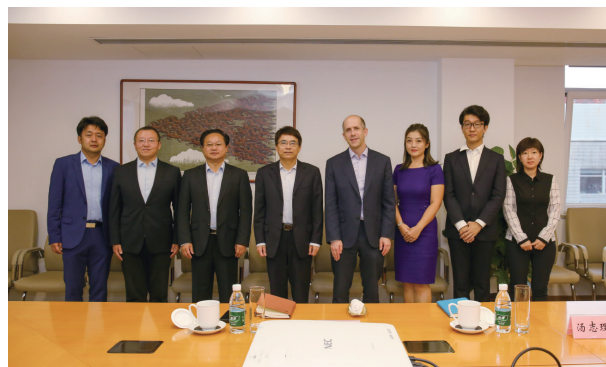
On September 9, Chinese Premier Li Qiang held talks with Spanish Prime Minister Sánchez, who was on an official visit to China, at the Great Hall of the People in Beijing. Witnessed by Premier Li Qiang and Prime Minister Sánchez, Dou Xiankang, President of NSFC, and José Manuel Albares Bueno, Minister of Foreign Affairs, European Union and Cooperation of Spain, signed a Memorandum of Understanding on cooperation between NSFC and the Spanish National Research Agency (AEI) on behalf of their respective institutions.



From September 9 to 12, Dou Xiankang, President of NSFC, led a delegation to Seoul, South Korea, to attend the 21st Chairpersons' Meeting of the Asian Research Council.



On September 20, Lan Yujie, Vice President of NSFC, met with a delegation led by Nicolas Thomas, Cultural and Educational Minister of the British Embassy in China and Director of the British Council (BC) China.



On September 25, Dou Xiankang, President of NSFC, met with a delegation led by Silvio Scerri, CEO of Science Malta.



October

On October 8, NSFC held a flag-raising ceremony to celebrate the 75th anniversary of the founding of the People's Republic of China. Dou Xiankang, Secretary of the CPC Leading Group and President of NSFC, attended the ceremony and delivered a speech, while Wang Xiqin, Member of the CPC Leading Group and Vice President of NSFC, presided over the ceremony. Over 360 participants attended, including members of the Commission's leadership team, department-level leaders, and representative cadres and staff from various departments.



On October 8, Jiang Song, Vice President of NSFC, met with a delegation led by Young-Kee Kim, President of the American Physical Society.



On October 9, Lan Yujie, Vice President of NSFC, met with Ismahane Elouafi, Executive Managing Director of the Consultative Group on International Agricultural Research (CGIAR).



On October 10, Lan Yujie, Vice President of NSFC, met with Katarzyna Zelichowska, Science Counselor of the EU Delegation to China.



From October 11 to 12, NSFC and Science Europe co-hosted the 4th China-EU Strategic Dialogue on Basic Science. Dou Xiankang, President of NSFC, and Mari Tveit, President of Science Europe, attended and delivered speeches. Jiang Song and Lan Yujie, Vice Presidents of NSFC, and Javier Fuentes, Vice President of Science Europe, also participated in the meeting.





On October 14, the Joint Cooperation Seminar between NSFC and the United Nations Environment Programme (UNEP) was held in Beijing. Lan Yujie, Vice President of NSFC, attended and delivered a speech.



On October 16, Dou Xiankang, President of NSFC, met with a senior delegation from the German Research Foundation (DFG), with Lan Yujie, Vice President of NSFC, participating in the meeting.



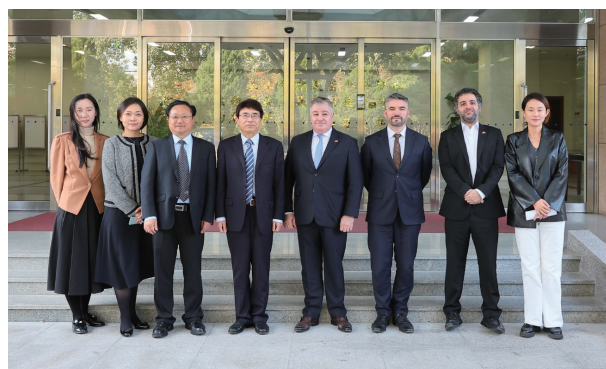
On October 18, the 27th Meeting of the China-Germany Joint Committee of the Sino-German Science Center was held in Beijing. Lan Yujie, Vice President of NSFC and Chinese Chair of the Joint Committee, attended the meeting.



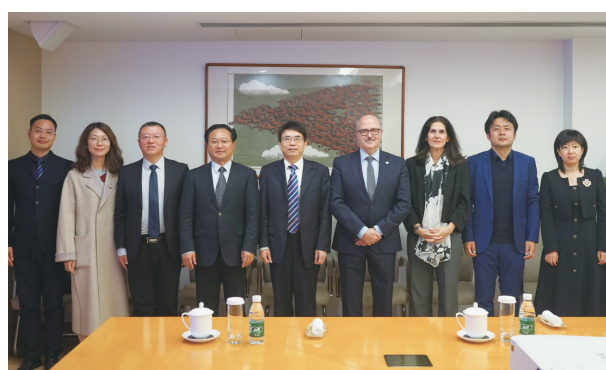
On October 21, Lan Yujie, Vice President of NSFC, met with a delegation led by Yan Zhaoji, Rector of Macao Polytechnic University.



On October 28, Lan Yujie, Vice President of NSFC, met with Sergio Valenzuela, Minister-Counselor of the Chilean Embassy in China, and his delegation.



On October 30, Lan Yujie, Vice President of NSFC, met with Domenec Espriu, Director of the Spanish National Research Agency (AEI), and his delegation.



From October 30 to November 1, the 2024 Global Research Council Asia-Pacific Regional Meeting was held in Beijing. Lan Yujie, Vice President of NSFC, attended the meeting and delivered the opening address.



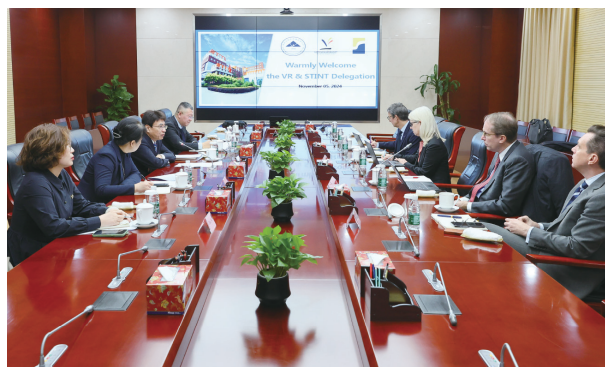
November

From November 4 to 8, Dou Xiankang, President of NSFC, led a delegation to Hong Kong for work research.





On November 5, Lan Yujie, Vice President of NSFC, met with Maria Thuvesson, Executive Director of the Swedish Research Council (VR), and Anders Göthenberg, Executive Director of the Swedish Foundation for International Cooperation in Research and Higher Education (STINT).



On November 8, Li Qiang, Premier of the State Council, signed a State Council decree to promulgate the revised Regulations on the National Natural Science Foundation of China (hereinafter referred to as the "Regulations"), which will come into effect on January 1, 2025. The Regulations consist of 7 chapters and 45 articles. The main revisions include: 1. Upholding the centralized and unified leadership of the Party Central Committee and clarifying work principles; 2. Improving the management system to adapt to new trends and requirements of scientific and technological innovation; 3. Perfecting the funding system to leverage the Foundation's role in promoting basic research; 4. Strengthening the construction of scientific research integrity systems to foster a sound innovation environment.

On November 8, Lan Yujie, Vice President of NSFC, met with Armando Rodriguez, Minister of Science, Technology and Environment of Cuba, and his delegation.



On November 18, the 11th Meeting of the Joint Leading Group for Discipline Development Strategy Research of NSFC and the Chinese Academy of Sciences (CAS) was held in Beijing. Dou Xiankang, Secretary of the CPC Leading Group and President of NSFC, and Wu Zhaohui, Deputy Secretary of the CPC Leading Group and Vice President of CAS, co-chaired the meeting and delivered speeches as leaders of the Joint Leading Group.



From November 18 to 27, Lan Yujie, Vice President of NSFC, led a delegation to attend the 2024 Autumn Council Meeting of the International Institute for Applied Systems Analysis (IIASA) and conducted working visits to Austria, Finland, and Norway.



On November 19, the Sixth Meeting of the Joint Leading Group for the "Research on the Development Strategy of China's Engineering Science and Technology for the Next 20 Years" jointly organized by NSFC and the Chinese Academy of Engineering was held. Dou Xiankang, Secretary of the CPC Leading Group and President of NSFC, and Li Xiaohong, Secretary of the CPC Leading Group and President of the Chinese Academy of Engineering, both serving as Co-Chairs of the Joint Leading Group, attended and spoke at the meeting.



On November 27, Han Yu, Vice President and Secretary-General of NSFC, met with a delegation led by Barri Weinstein, President of the Academic Research Division of Clarivate Analytics.



December

On December 2, Dou Xiankang, President of NSFC, met with a delegation led by John Schellnhuber, Director of the International Institute for Applied Systems Analysis (IIASA). Lan Yujie, Vice President of NSFC, participated in the meeting.





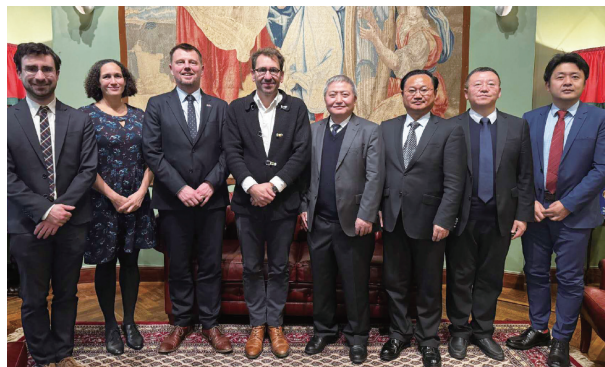
From December 2 to 6, Wang Xiqin, Vice President of NSFC, led a delegation on a working visit to Russia.



On December 3, Lan Yujie, Vice President of NSFC, met with Zheng Zhijie, Director of the Beijing Office of the Bill & Melinda Gates Foundation, and his delegation.



From December 11 to 18, Jiang Song, Vice President of NSFC, led a delegation on a working visit to Belgium and the Netherlands.



On December 23, the First Meeting of the 2nd Editorial Board of NSFC's English journal *Fundamental Research* was held in Beijing. Dou Xiankang, Secretary of the CPC Leading Group and President of NSFC, attended and spoke at the meeting, which was chaired by Han Yu, Member of the CPC Leading Group, Vice President, and Secretary-General. Han Zhiyong, Deputy Secretary-General, was also present.



On December 31, NSFC held a donation ceremony for the archival materials of Mr. Tsung-Dao Lee. Dou Xiankang, Secretary of the CPC Leading Group and President of NSFC, attended and spoke at the ceremony, which was chaired by Han Yu, Member of the CPC Leading Group, Vice President, and Secretary-General.





II. Shuangqing Forum

In 2024, the Shuangqing Forum fully implemented the spirit of the 20th CPC National Congress and its Second and Third Plenary Sessions, thoroughly implemented the important speeches of General Secretary Xi Jinping at the third collective study of the Political Bureau of the Central Committee and the National Science and Technology Conference, adhered to the "Four Orientations" and the principle of "walking on two legs," focused on cutting-edge scientific issues and major application challenges, and carefully prepared for the forum and designed its agenda. Through organizing strategic discussions among experts, it refined and proposed major scientific issues to better serve the project initiation of major NSFC programs and related national science and technology plans, and supported the forward-looking, strategic, and systematic layout of basic research.

NSFC held a total of 36 sessions of the Shuangqing Forum throughout the year (see Table 2-1), with nearly 1,700 expert participations, playing an important supporting and leading role (see Figures 2-1 and 2-2). First, it served the project initiation of major programs, currently supporting the initiation of 1 major research plan and 3 major projects, and forming a number of project initiation suggestions for major programs and special projects. Second, it strengthened the talent cultivation role of the forum, continuously increasing the proportion of young experts participating, continuing the pilot of the Shuangqing Youth Forum, inviting young student leaders of basic research projects to attend and observe, expanding the strategic vision of young talents, and stimulating innovative thinking. Third, it innovated the organization model of discussions, widely inviting interdisciplinary experts, industry enterprises, and experts from relevant management departments to participate, promoting interdisciplinary integration and interaction across the entire innovation chain; inviting experts from the Advisory Committee to attend, smoothing the path from strategic discussions to advisory suggestions. Fourth, it established a good forum style, using multiple measures to create a free and equal academic exchange atmosphere. Fifth, it deepened cooperation with local governments in jointly organizing scientific issue discussions and high-quality project initiation, launching the Shuangqing-Nan'ao Youth Science Forum to support the project initiation of regional joint funds and related programs, and enhancing the funding efficiency of NSFC and its joint funds.

In 2024, the collaborative achievement promotion mechanism between publications of NSFC, such as China Science Fund and Fundamental Research and other publications such as National Science Review, Science Bulletin, and Science China was continuously deepened to strengthen the leading role in the scientific and technological community. Fundamental Research published 4 special issues with a total of 33 articles, and China Science Fund published 6 special issues with a total of 58 articles, significantly improving the quality of forum discussion achievements and promotion effects. At the same time, the forum actively provided suggestions and submitted "Two Reports and One Reference" (briefings, special information reports, and internal references) to the central government based on discussion results, continuously playing a reference role in national science and technology policy decision-making.



Figure 2-1: "Financial Services for Scientific and Technological Innovation and High-Quality Economic Development"



Figure 2-2: "Shuangqing Forum on the Search for Extraterrestrial Life and Evolution of Habitable Environments"

Table 2-1 Catalog of Shuangqing Forum Themes in 2024

No. 362: Fundamental Scientific Issues in Modern Green Canal Construction and Operation Maintenance (March 28–29, 2024)	No. 380: Frontiers in Chemistry and Biomedical Cross-Disciplines of Multicellular Complex Systems (October 22–24, 2024)
No. 363: Efficient Material Conversion Beyond Biological Evolution (March 28–29, 2024)	No. 381: Frontiers and Development of Transient Extreme Diagnosis Technology (October 24–25, 2024)
No. 364: Economic Growth Theory and Macro Policy Optimization (March 29–30, 2024)	No. 382: New Paradigms for Basic Research on Chinese Herbal Compound Formulas (October 24–25, 2024)
No. 365: Integration and Analysis of Life Visualization (April 2–3, 2024)	No. 383: Multi-Sphere Interactions in East Asia–West Pacific and Deep Oil, Natural Gas, and Hydrogen Resources (October 25–26, 2024)
No. 366: Key Scientific Issues in Global Ocean Governance and Cooperation (April 2–3, 2024)	No. 384: Future Mobile Information Networks (October 30–31, 2024)
No. 367: Financial Services for Scientific and Technological Innovation and High-Quality Economic Development (April 15–16, 2024)	No. 385: Opportunities and Challenges in Microgravity Science and Technology (November 16–17, 2024)
No. 368: Data-Driven Hospital Operations and Policy Coordination (April 20–21, 2024)	No. 386: Scientific Foundations for Zero-Carbon Energy System Reconstruction and Low-Carbon Industrial Reengineering (November 18–19, 2024)
No. 369: Cross-Scale Life Measurement from an RNA Perspective (July 10–11, 2024)	No. 387: Molecular Regulatory Mechanisms of Phenotypic Plasticity and Trait Stability (November 18–19, 2024)
No. 370: Fundamental Scientific Issues and Countermeasures for High-Quality Development of Forestry in Arid Regions (August 12–13, 2024)	No. 388: Key Scientific Issues and Technical Bottlenecks in Applications of Organic Optoelectronic Materials (November 18–19, 2024)
No. 371: Basic Mechanisms and Core Technologies of Intelligent Computing Networks (August 16–17, 2024)	No. 389: Key Fundamental Scientific Issues in Low-Carbon Transformation of Chemical Metallurgy (November 25–26, 2024)
No. 372: Water at the Molecular and Nanoscale (August 19–20, 2024)	No. 390: Basic Theories and Key Technologies of New Power Systems for the "Double Carbon" Goals (November 28–29, 2024)
No. 373: New Paradigms for Oncology Research Driven by Clinical Issues (August 22–23, 2024)	No. 391: Future-Oriented Intelligent Materials and Materials Science (December 1–2, 2024)
No. 374: Material Science Cognition Based on Spectroscopic Large Models (August 31–September 1, 2024)	No. 392: Multidisciplinary In-Situ Observation Technology System and Seismogenic Mechanism of Continental Very-Shallow Source Earthquakes (December 5–6, 2024)
No. 375: Scientific Foundations and Countermeasures for Stress and Mental Illnesses (September 6–7, 2024)	No. 393: New Integration Paths and Technologies Beyond the Moore's Law Era (December 9, 2024)
No. 376: Major Chronic Diseases and Autonomic Nerve Regulation (September 20–21, 2024)	No. 394: Future-Oriented Crop Breeding: Scientific Issues and Key Technologies (Youth Forum) (December 5–6, 2024)
No. 377: Search for Extraterrestrial Life and Evolution of Habitable Environments (October 17–18, 2024)	No. 395: Fundamental Scientific Issues and Countermeasures for Systemic Ecological and Environmental Risk Control (December 12–13, 2024)
No. 378: Key Frontier Fundamental Scientific Issues in High-Toughness, Long-Life, Intelligent, and Green Road and Bridge Engineering (October 18–19, 2024)	No. 396: Funding Management of Applied Basic Research: General Offices and Preemptive Moves (December 16–17, 2024)
No. 379: Basic Theories and Key Technologies of Artificial Intelligence Empowering the Manufacturing Industry "Industrial Brain" (October 22, 2024)	No. 397: High-Temperature Superconducting Materials and Mechanisms (1st Shuangqing-Nan'ao Youth Science Forum) (December 21–22, 2024)



III. NSFC Policy Files

According to the Regulations of the National Natural Science Foundation, as of December 31, 2024 a total of 37 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.



IV. NSFC funding statistics for National S&T Awardees in 2023

In 2023, the National Natural Science Awards included 1 first prize and 48 second prizes, with all winners having been supported by NSFC at different levels.

Table 2-2 Statistics of the first prize winner of the National Natural Science Award receiving NSFC support

	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
1	Computational Prediction of Topological Electronic Materials	Fang Zhong (Institute of Physics, CAS) Dai Xi (Institute of Physics, CAS) Wen Hongming (Institute of Physics, CAS) Yu Rui (Institute of Physics, CAS) Wang Zhijun (Institute of Physics, CAS)	- Computational and Theoretical Studies of Novel Quantum Phenomena in Condensed Matter - First-Principles Computational Materials Design and Theoretical Investigations of Fundamental Physics in Transition Metal Oxides	22

Table 2-3 Statistics of the second prize winner of the National Natural Science Award receiving NSFC support

	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
1	Finite Coverings of 3-Manifolds	Liu Yi (Peking University)	- Topology and Geometry of 3-Manifolds - Profinite Rigidity Problems in the Geometry of Some 4-Manifolds	2
2	L(1/2) Theory and Adaptive Regularization Methods for Weakly Observed Imaging Inverse Problems	Xu Zongben (Xi'an Jiaotong University) Sun Jian (Xi'an Jiaotong University) Meng Deyu (Xi'an Jiaotong University) Yang Yan (Xi'an Jiaotong University)	- Fundamental Algorithms and Programming Support Environment for Big Data Analysis and Processing Based on Supercomputing - National Tianyuan Fund for Mathematics for Northwest Center	20
3	Variation of Numerical Geometric Invariants under Birational Transformations	Hu Jianxun (Sun Yat-sen University) Li Weiping (The Hong Kong University of Science and Technology)	- Symplectic Topology and Mathematical Physics - Studies on Moduli Spaces and Related Geometric Invariants	8
4	Catenary Optics	Luo Xiangang (Institute of Optics And Electronics, CAS) Pu Mingbo (Institute of Optics And Electronics, CAS) Li Xiong (Institute of Optics And Electronics, CAS) Ma Xiaoliang (Institute of Optics And Electronics, CAS) Guo Yinghui (Institute of Optics And Electronics, CAS)	- Far-Field Imaging and Lithography Beyond the Diffraction Limit via Electromagnetic Waves - Maskless Parallel Nano-Writing Technology Based on Surface Plasmons	16



(continued)

	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
5	Discovery of the "Four-Quark Matter" Zc(3900)	Yuan Changzheng (Institute of High Energy Physics, CAS) Zhu Kejun (Institute of High Energy Physics, CAS) Liu Zhiqing (Institute of High Energy Physics, CAS) Li Weidong (Institute of High Energy Physics, CAS) Ping Ronggang (Institute of High Energy Physics, CAS)	- Joint Theoretical and Experimental Exploration of Exotic Hadron Structures - Collaborative Theoretical and Experimental Research on Multi-Quark Hadronic States	19
6	Research on Superconducting Mechanisms in Iron-Based and Nickel-Based Materials	Wen Haihu (Nanjing University) Yang Huan (Nanjing University) Zhu Xiyu (Nanjing University) Wang Zhenyu (Nanjing University) Du Zengyi (Nanjing University)	- Study of Material Properties in Unconventional Electronic States - Investigations of Spin-Charge-Orbital Coupling and Exotic Electronic States in Doped Mott Insulators	22
7	Ferroelectric-Chemical Design of Molecular Piezoelectrics	Xiong Rengen (Southeast University) You Yumeng (Southeast University) Liao Weiqiang (Nanchang University) Tang Yuanyuan (Nanchang University) Ye Hengyun (Southeast University)	- ABX₃-Type Perovskite-Structured Molecular Ferroelectrics - Studies on Molecular-Based Ferroelectrics with High Piezoelectricity	28
8	Carbon Nitride Photocatalysis	Wang Xinchun (Fuzhou University) Zhang Jinshui (Fuzhou University) Yu Zhiyang (Fuzhou University) Zhang Guigang (Fuzhou University) Fu Xianzhi (Fuzhou University)	- Multiscale Microstructural Modulation for C₃N₄-Based Photocatalyst Development and Photocatalytic Air Purification Applications - Carbon Nitride-Based Photocatalysts for High-Efficiency Overall Water Splitting toward Hydrogen Production and Surface/Interface Kinetic Regulation	16
9	Low-Temperature Activation of Water and Hydrogen Production Process on Molybdenum Carbide Catalysts	Ma Ding (Peking University) Lin Lili (Peking University) Shi Chuan (Dalian University of Technology) Zhou Wu (University of Chinese Academy of Sciences) Zhang Xiao (Dalian University of Technology)	- Construction and Investigation of Molybdenum Carbide-Based Catalysts for Low-Temperature Water-Gas Shift via Strong Metal-Support Interaction - Electron Microscopy Studies on Defect Physics in Two-Dimensional Materials	23
10	Research on the Construction and Functional Modulation of Polymeric Drug Delivery Carriers	Shen Youqing (Zhejiang University) Gu Zhen (Zhejiang University) Zhou Zhuxian (Zhejiang University) Tang Jianbin (Zhejiang University) Shao Shiqun (Zhejiang University)	- Design of Non-Cytotoxic, High-Efficiency Antitumor Polymers Targeting the Tumor Microenvironment - Polymeric Drug Carrier Materials	16
11	Discovery and Development of Bimetallic Organic Reagents	Xi Zhenfeng (Peking University) Zhang Wenxiong (Peking University) Wei Junnian (Peking University) Song Qiuling (Peking University)	- Metal-Promoted Selective Cleavage and Applications of Inert Chemical Bonds - Novel Synthetic Reactions and Methods Based on Selective Cleavage of Carbonyl C=O Bonds	30

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	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
12	Research on Asymmetric Catalytic Methodologies Based on Angular Modulation and Synergistic Promotion Strategies	Zhang Wanbin (Shanghai Jiao Tong University) Zhang Zhenfeng (Shanghai Jiao Tong University) Huo Xiaohong (Shanghai Jiao Tong University) Chen Jianzhong (Shanghai Jiao Tong University) Yuan Qianjia (Shanghai Jiao Tong University)	- Study of Novel Asymmetric Catalytic Reactions via Bimetallic Synergistic Catalytic Systems - Investigations into Pd-Catalyzed Allylic Substitution Reactions of Allylamines and Ether Compounds Enabled by Hydrogen Bond Activation	16
13	Synthesis and Properties of One-Dimensional Subnanometer-Scale Materials	Wang Xun (Tsinghua University) Hu Shi (Tsinghua University) Liu Junli (Tsinghua University) Xu Xiangxing (Tsinghua University) Li Haoyi (Tsinghua University)	- Exploration of Polymer-Like Properties in Inorganic Subnanometer-Scale Materials - Aggregation State Modulation of Subnanometer-Scale Substances and Construction of Functional Systems	18
14	Biological and Environmental Evolution during the Critical Transition of Pangaea	Shen Shuzhong (Nanjing University) Fan Junxuan (Nanjing University) Zhang Feifei (Nanjing University) Zhang Hua (Nanjing Institute of Geology and Palaeontology, CAS) Zhang Yichun (Nanjing Institute of Geology and Palaeontology, CAS)	- Biological and Environmental Evolutionary Processes in the Eastern Tethys during the Late Paleozoic - Comparative Study of Permian Biostratigraphy and Paleobiogeography between the Russian Urals and the South China Region	30
15	Driving Factors and Environmental Health Effects of Atmospheric Composition Changes in China	Zhang Qiang (Tsinghua University) He Kebin (Tsinghua University) Liu Jun (Peking University) Zheng Bo (Tsinghua University) Zhu Tong (Peking University)	- Research on High Spatiotemporal Resolution Motor Vehicle Emission Inventory for Air Quality Modeling - International Institute for Applied Systems Analysis (IIASA) Young Scientists Summer Program	44
16	Continental Collision, Subduction, and Deep Geospheric Interactions in the Tibetan Plateau	Ding Lin (Institute of Tibetan Plateau Research, CAS) Zhao Junmeng (Institute of Tibetan Plateau Research, CAS) Cai Fulong (Institute of Tibetan Plateau Research, CAS) Bai Ling (Institute of Tibetan Plateau Research, CAS) Wang Houqi (Institute of Tibetan Plateau Research, CAS)	- Normal Faulting and Basin Formation in Southern Tibetan Plateau, Paleo-Elevation Changes, and Plateau Evolution - Academic Symposium on Tethyan Continental Convergence and Plateau Uplift	18
17	Novel Nonlinear Theories and Innovative Techniques for Reducing Forecast Uncertainty of High-Impact Air-Sea Events	Mu Mu (Institute of Atmospheric Physics, CAS) Duan Wansuo (Institute of Atmospheric Physics, CAS)	- Research on the Application of the Conditional Nonlinear Optimal Perturbation Method in Targeted Observations for Typhoons - Impact of the Arctic Sea-Ice-Atmosphere System on the Predictability of Extreme Winter Weather Events over Eurasia	10



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	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
18	Biotic and Abiotic Processes of Terrestrial Carbon Sequestration and Environmental Response Mechanisms	Yan Junhua (South China Botanical Garden, CAS) Yu Guirui (Institute of Geographic Sciences and Natural Resources Research, CAS) Tang Xuli (South China Botanical Garden, CAS) Zhang Deqiang (South China Botanical Garden, CAS) Zhang Leiming (Institute of Geographic Sciences and Natural Resources Research, CAS)	• Terrestrial Processes and Environmental Change • Mechanisms Underlying the Sustained Buffering of Acid Rain and Organic Carbon Accumulation in Deeply Acidified Forest Soils	26
19	Mechanisms Underlying the Formation and Dissemination of Antibiotic Resistance Genes in the Environment	Zhu Yongguan (Institute of Urban Environment, CAS) Su Jianqiang (Institute of Urban Environment, CAS) Qiao Min (Research Center for Eco-Environmental Sciences, CAS) Chen Qinglin (Institute of Urban Environment, CAS) An Xinli (Institute of Urban Environment, CAS)	• Microbial Ecological Mechanisms of Carbon, Nitrogen, and Iron Coupling Processes in Typical Paddy Soils • Key Biogeochemical Processes and Environmental Functions in Typical Paddy Soils	31
20	Neural Mechanisms Underlying Depression Induced by Negative Emotion and Social Competition	Hu Hailan (Zhejiang University) Li Kun (Center for Excellence in Brain Science and Intelligence Technology, CAS) Cui Yihui (Zhejiang University) Wang Fei (Center for Excellence in Brain Science and Intelligence Technology, CAS) Yang Yan (Zhejiang University)	• Role and Mechanisms of Lateral Habenula Glial Cells in Depression • Mechanistic Insights into the Habenula's Role in Depression: A Multilevel Investigation Spanning Molecular, Cellular, Neural Network, and Behavioral Perspectives	11
21	Biogenesis and Functional Mechanisms of Circular RNAs (circRNAs)	Chen Lingling (CAS Center for Excellence in Molecular Cell Science) Yang Li (Shanghai Institute of Nutrition and Health, CAS) Liu Chuxiao (CAS Center for Excellence in Molecular Cell Science) Zhang Yang (CAS Center for Excellence in Molecular Cell Science) Shen Nan (Shanghai Jiao Tong University School of Medicine, Renji Hospital)	• Processing, Maturation Mechanisms, and Functional Studies of a Class of Intron-Derived Long Non-Coding RNAs (lncRNAs) • Non-Polyadenylated RNAs; Long Non-Coding RNAs (lncRNAs); Intron-Derived Long Non-Coding RNAs	26
22	Epigenetic Regulatory Mechanisms of Cell Fate Stability and Plasticity	Zhu Bing (Institute of Biophysics, CAS) Li Yingfeng (Institute of Biophysics, CAS) Xu Mo (National Institute of Biological Sciences) Zhang Zhuqiang (Institute of Biophysics, CAS) Yuan Wen (National Institute of Biological Sciences)	• Identification of 5-Hydroxymethylcytosine-Binding Proteins and Their Regulatory Roles in DNA Demethylation and Somatic Reprogramming • Activity Regulation of Chromatin-Modifying Enzymes and Their Control of Chromatin Structure and Target Gene Expression	14

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	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
23	Triggering Mechanisms of T Cell Immunity	Xu Chenqi (CAS Center for Excellence in Molecular Cell Science) Yang Wei (CAS Center for Excellence in Molecular Cell Science) Shi Xiaoshan (CAS Center for Excellence in Molecular Cell Science) Wu Wei (CAS Center for Excellence in Molecular Cell Science) Li Boliang (CAS Center for Excellence in Molecular Cell Science)	- Regulatory Mechanisms of the Plasma Membrane on Phosphorylation of Membrane Protein Receptors - Mechanisms of T Cell Antigen Receptor Activation	23
24	Structure and Function Studies of Eukaryotic Photosynthetic Membrane Proteins	Kuang Tingyun (Institute of Botany, CAS) Sui Senfang (Tsinghua University) Wang Wenda (Institute of Botany, CAS) Han Guangye (Institute of Botany, CAS) Qin Xiaochun (Institute of Botany, CAS)	- Structural Basis of Photosynthetic Primary Reactions and Their Regulation and Control - Two-Dimensional Crystalline Assembly and Preliminary Structural Analysis of Eukaryotic Ribosomes on Lipid Monolayers	34
25	Discovery of transferable polymyxin resistance gene mcr and its transmission mechanism	Shen Jianzhong (China Agricultural University) Liu Jianhua (South China Agricultural University) Wang Yang (China Agricultural University) Zhang Rong (Zhejiang University) Shen Zhangqi (China Agricultural University)	- Study on the production mechanism and adaptability of carbapenem antibiotic-resistant Escherichia coli from chicken - Study on the spread of pan-drug-resistant Enterobacteriaceae among animals, food/environment and humans and its influence	28
26	A Genomic Study of Ruminant Evolution	Wang Wen (Northwestern Polytechnical University) Jiang Yu (Northwest A&F University) Qiu Qiang (Northwestern Polytechnical University) Li Zhipeng (Institute of Specialty Products, CAS) Chen Lei (Northwestern Polytechnical University)	- Roles and mechanisms of new genetic elements in the evolution of ruminants and their unique traits - Identification and fine annotation of functional elements of the ruminant genome	24
27	Molecular basis and intervention strategies of inflammatory-cancerous transformation and precancerous lesions	Li Mengfeng (Southern Medical University) Yin Yuxin (Peking University) Zhou Weijie (Southern Medical University) Xia Laixin (Southern Medical University) Cai Junchao (Sun Yat-sen University)	- Dengue Fever Tetravalent Virus-like Particle Vaccine and Its Immune Mechanism - Molecular mechanism of early breast cancer metastasis induced by proto-oncogene AEG-1	26
28	Study on epigenetic regulation mechanism and intergenerational transmission law of human reproductive development	Qiao Jie (Peking University Third Hospital) Tang Fuchou (Peking University) Yan Liying (Peking University Third Hospital) Yan Jie (Peking University Third Hospital) Li Rong (Peking University Third Hospital)	- Gynecologic Endocrinology: Applying Metabolomics to Study Polycystic Ovary Syndrome - Study on LHR and EGFR signaling pathways in follicular development disorders in polycystic ovary syndrome	33



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	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
29	Original discovery, function and application of extracellular small RNA	Zhang Chenyu (Nanjing University) Ba Yi (Cancer Hospital of Tianjin Medical University) Zhang Junfeng (Nanjing University) Zeng Ke (Nanjing University) Chen Xi (Nanjing University)	- Chemical biology study of decoupling protein 2-mediated signal transduction pathway using small chemical molecules - Regulation of metabolic nuclear receptors on cellular energy metabolism under mitochondrial and endoplasmic reticulum stress	34
30	Molecular mechanism and targeted intervention of Epstein-Barr virus carcinogenesis	Zeng Musheng (Sun Yat-sen University Cancer Center) LIU, QUENTIN QIANG (Sun Yat-sen University Cancer Prevention Center) Bei Jinxin (Sun Yat-sen University Cancer Center) Xu Miao (Sun Yat-sen University Cancer Center) Bai Fan (Peking University)	- Mechanisms of epigenetic regulation of cell programming and reprogramming by polycomb protein Bmi-1-induced EMT - Genomic analysis of oncogenic virus-associated head and neck tumors in US and Chinese populations	40
31	New subsets of immune cells and their regulatory mechanisms	Wu Yuzhang (Army Medical University) Ye Lili (Army Medical University) Liu Xindong (Army Medical University) Zhu Bo (Army Medical University) Xu Lifan (Army Medical University)	- Liver regulation mechanism of formation and maintenance of immune pool in HBV infection - Key factors affecting the effect intensity of coronavirus broad-spectrum nasal spray vaccine and its mechanism	32
32	New function and mechanism of growth factor FGFs in regulating glucose and lipid metabolism	Li Xiaokun (Wenzhou Medical University) Xu Aimin (University of Hong Kong) Huang Zhifeng (Wenzhou Medical University) Lin Zhuofeng (Wenzhou Medical University) Li Huating (Shanghai Sixth People's Hospital)	- Prevention of diabetic cardiomyopathy by non-mitotic fibroblast growth factor mutant and its mechanism - Effects of pancreatic FGF21 on systemic metabolism and islet cell function and its molecular mechanism	20
33	Channel Characteristics and Transmission Theory of High-speed Mobile Complex Scene	Ai Bo (Beijing Jiaotong University) SHUGUANG CUI [Chinese University of Hong Kong (Shenzhen)] Zhong Zhangdui (Beijing Jiaotong University) He Ruisi (Beijing Jiaotong University) Zhang Jiayi (Beijing Jiaotong University)	- Theory and Technology of Broadband Mobile Communication for High-speed Railway - Research on the Theory and Key Technologies of New Generation Mobile Communication for Typical Scenario Services and Applications of High-speed Railway	17
34	Research on Theoretical Methods of High Spatial Resolution Hyperspectral Imaging and Recognition	Li Shutao (Hunan University) Dian Renwei (Hunan University) Kang Xudong (Hunan University) Fang Leyuan (Hunan University) Lu Ting (Hunan University)	- Information acquisition and processing of high-resolution hyperspectral remote sensing images - Research on Unmixing, Reconstruction, Fusion and Enhancement Methods of Multi-dimensional High Resolution Images	18

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	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
35	Visual Computing Theory and Method of Multivariate Collaboration	Jiang Yugang (Fudan University) Wu Zuxuan (Fudan University) Xue Xiangyang (Fudan University) Fu Yanwei (Fudan University) Qian Xuelin (Fudan University)	• Video Content Recognition and Retrieval • Research on Video Content Generation and Identification	17
36	Optical FIB effect	Sun Hongbo (Jilin University) Chloe Wang (Jilin University) Li Zhenzhen (Tsinghua University) Han Dongdong (Jilin University) Chen Qidai (Jilin University)	• Fundamental Research on the Application of Femtosecond Laser Micro-Nano Machining in the Manufacturing of High Performance Micro-Optical Components • Development of high-speed turntable femtosecond laser nano direct writing device	12
37	Theory and Method of Relationship Representation Learning of Cross-Media Big Data Graph	Zhu Wenwu (Tsinghua University) Cui Peng (Tsinghua University) Wang Xiao (Tsinghua University) Wang Xin (Tsinghua University) Zhang Ziwei (Tsinghua University)	• Efficient expression, in-depth analysis and comprehensive utilization of video big data • Multi-source heterogeneous information mapping	16
38	Regulation and Device Design of Order Parameters of Ferric Materials	Lin Yuanhua (Tsinghua University) Nan Cewen (Tsinghua University) Pan Hao (Tsinghua University) Ma Ji (Tsinghua University) Hu Jiamian (Tsinghua University)	• Preparation of ferrous NiO/ZnO-based heterogeneous thin films and their magnetic, electrical and optical modulation • Synthesis of porous BiFeO₃ thin films and regulation of photocatalytic properties by external field	29
39	Microscopic origin and evolution mechanism of deformation and damage of metal materials	Shan Zhiwei (Xi'an Jiaotong University) Liu Boyu (Xi'an Jiaotong University) Xie Degang (Xi'an Jiaotong University) Tian Lin (Xi'an Jiaotong University) Wang Zhangjie (Xi'an Jiaotong University)	• Structure and properties of micro-and nano-scale materials • Study on Deformation Characteristics and Mechanism of Micro-nano Scale Structural Materials under Multi-field Coupling Conditions	14
40	Creation, Preparation and Physical Properties of New Two-dimensional Materials	Ren Wencai (Institute of Metals, CAS) Cheng Huiming (Institute of Metals, CAS) Xu Chuan (Institute of Metals, CAS) Hong Yilun (Institute of Metals, CAS) Gao Yang (Institute of Metals, CAS)	• Controlled Preparation and Physical Properties of Graphene Three-Dimensional Network Macrovolumes • Controlled preparation method of two-dimensional atomic crystal materials and exploration of their functional application	28



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	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
41	A new method of magnetic enhancement of thermoelectric properties and a new effect of thermo-electromagnetic coupling	Zhao Wenyu (Wuhan University of Technology) Wei Ping (Wuhan University of Technology) Liu Zhiyuan (Wuhan University of Technology) Zhu Wanting (Wuhan University of Technology) Zhang Qingjie (Wuhan University of Technology)	- Basic research on solar thermoelectric-photovoltaic composite power generation technology and its key materials - Electrothermal synergistic transport effect and mechanism of indium-doped skutterudite-based thermoelectric materials	25
42	Microstructure regulation and strengthening and toughening mechanism of high entropy alloys	Lu Zhaoping (University of Science and Technology Beijing) Liu Xiongjun (University of Science and Technology Beijing) Zhang Yong (University of Science and Technology Beijing) Wu Yuan (University of Science and Technology Beijing) Jiang Suihe (University of Science and Technology Beijing)	- Formation mechanism and dynamic deformation behavior of large-size phase transformation tough plasticized amorphous composites - Effect of oxygen impurities on atomic clusters and properties of soft magnetic amorphous alloys	26
43	Study on High Mobility Organic Semiconductor Materials and Devices	Hu Wenping (Tianjin University) Dong Huanli (Institute of Chemistry, CAS) Geng Yanhou (Changchun Institute of Applied Chemistry, CAS) Wang Shirong (Tianjin University) Zhang Xiaotao (Tianjin University)	- Research on Key Scientific Issues of Organic Field Effect Transistor Materials and Devices - Synthesis of Several Pentacene Analogs, Preparation and Properties of Single Crystal Micro-Nano Materials	32
44	PM2.5 generation and regulation in coal/biomass combustion process	Xu Minghou (Huazhong University of Science and Technology) Yao Hong (Huazhong University of Science and Technology) Yu Dunxi (Huazhong University of Science and Technology) Liu Xiaowei (Huazhong University of Science and Technology) Sheng Changdong (Southeast University)	- Study on leaching characteristics of trace heavy metals in coal ash of typical western coal-fired power station boilers - Generation and synergistic control of various pollutants in coal burning under oxygen/fuel combustion mode	36
45	Theory and method of extreme event defense and recovery in power system	Bie Chaohong (Xi'an Jiaotong University) Li Gengfeng (Xi'an Jiaotong University) Ding Tao (Xi'an Jiaotong University) Shao Chengcheng (Xi'an Jiaotong University) Wang Xifan (Xi'an Jiaotong University)	- Research on assessment and improvement strategies of Shanxi Power Grid's new energy consumption capacity considering the coordinated operation of wind, solar, thermal and storage - Theory and Method of Intelligent Planning of New Power System for Resilience Improvement	23
46	Unified Hardening Constitutive Theory of Soil	Yao Yangping (Beihang University) Sun De'an (Shanghai University) Zhou Annan (Beihang University) Lu Dechun (Beihang University) Hou Wei (Beihang University)	- Elasto-viscoplastic constitutive relation of overconsolidated soil - Study on Constitutive Relation of Soil Considering Small Strain Characteristics	25

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	Project Name	Awardees	Main project names supported by NSFC	No. of NSFC Grants
47	Theory and method of rock fracture under combined dynamic and static loading	Li Xibing (Central South University) Dong Longjun (Central South University) Zhou Zilong (Central South University) Gong Fengqiang (Central South University) Du Kun (Central South University)	• Rock fracture characteristics and energy loss under dynamic and static combined load coupling • Experimental study on dynamic constitutive relationship and cumulative damage of rock in middle strain rate section	33
48	Hydrovoltaic effect based on mechanical and electrical coupling at solid-liquid interface	Guo Wanlin (Nanjing University of Aeronautics and Astronautics) Yin Jun (Nanjing University of Aeronautics and Astronautics) Zhang Zhuhua (Nanjing University of Aeronautics and Astronautics) Qiu Hu (Nanjing University of Aeronautics and Astronautics) Li Xuemei (Nanjing University of Aeronautics and Astronautics)	• Physical and mechanical study on structural force-electromagnetic coupling and device principle of low-dimensional functional materials • Structure-function correlation and selective ion conduction mechanism of sodium and potassium ion channels	28

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