# NATIONAL NATURAL SCIENCE FOUNDATION OF CHINA

# 2023 ANNUAL REPORT

# FOREWORD

In 2023, the National Natural Science Foundation of China (hereinafter referred to as NSFC) launched the campaign of for studying Xi Jinping Thought on Socialism with Chinese Characteristics for a New Era, comprehensively implemented the spirits of the 20th CPC National Congress and its second plenary session, and thoroughly put President Xi's important speech at the 3rd group study session of the Political Bureau of CPC Central Committee 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 grasped the strategic plan of promoting the integration of education, science & technology, and talents, adhered to the "four aspects", took a dual-track approach to support both goal-oriented and free exploration basic research, conscientiously implemented the institutional reform, put original innovation and talent cultivation in a prominent position, and completed the funding management of 2023.

NSFC emphasized the forward-looking, strategic and systematic plan for basic research, so as to lay a solid foundation for self-reliance in science and technology. In 2023, we continued to formulate and implement annual funding plan scientifically, received 318,000 proposals from 2404 host institutions, and approved 52,500 awards with a funding amount of 31.879 billion yuan. We encouraged free exploration and emphasized original innovation, by approving 20,321 awards for General Program and 156 awards for Original Exploratory Program. Focusing on the strategic research on "four aspects", we launched 3 Major Research Plans including "Scientific Basis of cutting-edge technology of integrated chips", approved 751 awards for Key Program, 67 awards for Special Fund for Research on National Major Research Instruments, and planned for 53 projects for Major Program. We continued to expand the scope of Joint Funds. Jiangsu and Jiangxi Provinces, and Ningbo City joined the Joint Fund for Regional Innovation and Development, making it a total of 29 provinces (autonomous regions and cities) and 12 state-owned enterprises joining the Joint Fund for Regional/Corporate Innovation and Development. Ten Joint Funds have also been established with 9 industry sectors. A total of 1,160 awards for Programs of Joint Funds were granted. In 2023, the amount of fund attracted from outside NSFC was the equivalent of 8.66% of state financial input into NSFC. We also achieved a breakthrough in accepting donation from the society by receiving 100 million yuan from Xiaomi Foundation.

NSFC focused on the cultivation of young talents in order to build an elite cadre of scientists for basic research. We gave young researchers stronger support by approving 22,879 awards for Young Scientists Fund with a year-on-year increase of 617 awards and continuing the funding for Excellent Young Scientists Fund (Overseas). We supported middle-aged and young scientists to undertake major types of programs, and invited excellent young scientists to participate in the peer review process. We funded 129 undergraduate students as a pilot funding program. As a result of optimizing funding policy, postdoctoral researchers were no longer restricted from changing their host institutions when they undertook projects of General Program, Young Scientists Fund or Fund for Less Developed Regions. The *Scheme for post-evaluation and continued* *funding of grantees of National Science Fund for Distinguished Young Scholars* was formulated, so as to build a long-term and stable funding mechanism for outstanding talents. We also optimized the operating mechanism for Basic Research Center Program to ensure the S&T resources would be allocated to the most innovative.

NSFC thoroughly implemented the institutional reform based on the decision of the CPC Central Committee. We orderly carried out the transfer of institutions and staff, by establishing a leading group headed by the President of NSFC, formulating working plan, and organizing visits and research, to ensure smooth transfer in the aspects of administrative operation, integration of funding, financial management and network system. We advanced the innovation of funding pattern and mechanism for applied basic research, and strengthened the advisory system by revising *NSFC Advisory Committee Regulations* and *the Working Method of NSFC Science Departments Advisory Committees*. We also enhanced the capabilities to refine use-inspired scientific problems by strengthening collaborations with Chinese Academy of Sciences and Chinese Academy of Engineering, emphasizing the role of "Shuangqing Forum" in strategic research, and building platforms for interdisciplinary and trandisciplinary discussions. According to the concepts of "one goal, four platforms", the Administrative Center for China's Agenda 21 managed the National Key R&D Program and funded 630 projects. High-tech R&D Center expedited the progress of building one platform with two focuses, managed S&T Innovation 2030—Major Program and funded 746 projects.

NSFC deepened the reform of science funding system to elevate funding performance. NSFC carried out the 14$^{th}$ Five-Year Plan, with three major tasks well underway. Category-specific review was adopted for over 260,000 proposals, accounting for 85% of the total proposals. The pilot of "RCC" evaluation mechanism was expanded to 94% of the disciplines. The application codes were further adjusted and evaluated. We expedited the revision of *NSFC Regulations* to achieve the rule of law in science funding management. A joint limit was imposed on researchers leading or participating in NSFC major types of program and other national major S&T programs. Funding performance evaluation was continued in order to identify the weak link in program management and find solutions. We strengthened the capacity building of science popularization, formulated and published *the Opinions of the NSFC on Strengthening Science Popularization in the New Era*. We also built and improved the platforms for open access and results translation, to promote data sharing of NSFC-funded research, and carried out matchmaking activities with Beijing and Chongqing municipalities to promote the transformation of funding results.

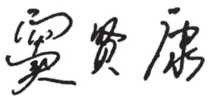
NSFC deepened international cooperation in scientific research and promoted the establishment of international cooperation platforms for basic research. We established the Department of International Programs, and formulated "the proposed plan for Global Science Fund operation". We promoted the pilot program of the Global Science Fund, and funded 277 projects for Research Fund for International Scientists. And we also jointly funded 654 projects for International (Regional) Cooperation and Exchange Programs with partner agencies in countries including the United States and Germany, as well as Hong Kong and Macau, including 40 scientific projects for Sustainable Development International Cooperation Program.

NSFC implemented the special rectification of "string-pulling" in the process of peer review to improve the ecosystem of scientific research. Following the principle of "positive guidance, strict laws and disciplines, extreme defense, and serious punishment", we contained "string-pulling" by optimizing the process of peer review, increasing the proportion of peers from a wider academic background, strengthening confidentiality and issuing list of prohibited acts. NSFC established a scientific research integrity system that integrates "education, motivation, regulation, supervision, and discipline", revised the *Constitution of NSFC Supervisory Committee* and *NSFC Measures for Investigation and Punishment of Research Misconducts*, and issued the *Handbook for Scientific Integrity Practices*. We seriously investigated and punished scientific research misconducts, 311 people and 6 host institutions involved in 199 cases were disciplined, of which 27 people and 1 host institution were involved in the "string-pulling".

NSFC thoroughly implemented the spirits of the $20^{th}$ National Congress of CPC, and used it as guidance to the daily operation of NSFC. We systematically carried out the work of rigorous self-governance, upholding integrity and anti-corruption. NSFC consciously accepted the supervision by the representative office of the CPC Commission of Discipline Inspection and National Supervisory Commission to the Ministry of Science and Technology, and seriously implemented the supervisory recommendations. We also developed a regular auditing mechanism together with National Audit Office to ensure prompt rectification.

In 2024, 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 $20^{th}$ CPC National Congress and its second plenary session, the Central Economic Working Conference, as well as President Xi's important speeches and remarks on S&T innovation especially on basic research, adhere to the "four aspects" and the dual-track approach for supporting basic research based on the decisions of the CPC Central Committee and the State Council, firmly grasp the strategic positioning of science funds, earnestly implement the task of institutional reform, deeply grasp the laws and trends of basic research development, and focus on "quality improvement", so as to optimize the science fund funding management system, strengthen the role of National Natural Science Fund as the main channel for funding basic research, and consolidate the foundation of scientific and technological self-reliance.

Prof. Dr. DOU Xiankang
President of NSFC



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# PART 1

## Overview

NSFC

# I. Review of the Achievements of NSFC's Systematic Reform

In 2023, NSFC implemented the decisions of the CPC Central Committee and the State Council, adhered to the requirements of "four aspects" and dual-track approach, strengthened the forward-looking, strategic and systematic plan for basic research, focused on the three major tasks of basic research, applied basic research and talent fostering, advanced the systematic reform of National Natural Science Fund, continuously enhanced funding performance, in an effort to ensure high level scientific and technological self-reliance and lay a solid base for building a power in science and technology.

NSFC deepened the reform talent funding mechanism, put the funding of talents in a more prominent position. NSFC conducted the pilot funding of excellent undergraduate students and PhD candidates, aiming to select them as early as possible so as to reserve a high-level cadre of basic research talents. The post evaluation and continued funding of National Science Fund for Distinguished Young Scholars were carried out, to ensure that the program served its purpose and provided long term stable support for excellent talents. For Basic Science Center Program, a separate track for outstanding young researchers was set up so that the most capable and innovative talents and teams would be funded. The age limit for women who apply for National Science Fund for Distinguished Young Scholars was extended to 48 years old so that they would have more opportunities to take the leading role in science and technology. The scientific research evaluation mechanism for clinicians was reformed to cultivate a cadre of leading clinicians in medical sciences. In addition to Excellent Young Scientists Fund and Young Scientists Fund, National Science Fund for Distinguished Young Scholars became open to the host institutions in Hong Kong and Macau for application. NSFC adopted the same funding mechanism and peer review criteria to applications of the three programs from Hong Kong and Macau as well as mainland.

NSFC pushed forward the reform of Programs of Joint Funds in the new era, improved the mechanism of diversified investment and funding performance. As of the end of 2023, 29 provinces (autonomous regions and municipalities) have joined the Joint Fund for Regional Innovation and Development, 12 enterprises have joined the Joint Fund for Corporate Innovation and Development, and 9 industry sectors have established Joint Funds with NSFC. Joint Funds of the New Era have attracted 16.2 billion yuan from outside of NSFC, with a matching fund of 5.17 billion yuan from NSFC, adding up to 21.37 billion yuan. In 2023, the amount of fund from outside of NSFC accounted for 8.66% of state financial input into NSFC. A continued and stable mechanism of diversified investment into basic research was established.

NSFC implemented the task of institutional reform and developed a plan for applied basic research funding. According to the requirements indicated in the Plan for CPC and State institutional reform, NSFC finished the transfer of the Administrative Center for China's Agenda 21 and High-tech Research and Development Center. NSFC explored to integrate National Key Research and Development Program and S&T Innovation 2030 - Major Program overseen by the two centers with major types of NSFC programs, to achieve synergy of the funding areas.

NSFC continued to stimulate original innovation by implementing the Original Exploratory Program. Original innovation was encouraged in the application and review of all types of programs, to further emphasize, protect and support such capabilities. While continuing to implement the Original Exploratory Program, NSFC set up a dedicated channel for projects that were highly original but difficult to obtain funding through conventional review mechanism, selected non-consensual, high-risk original proposals of disruptive innovation, and guided and motivated researchers to engage in original basic research.

As a science funding agency operated by internationally accepted rules, NSFC promoted high-level exchanges and collaborations in science and technology. NSFC further explored channels and opportunities for bilateral and multilateral collaborations, constructed platforms for international basic research collaborations and steadily carried out the joint funding for global S&T innovation collaborations. NSFC continued policy dialogues with overseas partners, and actively participated in global S&T

governance. NSFC also established the Department of International Programs and the Global Science Fund, creating platforms that are conducive to international collaborations and building an open and globally competitive innovation ecosystem.

Following the principle of “positive guidance, extreme defense, and serious punishment”, NSFC strengthened publicity and guidance, strictly enforced the review discipline, and resolutely rectified the deep-rooted problem of “string-pulling”. Through systematically summarizing experience, continuing to improve the review mechanism, and optimizing the review process, NSFC further improved the working mechanism and system to prevent and rectify “string-pulling” that covers the whole process from correspondence review to panel review, to effectively strengthen supervision and implementation, and to create a healthy culture and wholesome atmosphere for scientific research.

NSFC continued to simplify the requirements for application and ease the burden for applicants and reviewers. According to the new situation and new requirements of the development of basic research, NSFC simplified the four attributes of scientific problems to two attributes of research, namely, “free exploration basic research” and “goal-oriented basic research”, to further optimize category-specific application and review. The one-year suspension for PIs who fail to obtain grants of General Program in two consecutive years was removed. Postdoctoral researchers were allowed to change their host institutions when they undertake projects of General Program, Young Scientists Fund or Fund for Less Developed Regions. For General Program, Young Scientists Fund Program, Fund for Less Developed Regions, Key Program, Excellent Young Scientists Program, Science Fund for Creative Research Groups, Basic Science Center Program, Special Fund for Research on National Major Research Instruments, and Major Program, the funding period would be automatically calculated based on the program type and not modifiable, which gave researchers more convenience.

# II. Overview of Budget & Outlays and Funding

## (I) Overview of Budget and Outlays

In 2023, the fiscal budget of NSFC was 34,196.0333 million yuan, of which the budget for project funding was 33,672.7018 million yuan. In 2023, NSFC completed the appropriation of project funds with a total amount of 33,226.7676 million yuan, of which the direct cost was 28,043.6045 million yuan, and the indirect cost was 5,183.1631 million yuan. The fiscal budget statistics of NSFC in 2023 are shown in Table 1-2-1.

**Table 1-2-1 2023 NSFC Fiscal Budget and Outlays (in million yuan)**

| | Program Type | Fiscal Budget | Fiscal Outlays |
|---|---|---|---|
| 1 | General Program | 12,616.2618 | 12,596.3911 |
| 2 | Key Program | 2,381.97 | 2,373.7912 |
| 3 | Major Program | 885.74 | 876.4683 |
| 4 | Major Research Plan | 856.37 | 770.6889 |
| 5 | International (Regional) Joint Research Program | 854.73 | 843.6735 |
| 6 | Young Scientists Fund | 6,819.79 | 6,819.79 |
| 7 | Excellent Young Scientists Fund | 1,358.52 | 1,358.52 |
| 8 | National Science Fund for Distinguished Young Scholars | 1,428.19 | 1,420.0846 |
| 9 | Science Fund for Creative Research Groups | 484.52 | 484.378 |
| 10 | Fund for Less Developed Regions | 1,319.98 | 1,301.5279 |

(continued)

| | Program Type | Fiscal Budget | Fiscal Outlays |
|---|---|---|---|
| 11 | Programs for Joint Funds | 834.41 | 819.4367 |
| 12 | Special Fund for Research on National Major Research Instrument | 984.55 | 983.2304 |
| 13 | Basic Science Center Program | 1,161.3 | 1,153.4725 |
| 14 | Fund for Special Purpose Program | 1,237.85 | 1,138.8245 |
| 15 | Tianyuan Fund for Mathematics | 50.1 | 24.72 |
| 16 | Research Fund for International Scientists | 287.37 | 250.64 |
| 17 | International (Regional) Exchange Program | 9.38 | 9.38 |
| 18 | Global Science Fund Program | 101.67 | 1.75 |
| Total | | 33,672.7018 | 33,226.7676 |

## (II) Overview of Funding

In 2023, NSFC invested a total of 37,818.9028 million yuan to fund various types of projects, of which: the direct cost was 31,879.0138 million yuan, and the indirect costs of 1215 host institutions were 5,939.889 million yuan. The project funding statistics of NSFC in 2023 are shown in Table 1-2-2.

**Table 1-2-2 2023 NSFC Project Funding Statistics (unit: 10,000 yuan)**

| | Program Type | Number of Projects | Funding Amount | | |
|---|---|---|---|---|---|
| | | | Direct Cost* | Indirect Cost | Total |
| 1 | General Program | 20321 | 10,050.57 | 3,011.8188 | 13,062.3888 |
| 2 | Key Program | 751 | 1,685.3 | 496.6518 | 2,181.9518 |
| 3 | Major Program | 53 | 753.662 | 211.4672 | 965.1292 |
| 4 | Major Research Plan | 340 | 779.4113 | 203.7535 | 983.1648 |
| 5 | International (Regional) Joint Research Program | 360 | 629.326 | 183.2806 | 812.6066 |
| 6 | Young Scientists Fund** | 22879 | 6,800.3 | 6,800.3 | |
| 7 | Excellent Young Scientists Fund** | 655 | 1,310 | 1,310 | |
| 8 | National Science Fund for Distinguished Young Scholars** | 415 | 1,628.8 | 1,628.8 | |
| 9 | Science Fund for Creative Research Groups | 43 | 424 | 86 | 510 |
| 10 | Fund for Less Developed Regions | 3538 | 1,121.71 | 340.1413 | 1461.8513 |
| 11 | Programs for Joint Funds | 1160 | 3157.83 | 597.7533 | 3,755.5833 |
| 12 | Special Fund for Research on National Major Research Instrument | 67 | 832.1565 | 190.49 | 1,022.6465 |
| 13 | Basic Science Center Program | 19 | 1,139.88 | 223.9848 | 1,363.8648 |
| 14 | Fund for Special Purpose Program* | 1227 | 1,200.025 | 323.9365 | 1,523.9615 |
| 15 | Tianyuan Fund for Mathematics | 148 | 60 | 0 | 60 |
| 16 | Research Fund for International Scientists | 277 | 249.9 | 70.6112 | 320.5112 |
| 17 | International (Regional) Exchange Program | 294 | 56.143 | 0 | 56.143 |
| Total | | Total | 3,1879.0138 | 5,939.889 | 3,7818.9028 |

*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 Fund Special Purpose Program.

# III. Overview of Concluded Projects

In 2023, 44,225 projects supported by NSFC were concluded. Among the numerous achievements coming out of the concluded projects, 424 national awards including 121 National Natural Science Awards, 235 National Science and Technology Progress Awards, and 68 National Technology Invention Awards were received; 5,325 provincial and ministerial awards were received; 1,978 international patents on invention and 57,738 domestic patents on invention were obtained.

The statistics of research achievements coming out of the concluded projects supported by NSFC in 2023 are shown in Table 1-3-1

**Table 1-3-1 Research Achievements Coming Out of the Concluded Projects Supported by NSFC in 2023**

| Research Achievements | | Program Type | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | General Program | Key Program | Major Program | Major Research Plan | Young Scientists Fund | Fund for Less Developed Regions | Excellent Young Scientists Fund | National Science Fund for Distinguished Young Scholars | Science Fund for Creative Research Groups | Joint Research Fund for Overseas Chinese Scholars and Scholars in Hong Kong and Macao | Programs for Joint Funds | Special Fund for Research on National Major Research Instrument | Basic Science Center Program | Fund for Special Purpose | International (Regional) Cooperation &Exchange Program |
| No. of Concluded Projects | | 18468 | 668 | 216 | 522 | 18136 | 2925 | 623 | 196 | 38 | 21 | 759 | 86 | 4 | 635 | 928 |
| Publica-tions | Keynote Speeches at International Academic Conferences | 4183 | 1248 | 634 | 317 | 916 | 100 | 462 | 362 | 262 | 4 | 379 | 187 | 165 | 57 | 582 |
| | Keynote Speeches at Domestic Academic Conferences | 8445 | 1908 | 1138 | 459 | 1583 | 346 | 885 | 514 | 308 | 23 | 711 | 253 | 97 | 178 | 655 |
| | Journal Papers | 240878 | 28546 | 16807 | 9250 | 107075 | 26636 | 10655 | 7679 | 6868 | 277 | 17887 | 4002 | 1899 | 2739 | 11167 |
| | Conference Papers | 19730 | 2745 | 657 | 417 | 8222 | 1668 | 883 | 468 | 154 | 59 | 2651 | 382 | 0 | 174 | 747 |
| | SCI-indexed research articles | 144236 | 17544 | 6879 | 5227 | 62481 | 11560 | 7369 | 4847 | 4436 | 111 | 10660 | 2139 | 1260 | 902 | 6716 |
| | 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 |
| Patents | International | 883 | 140 | 50 | 43 | 406 | 88 | 71 | 72 | 37 | 0 | 72 | 64 | 11 | 1 | 40 |
| | Domestic | 26807 | 3271 | 1629 | 787 | 12757 | 3193 | 1461 | 1144 | 1129 | 23 | 3007 | 892 | 226 | 170 | 1242 |
| Awards | 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 | 241 | 55 | 78 | 46 | 268 |
| | PhD Students | 21424 | 399 | 2020 | 1332 | 2819 | 749 | 997 | 1221 | 1418 | 51 | 1640 | 557 | 256 | 292 | 1425 |
| | Master Students | 52947 | 5271 | 2904 | 1307 | 11758 | 7362 | 1740 | 1024 | 1127 | 65 | 4269 | 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

# The Funding Statistics and Selective Introduction of Projects Supported by NSFC in 2023

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 2023, 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 2023 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 2023 (by Scientific Department)**

(Unit: 10,000 *yuan*)

| Scientific Department | Applications | Grants | Direct Costs | Average Funding per Project① | Success rate② (%) |
|---|---|---|---|---|---|
| Mathematical and Physical Sciences | 8703 | 1 872 | 93 630.00 | 50.02 | 21.51 |
| Chemical Sciences | 9 694 | 2015 | 100 730.00 | 49.99 | 20.79 |
| Life Sciences | 17 005 | 3 188 | 159 400.00 | 50.00 | 18.75 |
| Earth Sciences | 10 085 | 2106 | 105 920.00 | 50.29 | 20.88 |
| Engineering and Materials Sciences | 21 921 | 3486 | 175 337.00 | 50.30 | 15.90 |
| Information Sciences | 12520 | 2 183 | 109 160.00 | 50.00 | 17.44 |
| Management Sciences | 4 699 | 844 | 34 240.00 | 40.57 | 17.96 |
| Health Sciences | 35 009 | 4 627 | 226 640.00 | 48.98 | 13.22 |
| Total or average | 119 636 | 20 321 | 1 005 057.00 | 49.46 | 16.99 |

Note: ①Average funding =Direct funding amount /No. of awards (the same below)
②Success rate= No. of applications/ No. of awards (the same below)

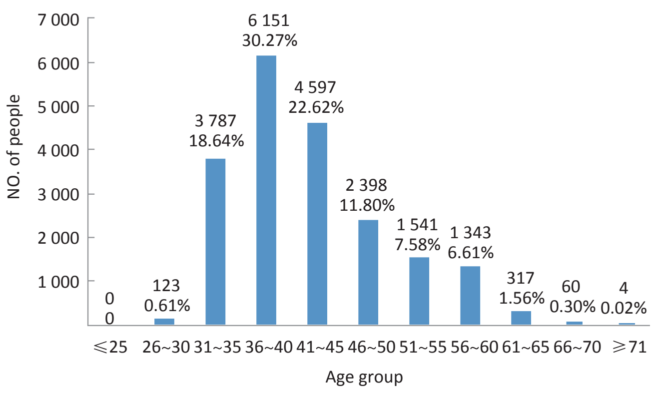



Figure 2-1-1 Age Distribution of Principal Investigators of General Program Projects in 2023

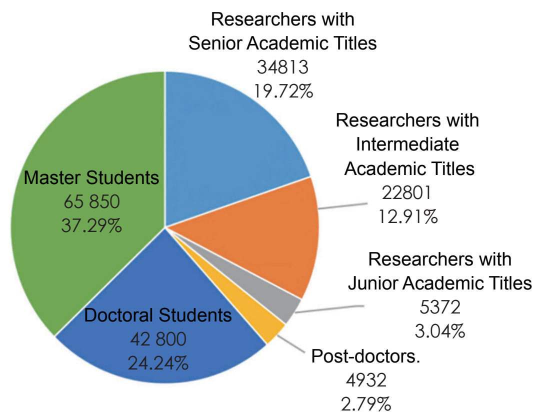



Figure 2-1-2 Project Team Composition of General Program Projects in 2023

**Table 2-1-2 Statistics of General Program Projects by Region in 2023**

(Unit: 10,000 *yuan*)

| No. | Region | Grants | Direct Costs | No. | Region | Grants | Direct Costs |
|---|---|---|---|---|---|---|---|
| 1 | Beijing | 3276 | 162 015.00 | 17 | Jilin | 346 | 17 197.00 |
| 2 | Shanghai | 2173 | 106 852.50 | 18 | Henan | 334 | 16 569.50 |
| 3 | Jiangsu | 2114 | 104 450.00 | 19 | Gansu | 199 | 9947.00 |
| 4 | Guangdong | 2085 | 102 533.50 | 20 | Shanxi | 169 | 8452.00 |
| 5 | Hubei | 1234 | 61 021.00 | 21 | Yunan | 147 | 7 353.00 |
| 6 | Shaanxi | 1 090 | 54 324.50 | 22 | Hebei | 139 | 6 930.00 |
| 7 | Zhejiang | 1094 | 54 188.00 | 23 | Jiangxi | 103 | 5 128.50 |
| 8 | Shandong | 955 | 47 521.50 | 24 | Guangxi | 62 | 3 101.00 |
| 9 | Sichuan | 808 | 39 896.50 | 25 | Hainan | 48 | 2391.50 |
| 10 | Hunan | 766 | 37 839.50 | 26 | Guizhou | 45 | 2282.00 |
| 11 | Liaoning | 579 | 28 653.50 | 27 | Xinjiang | 34 | 1684.00 |
| 12 | Anhui | 565 | 27 978.50 | 28 | Neimenggu | 25 | 1251.00 |
| 13 | Tianjin | 556 | 27 474.50 | 29 | Ningxia | 11 | 563.00 |
| 14 | Heilongjiang | 468 | 23 295.50 | 30 | Qinghai | 7 | 346.00 |
| 15 | Fujian | 465 | 22 887.50 | 31 | Tibet | 2 | 100.00 |
| 16 | Chongqing | 422 | 20 830.00 | | Total | 20 301 | 1005 057.00 |

## 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, promoting scientific development, and making breakthroughs in several important fields or scientific frontiers.

In 2023, a total of 4306 applications were received for the Key Program. Based on the nature of the scientific problems, 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. 4.46% of the total applications were under category I, 44.24% under category II, 47.70% under category III, and 3.60% under category IV.

Statistics on applications and funding for key Program projects in 2023 are shown in Table 2-1-3. The age of project PIs is shown in Figure 2-1-3, and the composition of research teams is shown in Figure 2-1-4.

**Table 2-1-3 Application and Funding statistics of Key Program Projects in 2023 (by Scientific Department)**

(Unit:10,000 yuan)

| Scientific Departments | Applications | Grants | Direct Costs | Average funding per project | Success Rate (%) |
|---|---|---|---|---|---|
| Mathematical and Physical Sciences | 496 | 91 | 20 930.00 | 230.00 | 18.35 |
| Chemical Sciences | 324 | 67 | 15410.00 | 230.00 | 20.68 |
| Life Sciences | 740 | 110 | 24 200.00 | 220.00 | 14.86 |

(continued)

| Scientific Departments | Applications | Grants | Direct Costs | Average funding per project | Success Rate (%) |
|---|---|---|---|---|---|
| Earth Sciences | 633 | 107 | 24 610.00 | 230.00 | 16.90 |
| Engineering and Materials Sciences | 814 | 103 | 23 690.00 | 230.00 | 12.65 |
| Information Sciences | 343 | 114 | 26 450.00 | 232.02 | 33.24 |
| Management Sciences | 131 | 32 | 5300.00 | 165.63 | 24.43 |
| Health Sciences | 825 | 127 | 27 940.00 | 220.00 | 15.39 |
| Total or average | 4 306 | 751 | 168 530.00 | 224.41 | 17.44 |

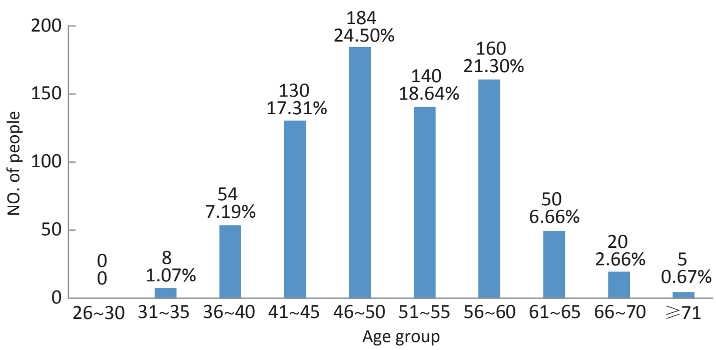



Figure 2-1-3 Age Distribution of Principal Investigators of Key Program Projects in 2023

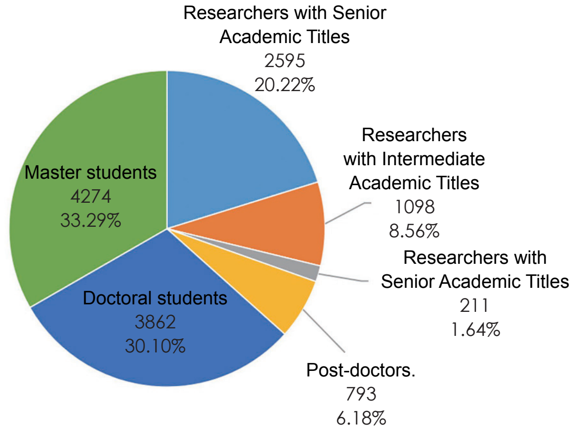



Figure 2-1-4 Project Team Composition of Key Program Projects funded in 2023

## 1.3 Major Program

The Major Program focuses 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 2023, a total of 143 applications were received for Major Program projects. 53 grants were approved, with a total direct cost of 753,662,000 yuan.

Statistics on applications and funding for Major Program projects in 2023 are shown in Table 2-1-4.

**Table 2-1-4 Application and Funding Statistics of Major Program Projects in 2023 (by Scientific Department)**

(Unit: 10,000 yuan)

| Scientific Department | Applications | Grants | Direct Costs | Average Funding per Project |
|---|---|---|---|---|
| Mathematical and Physical Sciences | 12 | 5 | 7364.00 | 1472.80 |
| Chemical Sciences | 12 | 6 | 8924.76 | 1487.46 |
| Life Sciences | 14 | 6 | 8960.10 | 1493.35 |
| Earth Sciences | 16 | 6 | 8315.84 | 1385.97 |
| Engineering and Materials Sciences | 17 | 9 | 11667.00 | 1296.33 |

(continued)

| Scientific Department | Applications | Grants | Direct Costs | Average Funding per Project |
|---|---|---|---|---|
| Information Sciences | 9 | 6 | 8 997.50 | 1499.58 |
| Management Sciences | 8 | 4 | 4 662.60 | 1 165.65 |
| Health Sciences | 45 | 6 | 8 980.40 | 1496.73 |
| Interdisciplinary Sciences | 10 | 5 | 7 494.00 | 1498.80 |
| Total or average | 143 | 53 | 75 366.20 | 1 422.00 |

## 1.4 Major Research Plan

Major Research Plan focuses 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 2023 are shown in Table 2-1-5.

**Table 2-1-5 Applications and Funding Statistics of Major Research Plan Projects in 2023**

(Unit: 10,000 yuan)

| No. | Title of Project | Applications | Grants | Direct Costs |
|---|---|---|---|---|
| 1 | Spatiotemporal network regulation of glucose and lipid metabolism | 25 | 8 | 31.90 |
| 2 | The precise construction of multiple layers of chiral matter | 50 | 10 | 124.90 |
| 3 | Multi - sphere interaction in the Western Pacific Earth system | 4 | 3 | 111.70 |
| 4 | High temperature materials for aeroengines/Fundamentals of Advanced Manufacturing and Fault diagnosis science | 59 | 11 | 413.20 |
| 5 | Physics and applications of novel light field regulation | 1 | 1 | 1500.00 |
| 6 | Mechanisms by which hydrospheric microorganisms drive the cycling of Earth's elements | 8 | 5 | 2500.00 |
| 7 | Formation, evolution and action mechanism of turbulent structure | 1 | 1 | 4700.00 |
| 8 | Dynamic modification and chemical intervention of biological macromolecules | 12 | 5 | 6650.00 |
| 9 | Study on organelle interaction network and its function | 52 | 8 | 2400.00 |
| 10 | Tethys geodynamic system | 5 | 4 | 5400.00 |
| 11 | Cluster structure, function and multistage evolution | 36 | 6 | 7000.00 |
| 12 | Study on the basis of high-performance materials for functional element ordering | 1 | 1 | 1 946.00 |
| 13 | Basic theory and key technologies of future industrial Internet | 92 | 20 | 4850.00 |
| 14 | Unconventional battery systems | 247 | 36 | 2400.00 |
| 15 | Scientific foundations of frontier technology for integrated chips | 108 | 29 | 3000.00 |
| 16 | Digital decoding of Immunity | 278 | 28 | 500.00 |

(continued)

| No. | Title of Project | Applications | Grants | Direct Costs |
|---|---|---|---|---|
| 17 | Molecular functional visualization of tumor progression and diagnosis and treatment | 139 | 8 | 3850.00 |
| 18 | Basic research of new devices in post-Moore era | 47 | 12 | 2300.00 |
| 19 | Information decoding and orderly regulation of tissue and organ regeneration and repair | 397 | 20 | 3000.00 |
| 20 | Construction and manipulation of the second-generation quantum system | 99 | 29 | 1 933.00 |
| 21 | Scientific basis of electromagnetic energy equipment in extreme conditions | 25 | 9 | 4500.00 |
| 22 | Panoramic dynamic mechanism and intervention strategy of coronavirus-host immune interaction | 109 | 23 | 3955.00 |
| 23 | Explainable and generalizable next-generation artificial intelligence methods | 325 | 40 | 3560.00 |
| 24 | Scientific basis and regulatory mechanisms of efficient flight in multi-physics fields | 125 | 23 | 3200.00 |
| Total | | 2245 | 340 | 2697.00 |

## 1.5 International (Regional) Cooperative Research Program

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

The Key International (Regional) Cooperative Rresearch Program funds researchers to work on priority areas of the National Science Fund, the research areas that China urgently needs to develop, the international large-scale scientific research projects or programs that Chinese scientists organize or participate in, and large international (regional) collaborative research based on large international scientific facilities.

The MoU-based Cooperative Research Program 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 transnational 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 Program projects in 2023 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 2023**

(unit: 10,000 yuan)

| Scientific Department | Applications | Grants | Direct Costs | Average Funding per Project |
|---|---|---|---|---|
| Mathematical and Physical Sciences | 18 | 5 | 1050.00 | 210.00 |
| Chemical Sciences | 22 | 5 | 1080.00 | 216.00 |
| Life Sciences | 75 | 12 | 2484.00 | 207.00 |
| Earth Sciences | 43 | 7 | 1470.00 | 210.00 |
| Engineering and Materials Sciences | 72 | 9 | 1890.00 | 210.00 |
| Information Sciences | 67 | 11 | 2340.00 | 212.73 |
| Management Sciences | 21 | 3 | 570.00 | 190.00 |
| Health Sciences | 134 | 22 | 4 620.00 | 210.00 |
| Total or average | 452 | 74 | 15 504.00 | 209.51 |

**Table 2-1-7 Application and Funding of Projects of MoU-based Cooperative Research Program in 2023**

(unit: 10,000 yuan)

| Scientific Department | Applications | Grants | Direct Costs | Average Funding per Project |
|---|---|---|---|---|
| Mathematical and Physical Sciences | 138 | 26 | 4 522.00 | 173.92 |
| Chemical Sciences | 470 | 45 | 7391.00 | 164.24 |
| Life Sciences | 323 | 51 | 9214.00 | 180.67 |
| Earth Sciences | 401 | 58 | 9 215.00 | 158.88 |
| Engineering and Materials Sciences | 290 | 31 | 4 832.00 | 155.87 |
| Information Sciences | 279 | 24 | 3909.00 | 162.88 |
| Management Sciences | 141 | 22 | 3 468.60 | 157.66 |
| Health Sciences | 275 | 29 | 4 877.00 | 168.17 |
| Total or average | 2317 | 286 | 47 428.60 | 165.83 |

## 1.6 Young Scientists Fund

The Young Scientists Fund (YSF) supports young researchers to conduct basic research on independently selected topics within the funding scope of the National 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 2023, 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.

In 2023, a total of 134,305 applications were received, 22 879 grants were approved, with a total direct cost of 6, 800,300,000 yuan.

The application and funding statistics of 2023 YSF projects are shown in Table 2-1-8 and Table 2-1-9. Statistics of academic titles of project PIs are shown in Figure 2-1-5, and statistics of academic degree of projects PIs are shown in Figure 2-1-6.

**Table 2-1-8 Application and Funding Statistics of Young Scientists Fund in 2023 (by Scientific Department)**

(Unit: 10,000 *yuan*)

| Scientific Department | Applications | Grants | Funding Amount | Success Rate (%) |
|---|---|---|---|---|
| Mathematical and Physical Sciences | 8795 | 2281 | 67 620.00 | 25.94 |
| Chemical Sciences | 11 143 | 2091 | 61 890.00 | 18.77 |
| Life Sciences | 18 316 | 3073 | 91 210.00 | 16.78 |
| Earth Sciences | 10 280 | 2263 | 67 150.00 | 22.01 |
| Engineering and Materials Sciences | 22 454 | 3909 | 116 200.00 | 17.41 |
| Information Sciences | 11 688 | 2703 | 80 170.00 | 23.13 |
| Management Sciences | 7376 | 1119 | 33 420.00 | 15.17 |
| Health Sciences | 44 253 | 5440 | 162370.00 | 12.29 |
| Total or average | 134 305 | 22 879 | 680 030.00 | 17.04 |

Note: there were 64,424 proposals from male applicants and 13,237 granted; 69,881 from female applicants, and 9,642 granted.

**Table 2-1-9 Statistics of Projects for Young Scientists Fund by Region in 2023**

(Unit: 10,000 *yuan*)

| No. | Region | Application | Awards | Funding Amount | Success rate (%) |
|---|---|---|---|---|---|
| 1 | Beijing | 14 356 | 3206 | 93 300.00 | 22.33 |
| 2 | Guangdong | 13 047 | 2339 | 69 300.00 | 17.93 |
| 3 | Jiangsu | 13084 | 2319 | 69 190.00 | 17.72 |
| 4 | Shanghai | 10 630 | 2014 | 59 730.00 | 18.95 |
| 5 | Zhejiang | 9226 | 1579 | 47 120.00 | 17.11 |
| 6 | Shandong | 8632 | 1275 | 38 170.00 | 14.77 |
| 7 | Shaanxi | 6296 | 1 201 | 35 960.00 | 19.08 |
| 8 | Hubei | 6 465 | 1 190 | 35 260.00 | 18.41 |
| 9 | Sichuan | 6053 | 1053 | 31 560.00 | 17.40 |
| 10 | Hunan | 4440 | 787 | 23 530.00 | 17.73 |
| 11 | Anhui | 4542 | 771 | 23 020.00 | 16.97 |
| 12 | Henan | 6504 | 725 | 21 740.00 | 11.15 |
| 13 | Liaoning | 3560 | 542 | 16190.00 | 15.22 |
| 14 | Chongqing | 3318 | 538 | 16 090.00 | 16.21 |
| 15 | Tianjin | 3145 | 530 | 15 840.00 | 16.85 |
| 16 | Fujian | 2646 | 421 | 12 530.00 | 15.91 |
| 17 | Heilongjiang | 1971 | 414 | 12 360.00 | 21.00 |
| 18 | Jilin | 1983 | 300 | 9 000.00 | 15.13 |
| 19 | Shanxi | 2464 | 275 | 8 240.00 | 11.16 |
| 20 | Hebei | 2072 | 231 | 6 930.00 | 11.15 |
| 21 | Jiangxi | 1978 | 207 | 6210.00 | 10.47 |

(continued)

| No. | Region | Application | Awards | Funding Amount | Success rate (%) |
|---|---|---|---|---|---|
| 22 | Gansu | 1236 | 184 | 5490.00 | 14.89 |
| 23 | Yunnan | 1 362 | 172 | 5 130.00 | 12.63 |
| 24 | Hainan | 762 | 123 | 3670.00 | 16.14 |
| 25 | Guangxi | 1474 | 112 | 3 360.00 | 7.60 |
| 26 | Guizhou | 1076 | 102 | 3040.00 | 9.48 |
| 27 | Hongkong | 200 | 94 | 2820.00 | 47.00 |
| 28 | Xinjiang | 701 | 61 | 1830.00 | 8.70 |
| 29 | Neimenggu | 547 | 49 | 1470.00 | 8.96 |
| 30 | Ningxia | 310 | 34 | 1020.00 | 10.97 |
| 31 | Macao | 40 | 17 | 510.00 | 42.50 |
| 32 | Qinghai | 171 | 14 | 420.00 | 8.19 |
| 33 | Tibet | 14 | 0 | 0 | 0 |
| Total/average | | 134 305 | 22 879 | 680 030.00 | 17.04 |

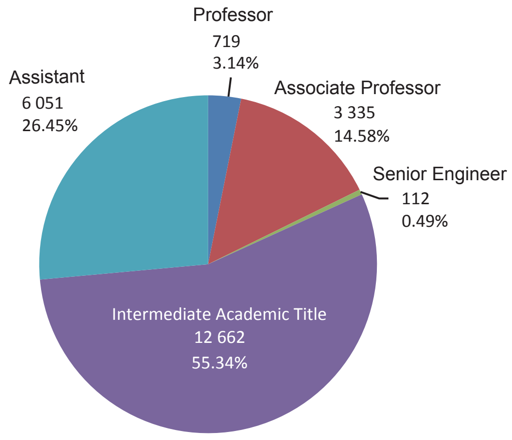



Figure 2-1-5 Academic titles of Project PIs funded by Young Scientists Fund in 2023

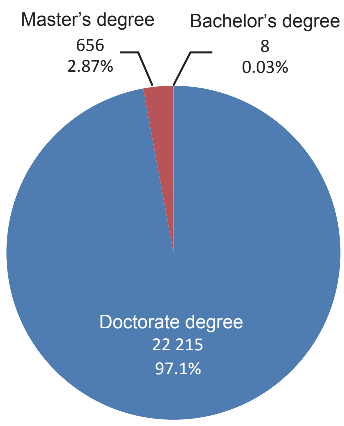



Figure 2-1-6 Academic degrees of PIs supported by Young Scientists Fund in 2023

## 1.7 Fund for Less Developed Regions

The Fund for Less Developed Regions supports researchers from host institutions in specific regions to carry out innovative scientific research within the scope of the National Science Fund, cultivates and supports 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 the Fund for Less Developed Regions projects in 2023 are shown in Table 2-1-10. Figure 2-1-7 shows the age statistics of project PIs, and Figure 2-1-8 shows the composition of project members.

**Table 2-1-10 Application and Funding Statistics of the Fund for Less Developed Regions by Regions in 2023**

(Unit: 10,000 *yuan*)

| No. | Region | Applications | Grants | Direct costs | Success rate (%) |
|---|---|---|---|---|---|
| 1 | Jiang Xi | 4810 | 758 | 23 954.70 | 15.76 |
| 2 | Guangxi | 3 659 | 535 | 16 947.30 | 14.62 |
| 3 | Yunnan | 3 459 | 488 | 15 482.10 | 14.11 |
| 4 | Gui Zhou | 3601 | 454 | 14 435.20 | 12.61 |
| 5 | Xin Jian | 2 190 | 286 | 9 155.10 | 13.06 |
| 6 | Gan Su | 1 963 | 284 | 8 966.40 | 14.47 |
| 7 | Hai Nan | 1278 | 236 | 7 465.80 | 18.47 |
| 8 | Neimenggu | 1580 | 229 | 7 260.70 | 14.49 |
| 9 | Ning Xia | 1060 | 121 | 3 833.60 | 11.42 |
| 10 | Qing Hai | 373 | 39 | 1 240.00 | 10.46 |
| 11 | Shaanxi | 391 | 38 | 1212.70 | 9.72 |
| 12 | Jilin | 171 | 23 | 734.20 | 13.45 |
| 13 | Hunan | 100 | 18 | 567.00 | 18.00 |
| 14 | Hubei | 119 | 12 | 370.20 | 10.08 |
| 15 | Tibet | 69 | 11 | 360.00 | 15.94 |
| 16 | Sicuan | 68 | 6 | 186.00 | 8.82 |
| Total or average | | 24 891 | 3538 | 112 171.00 | 14.21 |

Note: there were 15,644 applications from male applicants, of which 2278 were funded; and 9247 were from female applicants, of which 1260 were funded.

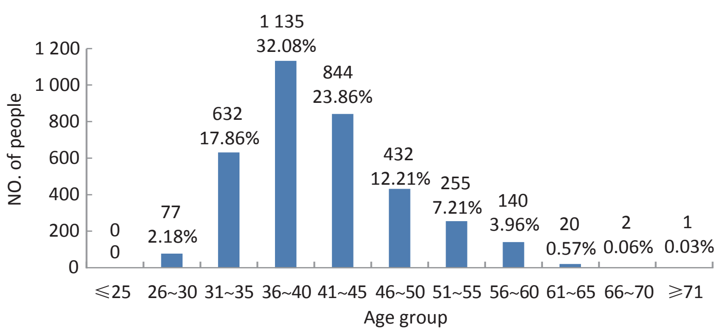



Figure 2-1-7 Age Distribution of Principal Investigators of Projects Funded by the Fund for Less Developed Regions in 2023

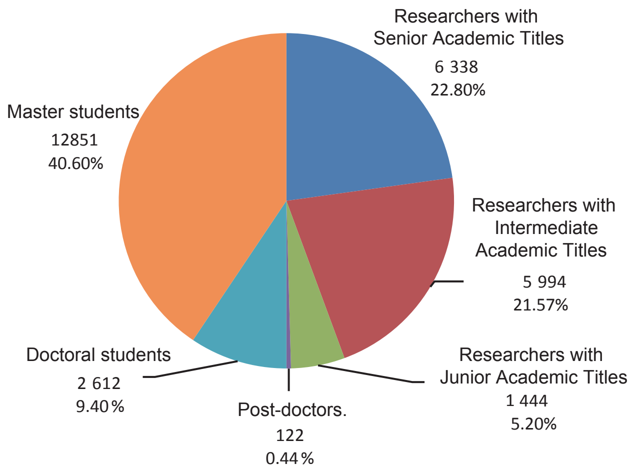



Figure 2-1-8 Research Team Composition of Projects Supported by the Fund for Less Developed Regions in 2023

## 1.8 Excellent Young Scientists Fund

The Excellent Young Scientists Fund (EYSF) 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, encourage high-quality scientific and technological talents from Hong Kong and Macao to participate in the central financial science and technology programs and contribute to the building of a strong science and technology country, the NSFC continued to open the EYSF to researchers of Hong Kong and Macao Special Administrative Region in 2023.

The 2023 EYSF Program received 7,726 applications. After peer review, 655 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 1.31 billion yuan.

The statistics of application and funding for EYSF projects in 2023 are shown in Tables 2-1-11 and 2-1-12.

**Table 2-1-11 Application and Funding Statistics of Excellent Young Scientists Fund in 2023 (by Scientific Department)**

(Unit: 10,000 *yuan*)

| Scientific Department | Applications | Grants | Funding amount |
|---|---|---|---|
| Mathematical and Physical Sciences | 872 | 71 | 14 200.00 |
| Chemical Sciences | 912 | 86 | 17 200.00 |
| Life Sciences | 1038 | 86 | 17 200.00 |
| Earth Sciences | 807 | 59 | 11 800.00 |
| Engineering and Materials Sciences | 1 376 | 110 | 22000.00 |
| Information Sciences | 984 | 90 | 18 000.00 |
| Management Sciences | 221 | 22 | 4 400.00 |
| Health Sciences | 965 | 76 | 15200 |
| Interdisciplinary Sciences | 364 | 30 | 6 000.00 |
| Total or average | 7 539 | 630 | 126 000.00 |

Note: There were 5764 applications from male applicants, of which 487 were funded; and 1775 were from female applicants, of which 143 were funded.

**Table 2-1-12 Application and Funding Statistics of Excellent Young Scientists Fund for Hong Kong and Macao SARs in 2023 (by Scientific Department)**

(Unit: 10,000 *yuan*)

| Scientific Department | Applications | Grants | Funding amount |
|---|---|---|---|
| Mathematical and Physical Sciences | 26 | 5 | 1000.00 |
| Chemical Sciences | 14 | 2 | 400.00 |
| Life Sciences | 29 | 5 | 1 000.00 |
| Earth Sciences | 18 | 3 | 600.00 |
| Engineering and Materials Sciences | 33 | 5 | 1000.00 |
| Information Sciences | 30 | 4 | 800.00 |

(continued)

| Scientific Department | Applications | Grants | Funding amount |
|---|---|---|---|
| Management Sciences | 20 | 1 | 200.00 |
| Health Sciences | 17 | 0 | 0 |
| Total or average | 187 | 25 | 5000.00 |

Note: There were 150 applications from male applicants, of which 21 were funded; and 37 were from female applicants, of which 4 were funded.

## 1.9 National Science Fund for Distinguished Young Scholars

The National Science Fund for Distinguished Young Scholars supports young scholars who have achieved outstanding results in basic research to independently conduct innovative research, promotes the growth of young scientific and technological talents, attracts overseas talents, and cultivates a group of academic leaders to enter the forefront of the international science and technology community.

In 2023, a total of 5141 applications were received for the National Science Fund for Distinguished Young Scholars. After peer review, 415 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 1.6288 billion yuan.

The application and funding statistics of the National Science Fund for Distinguished Young Scholars in 2023 are shown in Table 2-1-13.

**Table 2-1-13 Application and Funding Statistics of the National Science Fund for Distinguished Young Scholars in 2023**

(Unit: 10,000 yuan)

| Scientific Department | Applications | Grants | Funding Amount |
|---|---|---|---|
| Mathematical and Physical Sciences | 652 | 50 | 18 440.00 |
| Chemical Sciences | 655 | 55 | 22000.00 |
| Life Sciences | 602 | 50 | 20000.00 |
| Earth Sciences | 512 | 42 | 16 800.00 |
| Engineering and Materials Sciences | 893 | 75 | 00.00 |
| Information Sciences | 696 | 52 | 20 800.00 |
| Management Sciences | 145 | 13 | 3640.00 |
| Health Sciences | 600 | 50 | 20000.00 |
| Interdisciplinary Sciences | 386 | 28 | 11 200.00 |
| Total or average | 5 141 | 415 | 162 880.00 |

Note: There were 4490 applications from male applicants, of which 363 were funded; and 651 were from female applicants, of which 52 were funded.

## 1.10 Science Fund for Creative Research Groups

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

Leading role in the forefront of international science.

In 2023, a total of 376 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 Creative Research Group projects in 2023 are shown in Table 2-1-14.

**Table 2-1-14 Application and Funding Statistics for the Science Fund for Creative Research Groups in 2023**

(Unit: 10,000 yuan)

| Scientific Department | Applications | Grants | Direct costs |
|---|---|---|---|
| Mathematical and Physical Sciences | 33 | 5 | 4 800.0 0 |
| Chemical Sciences | 40 | 5 | 5000.00 |
| Life Sciences | 39 | 5 | 5000.00 |
| Earth Sciences | 52 | 5 | 5000.00 |
| Engineering and Materials Sciences | 56 | 6 | 6000.00 |
| Information Sciences | 51 | 5 | 5000.00 |
| Management Sciences | 11 | 2 | 1 600.00 |
| Health Sciences | 46 | 5 | 5000.00 |
| Interdisciplinary Sciences | 48 | 5 | 5000.00 |
| Total or average | 376 | 43 | 42400.00 |

## 1.11 Joint Funds

The Joint Funds are designed to give full play of 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.

By December 31, 2023, a total of 29 provinces (autonomous regions or municipalities) have reached agreement with NSFC in participating the Joint Fund for Regional Innovation and Development and a total of 12 large enterprises have participated in the Joint Fund for Corporate Innovation and Development, and 9 Joint Funds are established between NSFC and Ministry of Water Resources and other competent authorities of the industrial sectors. Within the valid period of the agreement, a total funding of 21.37 billion yuan was invested in the Joint Funds, with 16.202 billion yuan from the external joining parties and 5.168 billion yuan from NSFC.

In 2023, a total of 1160 projects were funded under the Joint Funds with a direct funding of 3.158 billion yuan. A total of 710 projects were funded under the Joint Fund for Regional Innovation and Development with a direct funding of 1.973 billion yuan; a total of 182 projects were funded under the Joint Fund for Corporate Innovation and Development with a direct funding of 547 million yuan; a total of 268 projects were funded under the Joint Funds with industrial sectors with a direct funding of 638 million yuan.

The 2023 Joint Fund project application and funding statistics are shown in Table 2-1-15.

**Table 2-1-15 Application and Funding Statistics of Joint Funds in 2023**

(unit: 10,000 yuan)

| No. | Joint Fund | Applications | Grants | Direct costs |
|---|---|---|---|---|
| 1 | Joint Fund for Regional Innovation and Development | 2779 | 710 | 197327.00 |
| 2 | Joint Fund for Corporate Innovation and Development | 785 | 182 | 54 702.00 |
| 3 | NSAF Joint Fund | 180 | 39 | 5 380.00 |
| 4 | "Qisun Ye" Science Foundation | 428 | 92 | 23 829.00 |
| 5 | Joint Fund of Civil Aviation Research | 86 | 18 | 3780.00 |
| 6 | Joint Meteorological Fund | 114 | 28 | 7 356.00 |
| 7 | NSFC-CR Joint Fund for Basic Research | 72 | 16 | 4 099.00 |
| 8 | NSFC-GenerTec Joint Fund for Basic Research | 72 | 14 | 3 704.00 |
| 9 | Joint Fund for Geology | 87 | 29 | 7 408.00 |
| 10 | Joint Fund of Yellow River Water Science Research | 178 | 32 | 8 198.00 |
| Total | | 4 781 | 1 160 | 315 783.00 |

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

The 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 2023, a total of 601 applications for the Special Fund for Development of National Major Research Instruments and Facilities were received. After peer review, 63 applications were funded, with a total direct funding of 498.95662 million yuan and the average direct costs was 7.9199 million yuan per project. The Ministries or Institutions recommended 48 applications and 4 of them got funded after peer review, with a total direct funding of 333.1999 million yuan and the average funding intensity of direct costs was 83.30 million yuan per project.

The statistics of application and funding for National Major Scientific Research Instrument Development Projects (free application) in 2023 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 (free application) in 2023 (by Scientific Department)**

(unit: 10,000 yuan)

| Scientific Department | Applications | Grants | Direct costs | Average Funding per Project |
|---|---|---|---|---|
| Mathematical and Physical Sciences | 92 | 9 | 6 975.48 | 775.05 |
| Chemical Sciences | 62 | 9 | 7 286.47 | 809.61 |
| Life Sciences | 20 | 2 | 1 629.85 | 814.93 |
| Earth Sciences | 75 | 6 | 4 877.90 | 812.98 |
| Engineering and Materials Sciences | 107 | 13 | 10 296.15 | 792.01 |

(continued)

| Scientific Department | Applications | Grants | Direct costs | Average Funding per Project |
|---|---|---|---|---|
| Information Sciences | 170 | 14 | 11 102.45 | 793.03 |
| Health Sciences | 75 | 10 | 7 727.36 | 772.74 |
| Total or average | 601 | 63 | 49 895.66 | 791.99 |

## 1.13 Basic Science Center Program

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 highland with academically important international influences.

The 2023 Basic Science Center program received 71 applications. After peer review, 16 projects were approved for funding, with a total direct cost of 960 million yuan.

In 2023, 3 Basic Science Center projects granted in 2017 were extended with a total direct funding of 179.88 million yuan.

The 2023 Basic Science Center project application and grant statistics are shown in Table 2-1-17.

**Table 2-1-17 Application and Funding Statistics of Basic Science Center Program in 2023 (by Scientific Department)**

(unit: 10,000 yuan)

| Scientific Department | Applications | Grants | Direct costs |
|---|---|---|---|
| Mathematical and Physical Sciences | 11 | 2 | 12000.00 |
| Chemical Sciences | 7 | 2 | 12000.00 |
| Life Sciences | 5 | 2 | 12 000.00 |
| Earth Sciences | 9 | 2 | 12 000.00 |
| Engineering and Materials Sciences | 8 | 2 | 12 000.00 |
| Information Sciences | 5 | 2 | 12 000.00 |
| Management Sciences | 4 | 0 | 0 |
| Health Sciences | 7 | 2 | 12000.00 |
| Interdisciplinary Sciences | 15 | 2 | 12000.00 |
| Total or average | 71 | 16 | 96 000.00 |

## 1.14 Fund for Special Purpose Program

Fund for Special Purpose Program supports innovative research that needs timely funding, and scientific and technological activities related to the development of NSFC, etc. Special Purpose 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 Projects is to fund strategic and management research, academic exchange, science communication, platform construction and other activities related to the development of NSFC.

The Original Exploration Projects aims 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 Basic Research Program for Young Students 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 program in 2023 are shown in Table 2-1-18.

**Table 2-1-18 Applications and Funding Statistics of the Fund for Special Purpose Program in 2023**

(unit: 10,000 yuan)

| No. | Types | | Grants | Direct costs |
|---|---|---|---|---|
| 1 | Research Projects | Comprehensive Research Projects of Scientific Departments | 430 | 67 026.50 |
| | | Emergency Projects of Department of Management Sciences | 32 | 673.00 |
| | | Theoretical Physics research Projects | 87 | 4 930.00 |
| 2 | Scientific and Technological Activities | Comprehensive Scientific and Technological Activities of Scientific Departments | 265 | 4 601.00 |
| | | Theoretical Physics Scientific Activity Projects | 18 | 790.00 |
| | | Shared Voyage Scientific Investigation Projects | 16 | 6 800.00 |
| | | Projects Entrusted by NSFC Bureaus and Offices | 86 | 3 330.00 |
| | | Special Funds for Poverty Alleviation | 6 | 150.00 |
| | | Shared Voyage Strategic Research Projects | 2 | 200.00 |
| 3 | Original Exploration Research Program | Original Exploration Research Program Based on Guidelines | 78 | 13 287.00 |
| | | Original Exploration Research Program Recommended by Experts | 68 | 14 979.00 |
| | | Extended Original Exploration Research Program | 10 | 1 946.00 |
| 4 | Basic Research Program for Young Students | | 129 | 1 290.00 |
| Total | | | 1227 | 120 002.50 |

## 1.15 Tianyuan Fund for Mathematics

Tianyuan Fund for Mathematics is set up to harness 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 researchers, 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 2023, the Tianyuan Fund for Mathematics received 481 applications, and 148 projects were funded with a total direct funding of 60 million yuan, and the average funding of direct costs was 405,400 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 is 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 2023 are shown in Table 2-1-19.

**Table 2-1-19 Application and Funding Statistics of Research Fund for International Scientists (by Scientific Department) in 2023**

(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 | 121 | 25 | 670.00 | 81 | 8 | 640.00 | 66 | 7 | 1 120.00 | 38 | 3 | 1 176.00 | 306 | 43 | 3 606.00 |
| Chemical Sciences | 162 | 21 | 576.00 | 42 | 3 | 240.00 | 51 | 6 | 960.00 | 31 | 2 | 784.00 | 286 | 32 | 2560.00 |
| Life Sciences | 123 | 39 | 1 296.00 | 56 | 11 | 880.00 | 71 | 11 | 1760.00 | 16 | 2 | 784.00 | 266 | 63 | 4 720.00 |
| Earth Sciences | 280 | 17 | 579.00 | 100 | 3 | 240.00 | 100 | 4 | 639.00 | 23 | 2 | 784.00 | 503 | 26 | 2242.00 |
| Engineering and Materials Sciences | 92 | 26 | 820.00 | 32 | 8 | 600.00 | 37 | 8 | 1 280.00 | 20 | 2 | 784.00 | 181 | 44 | 3 484.00 |
| Information Sciences | 211 | 9 | 299.00 | 83 | 6 | 480.00 | 73 | 8 | 1 280.00 | 26 | 2 | 784.00 | 393 | 25 | 2 843.00 |
| Management Sciences | 63 | 5 | 136.00 | 33 | 4 | 299.00 | 70 | 2 | 320.00 | 5 | 1 | 392.00 | 171 | 12 | 1 147.00 |
| Health Sciences | 141 | 4 | 140.00 | 40 | 4 | 320.00 | 21 | 9 | 1440.00 | 50 | 3 | 1 176.00 | 252 | 20 | 3 076.00 |
| Interdisciplinary Sciences | 44 | 4 | 120.00 | 35 | 3 | 240.00 | 51 | 4 | 560.00 | 8 | 1 | 392.00 | 138 | 12 | 1 312.00 |
| Total or average | 1 237 | 150 | 4 636.00 | 502 | 50 | 3 939.00 | 540 | 59 | 9 359.00 | 217 | 18 | 7 056.00 | 2496 | 277 | 24 990.00 |

## 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, talent 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 deepening 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) Exchange Programs in 2023 are shown in Table 2-1-20.

**Table 2-1-20 Application and Funding Statistics of International (Regional) Exchange Program in 2023**

(unit: 10,000 yuan)

| No. | Type | No. of Applications | No. of Grants | Direct Funding |
|---|---|---|---|---|
| 1 | Visits and Mobilities | 1042 | 199 | 4943.90 |
| 2 | Participation at Overseas Conferences/workshops | 129 | 69 | 231.40 |
| 3 | Organization of International Conferences/workshops in China | 69 | 26 | 439.00 |

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

## High-precision Quantum Manipulation and Detection

This Major Research Plan Project was approved in 2023, with a period of 8 years and a direct funding of 200 million yuan.

High-precision quantum manipulation and detection, stemming from the exploration of fundamental problems in quantum mechanics, is the inherent driving force for the development of quantum information technology. It provides new ideas, technologies, and methods for precision measurement and other fields. By constantly pursuing higher precision measurements of various physical quantities, it not only reveals new physical laws and phenomena but also promotes the emergence of new precision measurement devices, systems, and concepts. It provides new testing methods and research methods for scientific exploration, constantly pushing forward the rapid development of frontier disciplines. At the same time, high-precision quantum manipulation and detection is a cutting-edge field of interdisciplinary integration and development, which will comprehensively and actively promote the development of the entire scientific and technological field, playing an important role in economy, energy, national defense, civil affairs, etc.

This Major Research Plan Project aims to address the following three core scientific problems.

(1) New principles and methods for quantum enhancement. The improvement of the accuracy of quantum measurement technology is the core requirement of disciplines related to measurement and metrology. Focusing on the currently mature or highly promising precision measurement technologies, new principles and methods for quantum control and measurement can be further developed to improve measurement accuracy and sensitivity, thereby discovering new physics and promoting the development of quantum technology.

(2) High-precision quantum manipulation and detection technologies for the further development of quantum information. High-precision quantum manipulation and detection provide key tools and technical support for the field of quantum information science, and are the basic technologies for the development of related fields. The high-precision manipulation of quantum systems faces many technical challenges, such as manipulation accuracy, complexity, and scalability. Tackling these challenges through technological research and development can help promote and facilitate the further development of research in quantum simulation, cold molecules and chemistry, quantum computing, space quantum technology, etc.

(3) The application of quantum manipulation and detection technologies that surpass classical technologies. The mechanisms for high-precision measurements of several important physical quantities have been clearly defined and experimentally verified at present. It is extremely necessary to develop a batch of important quantum precision measurement devices and instruments next, taking the lead in demonstrating applications in exploring new physics beyond the standard model, astronomical observations, remote sensing, and inertial sensing.

The overall scientific goal is to achieve long-term strategic objectives such as expanding the way to test the fundamental principles of physics, realizing large-scale quantum information processing, precision remote sensing, and inertial sensing by developing high-precision quantum manipulation and detection technologies.

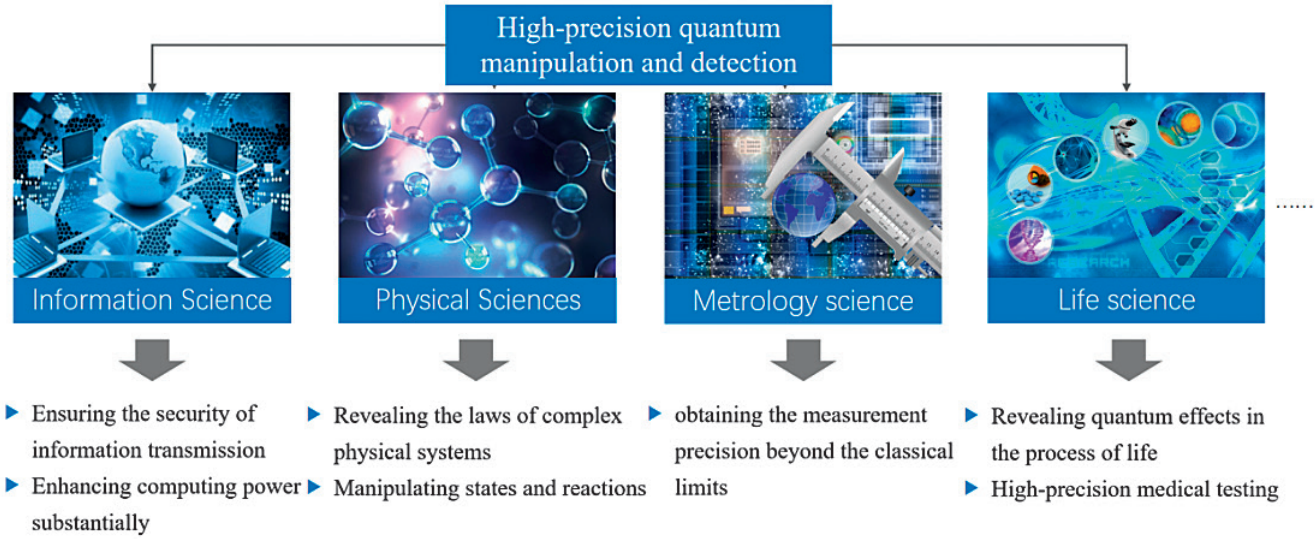


Figure.2-2-1 Intersection of multiple disciplines and high-precision quantum manipulation and detection technologies.

## Surface and Interfacial Sciences for Future Technologies

This Major Research Plan Project was approved in 2023, with a period of 8 years and a direct funding of 200 million yuan.

Surface and interfacial science is a multidisciplinary and interdisciplinary field, spanning key disciplines such as physics, chemistry, materials science, information technology, life sciences, energy technology, and aerospace. Its core scientific issues often encompass fundamental aspects of future technologies, including interface superconductivity, energy catalysis, intelligent sensing etc. The development of surface and interfacial science not only propels theoretical advances in these fields but also stands as a foundation for future technologies. As material science enters a new phase of interface exploration, its non-periodic, discontinuous, and non-uniform characteristics significantly increase the complexity of research, leading to exponential growth in challenges. This major research plan systematically extracts interface issues from various crucial technological fields, integrating surface science methodologies. Focused on the core scientific issue of ‘interface states’, it delves into precision intrinsic detection, accurate intelligent computation, and precise atomic construction, culminating in the creation of a box of methodologies and tools in surface and interfacial science. This groundwork is instrumental in advancing future technologies, thereby contributing uniquely to the forefront of scientific inquiry and bolstering the progression of national technological capabilities (see Figure2-2-2).

This Major Research Plan Project aims to resolve the following critical scientific problems:

**1. Principles of Deep Solid Interface State Detection:** The focus here is on pioneering new physical theories and technological approaches to overcome obstacles in detecting interface states, specifically targeting the direct detection of deep solid interface states. Additionally, the plan includes the development of advanced techniques for amplifying weak signals at the interface, enabling precise differentiation and interpretation of the intertwined signals from interface and bulk states.

**2. Theoretical Description and Calculation of Complex Interface States:** This involves investigating the intricate interactions at the interface that are dependent on distance, orientation, and time. The objective is to develop accurate models and calculations for non-periodic, discontinuous, and non-uniform interface systems, and to establish the interplay mechanisms of complex processes at interfaces, thereby facilitating the depiction and simulation of these processes across various temporal and spatial scales.

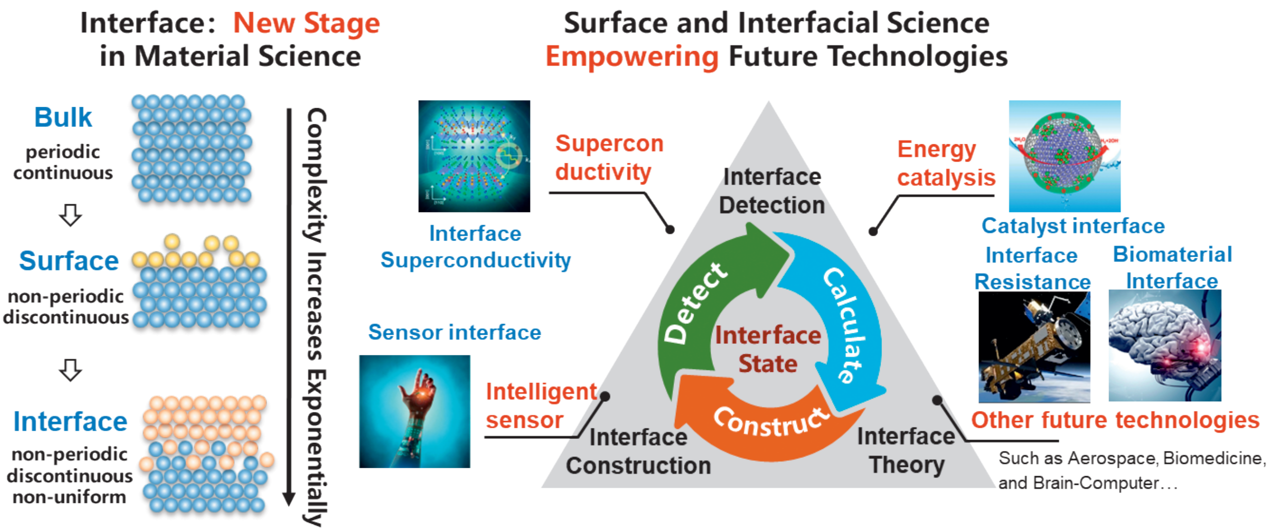



Figure.2-2-2 Focuses on 'common fundamental problems' in future technologies, developing universal surface and interfacial science methods and tools.

**3. Principles and Foundations for the Accurate Construction of Interface States:** Central to this is the comprehension of the fundamental principles underlying the construction of interface states, along with the establishment of a comprehensive theoretical model that bridges quantum mechanics and continuum mechanics. Crucial to this endeavor is the development of atomic-level precision techniques for constructing interface states, allowing for meticulous control over both the structure and electronic states of the interface.

**4. Fundamentals of Interface State Control for Specific Functions:** This focuses on unraveling the mechanisms by which interface states affect physical properties, with the aim of achieving accurate predictions that link interface structure, physical properties, and functional outcomes. The initiative will develop a systematic approach to the control of interface states, enabling precise adjustments of interface state functionalities for targeted applications.

The scientific object of this Major Research Plan Project is to tackle the prevalent interface challenges that are integral to the evolution of crucial future technologies. This objective will be approached through a synergistic collaboration across vital areas, including the development of theories for interface state formation and control, the creation of precise methodologies for constructing interface states, the advancement of high-resolution technologies for interface state detection, and the nuanced control of interface state functionalities. This concerted effort is directed toward gaining a profound understanding of interface properties and realizing groundbreaking technological advancements. By fostering interdisciplinary and cross-domain integration, this initiative seeks to assemble a team of top-tier talent and outstanding research groups. A key aim is to develop an exhaustive collection of interface state detection technologies and sophisticated computational tools. This will facilitate the meticulous and controllable construction of interface structures and functional systems, advancing the field of interface state engineering. Such efforts are expected to significantly boost our nation's innovative capabilities in essential technological fields, thereby paving new pathways for the development of future technologies.

## The Deep-Driving Mechanisms of Earth's Habitability

This Major Research Plan Project was approved in 2023, with a period of 8 years and a direct funding of 200 million yuan.

Earth is the only confirmed inhabitable planet in the solar system, and investigating into its development processes, driving factors, and mechanisms of Earth's habitability is crucial for predicting the future of our planet. It also serves as a vital foundation for finding more energy and resources, as well as sustaining human existence and promoting social sustainable development. This Major Research Plan Project, aligned with the important development concept of building a community of shared future for humanity and protecting the Earth's home, is centered on understanding the intrinsic mechanisms governing Earth's habitability, with a specific focus on the dynamic processes occurring deep within the Earth and their interplay with exospheres. Using the cycling of volatiles within the Earth's interior as a potential breakthrough point, the project aims to answer three interrelated core scientific questions (as shown in Figure 2-2-3) to decrypt the operating mechanism of Earth's habitability engine. The outcome of the project will help the implementation of China's "deep Earth" and "deep space" exploration strategies, embody the development concept of a community with a shared future for humanity, and make contributions to staying at the forefront of global technological competition while driving China's science and technology diplomacy.

The Major Research Plan Project aims to address the following three core scientific questions:

Distribution of deep C-H-O and Earth's internal properties: It is designed to clarify the occurrence, distribution, and content of volatile components (C-H-O) in the deep Earth's interior, to constrain the relative contributions of various geological processes to the global budget of volatiles, and to investigate the extent and mechanisms of the impact of volatiles on the properties of Earth's interior. The new data will be used to elucidate the causal connection between volatiles and major deep structures of Earth, such as large low-shear-velocity provinces, ultra-low velocity zones, and areas with electrical conductivity anomalies.

Cycling of deep C-H-O and Earth's dynamic processes: It is desirable to reveal the transport mechanism and cycling dynamics of C-H-O during plate subduction, to elucidate their control on (big) mantle wedge melting, and to clarify the role of volatiles in the origin of mantle superplumes and the formation of large igneous provinces. Through studying the behavior of volatiles during the interaction between mantle plumes and subducting slabs, it aims to understand fluid-induced melting and the effect of the combined high-temperature thermal anomalies and volatile invention on large-scale mantle melting.

Mechanisms linking deep and shallow Earth and Earth's habitability: It is designed to understand the formation of super volcanic systems and their links with large magma reservoirs and volatile inventory, and to elucidate their environmental/climatic effects and biological responses. Experiments will conducted to simulate the reactions of bridgmanite, perovskite, and $SiO_2$ with water under deep mantle conditions in order to determine the stable temperature-pressure conditions and physical properties of superoxides produced from new deep chemical reactions. Finally, multi-disciplinary data will be integrated to investigate the role of new deep chemical reactions as an engine in connecting Earth's deep-shallow systems and driving major geological events in Earth's evolution.

The overall scientific goal of this Major Research Plan Project is, by using the "catalytic role" of deep volatiles and new chemical reactions under deep conditions as an entry point, to elucidate the impact of volatiles on the physical properties, dynamic processes, and interactions between different spheres within the Earth's interior. The Project aims to unravel the mysteries of the deep engine and to establish a theoretical framework for the deep processes that drive the evolution of Earth's habitability.

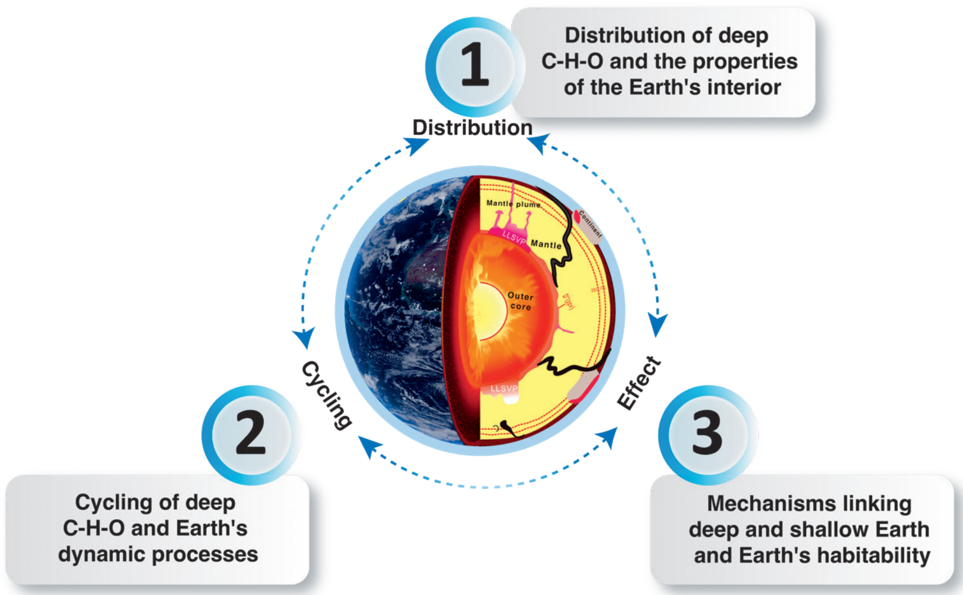



Figure 2-2-3 The Interconnected Schematic of the 'Deep Earth' Program's Three Core Scientific Questions.

## Deciphering Life's Glycocode

This Major Research Plan Project was approved in 2023, with a period of 8 years and a direct funding of 200 million yuan.

Glycan is one of the three biological macromolecules that make up life. Mainly located on the cell surface, glycans play essential roles in mediating the cell-cell interaction and cell-pathogen interaction in extracellular space. Therefore, the sequence of glycans carries important life information in multiple cellular organisms. In this regards, glycan is considered "the third chain of life" in addition to nucleic acids and proteins and is involved in almost every human disease. However, compared with nucleic acids and proteins, glycans have much higher degree of chemical complexity, making it an underexplored virgin land in modern life sciences. Aiming at this life science frontier in the post-genomic era, this major research plan proposes to study the function of glycans from a bioinformatics perspective. By developing tools to read the information carried by glycan sequences, this major research plan Project hopes to decipher life's "glycocode" and to find answers for the unsolved problems in human health and life sciences. Eventually, this major research plan Project aims to develop novel diagnostic and therapeutic strategies for major human diseases, which will lay the foundation for the future development of glycan-related biotech industry in China.

The core scientific questions to be addressed include:

1. Establishing efficient methods for sequencing, synthesis and editing of glycans. Data is the basis for information decoding. The development of such research tools are the key to promote multidisciplinary research of glycan functions.

2. Elucidating the biological functions of glycans. Due to the high degree of information capacity of glycan sequence, developing methods of dimensionality reduction and module analysis is necessary to elucidate the biological function of glycan sequences and related regulation mechanism in various biological scenarios, such as glycan-protein interactions, pathogen-host interactions, and tumor-immune

interactions.

3. Developing glycan-related therapeutic strategies for major human diseases. Based on the molecular functions of glycans in pathological processes such as viral infection, autoimmunity, and tumor progression, corresponding therapeutic strategies can be developed such as glycan-optimized vaccines, in situ glycocode editing tools.

The long term goal of this Major Research Plan Project is to improve the understanding of major human diseases through decoding the life information carried by glycan beyond the central dogma. It aims to generate new methods, new tools and new research models for glycan research, to make breakthroughs in the discovery of biological functions of glycans, and to develop glycan-based strategies for the diagnosis and treatment of related diseases. The implementation of this Major Research Plan Project will cultivate an interdisciplinary research team and eventually enhance China's pioneering position in glycan-related life sciences in the world.

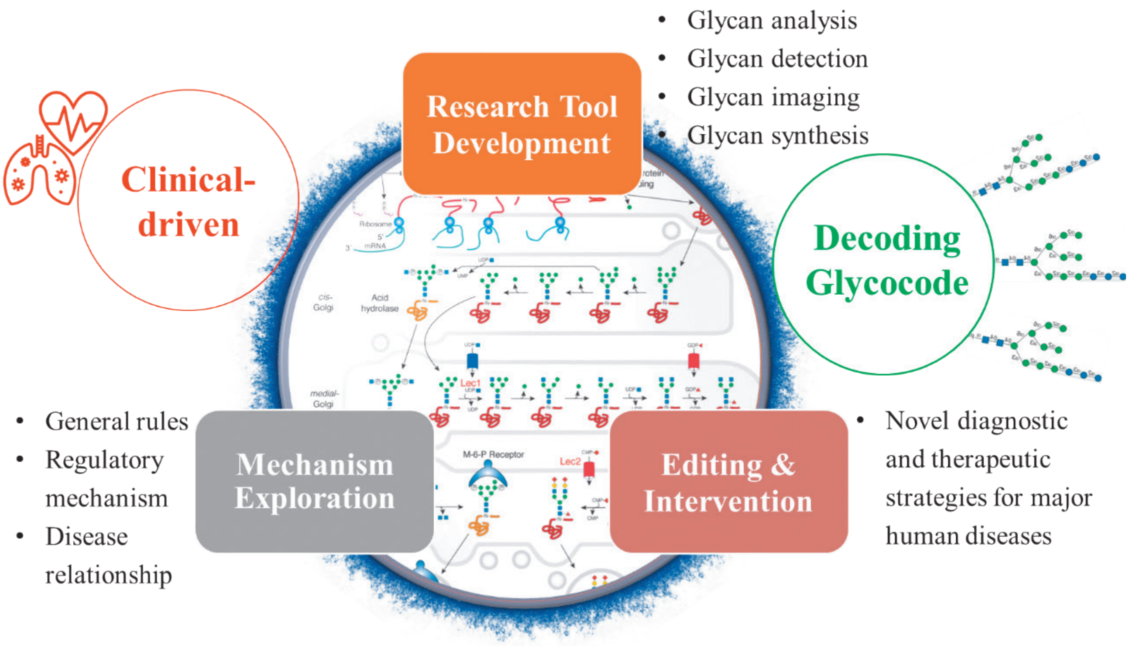



Figure. 2-2-4 The overall strategy for "Deciphering Life's Glycocode".

# PART 3

## Funding Achievement Tour

NSFC

# Finite Quotient Groups of Fundamental Groups of 3-Manifolds

Under the support of the National Science Foundation of China (National Science Fund for Distinguished Young Scholars Project 11925101), Yi Liu from Peking University has made breakthrough advances in low dimensional topology and hyperbolic geometry, proving that the fundamental group of any finite-volume hyperbolic 3-manifold is almost determined by the collection of its finite quotient groups, up to at most finitely many possibilities. This work was published in *Inventiones Mathematicae* in 2023, entitled "Finite-volume hyperbolic 3-manifolds are almost determined by their finite quotient groups".

In 3-dimensional topology over the past forty year, the geometrization program after Thurston emphasizes the decisive influence of the fundamental group on the topology of the manifold, and especially the significant role of hyperbolic geometry in the study. The development of 3-manifold topology over the past decade have been converging, from individual finite covers, to the system of all finite covers. Liu creatively combines recent new methods on finite cover constructions, and the traditional Nielsen fixed point index theory. As a key step, Liu establishes the invariance of the Thurston norm under the assumptions of the main theorem.

Liu is an invited speaker at the 2022 International Congress of Mathematicians.

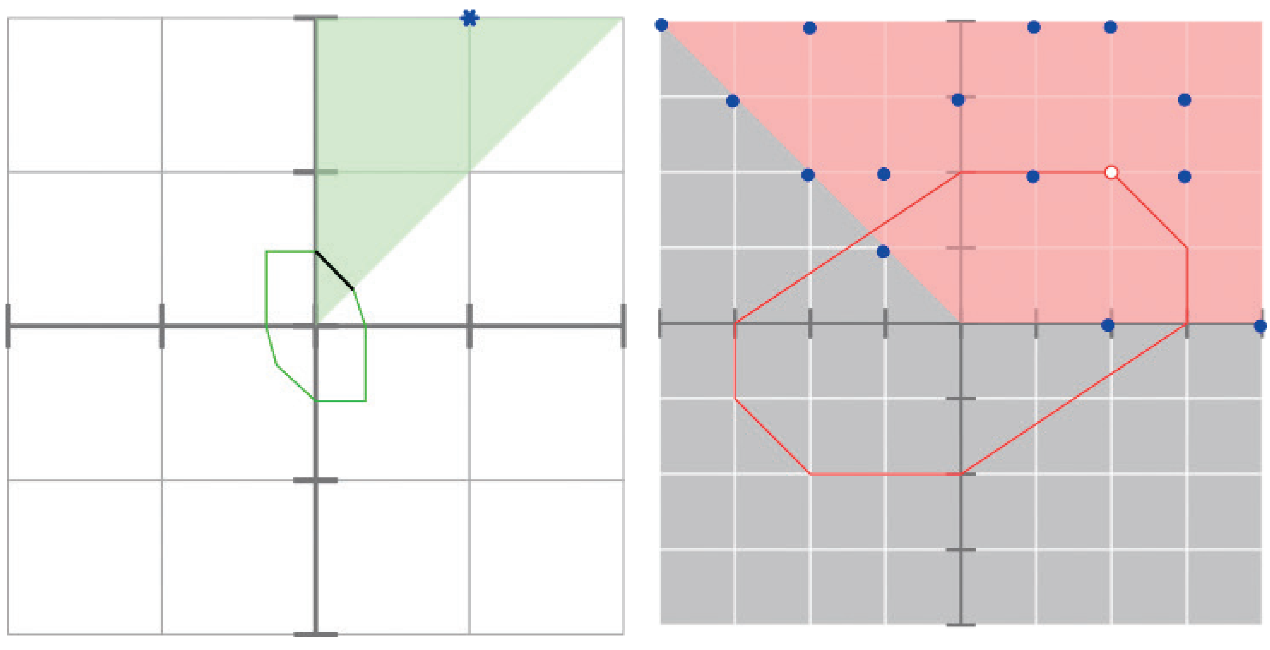


Fig.3-1-1 An illustration of the Thurston norm for finite-volume hyperbolic 3-manifolds. Left: the Thurston norm unit ball and a fibered cone in the first cohomology. Right: the dual unit ball, the dual cone, and some homolog classes of periodic orbits in the first homology.

# Programming 3D Curved Mesosurfaces Using Novel Microlattice Designs

Marrying electronics with biological systems in 3D geometric layouts would generate a broad spectrum of potent technologies for intelligentsensing, implantable energy harvesting, biomedical practices, human-machine interactions and so on. However, the manufacturing of 3D electronics with complex topological configurations remains highly challenging. While the mechanics-guided 3D assembly approach represents one of the most promising manufacturing approaches of 3D inorganic electronics, the programming of 3D curved geometries with desired curvature distributions remains elusive, due to the highnonlinearity induced by largedeformations, the complex 2D-3D mapping, and the technical challenges in finely tuning stiffness distribution of micro-films. Supported by the National Natural Science Foundation of China (Innovative Exploration Program 12050004, National Science Fund for Distinguished Young Scholars Project 12225206), a research team led by Prof. Yihui Zhang from the Laboratory of Flexible Electronics Technology in Tsinghua University, reported progress in programming 3D curved mesosurfaces.

Cellular microstructures form naturally in many living organisms to provide diverse and vital functions in their 3D shape formation, synthesis/transport of nutrients, and regulation of growth/reproduction (Fig.3-1-2a). Inspired by cellular biological surfaces, Prof. Yihui Zhang led his group at Tsinghua University to develop a microlattice design strategy as a powerful route to achieve desired stiffness distribution of 2D micro-films, thereby allowing their transformation into programmable 3D curved mesosurfaces through the mechanically-guided assembly. A beam-based mechanical model is established for the inverse design of target 3D symmetricalcurved mesosurfaces from 2D microlattice patterns with optimized distributions of porosity and cell sizes, along with a machine-learning-aided computational approachcapable of implicitly mapping the curvature distributions of 3D complex mesosurfaces and the corresponding design parameters of 2D microlatticestructures (Fig. 3-1-2b). With the developed microlattice designs, this work presents more than 30 examples of rational assembly of regular curved mesosurfaces and complex biological mesosurfaces, in diverse materials (e.g., silicon, metal, chitosan and graphene), with feature sizes spanning from ~ 2.7 μm to 30 μm in film thickness, and ~ 250 μm to 30 mm in lateral dimension. The bioinspired microlattice designs allow construction of 3D electronic systems with desired curvature distributions. Demonstrations of conformable cardiac electronic device, stingray-like dual-mode actuator and 3D electronic cell scaffold suggest rich opportunities in fields of bioelectronics, microelectromechnical systems, micro-robotics and so on.

The research results were published in Science on March 23, 2023, with the title of “Programming 3D curved mesosurfaces using microlattice designs”, which was featured on the Table of Contents of Science and extensively covered by research institutes and news media (e.g., NSFC, TechXplore and MIT Technology Review China). Nature published a Research Highlight paper entitled “microstructures mimic life’s endless forms” to report this work, highlighting that the bioinspired microlattice strategy “allows scientists to recreate biological shapes in a wide variety of materials”.

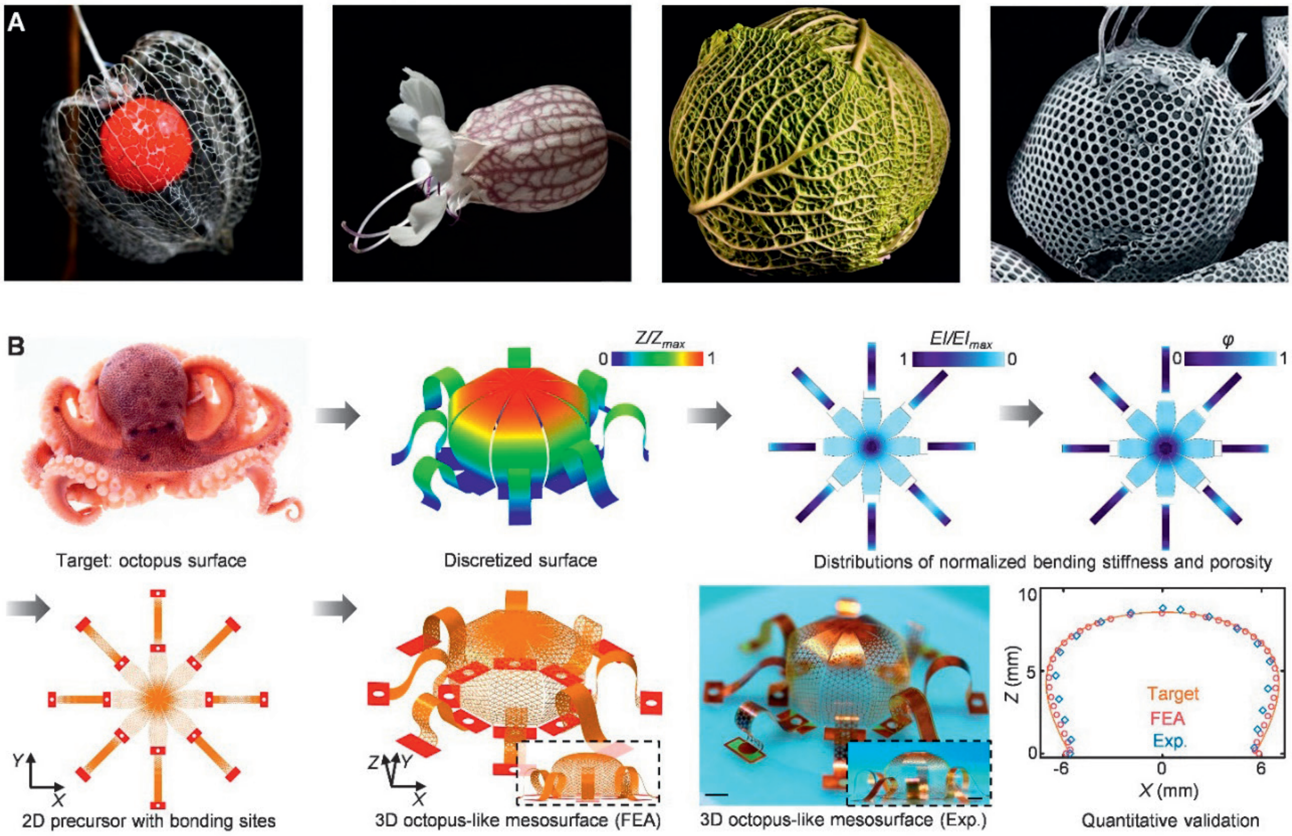



Figure 3-1-2 Programming of 3D mesosurfacesusing bioinspired microlattice designs. (A) 3D cellular microstructures in living organisms. (B) Design and assembly of an octopus-like mesosurface based on the microlattice designs.

## Research on the Chemical Signatures of Very Massive First-generation Stars

The first-generation stars dominated the chemical enrichment and evolution of the early universe. Numerical simulations of the formation of the first-generation stars predict that the mass of the first-generation stars can reach up to several hundred solar masses. Among them, the first-generation stars with masses between 140 and 260 solar masses would end up as pair-instability supernovae (PISNe) with the creation of electron-positron pairs. The PISNe are quite different from ordinary supernovae (i.e. core-collapse supernovae) and would have imprinted unique chemical signature in the atmosphere of the next generation stars. However, no such signature has been found by decades of observations.

With the support of the National Science Foundation of China (Basic Science Center Program 11988101, 12288102, Major Program 11890694, Excellent Young Scientists Fund Program 12222305), an international team led by Prof. Gang Zhao from the National Astronomical Observatories, Chinese Academy of Sciences has identified a chemically peculiar star in the Galactic halo to be a clear evidence of the existence of pair-instability supernovae (PISNe) from very massive first-generation stars in the early universe, based on the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) survey. This star has been confirmed to be formed in the gas cloud dominated by the yields of a PISN from first-generation stars with 260 solar masses, refreshing the understanding of the mass distribution range of the first-generation stars.

Figure 3-1-3 The second-generation stars retain the products of supernovae from the first-generation stars.

The team performed a large sample study of metal-poor stars with extremely low magnesium abundance based on LAMOST data, and identified the first metal-poor star with an abundance pattern from PISN models. Compared to all other known stars, this star has the lowest sodium abundance and the

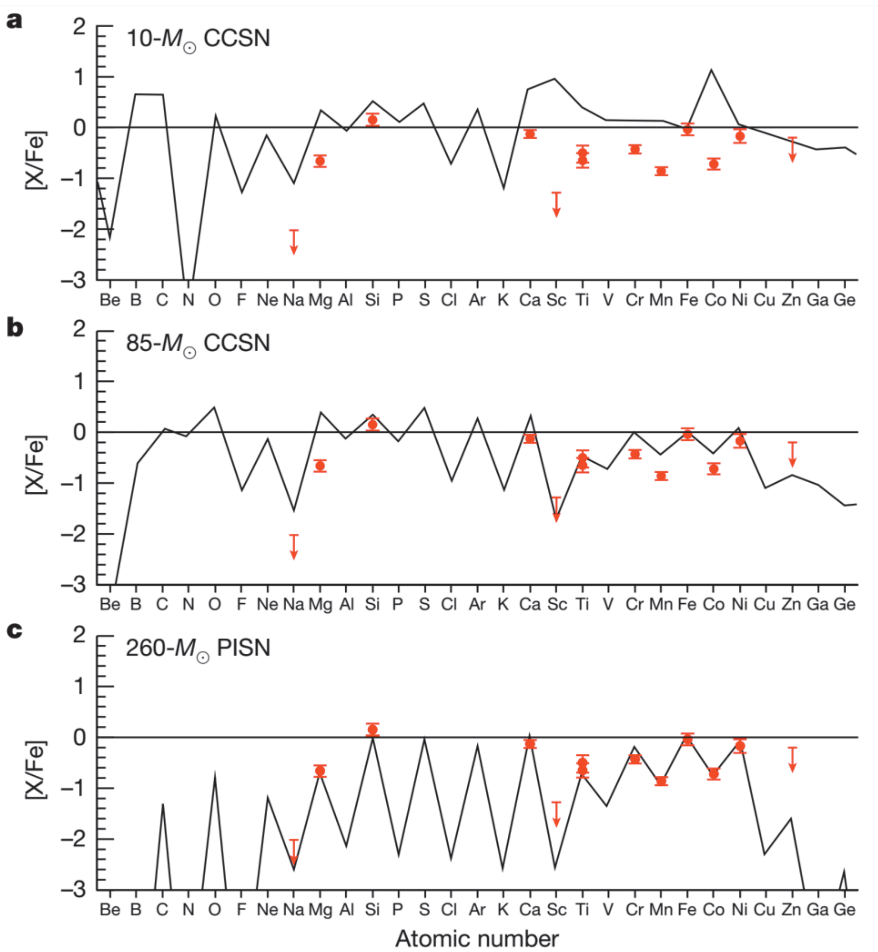



Figure 3-1-4 A metal-poor star with abundances from a PISN. Abundances of the star are shown as red filled circles. The solid lines represent supernova models.

most significant odd-even effect (very large abundance variance between the odd and even charge number elements). This is the first time to confirm that the mass of first-generation stars can reach up to several hundreds of solar masses and PISN from very massive first-generation stars have contributed to the chemical enrichment of the early universe, which is of great significance to study the initial mass function of the first-generation stars and chemical evolution of galaxies.

The results were published in *Nature* entitled “A metal-poor star with abundances from a pair-instability supernova” on June 7, 2023. Prof. Tim Beers from University of Notre Dame, an expert in the field of metal-poor star observation, commented that “This paper is one of the most important papers over the past decade for understanding the nature of the very first stars in the universe. We have not seen any signatures before this paper that very massive first-generation stars have formed. We can design survey to find stars with similar abundances to this star in future.”

## Structure Evolution at the Electrode Interface in Hydrogen Evolution Reaction

With the gradual reduction in the cost of solar and wind power generation, electrolysis of water for hydrogen production has become an efficient method for converting and storing clean renewable energy. It is well known that the efficiency of electrocatalytic processes depends on the physical and chemical properties of the interface. However, in complex solution environments, how to achieve molecular-level control and detection of interfacial layering structures poses an urgent and complex challenge for electrocatalysis research. Recently, with the support of grants from the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars 12125403, General Program11874123, Creative Research Group12221004, Major Program12293053), Prof. Chuanshan Tian’s research group at Fudan University has made progress in the study and characterization of the microstructural evolution of electrochemical interfaces. The research team utilized a newly developed high precision nonlinear spectroscopic technique to investigate the evolution of the microstructure of electrochemical interfaces as a function of electrode voltage in situ, obtaining the spectroscopic fingerprints of interfacial water molecules directly involved in charge transfer during hydrogen evolution in water electrolysis. The main innovative findings are as follows:

(1) A novel method has been invented to prepare substrate-free and suspended centimeter-scale graphene electrodes, which not only avoids surface contamination but also preserves the integrity and good mechanical properties of the samples at both macroscopic and microscopic levels. This successfully solved the experimental challenge of probing the intrinsic properties of graphene. By bringing platinum wires into contact with the suspended graphene sample, continuous control of the graphene Fermi level and electrode potential on the water surface was achieved (Figure 3-1-5A, 3-1-5B).

(2) Using the nonlinear spectroscopic analysis technique, the characteristic peak of the O-H dangling bond at the graphene-water interface was observed for the first time, confirming the hydrophobicity of graphene. Through in situ electrochemical control and spectroscopic analysis, it was found that the hydrogen bonding network adjacent to the electrode (Stern layer) is almost insensitive to voltage within the voltage threshold window for hydrogen and oxygen evolution (Figure 3-1-5C). Only when the voltage approaches the electrolysis threshold of water does the structure of the Stern layer undergo substantial changes. It was discovered that when the voltage is slightly higher than the threshold for hydrogen evolution, the dangling O-H mode at the outermost surface completely disappears (Figure 3-1-5D), indicating that the intermediates and products of the hydrogen evolution reaction begin to aggregate at the electrode interface, significantly influencing the hydrogen bonding network structure.

The above research findings are titled “Structure evolution at the gate-tunable suspended graphene-water interface” and were published in the journal *Nature* on August 30, 2023. This work provides an ideal model system for studying electrochemical interfaces and lays the experimental foundation for tracking and controlling microreactive pathways at the molecular level.

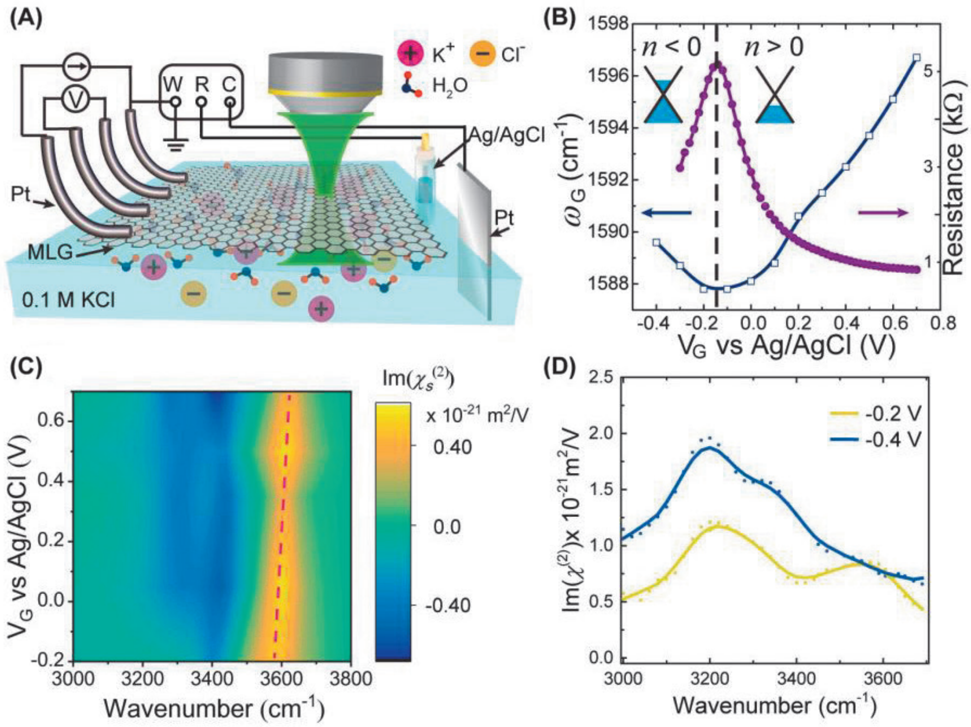



Figure 3-1-5 Investigating the microstructural evolution at the electrode interface in hydrogen evolution reaction based on substrate-free suspended graphene. (A) Illustration of the graphene-electrolyte interface. (B) Fermi level of graphene versus gate voltage. (C) Contour plot of the Stern layer spectra at different gate voltage. (D) The dangling O-H peak (@~3600 $cm^{-1}$) which exhibits the hydrophobic of graphene disappears when the gate voltage exceeded the threshold of the hydrogen evolution reaction.

## Discovery of a High-$T_c$ Nickelate Superconductor under Pressure

Exploration of unconventional superconductors and elucidation of their mechanism has been one of the most important frontiers in condensed matter physics for more than 40 years. Investigations on copper oxide high-$T_c$ superconductors and iron-based superconductors have shed important information on the role of magnetism, electronic correlations, and emergent orders. However, the mechanism of unconventional superconductivity is still a mystery. Cuprates are the only family that hosts high superconducting transition temperature above the boiling point of nitrogen at ambient pressure. New high-$T_c$ superconductors are highly desired to elucidate the mechanism of unconventional superconductivity and extend their applications. Supported by the National Natural Science Foundation of China (General Program 12174454, Young Scientists Fund11904414, 11904416), a research team led by Prof. Meng Wang at the School of Physics Sun Yat-sen University and collaborators have made important progress. A new high-$T_c$ superconductor, the bilayer nickelate $La_3Ni_2O_7$, was discovered to be superconducting under 14 GPa at 80 K. The main innovative results are as follows: 1) High-quality single crystals of $La_3Ni_2O_7$ were grown with high oxygen pressure floating zone furnace. The single crystals are metallic and show evidence of density-wave-like transitions. 2) By measuring the resistance using the diamond anvil cell, superconductivity with the critical transition temperature of 80 K was found above 14 GPa. The crystal structure and electronic band structure were also determined.

The above research entitled "Signatures of superconductivity near 80 K in a nickelate under high pressure" was published in *Nature* on July 12th, 2023. This work demonstrates that $La_3Ni_2O_7$ is the second high-$T_c$ superconductor with $T_c$ above the liquid nitrogen boiling point. $La_3Ni_2O_7$ is also the first nickelate bulk superconductor with the perovskite structure and $NiO_6$ octahedra. The reviewers highlighted this work as "a breakthrough", "outstanding importance", "this highly significant result", and "of the utmost importance" etc. This work has a worldwide impact on the high-$T_c$ superconductor community. Professor Matthias Hepting published a recommendation paper entitled "Elite superconductor club has a new member" [Nature 621, 475(2023)]. Based on this discovery, Meng Wang collaborating with Professor Daoxin Yao proposed a multiple orbital model which has been a fundamentally theoretical work on $La_3Ni_2O_7$ [Physical Review Letters 131, 126001(2023)]. The details of the single crystal growth and properties at ambient pressure were reported previously by the same group [Sci. China-Phys. Mech. Astron. 66, 217411 (2023)].

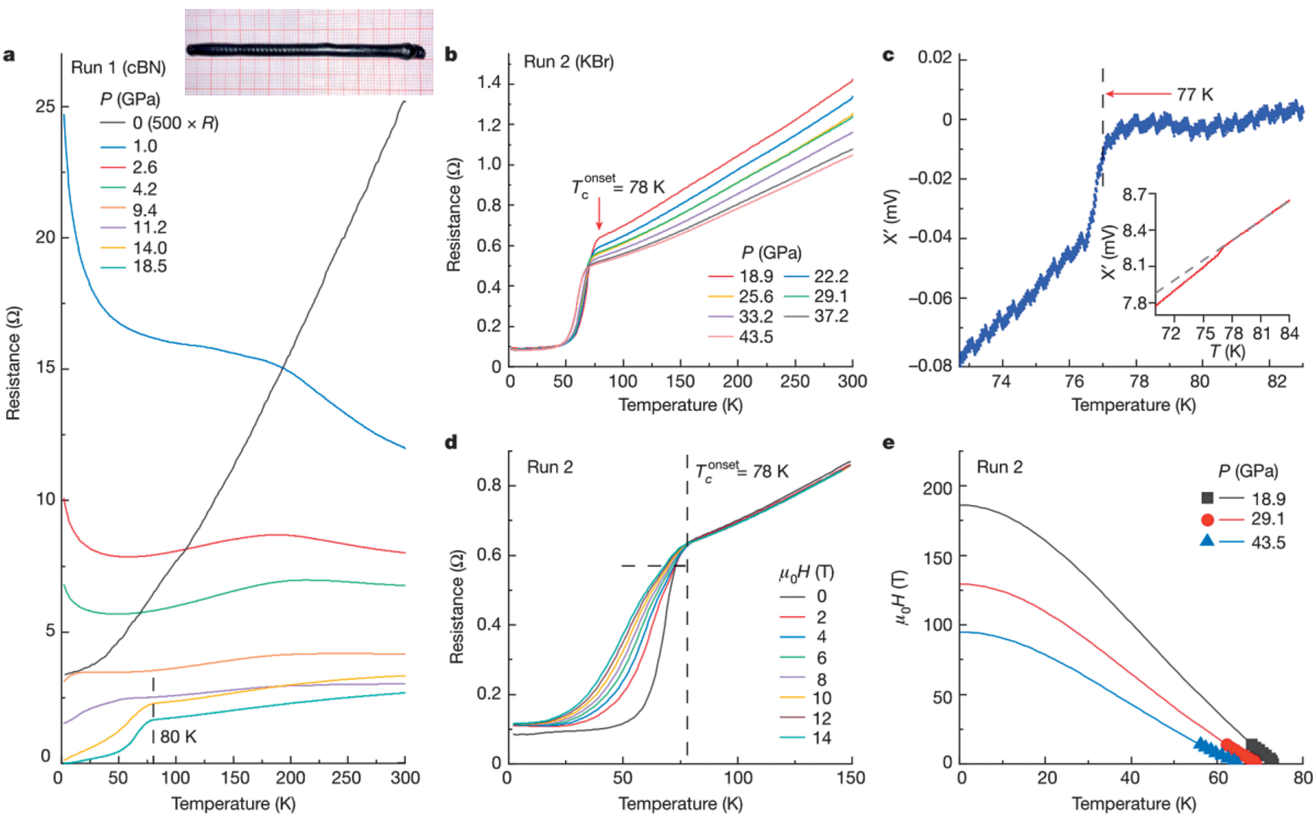



Fig 3-1-6 Superconducting transitions in $La_3Ni_2O_7$ single crystals under pressure. a, b, and d, Resistance of $La_3Ni_2O_7$ versus temperature at various pressures and temperatures. c, The *ac* susceptibility showing a prominent diamagnetic response at 25.2 GPa. e, The Ginzburg-Landau fittings of the upper critical fields, $\mu_0H_{c2}$ at pressures of 18.9, 29.1, and 43.4 GPa.

## Study of the Luminance of Dark Matter from Xenon Recoil Data

Over the past century, a large number of astronomical and cosmological observations have confirmed the existence of a substantial amount of unknown matter in the universe, including phenomena such as galaxy rotation curves, galaxy distributions, and cosmic microwave background radiation. These observations are all based on gravitational interactions, and the unknown matter has never been directly observed through electromagnetic interactions. Therefore, it is referred to as "dark matter." Until now, the fundamental properties of dark matter particles remain unknown. They are generally believed to be electrically neutral but may resemble electrically neutral neutrons, possibly composed of charged components forming a composite state. As a result, they may exhibit a weak interaction with photons and possess electromagnetic properties such as charge radius, electric dipole moment, magnetic dipole moment, and anapole moment, contributing to their faint "brightness."

Under the financial support of NSFC funding (Major Program 12090061), Professor Liu Jianglai and Professor Zhou Ning's team at Shanghai Jiao Tong University conducted research on the faint electromagnetic properties of dark matter using experimental data from the PanaX-4T liquid xenon detector. An upper limit on the charge radius of dark matter is obtained for the first time and the following are the major innovative achievements:

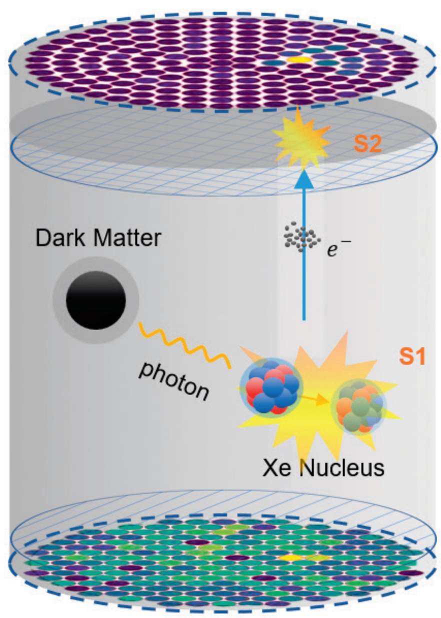



Figure 3-1-7 A diagram of photon-mediated interaction in xenon detector.

In contrast to the traditional assumption of short-range interactions, the electromagnetic properties of dark matter will generate long-range interactions through the exchange of photons with xenon nuclei, exhibiting unique recoil characteristics. Based on the effective field theory developed by Professor Wick Haxton, a member of the National Academy of Sciences in the United States, the team converted electromagnetic interaction into linear combinations of effective operators and got the corresponding recoil spectra of each electromagnetic property.

The team conducted a search for the electromagnetic properties of dark matter based on the high-sensitivity data from PandaX-4T. They obtained the world's first experimental upper limit on the charge radius of dark matter. The lowest excluded value reached 1.9×10^(-10) femtometer squared, and is more stringent than that for neutrinos by 4 orders of magnitude. The constraints of other electromagnetic properties including millicharge, electric dipole moment, magnetic dipole moment, and anapole moment are also significantly improved by 3-10 times. They provide a quantitative answer of the fundamental question of how "dark" dark matter truly is, from particle physics perspective.

The above research results were published in *Nature* on May 17, 2023, under the title of "Limits on the luminance of dark matter from xenon recoil data". As one of the initial achievements of the PandaX-4T experiment, this accomplishment significantly deepens our quantitative understanding of the fundamental electromagnetic properties of dark matter. It is also the first time that a dark matter direct detection experiment has published an article in Nature. The reviewer of Nature comments that "So the PandaX-4T result is the most sensitive one, providing the strongest constraints on dark matter electromagnetic properties and the first one on its charge radius". Professor Yang Bai from the University of Wisconsin-Madison published a commentary article titled "Dark matter is darker," in which he says "the publication in *Nature* by the PandaX Collaboration showcases the impressive capabilities of the PandaX-4T experiment in the search for dark matter particles. Even with just the data collected during the commissioning run, the experiment has achieved the most stringent constraints on dark matter electromagnetic interactions to date. Undoubtedly, when the collaboration completes their full-scheduled science run in the near future, we can anticipate even more significant advancements in our understanding of dark matter".

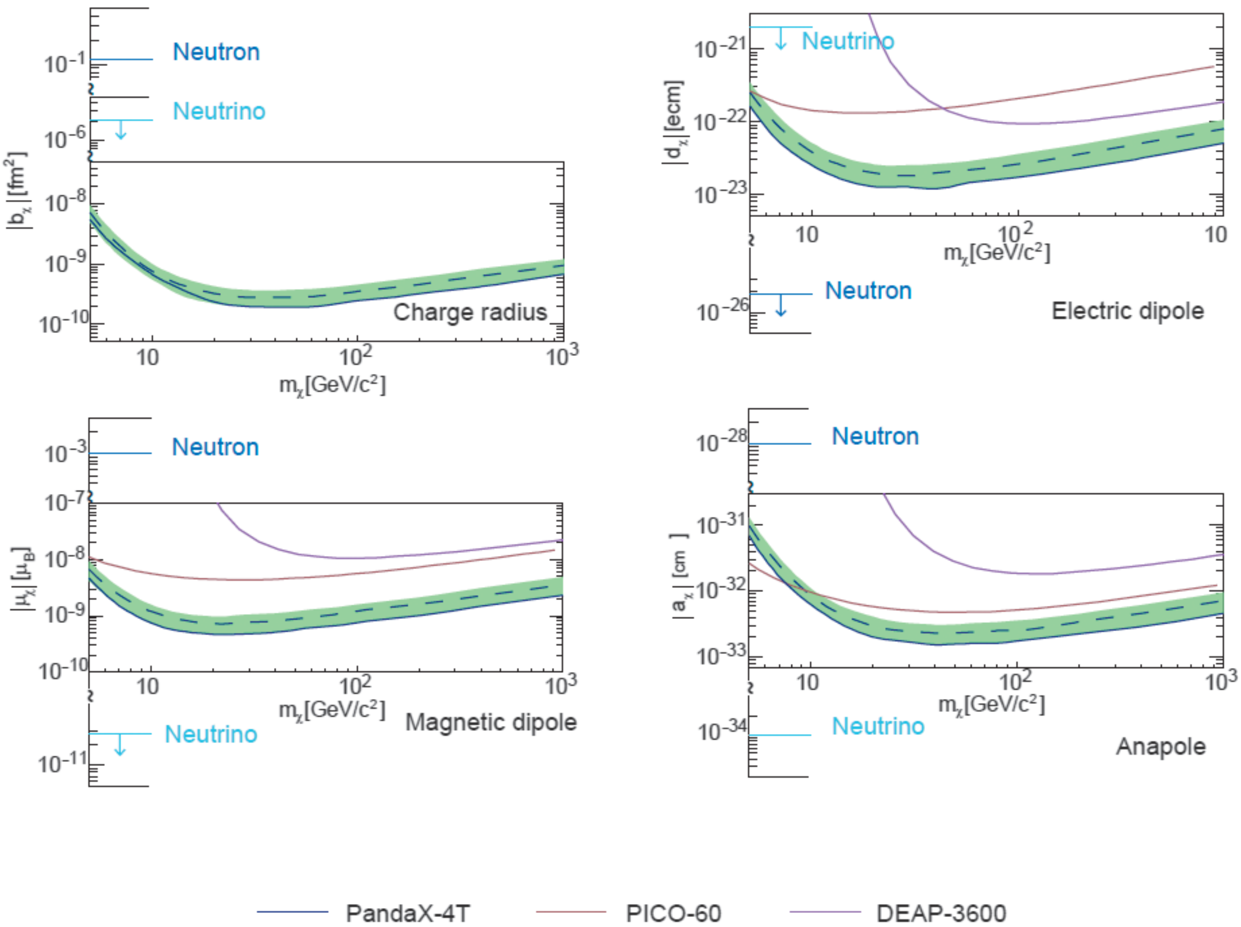



Figure 3-1-8 Constrains on the luminance of dark matter from PandaX-4T experiment.

## 1D-to-3D Topological Condensation: Click Chemistry in Zeolite Synthesis Enabling a Stable Three-dimensional Extra-large-pore Zeolite

Supported by the National Natural Science Foundation of China( Basic Science Center Project 22288101, International (Regional) Cooperative Research Project 21920102005), the team of Prof. Jihong Yu and Fei-Jian Chen from Jilin University, together with domestic and international collaborators, have made significant progress in the synthesis of novel three-dimensional stable extra-large pore zeolite. The work, titled "A 3D Extra-Large-Pore Zeolite Enabled by 1D-to-3D Topotactic Condensation of a Chain Silicate" was published online on January 20, 2023 in *Science*.

Zeolites are a class of crystalline microporous materials, which has a wide range of applications as catalysts and adsorbents in the fields of petroleum refining, petrochemicals, coal chemical industry, and daily-use chemical industry, because of their tunable active centers, molecular selectiveadsorption and separation, and excellent hydrothermal stability. Due to the unclear crystallization mechanism of zeolites, it is extremely challenging to realize the targeted synthesis of specific zeolite structures, among which three-dimensional stable extra-large pore zeolite has always been the a significant challenge, which has been difficult to breakthrough.

The researchers first synthesized a novel 1D chain silicate, ZEO-2, which underwent direct topological

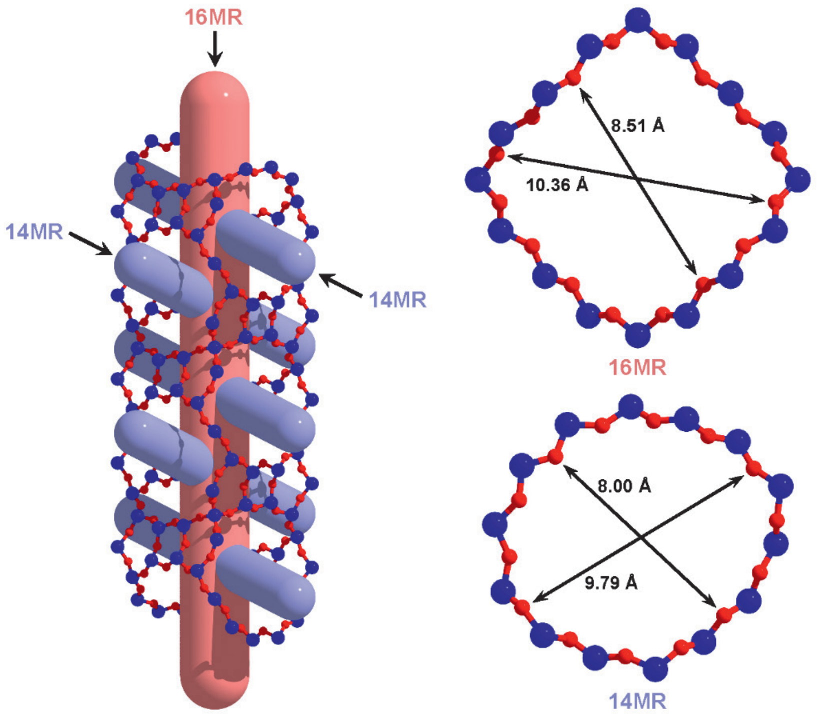



Fig. 3-1-9 3D 16*14*14MR Extra-Large Pore System in ZEO-3

condensation by calcination to generate a 3D stable full-connected extra-largepore zeolite, ZEO-3. ZEO-3, with a 16*14*14 membered rings (MR) interspersed extra-largepores (Fig.3-1-9), is the first stable pure silica zeolite with 3D stable full-connected extra-largepores, which is the less dense polymorph of silica known so far. It is ultra-stable even under calcination at 1200°C.With a specific surface area over 1000 $m^2$/g, ZEO-3 shows an extraordinary performance for Volatile Organic Compounds (VOCs) abatement and recovery superior to other commercial zeolites and even metal organic frameworks (MOFs).Further by incorporating heteroatoms as active centers,ZEO-3 is expected to play an important role in catalytic reactions involving bulky molecules.

Discovery of the new 1D-to-3D topological condensation mechanism in this research is of great significance for the design and synthesis of new zeolites that cannot be synthesized by conventional hydrothermal synthesis, and *Science* has published a perspective paper by Prof. Russell E. Morris of the University of St. Andrews in the same issue, comparing this 1D-to-3D topological condensation to "click chemistry " in zeolite synthesis (Fig. 3-1-10), pointing out that the discovery of this mechanism will definitely lead to new topologies, which is very attractive for the breakthrough in the laboratory synthesis of a large number of new structures of zeolites predicted by theory. The material has also been granted the structure code JZT (Jilin University-ZEO-3) by the International Zeolite Association.

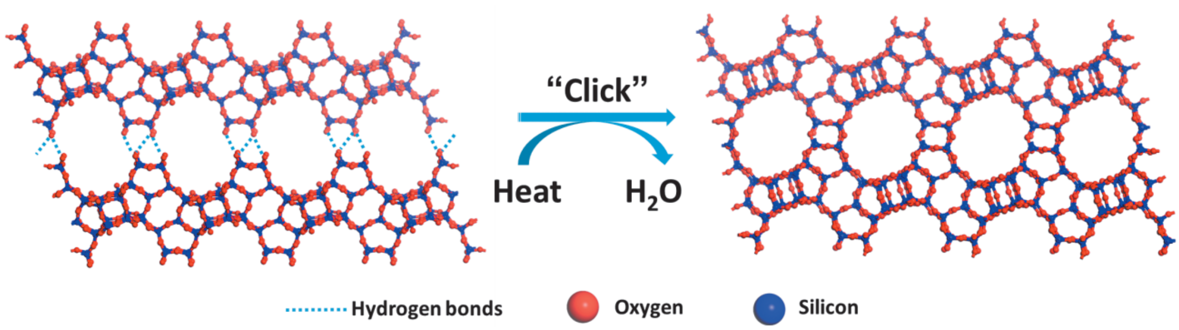



Fig. 3-1-10 1D-to-3D Topological Condensation: "Clicking Chemistry" in Zeolite Synthesis

## Atomic Manufacturing via Liquid Metal

Under the support of the National Natural Science Foundation of China (The National Science Fund for Distinguished Young Scholars 22025303), Lei Fu's research group from Wuhan University, in collaboration with Yuzheng Guo's research group from Wuhan University and Junhao Lin's research group from Southern University of Science and Technology, have realized the atomically precise synthesis (i.e. atomic manufacturing) of high-entropy alloys(HEAs) through using liquid metal as thereaction medium. The research titled "Liquid metal for high-entropy alloy nanoparticles synthesis" was published in *Nature* on June 14th, 2023.

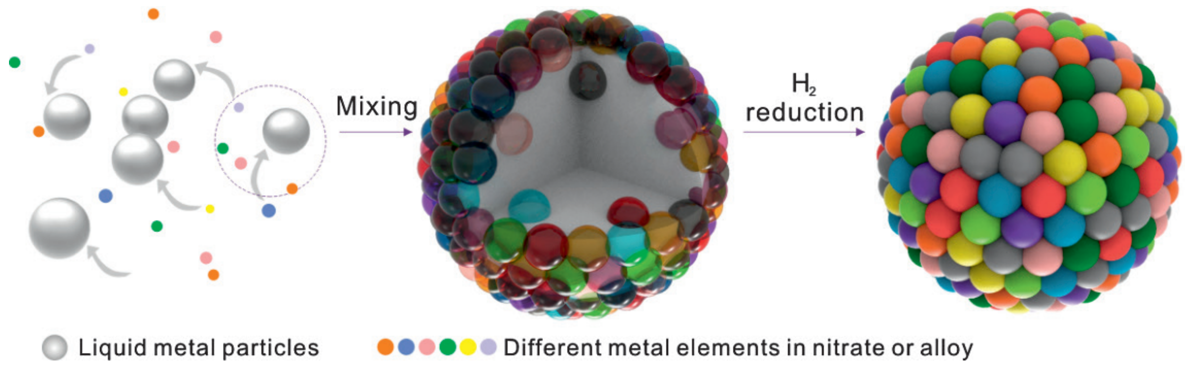



Figure 3-1-11 Schematic diagram of the atomicmanufacturingof HEAsvialiquid metal.

HEAs are usually composed of more than five principal metal elements. As a new type of alloy breaking the traditional alloy design philosophy, they exhibit unique and exceptional properties, making them promising for various applications, such as aerospace and biomedical fields. However, the immiscibility originated from the vast difference in physicochemical properties among various elements leads to phase separation and element segregation. At present, researchers mainly utilize high reacting temperatures and quenching to increase the entropy contribution to synthesize HEAs. Such extreme reaction conditions make it difficult to achieve the precise regulation of the composition and structure of HEAs (i.e. atomic manufacturing). Meanwhile, it is not in favor of the demand for scale production. Therefore, it is vital to realize the atomic manufacturing of HEAs under mild reaction conditions.

To solve this problem, Lei Fu's research group puts forward a new idea of regulating mixing enthalpy to achieve the atomic manufacturing of HEAs under mild reaction conditions via the liquid metal reaction system. Liquid metal Ga (melting point: 29.8°C) endowing negative mixing enthalpy with mostly metal elements can create a negative mixing enthalpy environment to decrease Gibbs free energy, which is beneficial to the synthesis of HEAs from the perspective of thermodynamics. Meanwhile, the unique fluidity of liquid metal Ga could facilitate the mass transfer, resulting in the uniform mixing of multiple metal elements dynamically. Thus, various HEAs with a high element selection can be synthesized under mild conditions. The strategy exhibited good applicability to manufacturing multiple HEA systems, which involve diverse elements with different crystal structures, large melting point variations, and a wide range of atomic radii.

Through *in situ* environmental Cs-TEM and *in situ* synchrotron radiation X-ray diffraction technique, the unique fusion-fission behavior and crystallization phenomena can be found in the process of atomic manufacturing of HEAs assisted by liquid metal. The molecular dynamics based on the machine learning potential further verify the alloying mechanism. This research can significantly extend the atomic manufacturing methodology via liquid metal, providing new access to the atomically precise synthesis of functional materials and advanced materials.

# Fluidic Memristor with Diverse Neuromorphic Functions

Neuromorphic devices, devices with functionalities of biological neurons, played key role in brain-computer communication, smart sensing and neurophosetics. These neural functions were strongly related to chemical signals in brain. However almost all neuromorphic devices focused on the recognition of electrical signal and the direct perception of chemical signal remains a long-standing challenge. In this case an artificial chemical synapse was highly desired in the field of intelligent sensing and brain-inspired computing.

With the support of the National Natural Science Foundation of China (Major Program 21790390 and National Science Fund for Distinguished Young Scholars 22125406), a research team of Prof. Lanqun Mao (Institute of Chemistry, Chinese Academy of Sciences/Beijing Normal University) and Prof. Ping Yu (Institute of Chemistry, Chinese Academy of Sciences) developed a polyelectrolyte-confined fluidic memristor (PFM), realizing the emulation of chemical-electrical transduction of neurons with artificial system. This work entitled "Neuromorphic Functions with a Polyelectrolyte-confined Fluidic Memristor" was published in *Science*.

Based on the understanding in brain chemistry and confined ion transport, the research team first fabricated the polyelectrolyte-confined fluidic micropipettes using surface-initiated atomic transfer polymerization. By systematically studying the current-voltage relationship, they found that the fabricated fluidic micropipettes well satisfied the memristor fingerprints. Theoretical and experimental results showed that time-dependent ion redistribution contributed to this memristor effect.

Using this ion-based memory effect, a series of electrical behaviors of synapses like paired-pulse facilitation and paired-pulse depression were emulated with PFM at low voltage and pJ/spike level ultra low energy consumption, suggesting the potential application in bioinspired sensorimotor implementation, intelligent sensing and neuroprosthetics. The PFM could also emulate the chemical-regulated STP electric pulses by regulating the ion redistribution dynamic with polyelectrolyte-ion interactions. For example, 1 mM adenosine triphosphate (ATP) would regulate the retention time of PFM from 156 ms to 138 ms. This result indicates that the PFM may allow direct interfacing and communicating with biological systems, given that its neuroplastic behaviors are controllable by bioactive molecules.

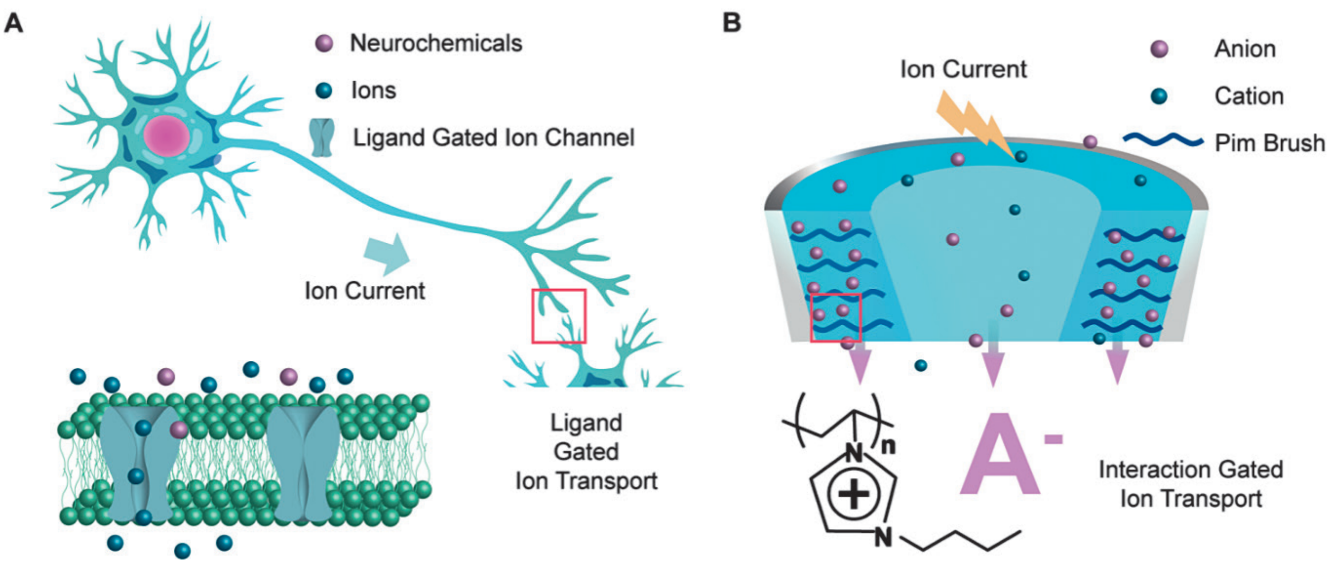



Figure. 3-1-12 Schematic illustration of neural functions realized by biological neurons (A) and PFM(B).

More importantly, based on the synergism of multiple ion species as well as the polyelectrolyte-ion interactions, the chemical-electric signal transduction was accomplished with the PFM, which is a key step towards the fabrication of artificial chemical synapses. With structural emulation to ion channels, PFM features versatility and easily interfaces with biological systems, paving a way to building neuromorphic devices with advanced functions by introducing rich chemical designs. This study would open a new door for interfacing the chemistry with neuromorphic device.

## Investigation of Americium Separation Chemistry in Used Nuclear Fuel Reprocessing

The transuranic element, americium (Am), is a major contributor to the long-term radiotoxicity of high-level waste. Efficient separation of Am and subsequent neutron transmutation is one of keys to reduce long-term radiation toxicity of nuclear waste, which is of great significance for the sustainable development of nuclear energy. However, the chemical behaviors of Am and the coexisting lanthanides (Ln) are very similar. They all exist in aqueous solution as thermodynamically stable trivalent cations with nearly identical ionic radii and coordination chemistry. Efficient separations between trivalent americium and lanthanides is not only one of the most challenging target in nuclear waste disposal, but also a major bottleneck issue in dealing with the long-term radiotoxicity of nuclear waste. One proposed method to mitigate this separation challenge is the oxidation of Am (III) to the higher oxidation states of Am(VI). However, Am (VI) ion, being an unconventional valence state of americium, is prone to be reduced back to Am(III) species in traditional extraction separation processes, making these separations impractical. To date, there has been no feasible method to stabilize Am(VI) ion and achieve effective separation (Figure 3-1-13A).

With funding supported by the National Natural Science Foundation of China (Major Program 21790370), Professor Wang Shuao's team from Soochow University, in collaboration with several international research teams, designed and synthesized a nanoscale polyoxometalate (POM) cluster with a vacancy site compatible with the selective coordination of hexavalent actinides based on the coordination chemistry of Am(VI). A stable water-soluble nanoscale complex was formed between Am (VI) ion and the POM cluster through strong complexation, achieving ultra-long-term stability of Americium(VI) in aqueous solution (only 0.67% of the Am(III) was produced over a period of 24h). Meanwhile, the Ln (III) ions don't interact with the POMs and exists as hydrated cations. By utilizing the size difference between Am(VI)-POMs and hydrated Ln (III) ions combined with commercially available ultrafiltration technique, a new lanthanide/actinide ultrafiltration separation method was developed (Figure 3-1-13B), achieving an Am(VI)/Eu (III) separation factor of 780 and a single-step recovery rate of 91% for Am. This is also significantly higher than those of other reported Am (VI) associated separation techniques so far.

The developed separation method, as delineated in the aforementioned study, exhibits promising potential for application in the separation and purification of americium during the used fuel reprocessing. Notably, its adaptability and universality render it well-suited for various radiochemical separation scenarios, encompassing applications such as radioactive contamination control and the separation and purification of critical radioisotopes. The results of this research have been published in *Nature* with the title of "Ultrafiltration separation of Am(VI)-polyoxometalate from lanthanides". Simultaneously, *Nature* published a commentary article of "Metal-oxide cages open up strategy for processing nuclear waste", which concludes that this work holds the potential to resolve a long-standing problem in reprocessing used fuel from civilian nuclear reactors, thereby enhancing the efficiency and safety of the nuclear industry.

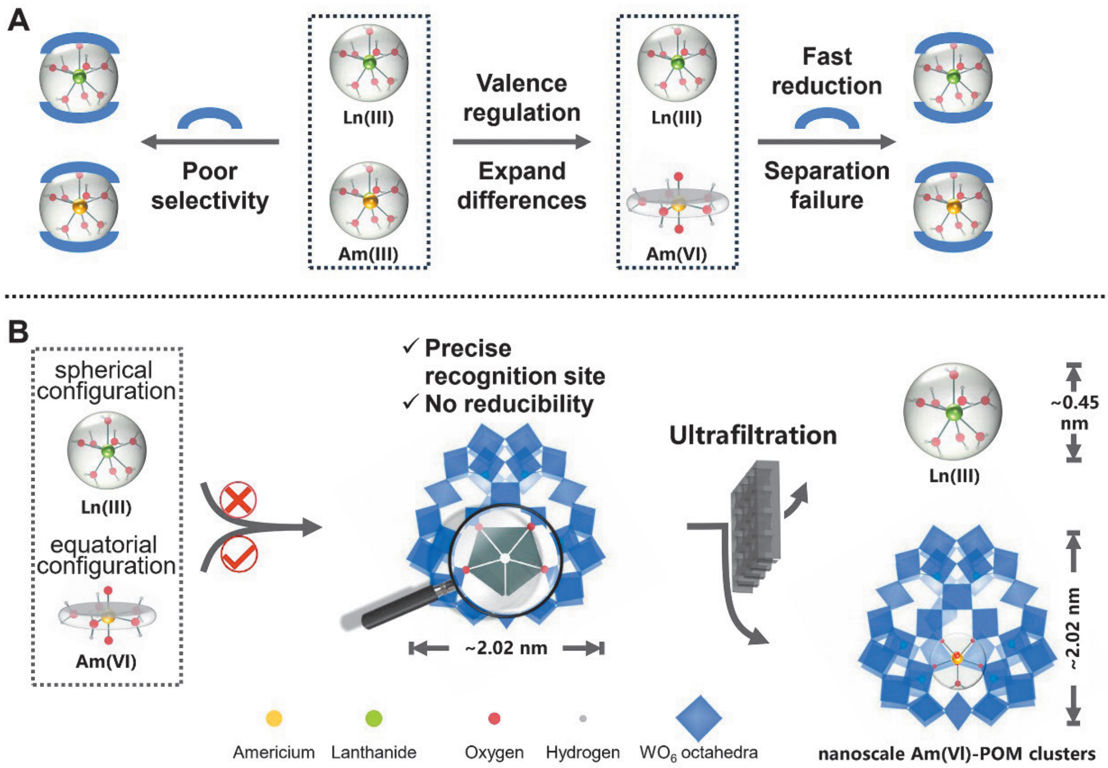



Figure 3-1-13 Separation of americium from lanthanide elements.
A. Difficulties and status of lanthanide/actinide separation; B. Ultrafiltration separation of Americium from lanthanides based on size difference

## Minimizing Buried Interfacial Defects for Efficient Inverted Perovskite Solar Cells

Under the support of the National Natural Science Foundation of China (General Program 22179037), Professor Yongzhen Wu and Professor Weihong Zhu's team from East China University of Science and Technology, in collaboration with partners, conducted systematic chemical research on interface materials in perovskite solar cells. Through a comprehensive exploration of the working principles of anchoring group involved small-molecule hole-transporting materials (HTMs)at the device interface, as well as ingenious molecular engineering on HTMs, both morphology and electronic defects were substantially decreased at the buried interface in inverted perovskite solar cell, which led to a remarkable enhancement in device performance. A new concept for the design of organic hole-transporting materials was proposed, along with the introduction of a novel method for buried interface modulation. These findings were published as a research paper with the title of "Minimizing buried interfacial defects for efficient inverted perovskite solar cells" in the *Science* on April 28, 2023.

In recent years, perovskite solar cells have garnered substantial attention from both academic and industrial communities due to their rapidly rising photovoltaic performance. Morphology and electronic defects at interfaces are the major factors limiting further improvement of photovoltaic performance, especially for the buried, unexposed interfaces between perovskite and substrate. To address the defects at the buried interface arising from traditional hydrophobic organic hole-transporting materials, a novel organic hole-transporting material featuring with a cyano-phosphonic acid as the anchoring group was designed and synthesized by the research team (MPA-CPA, Figure 3-1-14A). The strong electron-withdrawing capability of the cyano group enhanced the deprotonation ability of the phosphinic acid, imparting unique amphiphilicity and awide solvent-processing window to the material. They revealed the working mechanism by which these materials dynamically assemble onto transparent conductive oxide substrates to form a "bilayer" stacking structure, enhancing surface wettability and thereby improving the deposition quality of perovskite thin films (Figure 3-1-14B). Consequently, this led to uniform morphology in large-area perovskite thin films and improved contact at the buried interface (Figure 3-1-14C). Simultaneously, the designed cyano-phosphonic acid anchoring group exhibited a unique chelating effect with lead ions (Figure 3-1-14D). Theoretical calculations and experimental results validated that the cyano-phosphonic acid anchoring group efficiently and stably passivate electronic defects at the buried interface (Figure 3-1-14E), suppressing non-radiative recombination losses.

Inverted perovskite solar cells fabricated using the newly developed organic hole-transporting material achieved an efficiency of 25.4% as certified by a third-party institution. Additionally, the excellent wettability of this novel material facilitated the fabrication of large-area devices, achieving efficiencies of 23.4% for a 1-square-centimeter device and 22.0% for a 10-square-centimeter module. This work presents new avenues for developing efficient organic hole-transporting materials and reducing interface defects in optoelectronic devices.

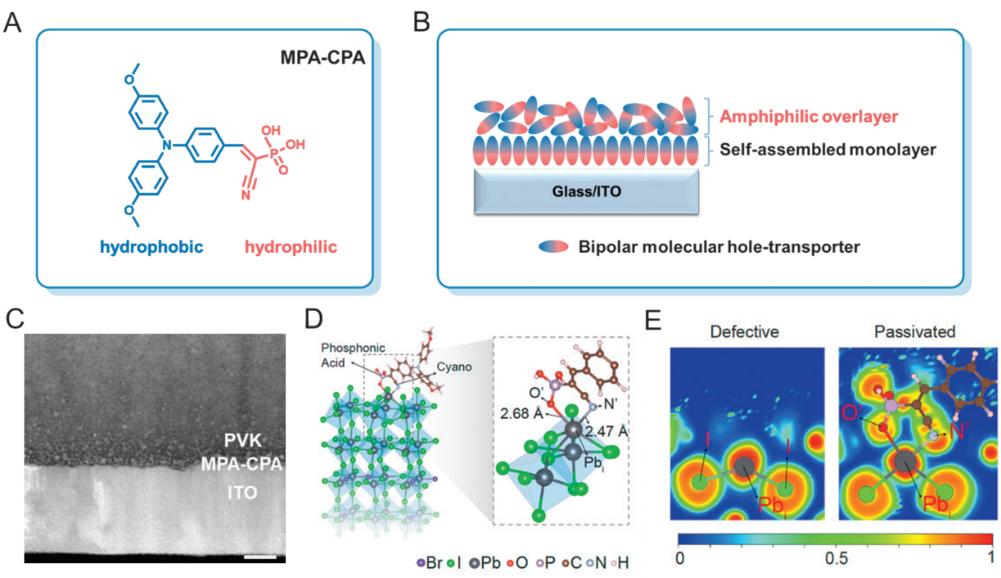



Figure 3-1-14 Minimizing buried interfacial defects by amphiphilic small-molecule hole-transporting materials
A) Molecular structureof MPA-CPA;B) Bilayer stacking structure;C)High-quality interface contact between perovskite and substrate;D)Chelating of cyano-phosphonic acid to lead ion;E) Passivation of electronic defects

## Radical-Mediated Reversible C–H Sampling for Direct Functional Group Translocation

Inert C–H bonds are widespread in organic molecules but remain unreactive in conventional chemical transformations. Achieving direct and selective elaboration of these inert C–H bonds is regarded as a holy grail in synthetic chemistry, as it demands no pre-installed functional groups, offers high atom and step economy, and holds vast potential in molecular synthesis and modification. Among various approaches, radical-mediated C–H transformation stands out for activating aliphatic C–H bonds due to its high reactivity.

However, controlling selectivity poses significant challenges, often necessitating the use of special substrates or auxiliaries to enable site-selective C–H cleavage. Thus, discovering new strategies to control site-selectivity in radical-mediated C–H transformations stands as a crucial challenge and an essential demand in this important branch of synthetic chemistry.

The recent work by Yan Xu et al. from Peking University, supported by the National Natural Science Foundation of China (Young Scientists Fund 22201015) and other grants, introduces an innovative reversible C–H sampling strategy to control site-selectivity in radical-mediated C–H transformations. Unlike prior methods, this novel approach doesn't selectively cleave a single C–H bond or form a single intermediate; instead, it non-selectively generates a range of C–H cleaved intermediates and selectively captures one (Figure 3-1-15A). As a convincing proof-of-concept, the researchers combined a multi-positioned hydrogen atom abstraction with a site-selective intramolecular radical trapping, leading to a novel and valuable C–H transformation: the direct "position swapping" between cyano groups and unactivated δ C–H bonds. Notably, this reaction operates under mild conditions, exhibiting a broad substrate scope, and has already facilitated the expedited synthesis and derivatization of several bioactive molecules (Figure 3-1-15B). The team also offered in-depth insights into the mechanism, revealing that the reaction's overall selectivity primarily relies on the site-preference of the intramolecular radical addition for forming 5-membered rings after C–H cleavage (Figure 3-1-15C). Published in *Nature* on June 26, 2023, titled "Functional-group translocation of cyano groups by reversible C–H sampling"(Figure 2), these findings elucidate the feasibility and great potential of this new mechanistic paradigm and may open a new door for the development of synthetically useful C–H transformation reactions.

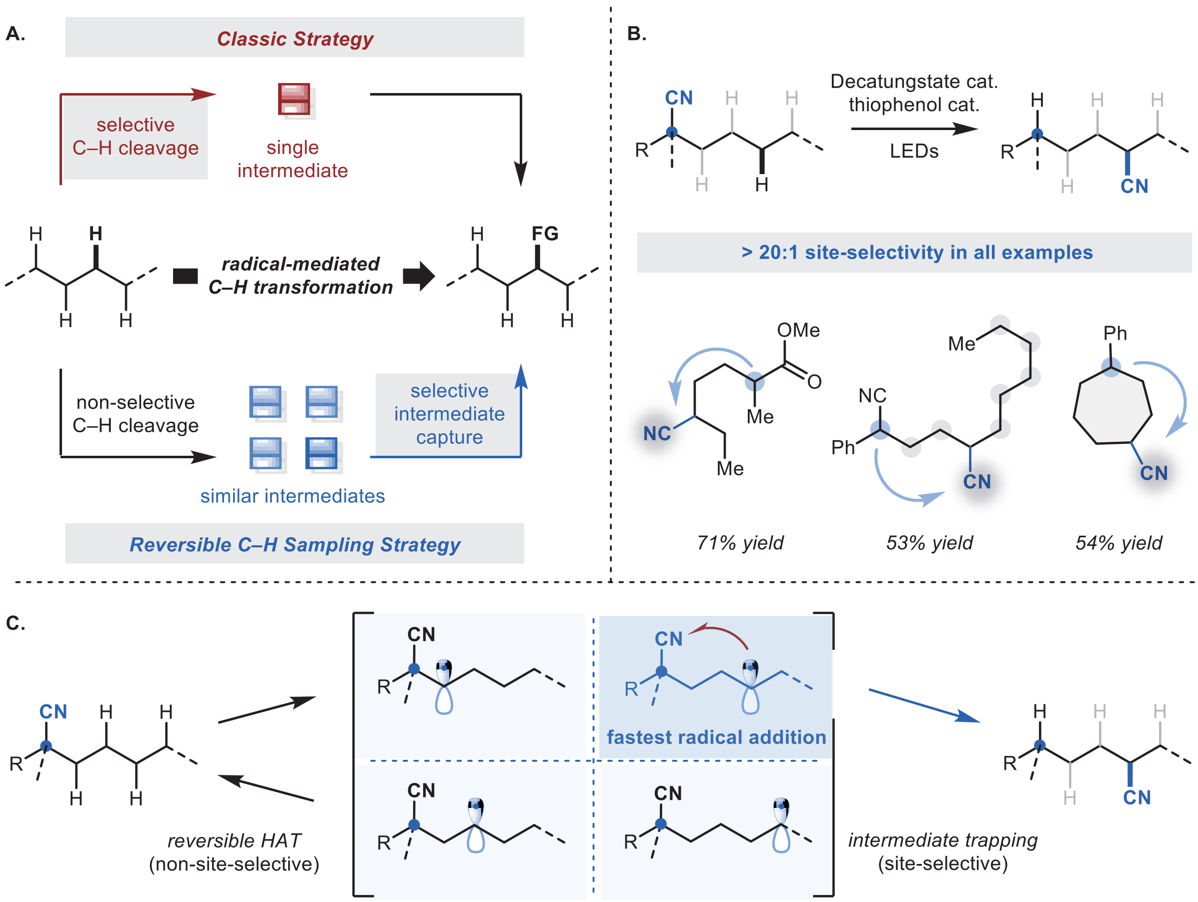



Figure 3-1-15 Radical-Mediated Direct Translocation of Cyano Groups via Reversible C–H Sampling.
A. Comparison between the classic strategy and the reversible C–H sampling strategy for radical-mediated C–H transformations; B. Direct translocation between cyano groups and δ C–H bonds; C. Reaction mechanism

## Dual Domestications and Origin of traits in Grapevine Evolution

In the historical course of human evolution, the advent of agriculture preluded a stable food supply and a lifestyle transition from roaming hunter-gatherers to sedentary farmers. This episode relied on ancient humans' successful domestication of various animals and plants. The grapevine played an important role in the thousands of years of human civilization. As a food source and wine ingredient, the grapevine influenced literature, history, art, and regions across Eurasian cultures. However, the evolutionary origin of grapevine remains elusive. The time, location, and route of the wild grapes evolving into cultivated grapes are outstanding scientific questions.

With the support of the National Natural Science Foundation of China (General Program 32070599) and other funding agencies, Drs. Wei Chen and Jun Sheng from Yunnan Agricultural University, as well as Dr. Shaohua Li from the Institute of Botany, Chinese Academy of Sciences collaborated with more than 40 domestic and overseas research groups to investigate the grapevine domestication history and trait origin by utilizing the genetic information of a global grape cohort. Their findings were published in the March 3rd issue of Science as a cover story entitled "Dual domestications and origin of traits in grapevine evolution" (Figure 3-1-16).

Figure 3-1-16 Current issue cover of *Science*

Wei Chen's team and collaborators applied population genomic analyses to 3,525 wild and cultivated grapevines worldwide and systematically investigated the genetic variations. They first found that in the Pleistocene, harsh climate change resulted in continuous fragmentation of the wild grape habitat thereby leading to the separation of wild grape ecotypes. About 11,000 years ago, ancient humans in Western Asia and the Caucasus separately domesticated local wild grapes to obtain table and wine grapes. The researchers also found that, as early farmers dispersed across Europe, the Western Asia domesticates received genetic information from the Western wild ecotypes through introgression. This event created muscat and unique western wine grapes along the early human dispersal routes. In addition, the researchers provided new insights into the genetic basis for selecting berry palatability, flower hermaphroditism, muscat flavor, and berry color. This up-to-date evidence supports grapevine being the first domesticated fruit crop inhuman history. It reveals an essential role of grapevine domestication in the early development of agriculture in the Eurasian continent (Figure 3-1-17).

This research was highlighted in a Perspective article in the same issue of Science, and featured at the 2023 AAAS Annual Meeting. This research also received positive reviews in *Current Biology*, *Scientific American,* and various domestic and foreign mainstream media. This achievement is important for the ongoing research of the origin of human civilization and the investigation of many other fruit crops.

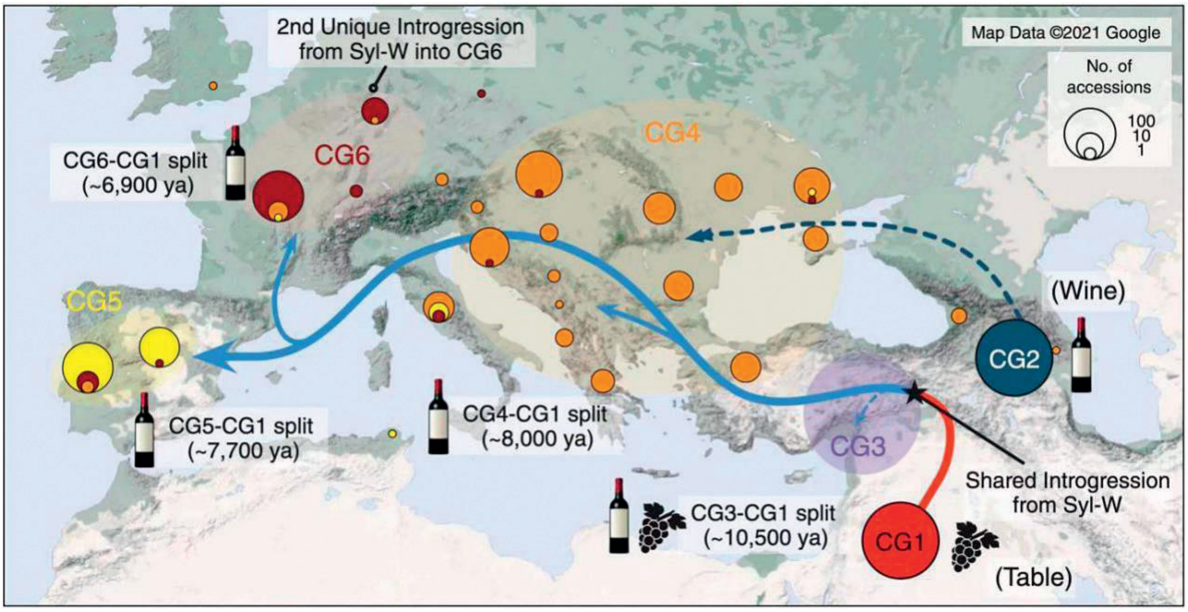
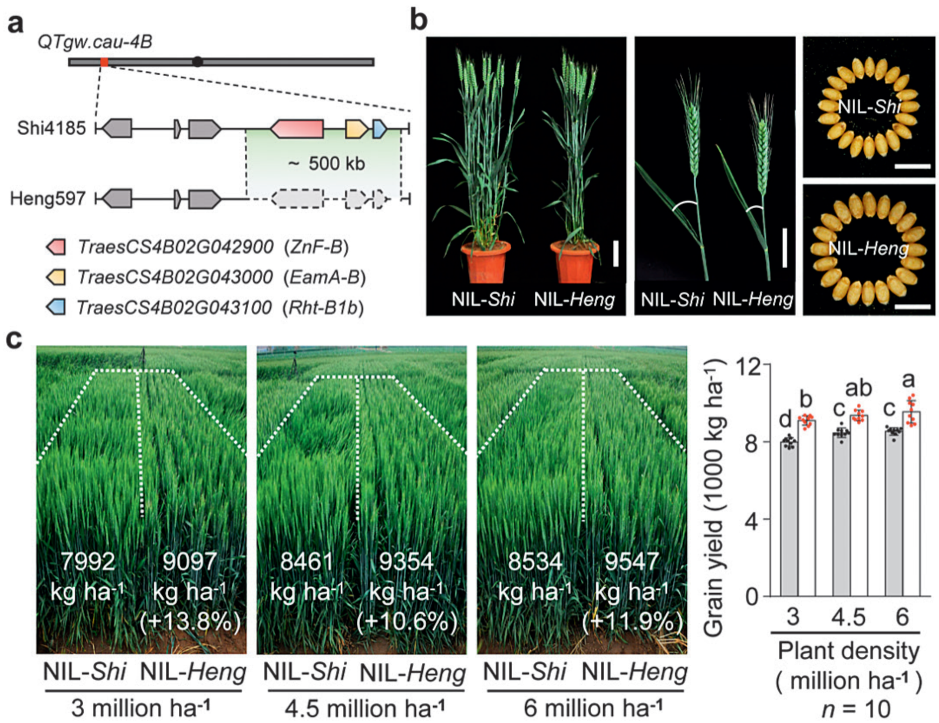



Figure 3-1-17　Schematic diagram of grape evolution and domestication history

## Reducing Brassinosteroid Signalling Enhances Grain Yield in Semi-dwarf Wheat

Supported by grants from the National Natural Science Foundation of China (Major Program 31991210, Joint Funds 22A6009, General Program 32172069 and 32072055), the research group, wheat genetics and genomics center from China Agricultural University (WGGC, CAU) led by Professor Qixin Sun, has identified a key locus that significantly improves nitrogen utilization efficiency (NUE) and population yield of wheat, providing an important genetic resource and a new strategy for breeding semi-dwarf wheat varieties. The findings have been reported in *Nature* (April 26, 2023).

Wheat (*Triticum aestivum* L.) is one of the most widely cultivated staple food crops worldwide, providing 21% of dietary calories and 20% of the protein source for humans. The green revolution in the 1960s has markedly increased cereal crop yield through widespread cultivation of semi-dwarf and lodging-resistant varieties. The beneficial semi-dwarf plant architecture of these green revolution varieties (GRVs) is mainly conferred by the introduction of either of the two gain-of-function mutant alleles, *Rht-B1b* and *Rht-D1b* that strongly repress gibberellin (GA) signalling and plant growth. However, these green revolution alleles also reduce nitrogen (N)-use efficiency (NUE) and carbon fixation, resulting in decreased biomass, spike size and grain weight. Therefore, the GRVs require extremely high N fertilizer inputs to maintain their high yields, but high N input is detrimental to both environments and agriculture sustainability. Professor Qixin Sun's group reported a new strategy to design semi-dwarf wheat varieties without the need for *Rht-B1b* or *Rht-D1b* alleles. They used a natural deletion of a haploblock of about 500 kilobases to remove *Rht-B1* and *ZnF-B* (encoding a RING-type E3 ligase) genes simultaneously, and enabled the shaping of semi-dwarf wheat varieties with more compact plant architecture and substantially improved grain yield (up to 15.2%) in field trials (Figure 3-1-18). Further genetic analysis confirmed that the deletion of *ZnF-B* induced the semi-dwarf trait in the absence of the *Rht-B1b* and *Rht-D1b* alleles through attenuating brassinosteroid (BR) perception. ZnF acts as a BR signalling activator to facilitate proteasomal destruction of the BR signalling repressor BRI1 kinase inhibitor 1 (TaBKI1), and loss of ZnF stabilizes TaBKI1 to block BR signalling transduction. These findings




a Schematic representation of the *r-e-z* haploblock deletion harbored in Heng597.bPlant height, spike morphology and grain size between NIL-*Shi* and NIL-*Heng* (containing the *r-e-z* haploblock deletion).c Comparison of the final yields between NIL-*Shi* and NIL-*Heng* planted at three different planting densities in standard field plots.
Figure 3-1-18 The *r-e-z*haploblock deletion improves green revolution plant architecture and grain yield in wheat

not only identified a pivotal BR signalling modulator but also provided a creative strategy to design high-yield semi-dwarf wheat varieties by manipulating the BR signal pathway to sustain wheat production, laying a new theoretical foundation for the development of sustainable agriculture.

This study has gained widespread attention, and has been highlighted by several perspective articles published in Chinese Bulletin of Botany, Nature Plants, Trends in Biochemical Sciences, Seed Biology, Journal of Genetics and Genomics and Science China Life Sciences, describing it as one of the most important breakthroughs in the field of wheat functional genome research.

## Nuclear Export of the Pre-60S Particles through Nuclear Pore Complex

The nucleus controls almost all cellular activities through the exchange of information and materials with the cytoplasm. The nuclear pore complex (NPC), embedded into the double-layered nuclear envelope, is the sole gate to mediate the nucleocytoplasmic transport of macromolecules and the structural and functional disorder of NPC can cause a variety of serious diseases including cancers. Ribosomes are macromolecular machines responsible for protein synthesis in cells and their biosynthesis process begins in the nucleus and is then transferred to the cytoplasm through the NPC to complete the final maturation. But how does the NPC transport ribosome precursor molecules? This crucial biological question remains a mystery. The huge size and complex architecture of the NPC and ribosomes, as well as the instantaneous translocation process, make it challenging to study the nuclear export of ribosome precursors through the NPC.

Funded by the National Natural Science Foundation of China (General programs 32071192 and 32271245), Professor Sen-Fang Sui's team from Tsinghua University/Southern University of Science and Technology has carried out the study on the molecular mechanism of nuclear export of ribosome precursors through the NPC (Figure 3-1-19). Combining a variety of biochemical approaches, the team successfully captured the transient state of transporting ribosome precursors through NPC, isolated and purified the high-quality samples of NPC-ribosome precursors complex, and finally successfully determined the high-resolution structure of ribosome precursors supported by the high-performance cryo-electron microscopy platforms from Tsinghua University/Southern University of Science and Technology. The related results have been published in *Nature* journal with a title of "Nuclear export of the pre-60S particles through the nuclear pore complex" on May 31, 2023. This study further improves the process of ribosome biosynthesis, reveals the molecular mechanism of nuclear export of ribosome precursors through the NPC, which provides an important theoretical basis for the development of novel drugs targeting NPC and ribosome.

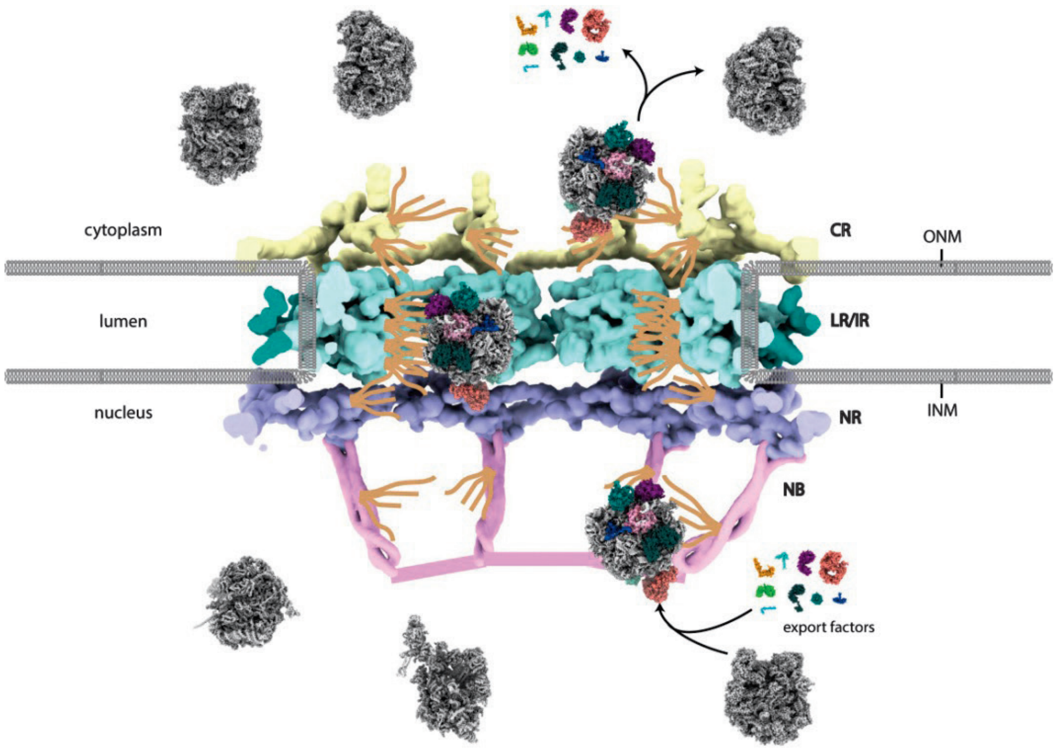



Figure 3-1-19 Molecular mechanism of nuclear export of ribosome precursors through the NPC

## Study on the Molecular Mechanism of Rhythmic Translation Regulated by Phase Separation

Human activities vary in time and space with day and night owing to circadian rhythm, such as body temperature oscillation and sleep-wake cycle. Previous studies have shown that a group of "clock genes" regulate circadian rhythm through a negative "transcription-translation feedback loop" (TTFL). The consecutive events in TTFL, including transcription and mRNA processing, occur in a circadian fashion, to maintain the exact 24-hour periodicity for many genes. However, major questions regarding how these rhythmic processes are spatiotemporally orchestrated remain unanswered. Circadian rhythm disorders have been linked to a variety of diseases, including type 2 diabetes and neurodegenerative diseases. Based on the fact that it is significant to treat disorders related to abnormal circadian rhythm and to keep life health, many researchers try to understand the dynamics of biomacromolecules in rhythmic activities and explore the molecular mechanisms controlling the circadian rhythm.

Funded by the National Natural Science Foundation of China (General Program 32170684), Dr. Yi Lin's group and Dr. Xuerui Yang's group, from the School of Life Sciences of Tsinghua University, illustrated the molecular mechanism behind rhythmic translational activation. That is, cells coordinated the fine spatiotemporal regulation of protein synthesis by phase separation and thus maintained the circadian cycle (Figure 3-1-20). On June 26, 2023, Dr. Yi Lin's and Dr. Xuerui Yang's groups published a research paper in *Cell*, entitled "Circadian Clocks are Modulated by Compartmentalized Oscillating Translation", to clarify the above mechanism of rhythmic translation.

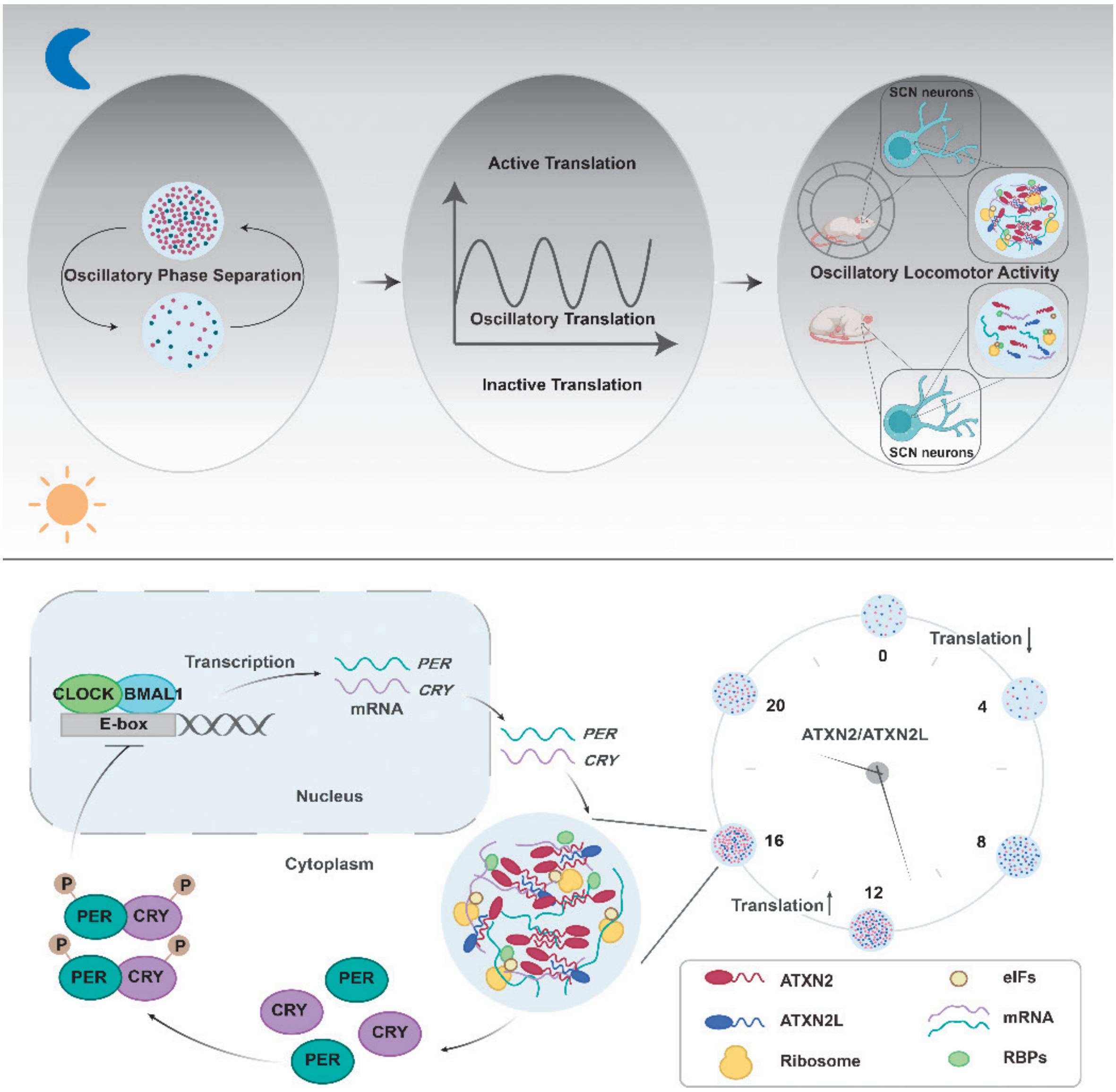



Figure 3-1-20 Schematic model illustrating that ATXN2/2L phase separation regulated the translational activation of rhythmic proteins

Previous studies on biological clocks focused on the regulation at the transcriptional level, while little is known about how cells regulate circadian rhythms at the level of protein translation. The research team clarified the existence of rhythmic oscillations in protein synthesis in mammals and the oscillated phase separation also provides a new perspective for the spatiotemporal regulation of rhythmic translation. They found ATXN2/2L underwent phase separation and formed cellular condensates in the suprachiasmatic nucleus (SCN), which served as the principal circadian clock of the brain (Figure 4-2). These condensates oscillated in size and quantity with circadian rhythm. ATXN2 condensates regulated different steps of mRNA-related events in a sequential manner. At the oscillation peak of condensates formation, ATXN2 condensates enriched translation initiation machinery and ribosome components for translational activation of clock genes. This acceleration step in translation contributed to stabilizing and precisely regulating the rhythmic cycle throughout the TTFL. Finally, the researchers verified this regulatory mechanism in mouse models and found the mice without ATXN2 and ATXN2L showed abnormal circadian behaviors.

Peer experts commented that this study filled the gap in how endogenous circadian clocks were finely regulated at the translational level, and provided a new perspective for future research on the molecular mechanisms of circadian clocks. And they also thought this research brought new ideas for the treatment of diseases related to circadian rhythm disorders.

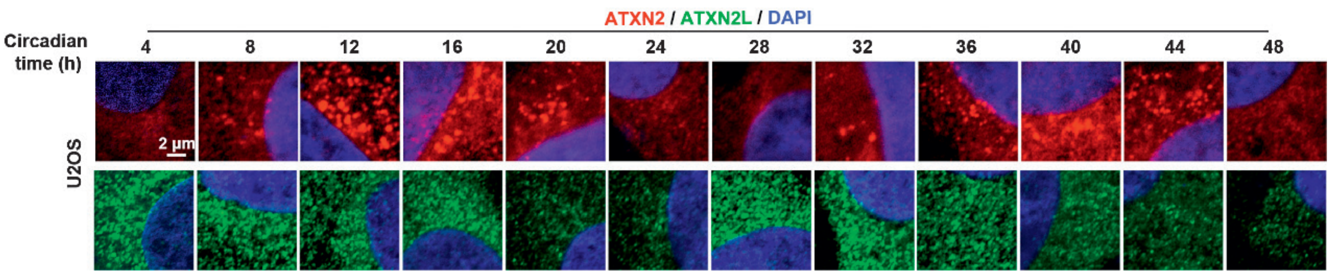



Figure 3-1-21 ATXN2 and ATXN2L underwent phase separation and formed cellular condensates along with circadian rhythm in U2OS cells

## Molecular Mechanism Highlighting the "Pollen Mentor Effect" and Its Utility in Plant Distant Hybridization

The emergence of new species is of great significance for generating and maintaining the biodiversity on the Earth. Hybrid speciation is a crucial mechanism for the formation of new species. However, in order to achieve hybridization between plants of distantly-related species/genus, pre-zygotic and post-zygotic reproductive hybridization barriers need to be overcome. The stigma is the first and most critical place for recognition of pollen by the pistil. The reproductive barrier at the stigma is the first barrier that need to be overcome to achieve interspecific/intergeneric hybridization. In the 1950s, some scientists attempted to promote interspecific/intergeneric hybridization by using mixed pollination with both self-pollen and interspecific/intergeneric pollen to help the alien pollen overcome reproductive barriers at the stigma, leading to the famous term "pollen mentor effect". However, after over seventy years, the molecular mechanism of the "pollen mentor effect" remains unclear.

Supported by the National Natural Science Foundation of China (Major Program 31991202, Key Program 31830004, Excellent Young Scientists Fund 32122014 and General Program 32070854), the research team led by Professor Li Jia Qu and Associate Research Professor Sheng Zhong at Peking University elucidated the molecular mechanism of how Arabidopsis recognizes and accepts self-pollen while rejecting the interspecific/intergeneric pollen at the stigma. They proposed a "lock-and-key" model of stigma-pollen recognition, clarifying the mechanism controlling the formation of the reproductive barrier at the stigma between different species/genera, and clearly explaining the "pollen mentor effect" at the molecular level. The "lock" formed by the receptor FER/ANJ/HERK1/CVY1 on the stigma papilla cells, the autocrine small peptides sRALF1/22/23/33, and the cell wall proteins LRX3/4/5, which collectively prevent pollen tubes from penetrating the stigma. The "key" carried by self-pollen, consisting of seven paracrine small peptides pRALF10/11/12/13/25/26/30, can "unlock" the stigma, allowing the pollen tube to penetrate the stigma. Interspecific/intergeneric pollen lacks the "key" and cannot "unlock" the stigma, resulting in the formation of an interspecific/intergeneric reproductive barrier. If self-pollen and interspecific/intergeneric pollen are mixed for pollination, the self-pollen, carrying the "key", can "unlock" the stigma, allowing the interspecific/intergeneric pollen tube to penetrate the stigma, forming the base of the "pollen mentor effect". The study found that removing any of the components in the stigmatic "lock" can break the reproductive barrier, allowing the interspecific/intergeneric pollen tube to penetrate the stigma. More importantly, application of artificially synthesized "keys" (*i.e.*, pRALF peptides from self-pollen) to the stigma can replace "mentor pollen", enabling to help interspecific/intergeneric pollen tubes to effectively penetrate the stigma, thus successfully overcoming this critical reproductive barrier (Figure 3-1-22).

The paper of the above findings, entitled "Antagonistic RALF peptides control an intergeneric hybridization barrier on Brassicaceae stigmas", was published in *Cell* on October 26th, 2023. Meanwhile, a Leading Edge Preview was published in the same issue of *Cell* to highlight this important discovery. Other internationally well-known journals such as *Nature Plants*, *Molecular Plant* and *Trends in Plant Science* have also published Research Highlight or Spotlight papers to introduce the discovery. It is believed that this discovery provides a theoretical basis and innovative strategies to break reproductive barriers and achieve interspecific hybridization in plants.

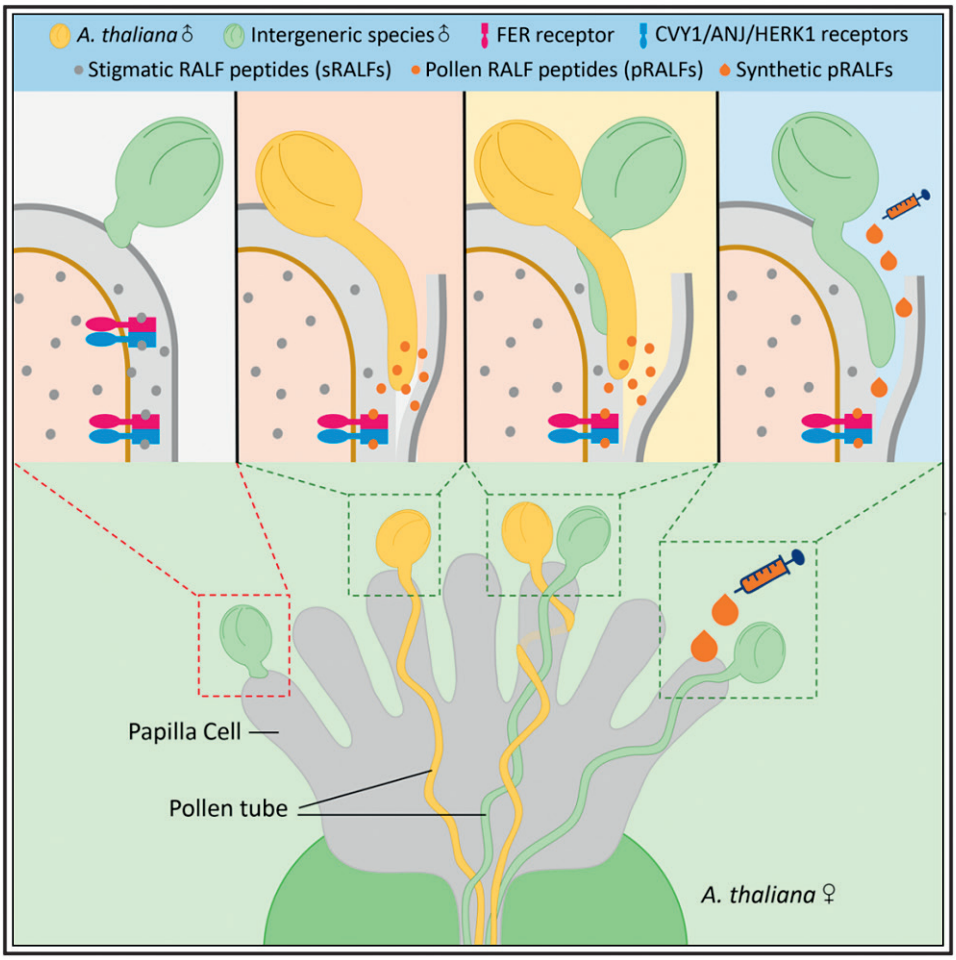



Figure 3-1-22 The "lock and key model" of pistil-pollen recognition in angiosperms and the molecular mechanisms of "pollen mentor effect"

# Neural Circuit-targeted Modulation Technology Rescues Parkinsonian Motor Phenotypes

Parkinson's disease (PD) is a common neurodegenerative disorder that affects more than 6 million people worldwide, with more than half of the patients in China. PD symptoms are most commonly treated with L-Dopa to restore activity of the basal ganglia (BG) movement control pathways. However, the action of these drugs lacks specificity due to the widespread distribution of dopamine receptors in the brain and peripheral organs, resulting in side effects caused by activation of non-motor dopamine systems. Therefore, development of precision therapeutic solutions for PD is in great demand.

Funded by the National Natural Science Foundation of China (General program31871090, Young Scientist Fund 32000730), Dr. Zhonghua Lu, Dr. Ji Dai, and Dr. Jin Bao from Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences successfully developed a neural circuit-targeted modulation strategy to treat PD-related motor symptoms. The study was published on Nov. 22$^{nd}$, 2023 in *Cell* with a title "Circuit-specific gene therapy reverses core symptoms in a primate Parkinson's disease model" as a Featured Article (Figure 3-1-23).

The team developed a retrograde AAV-based targeting strategy to isolate and activate the suppressed BG direct pathway in PD. The tool kit comprises a highly efficient novel retrograde AAV capsid, AAV8R12, for D1 medium spiny neuron (D1-MSN), promoter elements, G88P2/3/7, with strong MSN activity, and a chemogenetic effector, rM3Ds, allowing precise D1-MSN activation after systemic ligand administration (Figures 3-1-24 and 3-1-25). Application of this therapeutic approach rescues motor phenotypes in primate models of PD: reversing bradykinesia, eliminating tremor, and restoring motor skill defects.


Figure 3-1-23

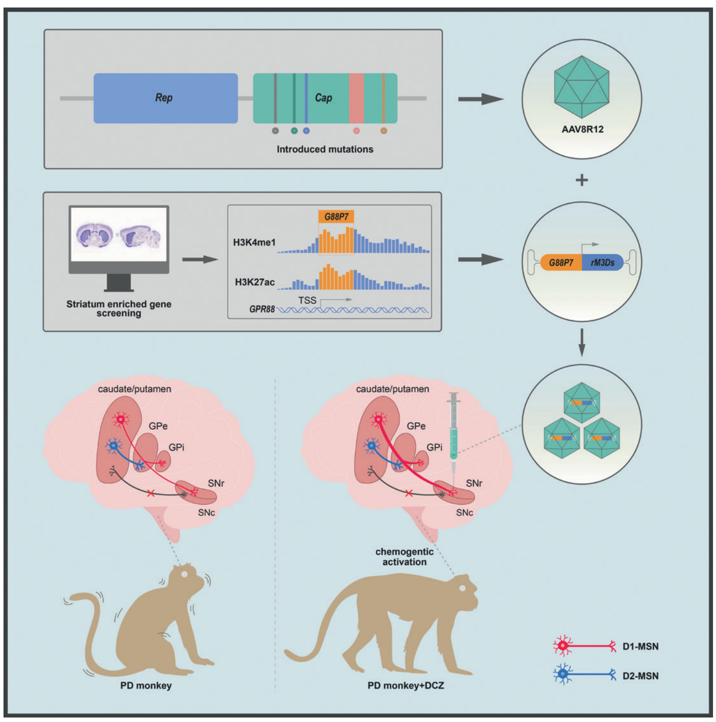



Figure 3-1-24 Neural circuit-targeted modulation rescues Parkinsonian motor phenotypes (Option 1)

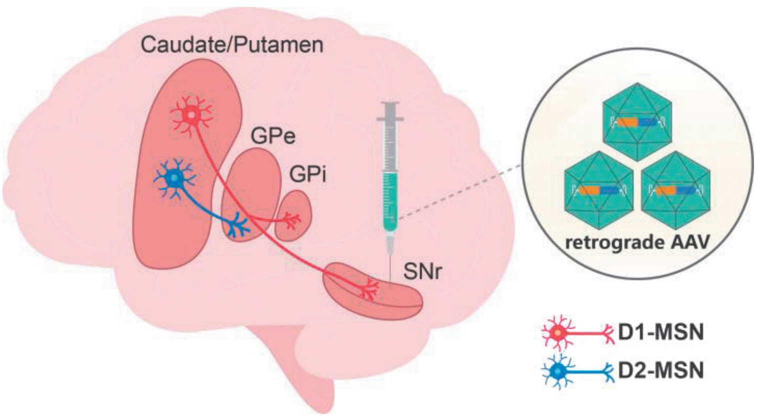



Figure 3-1-25 Neural circuit-targeted modulation rescues Parkinsonian motor phenotypes (Option 2)

The study was reported as "Research Highlight" in *Zoological Research* and *Nature Reviews Drug Discovery* with comments emphasizing that this work has established a precisely targeted, chemogenetically controlled therapeutic strategy to treat the motor symptoms of PD.

## Development of Atom-Trap Instrumentation for Krypton- and Argon-Isotope Dating

The radioactive noble-gas isotopes, krypton-81, krypton-85 and argon-39 ($^{81}$Kr, $^{85}$Kr and $^{39}$Ar), are ideal tracers in the earth and environmental sciences. They are uniformly distributed in the atmosphere with well-defined initial abundances and simple transport mechanisms in the environment. For radio-isotope dating, they combine to cover an effective age range from a few years to 1.3 million years. Due to their extremely low isotopic abundances, however, it has long been a challenge to perform quantitative analysis of these isotopes in environmental samples of limited sizes. A scientific instrument capable of overcoming this challenge is urgently needed.

Supported by the National Natural Science Foundation of China ( National Major Scientific Instrumentation Program 41727901), a research team led by Professor Zheng-Tian Lu at the University of Science and Technology of China (USTC) has advanced the Atom Trap Trace Analysis (ATTA) method. The team developed a laser system, a metastable noble-gas atomic beam system, an atom optics system, an ion current collection and measurement system, and an ultra-high vacuum system. They made multiple breakthroughs, realizing an intense metastable atomic beam, efficient atom trapping, sensitive single-atom detection, and precise atom counting. These efforts have led to the successful development of a major scientific instrument: ATTA for radiokrypton and radioargon dating. Moreover, the team has also developed a sample preparation system. With modern samples, the instrument has achieved atom-counting rates of 1,000/hr for $^{81}$Kr, 10,000/hr for $^{85}$Kr, and 10/hr for $^{39}$Ar. The required sample size for a single analysis has also been reduced significantly, reaching 20 kg of groundwater or 3 kg of ice core. This ATTA instrument not only demonstrates top-notch specifications, but also makes possible $^{81}$Kr dating of ice cores. These works help the USTC laboratory establish a world-leading position in the field of radiokrypton and radioargon dating.

An interdisciplinary team with expertise in instrumentation is built up through this program. The team has established scientific collaborations with about 50 research institutions worldwide, dating groundwater, sea water and ice cores. A series of works with high visibilities have been published in *Nature Physics, the Proceedings of the National Academy of Sciences, Physical Review Letters, Earth and Planetary Science*

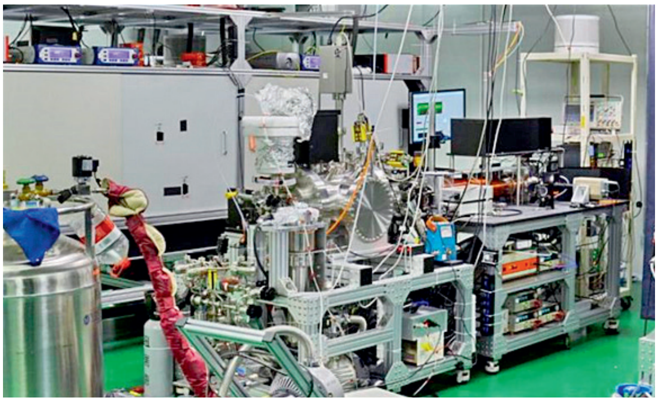


Figure 3-1-26 (a) ATTA apparatus for $^{81}Kr$

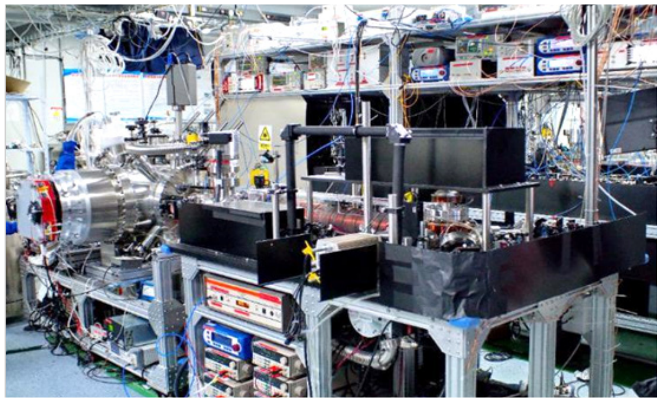


Figure 3-1-26 (b) ATTA apparatus for $^{85}Kr$

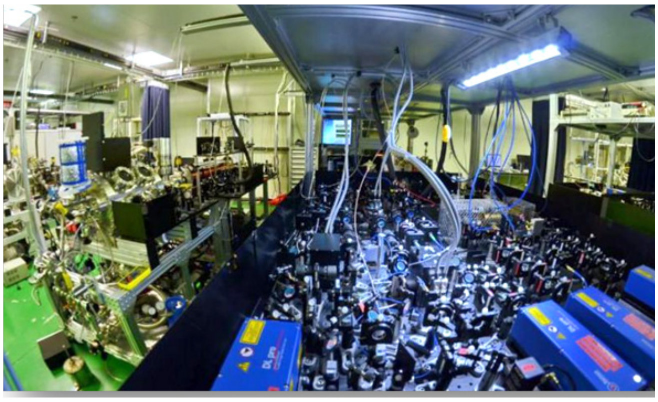


Figure 3-1-26 (c) ATTA apparatus for $^{39}Ar$

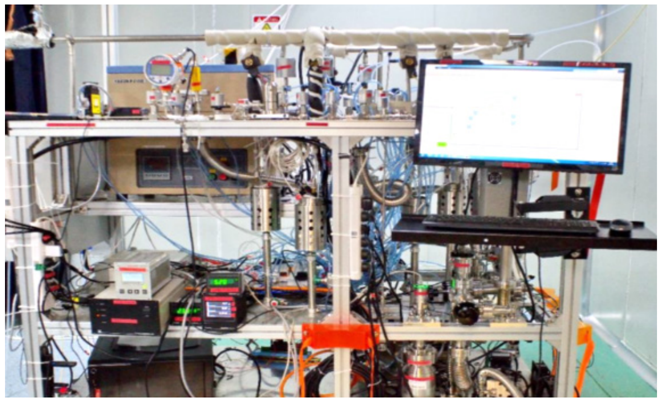


Figure 3-1-26 (d) Apparatus for automated separation and purification of krypton and argon samples

*Letters*, etc. Four domestic patents have been awarded. Team members have received funding of the National Science Fund for Distinguished Young Scholars by the National Natural Science Foundation of China Meanwhile, the USTC team has also collaborated with IAEA and relevant institutions in China, Japan, and European countries to provide groundwater dating support in site evaluations of nuclear fuel repositories.

## Research on Lunar Tidal Effects in Earth's Plasmasphere

As the Earth's natural satellite, the Moon has a significant impact on Earth's ecological environment and human activities. Among these, the most direct influence is the lunar tidal effect. In addition to the most representative ocean tides, lunar tidal phenomena exist in different altitude regions such as the crust, atmosphere, and ionosphere. Lunar tides were mainly found to affect the first three states: solid Earth tides, liquid ocean tides and neutral gas-dominated atmospheric tides. These lunar tides are directly caused by the gravity of the moon, and mainly have semidiurnal and semimonthly periods, as shown in the blue part near the Earth's surface in Figure 3-1-27, depicting ocean tides. However, whether lunar tides can influence the vast Earth's magnetosphere, which is filled with the fourth state of matter—plasma, has not yet been explored.

Funded by the National Natural Science Foundation of China (National Science Fund for Distinguished

Young Scholars Program 42225405, General Program 41974189), Professor Shi Quanqi's team from Shandong University, Professor Liu Wenlong's team from Beihang University and Professor He Fei's team from Institute of Geology and Geophysics, Chinese Academy of Sciences, systematically analyzed data from over ten satellites (including China's Chang'e 3, the United States' THEMIS, and Europe's Cluster) that have traversed the "cold plasma ocean" of the Earth's magnetosphere, i.e., the plasmasphere, over the past 40 years. For the first time, they discovered a clear diurnal and monthly lunar tidal signal in the position of the plasmapause (the outer boundary of the plasmasphere), as shown in the orange part of Figure 3-1-27. The lunar tide can cause the plasmapause position to vary by up to 800 km, and its characteristics significantly different from the lunar tidal signals in low-altitude regions such as the crust, oceans, and atmosphere. The team further demonstrated through electric field observations and simulations that the perturbations of plasmapause position result from the disturbed radial electric field. This indicates that the combined effects of gravity and electromagnetic forces lead to the lunar tidal signal characteristics at the plasmapause that are markedly different from the gravitationally induced tidal signals in near-surface regions.

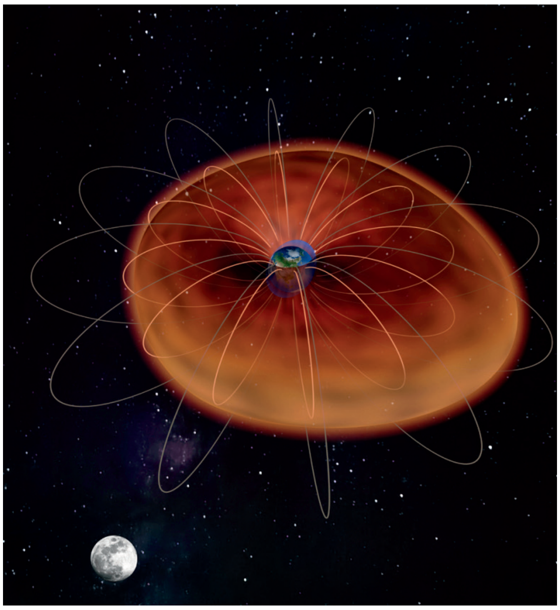


Figure 3-1-27 Comparison of Ocean Tides (blue part) and Plasmapause Tides (orange part)

The related findings, titled "Evidence for Lunar Tide Effects in Earth's Plasmasphere", were published online in *Nature Physics* on January 26, 2023. This study shows the first observation of lunar tidal signals in the Earth's plasmasphere, advancing the understanding of lunar tidal phenomena and the Moon's effects on the near-Earth space environment, extending the knowledge of the Earth–Moon system, and opening new perspectives for further studies of tidal interactions in other planetary and larger-scale system.

## Chinese Scholars and Overseas Collaborators Clarified Cause of Atmospheric Methane Surge in 2020

Methane is a powerful greenhouse gas. Its atmospheric concentration has increased by a factor of two during the Anthropocene. Cutting human-caused methane emissions is an urgent priority to keep climate warming to well below 2°C, the target of Paris Agreement. Remarkably, growth rate of atmospheric methane has been increasing in the past 15 years, and in the year 2020, reached the highest growth rate since atmospheric measurements started in the early 1980s. Thus, why growth rate of atmospheric methane has been increasing recently is an incredibly challenging puzzle.

The growth rate of atmospheric methane concentration is controlled by anthropogenic emissions, natural emissions and atmospheric methane sink. However, large uncertainties in both emissions and sinks disrupt the attribution of recent surge of atmospheric methane. In 2020, atmospheric methane level shows an enigmatic surge, although worldwide COVID-19 lockdown could likely decrease anthropogenic methane emissions. This very special year is a real-world 'natural experiment' that provided us new insights about recent surge of atmospheric methane.

To solve the methane enigmatic mystery, Prof. Shushi Peng and collaborators, combined bottom-up inventories and top-down inversions with "big" data of methane emissions and sinks, and elucidated the cause of the 2020 surge in atmospheric methane. Funded by the National Natural Science Foundation of China (Excellent Young Scientists Fund 41722101 and Key Program 41830643), the results show higher wetland emissions due to warmer and wetter climate in the Northern Hemisphere, contributing half of the 2020 surge in atmospheric methane. The atmospheric methane sink in 2020 is lower relative to 2019, resulting from decreased hydroxyl radical (OH) concentration due to lower anthropogenic nitrogen oxide (NOx) emissions during COVID-19 lockdown in 2020. The decrease in OH concentration explains another half of the 2020 surge in atmospheric methane. This highlights and warns that future anthropogenic pollution emissions (NOx etc.) that indirectly change lifetime of atmospheric methane through OH concentration, must be taken into account to meet the Global Methane Pledge launched at COP26 in 2021.

This study provides new insights for global methane budget, and offers new scientific evidences for Global Methane Pledge and achieving the warming target of Paris Agreement. Prof. George H. Allen, who did not involve in this study, wrote news and views for this study, entitled "Cause of the 2020 surge in atmospheric methane clarified", which applauds that this study is remarkable and "allow us to understand the relative contributions from changes in sources and the OH sink during the pandemic" (https://www.nature.com/articles/d41586-022-04352-6).

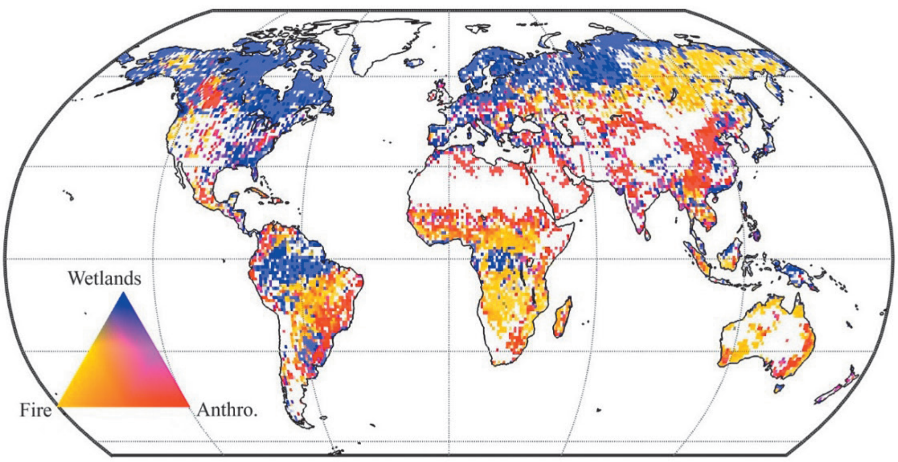



Figure 3-1-28 S patial distribution of contribution sources (wetlands, fire and anthropogenic) to change in emissions derived from bottom-up estimates

## Origin of Continents and Tectonic Evolution on the Early Earth

The origin of the Earth's early continents and the initiation of plate tectonics are among the core scientific problems in Earth Science. Various models have been proposed by previous researchers, but there are still many controversies. Therefore, a new perspective is required to provide new constraints to this problem. Magma oxygen fugacity and water content are the key variables controlling magma formation, evolution, and mineralization. High oxygen fugacity and water content are the essential characteristics of island arc magmas formed at subduction zones that distinguish them from magmas formed in other tectonic environments. However, quantifying magma oxygen fugacity and water content of Archean rocks has been a difficult problem due to widespread metamorphism of these ancient rocks.

Supported by the National Natural Science Foundation of China (General Program 41872191, Excellent Young Scientists Fund 41922017, National Science Fund for Distinguished Young Scholars 42025202), Profs. Ge Rongfeng, Zhu Wenbin and Wang Xiaoliei from School of Earth Science and Engineering, Nanjing

University, collaborated with Prof. Simon Wilde from Curtin University, Australia, and proposed a novel zircon oxybarometer - hygrometer through a combination of two oxybarometers based on zircon trace elements. This method can be used to calculate magma water content according to the oxygen fugacity and composition of zircon and equilibrium magmas, with an accuracy within 1 wt% (wt%: weight percentage) (Fig.3-1-29 a). On this basis, the research team calculated the magmatic oxygen fugacity and water content of Archean granitic rocks in the major cratons worldwide, and found that the oxygen fugacity and water contents of most Archean granitic magmas are significantly higher than those of ambient mantle derived magmas, but are similar to those of Phanerozoic island arc magmas formed at subduction zones (Fig. 3-1-29 b). The study also found a significant increase in oxygen fugacity and water content of granitic magmas in the Eoarchean (3.6 to 4.0 billion years ago), about 500 million years after the formation of the Earth, which likely indicates the initiation of subduction during that period. These results were published online in *Nature* on September 27, 2023, in the title of "Earth's early continental crust formed from wet and oxidizing arc magmas".

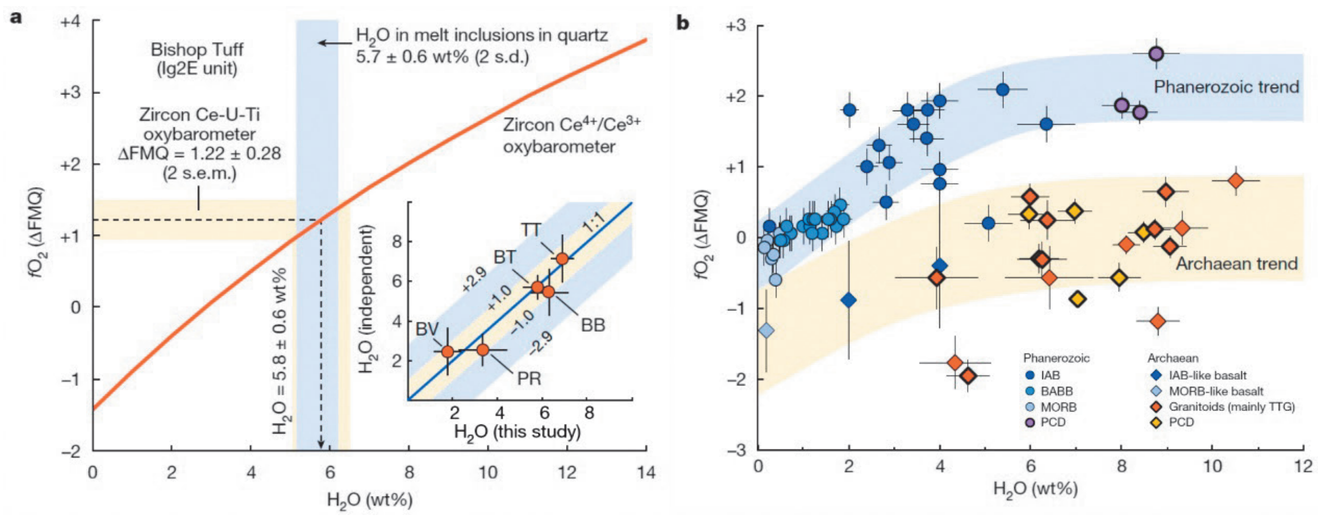



Figure 3-1-29 (a) Principle of zircon oxybarometer-hygrometer; (b) Comparison of oxygen fugacity and water content in Archean and Phanerozoic magmas

These results have significant implications for the origin of early continents, the initiation of plate tectonics, and the formation of key metal mineral resources. Several international experts spoke highly of the results, saying that "the work provides a new insight on a very classic debate in the geosciences. The resolution of the key question discussed here has implications on a wide range of processes that may have shaped our planet in its first evolutionary stages".

## Global Iron and Steel Plant Carbon-neutrality Pathways

The iron and steel industry accounts for approximately 25% of global industrial $CO_2$ emissions, making it the sector with the highest carbon emissions among all global industries. Due to accelerated urbanization and industrialization in recent decades, the global steel demand surged, resulting in the construction of numerous new steel production facilities worldwide. Consequently, this development has posed significant challenges for reducing emissions in the global iron and steel industry. Currently, carbon emissions from the iron and steel industry mainly stem from the complex and long steelmaking process, encompassing numerous emission-generating steps, coupled with immature emission reduction technologies.

Funded by the National Natural Science Foundation of China (Science Fund for Creative Research Groups 41921005), Professor Guan Dabo and his team at Tsinghua University has conducted an in-depth analysis of global iron and steel industry carbon emission characteristics based on their self-developed, facility-level carbon emission database for the global iron and steel sector. Based on this research, they have devised tailored decarbonization plans for individual iron and steel plants worldwide and suggested a unique, differentiated roadmap towards carbon neutrality for the entire industry.

The team first collected basic information on global iron and steel industry facilities, including coking, sintering, pelletizing, ironmaking, and steelmaking processes. Based on this information, they developed a dynamic emission characterization algorithm and established a carbon emission database covering over 10,000 facilities worldwide. This database significantly improved the global iron and steel emission characterization capability from the regional and industrial scales to the individual facility and process scales (Figure 3-1-30).

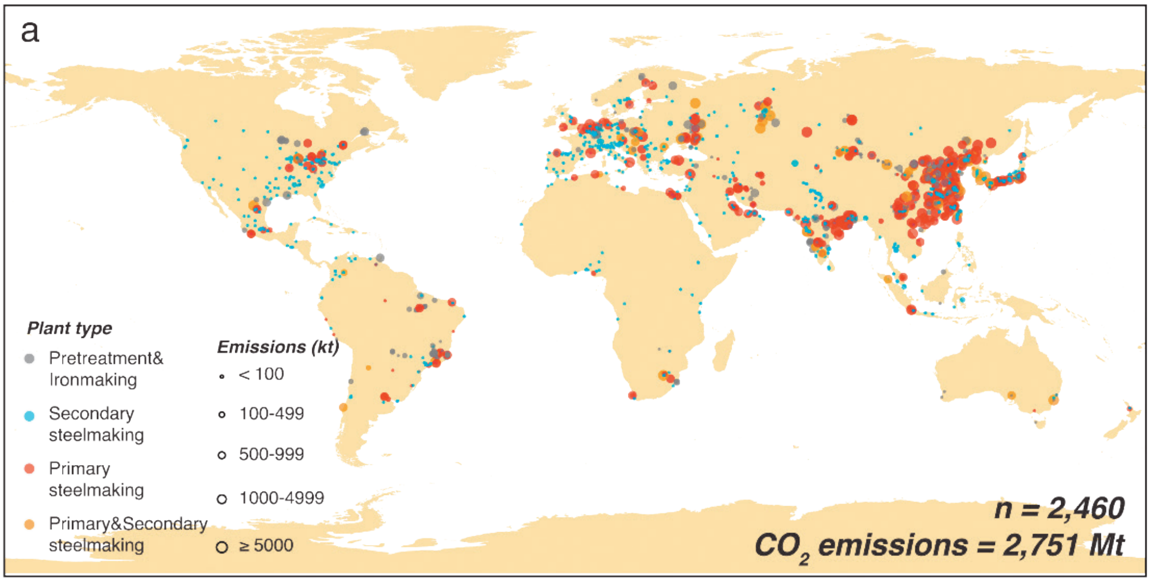



Figure 3-1-30 Maps of Geographical location, Plant type (scatter color of dots) and $CO_2$ emissions (size of dots) of the active iron and steel plants worldwide in 2019

Furthermore, the team discovered significant differences in facility size, technology, service life, and carbon emissions among iron and steel plants across various countries. Focusing on the long-steelmaking process BF-BOF, the team designed two targeting indicators: carbon emission intensity (defined as carbon emissions per unit of crude steel production) and service life-capacity ratio (defined as the ratio of the average service life of iron and steel plant equipment to crude steel production capacity). These indicators help prioritize decarbonization efforts in long-steelmaking process plants from both emission reduction potential and economic perspectives, and outline the most cost-effective, plant-specific decarbonization strategy for the global iron and steel industry. Using scenario simulations, the team emphasized the importance of early adoption of low-carbon and zero-carbon technologies to achieve the significant carbon emissions reduction of the global iron and steel sector. By implementing essential emission-reducing strategies and technological advancements, the cumulative carbon emissions from this industry could potentially drop by more than 65% between 2020 and 2050.

The relevant research results have been published in *Nature* and *Nature Climate Change*. This study innovatively constructed a comprehensive carbon emission database for the global steel industry at the facility level and proposed a plant-by-plant decarbonization strategy and carbon neutrality path for the global iron and steel industry. It introduced a targeted “one plant, one policy” approach to achieve a low-carbon transformation in the global iron and steel industry, providing a valuable scientific basis for developing an emission reduction roadmap for the sector.

## Changes of the Seas around China in a Warming Climate

The seas around China (SAC) collectively refer to the Bohai Sea, Yellow Sea, East China Sea, and South China Sea. Billions of people residing in surrounding countries rely on the functions, goods, and services provided by these seas, including fisheries, aquaculture, shipping, water resource, tourism, and recreation. Under anthropogenic climate change, significant changes have taken place in the physical and biogeochemical properties and biodiversity of the SAC, leaving profound impacts on regional sustainable development. With this regard, interdisciplinary investigations of the long-term change of the SAC are of urgent priority. Supported by the National Natural Science Foundation of China (Major Program 42090040), Dr. Fan Wang from the Institute of Oceanology and collaborators have made progress in understanding the long-term change of the SAC, with the main results published in *Nature Reviews Earth & Environment*. Through a combination of observational datasets, proxies, and model simulations, this study underpins the spatial-temporal characteristics and significant levels of warming, marine heatwaves, eutrophication, hypoxia, acidification, and changes in species distribution range and community structure and elucidates their causes and interaction. Through a synthesis of observation-based facts and knowledge, this study, for the first time, points out the essence of coupling between physical, biogeochemical, and biological processes in the long-term change of the SAC.

Estimates based on in-situ observations suggest that the mean sea surface temperature of the SAC has been warming at 0.10-0.14 ℃ per decade since the 1950s and significantly accelerated since the 1980s. (Figure 3-1-31)Among major seas, the East China Sea shows the strongest warming pace, with the winter pace exceeding the summer pace. The warming has given rise to increasing extreme warm events. The frequency, duration, and average intensity of marine heatwaves have dramatically increased in recent decades. The nutrient concentrations showed increasing trends in most coastal waters of the SAC at the end of the 20th century. Surface warming and eutrophication mutually cause increasing severity of hypoxia and acidification in coastal waters. Accompanying physical and biogeochemical changes in the SAC, species distribution range and biodiversity across plankton, benthos, and fish communities have also shown complex changes, with the miniaturization (down-sizing) and warm-water species invasion emerging as the most striking features. Since the 21st century, owing to the efforts of ecological civilization construction and environment management, eutrophication in coastal waters and its impact have been significantly alleviated.

This study also proposed emerging multidisciplinary scientific hotspots for the upcoming decade, including the warming of coastal and subsurface waters, circulation and surface heat fluxes in coastal regions, compound stressors and their interplay, and prediction models for marine biodiversity. Artificial intelligence (AI) techniques may play the central role in addressing these issues. According to the projection of dynamic and statistical models, the warming trend and its impacts on marine ecosystems in marginal seas will amplify in the upcoming decades, posing severe stress on the surrounding countries and human activities, which highlights the urgent necessity of the research effort on the long-term change of the SAC. Therefore, through underscoring the importance of interdisciplinary effort and AI techniques, this study points out the pathway toward a better understanding of the SAC under a warming climate.

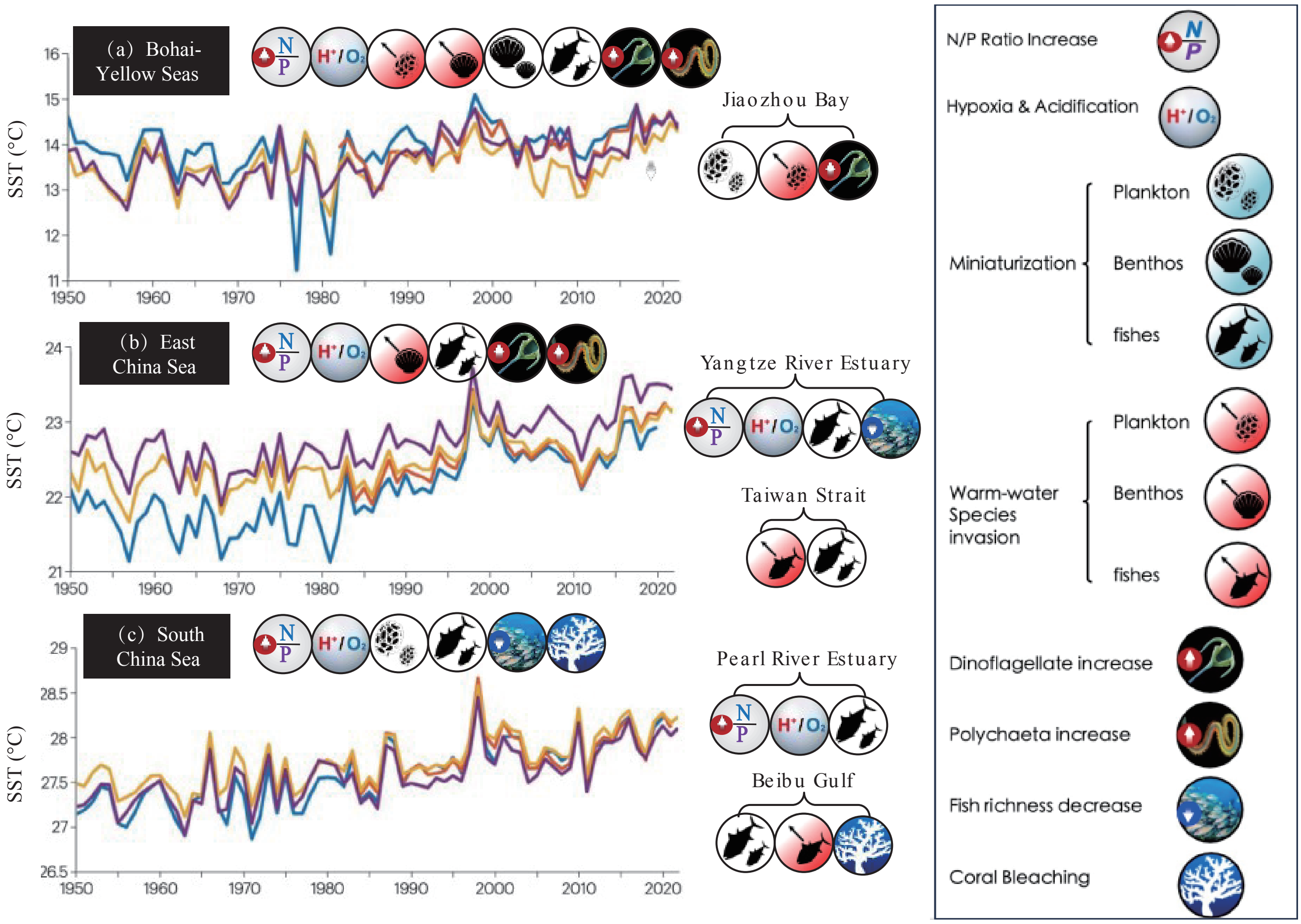



Figure 3-1-31 Historical changes in the seas around China (SAC), including increased nitrogen-to-phosphorus concentration ratio, hypoxia and acidification, and fish richness decrease, coral bleaching, and biodiversity trends. Major biodiversity trends detected in the seas around China include miniaturization (down-sizing), warm-water species invasion, dinoflagellate increase and polychaeta increase.

## Piezoelectric Ceramics Goes Textured

Since 1970s, lead zirconate titanate [Pb(Zr, Ti)$O_3$, PZT] ceramics have become one of the key piezoelectric materials in various electromechanical devices such as medical imaging transducers and high-precision actuators, owing to their high piezoelectric performance and relatively high phase transition temperatures. Nowadays, further improving the imaging resolution of medical transducers and increasing the sensitive of sensors are of great importance for the development of next-generation piezoelectric transducers, which requires piezoelectric ceramics with even higher performance. Engineering ceramic grains along a specific crystallographic orientation (i.e., fabricating textured ceramics) enables the utilization of crystal anisotropy, which provides an effective way to further enhance piezoelectric properties of PZT ceramics. However, fabricating highly textured PZT ceramics has been a great challenge since 1990s in the piezoelectric research field.

Supported by the National Natural Science Foundation of China (Excellent Young Scientists Fund 51922083, General Program 52172129 and 52072092), Prof. Fei Li's group in Xi'an Jiaotong University and collaborators proposed a seed-passivated texturing process to fabricate the textured PZT ceramics. First, a new type of templates (i.e., barium zirconate titanate templates) is developed to replace the generally used titanate templates, which improves the stability of the templates in the PZT matrix. Second, a multilayer architecture of PZT matrix with different $Zr^{4+}$ concentration is designed to replace the generally used uniform matrix, which not only ensures the template-induced grain growth in Ti-rich PZT layers but also facilitates desired homogeneous composition through interlayer diffusion of Zr/Ti during sintering. Based on the above approach, the research team resolves the long-standing challenge of fabricating highly textured PZT ceramics. For the first time, the high-quality <001>-textured PZT textured ceramics with compositions around morphtropic phase boundary were successfully fabricated (Figure 3-1-32). Moreover, significantly enhanced piezoelectric and electromechanical properties are achieved in the textured PZT ceramics. At the same Curie temperature, PZT-based textured ceramics exhibit piezoelectric coefficients that are higher by ≥60% when compared with those of non-textured counterpart. This resolves the dilemma that the piezoelectricity and Curie temperature can only be enhanced at the expense of each other for PZT ceramics(Figure 3-1-33).

The research was published in *Science* in April, 2023. This work may provide a new pathway for texturing various perovskite ceramics. Meanwhile, the newly developed high-performance PZT textured ceramics offer new opportunities to improve the performance of various piezoelectric devices, i.e., large-displacement & high-precision piezoelectric actuators.

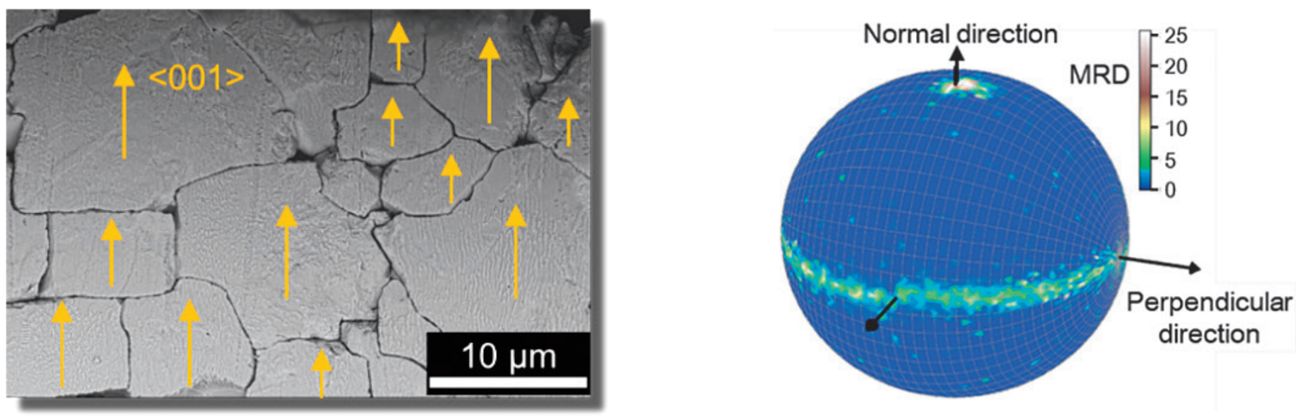



Figure 3-1-32 (a) Cross-sectional SEM image of a PZT textured ceramic, where grains are oriented along <001> direction; (b) The {002} pole figure obtained from the synchrotron XRD experiment.

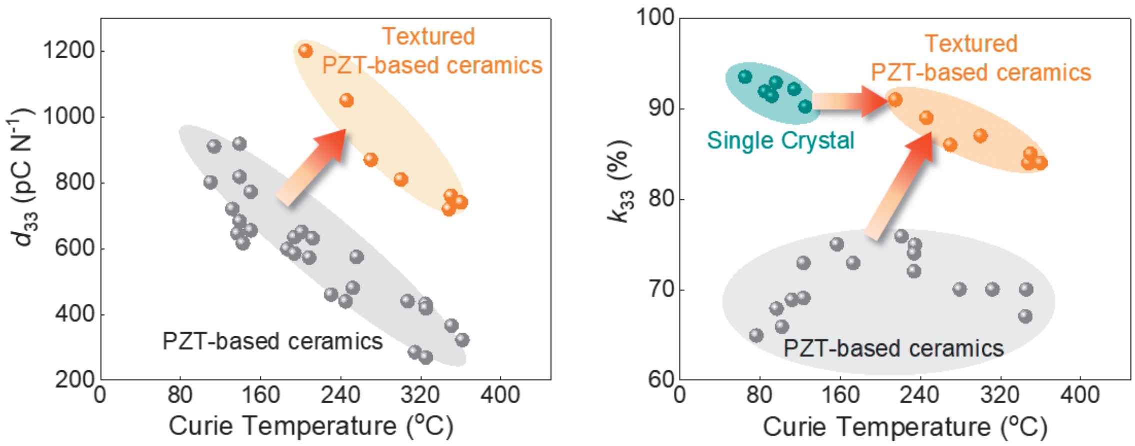



Figure 3-1-33 (a) Piezoelectric coefficient $d_{33}$ and (b) electromechanical coupling factor $k_{33}$ as a function of Curie temperature for PZT-based textured ceramics. The data of randomly oriented PZT-based piezoelectric ceramics and single crystals are given for comparison.

## On-demand Autonomous Shape Morphing of Shape Memory Polymers

Shape memory polymers (SMPs) have shown unique promise in emerging applications, including soft robotics, medical devices, aerospace structures and flexible electronics. Their externally triggered shape-shifting behavior offers on-demand controllability essential for many device applications. Ironically, accessing external triggers (for example, heating or light) under realistic scenarios has become the greatest bottleneck in demanding applications such as implantable medical devices. Certain shape-shifting polymers rely on naturally present stimuli (for example, human body temperature for implantable devices) as triggers. Although they forgo the need for external stimulation, the ability to control recovery onset is also lost. Naturally triggered autonomous, yet actively controllable, shapeshifting behavior is highly desirable but these two attributes are conflicting.

Supported by the National Natural Science Foundation of China (Key Program 52033009, General Program 52273112, Integration Program U20A6001), the team of Professor Tao Xie and Professor Qian Zhao from the College of Chemical and Biological Engineering at Zhejiang University demonstrated a shape memory polymer that can conduct on-demand autonomous shape shifting. The work titled "Shape memory polymer with programmable recovery onset" was published on Nature in September 2023.

The shape memory polymer is a hydrogel with thermally induced phase separation behavior. The hydrogel can be deformed upon imposing an external force at room temperature, and the temporary shape can be fixed by phase separation occurred at high temperature. After returning to room temperature, the shape of the hydrogel remains unchanged for a period of time (that is, the onset delay) before autonomous recovery. The study shows that the shape-shifting kinetics is dominated by internal mass diffusion instead of heat transport for common shape

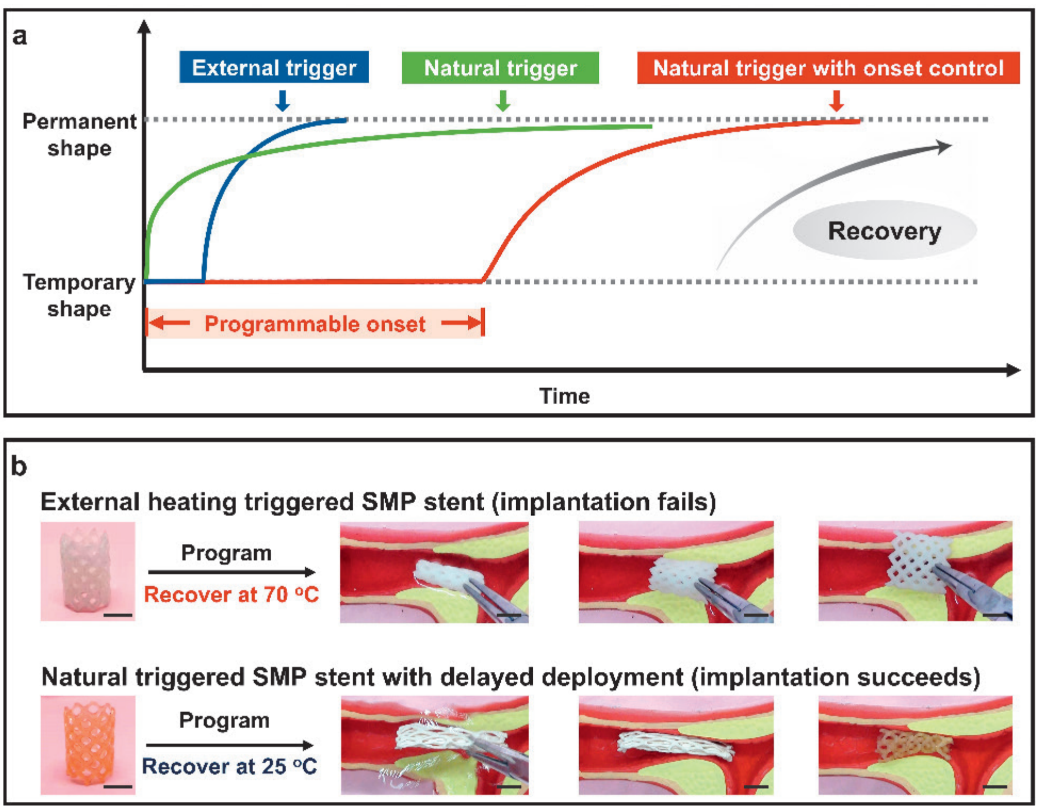



Figure 3-1-34 SMP with programmable recovery onset enabling on-demand autonomous shape-shifting. a. Comparison of different shape-shifting modes of shape memory polymers. b. Comparison of a typical implantation process between a 4D printed device with recovery onset and a common SMP device.

memory polymers. This onset delay is programmable by altering the structure of the polymer network during synthesis or the degree of phase separation upon shape programming. The unique potential of the on-demand yet autonomous shape memory polymer is conceptually demonstrated with 4D printed devices (Figure 3-1-34).

## Testing Technology and Instrument for Mechanical Properties of Complex Mechanical Load and Multi-field Coupling Materials

Materials and products that serve safely and stably are the foundation of the national economy and national security. In the service of key materials in fields such as aerospace, nuclear energy, and ocean, they are inevitably subjected to complex loads and even multi field coupling effects, leading to damage, failure, and even destruction, and malignant accidents occur from time to time. Traditional techniques are unable to simulate complex working conditions and characterize mechanical behavior in situ, which is no longer sufficient to meet the needs.

Supported by the National Natural Science Foundation of China (Excellent Young Scientists Fund 51422503, National Science Fund for Distinguished Young Scholars 51925504, and Special Fund for Research on National Major Research Instruments 52227810), Professor Zhao Hongwei's team from Jilin University has made new progress in the field of material mechanics testing technology. The team has invented the principles and methods for constructing complex working conditions, developed complex static and dynamic mechanical loads, multi physics field coupling, and environmental atmosphere loading technology. We have conquered theories and key technologies such as multi parameter collaborative control/parallel detection, neutron/synchronous light source beam incidence position/angle control, and heterogeneous data registration and fusion analysis. Invented in-situ testing technology for simulating complex working conditions, independently developed 26 types of instruments in 3 categories, filled the domestic gap, broke foreign monopolies and technological limitations, established instrument technology standards, and achieved engineering, industrialization, and standardization.

The team has published a batch of papers in important journals such as *IEEE T Ind Electron*, *IEEE T Instrum Meas*, *MSSP*, *RSI*, *MST*, etc., and praised by scholars from the United States, Britain, Japan, and other countries. The achievements have been featured on the official website of the State Council of China, as well as more than ten famous science and technology media outlets such as AAAS, Science Daily, etc. Two international conferences on the forefront of material testing technology have been initiated and hosted. Authorized more than 100 patents from China, the United States, and Japan, partially converted and implemented, and established an industrialization base at China National Machinery Industry Corporation. The series of instruments developed and promoted for application in more than ten key fields such as aviation, aerospace, nuclear energy, ocean, ships, vehicles, and quality inspection, providing key mechanical testing equipment for five major scientific and technological infrastructure projects in China (including one pre research line station), contributing to the safe and stable service of multiple major projects and key models, and have been applied overseas, promoting the leapfrog development of mechanical testing technology from non in-situ testing under single working conditions to in-situ testing under complex working conditions.

Part of the achievements won the first prize of the Machinery Industry Science and Technology Award (Technology Invention category) in 2023.

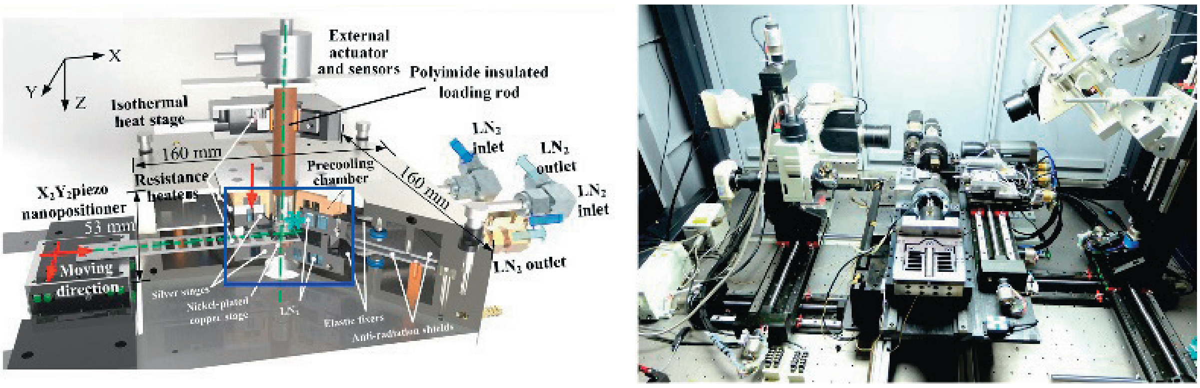



Figure 3-1-35　Complex Mechanical Load/Multi-field Coupling Test Techniques and Some Instrumentation

## Polymer Dielectric Materials with Both High Thermal Conductivity and Low Electrical Conductivity

With the support of the National Natural Science Foundation of China (General Program 51877132) and other funding, Professor Xingyi Huang's team at Shanghai Jiao Tong University, in collaboration with partners, has made a new breakthrough in the research field of polymer dielectric materials. The relevant research results, titled "Ladderphane copolymers for high temperature capacitive energy storage" were published in the *Nature* journal on March 2, 2023. The paper's link is: https://www.nature.com/articles/s41586-022-05671-4. The research simultaneously achieved the regulation of thermal and electrical conductivity in polymer dielectric films, breaking the traditional trade-off between insulation and thermal conductivity in polymer films.

Polymer dielectric film capacitors have a very high energy conversion rate, and they play a crucial role in the fields of electromagnetic energy equipment, power electronics, and new energy equipment. As devices and equipment continue to move towards compact, lightweight, and extreme working environments, the demand for the energy storage density and high-temperature resistance of polymer dielectric films is increasing. The charge storage density is directly proportional to the square of the electric field strength. Therefore, increasing the breakdown field strength of the dielectric film is crucial to increase the charge storage capacity of the capacitor. However, polymer films mainly conduct electricity through electron conduction under high electric fields, no longer following Ohm's law. The conduction current increases exponentially with the increase of the electric field strength, leading to the generation of a large amount of Joule heat. The thermal conductivity coefficient of traditional polymer dielectrics is generally low (<0.2W/(mK)), leading to poor heat dissipation efficiency, causing the temperature of the dielectric to rise rapidly, which in turn leads to a rapid decrease in the breakdown field strength due to the increase in the conduction index, resulting in serious problems such as device and equipment failure. The heat dissipation issue of devices and equipment operating at high temperatures is particularly prominent. Although the thermal conductivity coefficient of polymer dielectrics can be increased through methods such as nano-additives, this presents significant challenges for film manufacturing processes. Therefore, developing polymer dielectric films with high-temperature resistance and intrinsic high thermal conductivity is the best choice.

The research team constructed an arrayed nano-region by arranging the segment chains, and introduced electropositive trap groups into the arrayed nano-region. This significantly improved the thermal conductivity of flexible polymer dielectric thin films, leading to an increase in resistivity by an order of magnitude, thereby resolving the contradiction between thermal conduction and insulation. The intrinsic thermal conductivity in the thickness direction of the polymer dielectric film is 1.96 ± 0.06 W/(mK), the highest reported value for the intrinsic thermal conductivity of insulating polymers. The discharge energy density of the polymer dielectric thin film at 200°C and 90% efficiency is 5.34 J/cm3, and the energy storage performance remains stable after 50000 charge-discharge cycles, exhibiting excellent self-healing breakdown characteristics. This presents great potential for applications in electromagnetic energy equipment, new energy vehicles, power electronic devices, and other related fields.

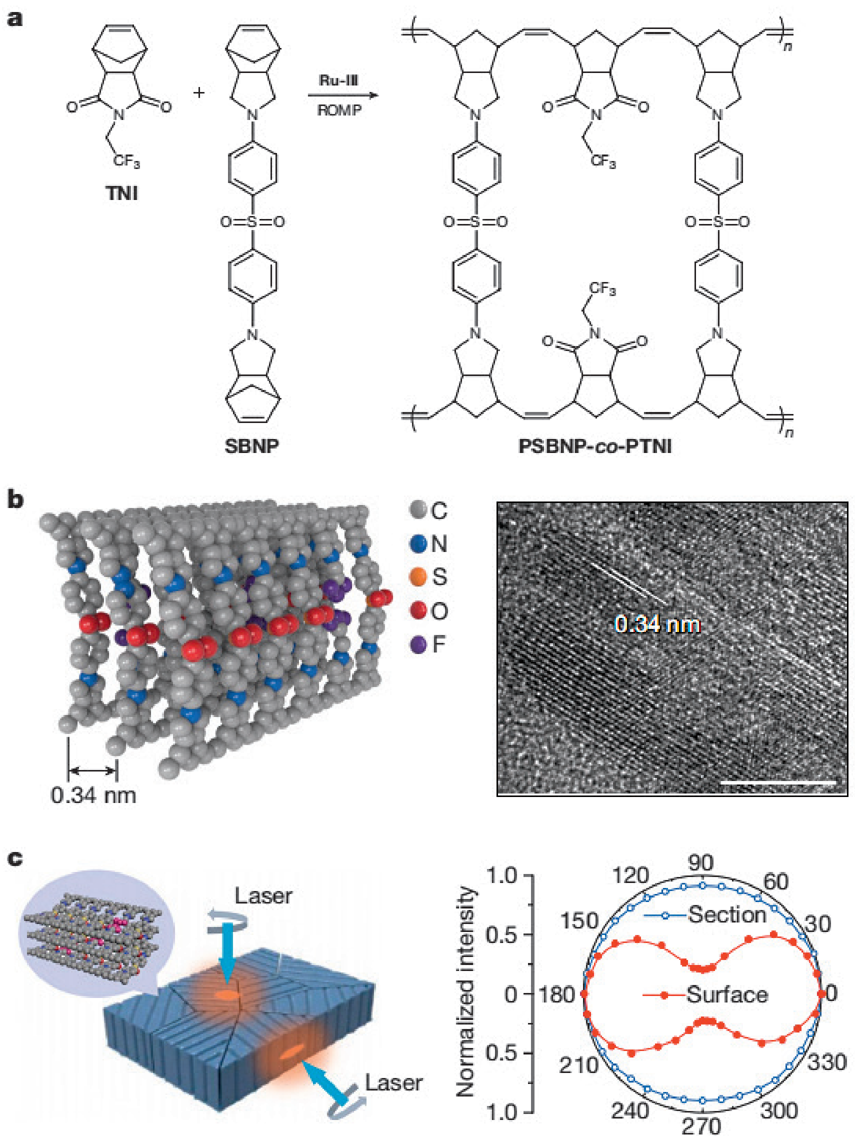



Figure. 3-1-36 Molecular structure and self-assembly morphology of double-stranded structured polymer dielectric films

## Pre-stressed Concrete-filled Steel Tube Lattice Tower Structure for Large Scale

The development of wind power plays a crucial role in adjusting China's energy structure. Currently, the development, construction, and operation of wind power in China face challenges posed by complex terrains, geology, and climatic environments. In order to achieve grid parity, individual turbine capacities are continuously increasing (10 MW and above onshore, 20 MW and above offshore), hub heights are significantly rising (160 meters and above), and blade lengths are continuously growing (120 meters and above). However, there is a lack of high-performance tower structures and corresponding design theories and methods, leading to frequent tower collapse incidents and significant economic losses.

In response to the aforementioned challenges, under the support of the National Natural Science Foundation of China (Excellent Young Scientists Fund 51822804 and General Program 51778085), a team led by Academician Zhou Xuhong and Professor Wang Yuhang from Chongqing University has innovatively proposed a pre-stressed concrete-filled steel tube (CFST) lattice tower structure. In this tower structure, the upper region, experiencing lower forces, adopts a traditional steel tower, while the lower region, subject to higher forces, is composed of four CFST columns and cross-diagonal hollow steel tubes. Longitudinal pre-stressed tendons are applied in the CFST columns. As the components primarily bear axial forces, the strength of the materials can be fully utilized. Applying pre-stress to the CFST columns effectively avoids the cracking problem of concrete inside the steel tubes when subjected to tension, resulting in high load-bearing efficiency. All components are factory-prefabricated and assembled on-site with bolts, ensuring high efficiency in production and installation. The research team carried out theoretical research and successfully addressed key scientific issues, including the complex compression-bending-shear-torsion stress mechanism of CFST members, the fatigue damage mechanism of joints, and the failure mechanism of the overall structure under compression-bending-shear-torsion coupled loads. The mechanical performance analysis method of CFST components under uniaxial reciprocating and compression-bending-shear-torsion coupled loads, the fatigue performance analysis method of T-shaped CFST-plate joints with stiffeners, and the refined and efficient calculation method of pre-stressed CFST lattice tower structures were proposed. These researches solve the problems associated with traditional steel structure towers, such as high cost and easy collapse, as well as issues with traditional concrete towers, such as cracking and low construction efficiency. The research results were awarded the gold medal at the 48th International Exhibition of Inventions of Geneva in 2023.

While achieving high performance, the comprehensive cost of this tower structure is more than 10% lower than that of traditional tower structures. A prototype project demonstration of the 165-meter tower structure (Figure 3-1-37) has been successfully completed in Shandong Province, China. This marks the first application of the pre-stressed CFST lattice tower structure, showcasing its viability. In comparison to neighboring wind turbines, there is an approximate 15% increase in power generation. In August 2023, a 5.5-magnitude earthquake occurred in Dezhou, Shandong, with an epicenter depth of 10 kilometers. The turbine site is located 90 kilometers from the epicenter, and remarkably, no damage occurred in the tower structure. The research outcomes are of significant importance for advancing the theoretical development of wind turbine tower structures, promoting "cost reduction and efficiency improvement" in the wind power industry, and ensuring the efficient and safe development of wind power.


Fig.3-1-37 Engineering demonstration of pre-stressed concrete-filled steel tube lattice tower structure

## Intelligent Construction Theory and Technology for Major Water Conservancy and Hydropower project under Complex Conditions Wind Turbines

With continuous support from the National Natural Science Foundation of China (Creative Research Group 51021004, 51321065, 51621092, and Joint Funds U1965207), the team led by Academician Zhong Denghua at the National Key Laboratory of Intelligent Construction and Operation of Hydraulic Engineering, Tianjin University, has conducted in-depth research for several years in areas such as intelligent simulation of construction, intelligent monitoring throughout the construction process, intelligent unmanned equipment, and construction and digital twin cloud platforms (Figure 3-1-38).

The main innovative achievements of this research are as follows: (1) An integrated intelligent simulation model for the construction of major water conservancy and hydropower projects under complex and uncertain conditions was contructed. Breakthroughs were achieved in the intelligent identification of construction simulation parameters, dynamic updating of simulation models, and visualization analysis of the simulation process in complex environments. This has enabled precise control of construction progress for major water conservancy and hydropower projects under complex conditions. (2) A series of intelligent monitoring equipment and intelligent unmanned operation equipment for the entire process of construction in major water conservancy and hydropower projects under complex conditions were independently developed. Overcoming challenges such as intelligent perception of multi-source cross-modal information under complex conditions, intelligent analysis of progress, quality, and safety, and coordinated operation of equipment fleets. This has effectively alleviated the problem of reduced efficiency in human-machine collaboration in the construction of projects in high-altitude frozen soil areas, ensuring the quality, progress, and safety of construction projects. (3) Advanced modeling and automatic updating technology for the digital twin space of major water conservancy and hydropower projects were developed. A method for synchronous mapping between physical space and twin space was proposed, achieving intelligent and efficient construction of major water conservancy and hydropower projects based on digital twins.

The research results have been published multiple times in top-tier journals such as *Automation in Construction and Computer-Aided Civil* and *Infrastructure Engineering*, receiving high praise and recognition from researchers both domestically and internationally. The research outcomes have been successfully applied in several world-class major water conservancy and hydropower projects, including Lianghekou, Shuangjiangkou, Baihetan, and Huangdeng. These applications have yielded significant economic benefits, pioneering a new and intelligent construction management model. This has propelled a revolutionary shift in China's major water conservancy and hydropower projects from digitization to intelligence, serving as a leading and demonstrative force for the intelligent development of hydropower projects in China. The relevant achievements have been awarded the first prize for technological progress in Yunnan Province, two special prizes, and one first prize from the Chinese National Committee on Large Dams.

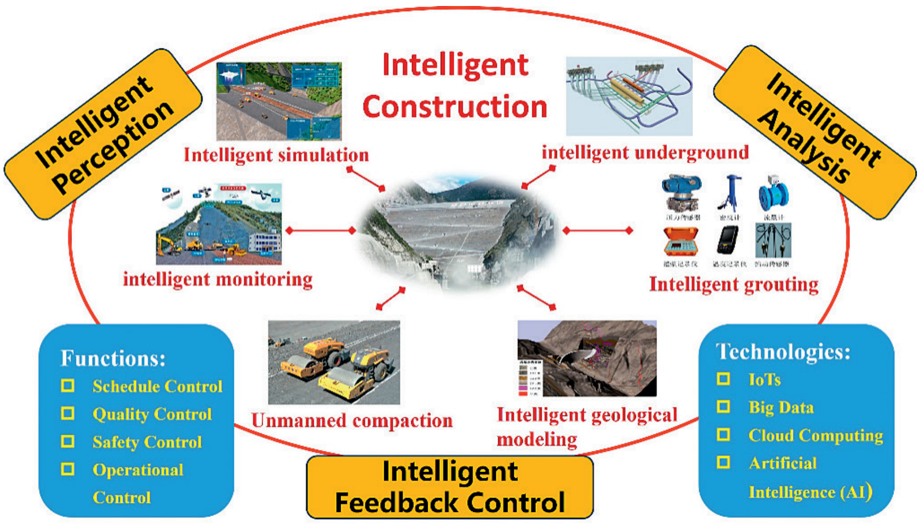



Figure 3-1-38 Intelligent Construction Theory and Technology for Major Water Conservancy and Hydropower project

## Methodological Research on Measurement of Atmospheric Turbulence Strength Fields via Thermal Infrared Imaging

How to measure the strength fields of atmospheric turbulence quickly and accurately is an important scientific problem of wide interest in aerospace, meteorological science, atmospheric physics, and other fields. However, the presence of atmospheric turbulence causes atmospheric systems to be characterised by nonlinear responses, complex boundary conditions and extreme variability in scale, making it extremely difficult to measure the strength of atmospheric turbulence. Existing measurement techniques generally rely on expensive equipment such as VHF radars, radio sounders, etc., and only sparse point measurements can be obtained. Therefore, it is of urgency to explore a fast, convenient, and highly accurate method for measuring the atmospheric turbulence strength fields.

Funded by the National Natural Science Foundation of China (General Program 62271016), Professor Bai Xiangzhi's team at the Beihang University has conducted research on the measurement method of atmospheric turbulence strength fields via thermal infrared imaging. By establishing an analytical model of the thermal infrared imaging effects of atmospheric turbulence, the team found that the thermal infrared image degradation caused by the photothermal effects of atmospheric turbulence is a direct result of the atmospheric turbulence strength fields acting on the propagation of thermal radiation. On this basis, the physically boosted cooperative learning framework (PBCL) for atmospheric turbulence measurement and infrared imaging turbulence degradation suppression has been proposed. The constructed turbulence measurement module and turbulence suppression module are organically integrated and mutually reinforced through cooperative learning, which can simultaneously achieve the dual tasks of accurate measurement of atmospheric turbulence strength fields and suppression of turbulence degradation in infrared imaging. A large-scale dataset containing 137,336 infrared images and corresponding turbulence strength fields has been constructed. The results show that the peak signal-to-noise ratio between the degraded infrared imaging data and the original undegraded imaging data is as high as 35 dB, and the similarity decision coefficient between the measured atmospheric turbulence strength fields and the pre-set true value is higher than 0.9. In the real-world environment, the PBCL measurement results are in good agreement with the results of the traditional temperature pulsation method, which facilitates the analysis of fluctuations and power spectra of physical quantities of atmospheric turbulence (Figure 3-1-39), opening a new way to obtain the rich physical characteristics of atmospheric turbulence quickly and effectively.

The research was published in *Nature Computational Science* on 10 August 2023 under the title "Revelation of hidden 2D atmospheric turbulence strength fields from turbulence effects in infrared imaging". The team was also invited to publish a Research Briefing in *Nature Computational Science* at the same time. This research reveals the high correlation between atmospheric turbulence strength fields and complex turbulence thermal infrared imaging effects, realizes the fast and accurate measurement of two-dimensional strength fields of atmospheric turbulence, and helps to promote the application of imaging and deep learning techniques in the field of complex physical field detection.

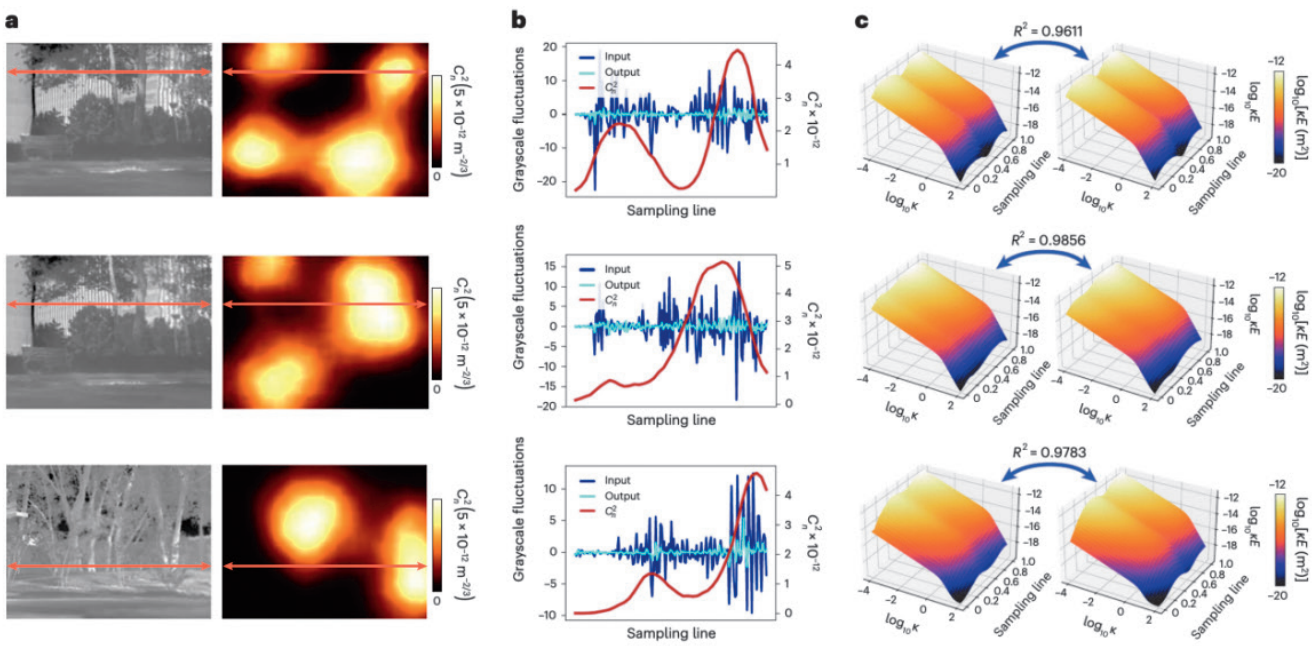



Figure 3-1-39　Turbulence fluctuation and spectral analysis based on the turbulence strength fields obtained by PBCL

Jie Pan, Senior Editor of *Nature Computational Science*, commented that the physical quantities of turbulence obtained by learning from infrared images in this research have a wide range of applications in atmospheric science, meteorology, and other fields ("…enable the learning of turbulence quantities from infrared images, which are widely used in many areas including atmospheric and meteorological research. With fruitful benchmark results…"). Ricardo Vinuesa, Vice Director of the KTH Digitalization Platform, pointed out that the measurement of atmospheric turbulence is extremely challenging, and evaluated that the research has achieved reliable measurement of turbulence in large-scale data ("…turbulence is difficult to accurately measure owing to its multiscale character and chaotic behavior. This becomes even more challenging in the context of atmospheric turbulence… The demonstration of their method on full-scale data indicates promise for turbulence measurements.").

## Research on Large Artificial Intelligence Models for Extreme Precipitation Nowcasting

Extreme precipitation nowcasting is one of the most important research topics in the field of earth sciences. In recent years, influenced by global climate change, the frequency of short-term heavy rainfall, rainstorm and blizzard has been increasing year by year, posing a serious threat to economic growth and people's safety, and exerting a huge impact on many industries especially agriculture, new energy, transportation, aviation, aerospace, and navigation. Thus there is urgent need to guarantee the socioeconomic safety by meteorological forecasting techniques that endow high resolution, long lead times and accurate details of the weather processes. However, the process of extreme precipitation mostly only lasts for a few tens of minutes and is limited to a few kilometers. It is difficult to accurately forecast it using mesoscale numerical weather prediction systems or purely data-driven methods due to the influence of convective vortex processes, topographical factors, and atmospheric chaotic effects. Extreme precipitation nowcasting was outlined as one of the important open scientific challenges at the World Meteorological Organization Summit (May 27, 2023), and it was also highlighted as one of the key research directions in the field of "AI for Science" in *Nature* (August 2023).

Under the support by the National Natural Science Foundation of China (Creative Research Group 62021002 and Excellent Young Scientist Fund 62022050), the research team led by Prof. Jianmin WANG and Prof. Mingsheng LONG from Tsinghua University engaged in long-term cooperation with the production teams from National Meteorological Centre (Central Meteorological Observatory) and National Meteorological Information Centre. Throughout the three-year research, the joint team developed NowcastNet, an AI foundation model for extreme precipitation nowcasting. NowcastNet closely integrates data-driven and physics-driven paradigms, with neural evolution operator as its core that enables end-to-end modeling of physical processes and differentiable fusion of deep learning methods and physical first principles. Technically, a mesoscale evolution network is designed to simulate the mesoscale advection movements governed by more significant physical properties, using the neural evolution operator derived from the continuity equation (i.e. conservation law) to simulate the 10-km-scale movements of extreme precipitation. Due to the differentiable architecture, the accumulated error, a major dilemma in forecasting, can be jointly minimized by backpropagation through the whole modular system. Further, a convective-scale probabilistic generative network is designed to capture chaotic processes of convective details at a 1-km scale, conditioned on the physically plausible predictions by the mesoscale evolution network. NowcastNet unleashes the power of combining physical modeling and deep learning, which achieves extreme precipitation nowcasts at a spatial resolution of 1-km-scale and a lead time of 3 hours. This is the highest technical level achieved for the first time for precipitation nowcasting in the world. In a weather process evaluation by 62 expert meteorologists from 23 provincial observatories across China, this large AI model was considered to yield the highest forecast value in 71% of the 2,400 extreme weather processes, surpassing related methods of the meteorological agencies in Europe and the UK, and technolgy companies such as Google and DeepMind. It holds the highest forecast skill currently among all the nowcasting techniques for extreme precipitation.

The above research achievements were published in *Nature* (July 5, 2023) with the title "Skilful Nowcasting of Extreme Precipitation with NowcastNet". This breakthrough was also introduced in *Nature News & Views* with the report "The Outlook for AI Weather Prediction." As the first large-scale Artificial Intelligence model for meteorological forecasting in China, NowcastNet has been deployed in Severe Weather Analysis and Nowcast system (SWAN 3.0) of China Meteorological Administration, providing accurate forecasts and timely warnings for severe weather. This innovation has not only provided accurate meteorological decision support for disaster prevention to safeguard China's real economy and industries, but has also pioneered the advancement in large AI models that combines physical-driven and data-driven paradigms for meteorological forecasting.

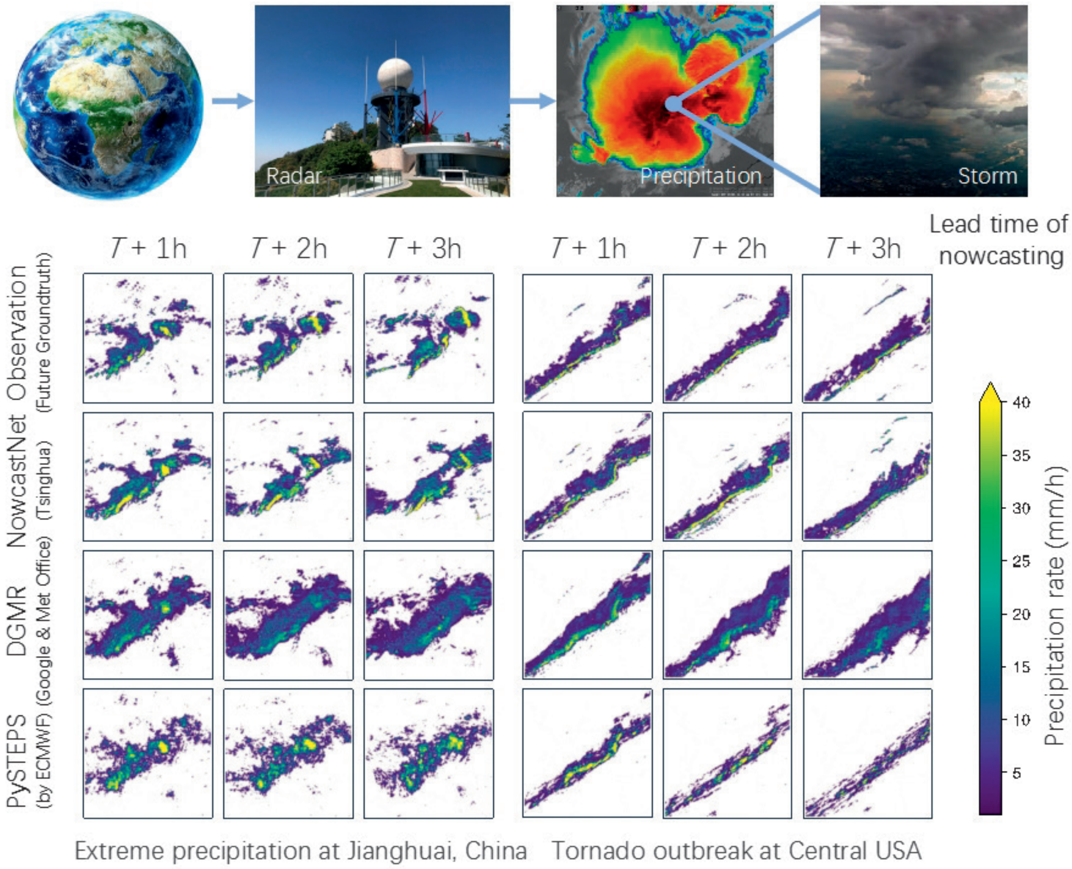



Fig 3-1-40 Representative case study of extreme precipitation weather processes in China

## An Interpretation Method for Artificial Neural Networks and Its Application in Gene Regulatory Sequence Analysis

Interpreting and transparentizing the black-box of artificial neural networks (ANNs) can benefit the understanding of the patterns learnt from data, which can enhance the interdisciplinary knowledge discovery and advance the development of artificial intelligence. In many studies on the gene regulatory function of DNA sequences, architectures such as convolutional neural networks (CNNs) have achieved great prediction performance, but the lack of interpretation methods severely limits the deciphering of gene regulatory rules. It is urgent to establish methods that can extract and summarize syntax rules for gene regulatory sequences from artificial neurons of ANNs.

With the support of the National Natural Science Foundation of China (Original Exploration Plan 62250007, National Fund for Distinguished Young Scholars 62225307, and Creative Research Group 61721003), Prof. Xiaowo Wang's team at Tsinghua University, collaborating with Prof. Wing Hung Wong's team at Stanford University, conducted research on ANN interpretation methods for gene regulatory studies. They found that most deep-layer neurons in CNNs are multifaceted neurons. These neurons can be activated by different sequence patterns simultaneously, which causes the direct visualization results of these neurons difficult to be understood. They identified that the maximum pooling structure is the key driver of the multifaceted phenomenon. Therefore, they proposed the NeuronMotif algorithm which utilizes the Monte Carlo sampling and genetic algorithm to acquire a sequence set that activates neurons. Through backward layer-wise clustering, sequences are categorized into different subsets, and these subsets are then visualized to obtain understandable sequence patterns. NeuronMotif was shown to be able to perform automated knowledge extraction to extract and summarize regulatory sequence syntax rules from data, including transcription factor binding site patterns as well as their combinations, spacing, and orders (Figure 3-1-41). The interpretation results can also be used for diagnosing and improving CNN architectures.

The research published on *Proceedings of the National Academy of Sciences* (*PNAS*) with a title "NeuronMotif: Deciphering cis-regulatory codes by layer-wise demixing of deep neural networks" on April 6, 2023. NeuronMotif can extract human understandable patterns from ANNs, aiding in gaining deeper insights into the intricate gene regulation rules of complex biological processes. It can also benefit the reverse engineering of artificial gene regulatory sequences for various applications such as gene therapy.

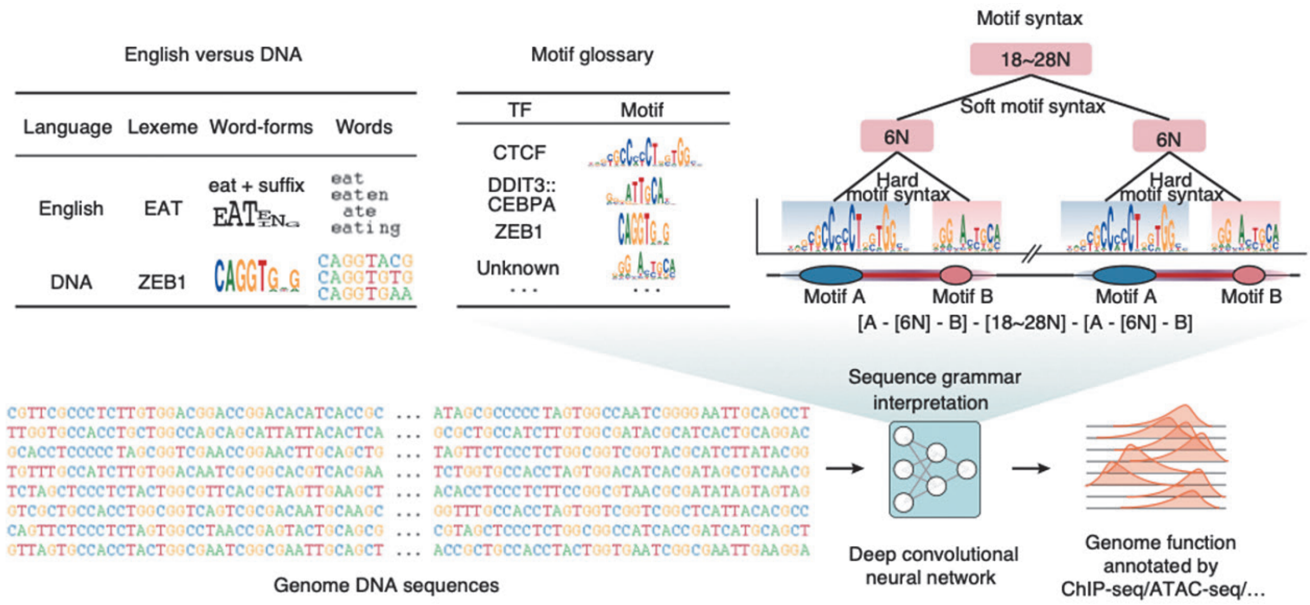



Figure. 3-1-41 Extracting regulatory sequence syntax rules from CNNs with NeuronMotif

## Research on Perception and Environmental Interaction of Soft Continuum Robots

Currently, the modeling, perception, and control of soft continuum robots are major challenges in the field of robotic research. Due to the high degree of freedom and redundancy of soft continuum robots, the speed and precision cannot be satisfied at the same time especially when numerically solving its nonlinear partial differential equation. The perception of soft continuum robots also faces several challenges, including difficult to match the sensing circuit's stiffness to the robot body (Young's modulus < 1 GPa) and hard to design the functional structures distribution of sensing circuit to match the structures of soft robot.

Natural soft-bodied animals provide inspirations in solving above problems of soft robots. Take the movement pattern of an octopus catching prey as an example, they use a simple but unique feed-forward wave of muscle activation called "bend propagation" to reach toward the target, then sense and quickly grasp the target via the highly sensitive arm/sucker neural network. Mimicking this octopus behavior can create a valuable model for actuation and control patterns of bioinspired soft continuum robots that can sense and interact with complex environments.

With the support of the National Natural Science Foundation of China (Excellent Young Scientists Fund 61822303, Creative Research Group T2121003, Major Research Plan 92048302), Professor Li Wen's research team from Beihang University conducted research on the "perception-motion-environmental interaction" of bio-inspired soft continuum robots. Firstly, the research team took observations from the prey capture process of a biological octopus and established a kinematic model of "bend propagation", the team validated the model on a high-degree-of-freedom soft continuum robot and achieved a rapid kinematic calculation of the "bend propagation" kinematics (model solving time: 3ms). The results provide the foundation for the real-time motion control of soft continuum robots.

To achieve similar flexible perception as the functionality of a biological octopus nerve network, the team raised a gradient stiffness design method and developed a highly stretchable electronic skin based on liquid metal. The team overcomes the challenge that the delamination failure occurred at the junction between the soft substrate and the silicon electronic components when stretched to a large extension rate and improved the uniaxial stretching and biaxial stretching rates of the stretchable electric circuit up to 710% and 270%, respectively. Based on this unique technological breakthrough, the research team developed stretchable electric circuit with multi-directional stretching sensation and fabricated an octopus inspired soft terminal gripper that combined all of the bending/suction capabilities, haptic sensation, and decision making capability together (Fig.3-1-42). The proposed integrated gripper can sense the deformation of its own (error < 1%), environmental temperature from 0 to 100℃, and suction of objects with hardness from 55 kPa to 3000 MPa. Finally, to achieve the human in the loop control of the soft continuum robot, the team proposed a bidirectional interaction method between the human and soft continuum robot via suction haptic feedback, and developed a liquid

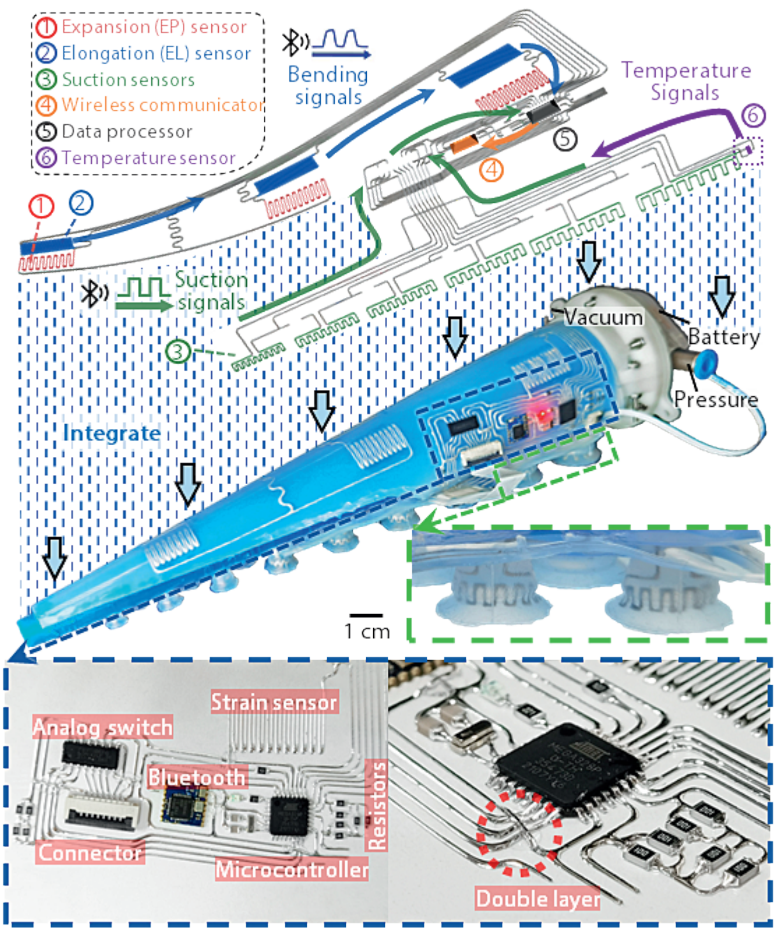



Fig. 3-1-42 The octopus inspired soft robotic gripper embedded with a liquid metal electronics system.

metal circuit–based soft wearable haptic device. By changing the finger's bending and attitude (x-axis acceleration $a_x$, pitch angle $\alpha$, and roll angle $\beta$), a human can remotely and interactively control the soft continuum robot, and eventually achieve the reaching and grasping in an underwater environment, just like the biological octopus do (Figure 3-1-43).

This study was titled "Octopus-inspired sensorized soft arm for environmental interaction" and published on the journal *Science Robotics* on Nov. 29, 2023. This study not only revealed the new mechanism of octopus "bend propagation", but also developed the key technologies of perception and interaction between a soft continuum robot, human, and the environment. This study may pave a way for future applications of soft continuum robots in the complex fields.

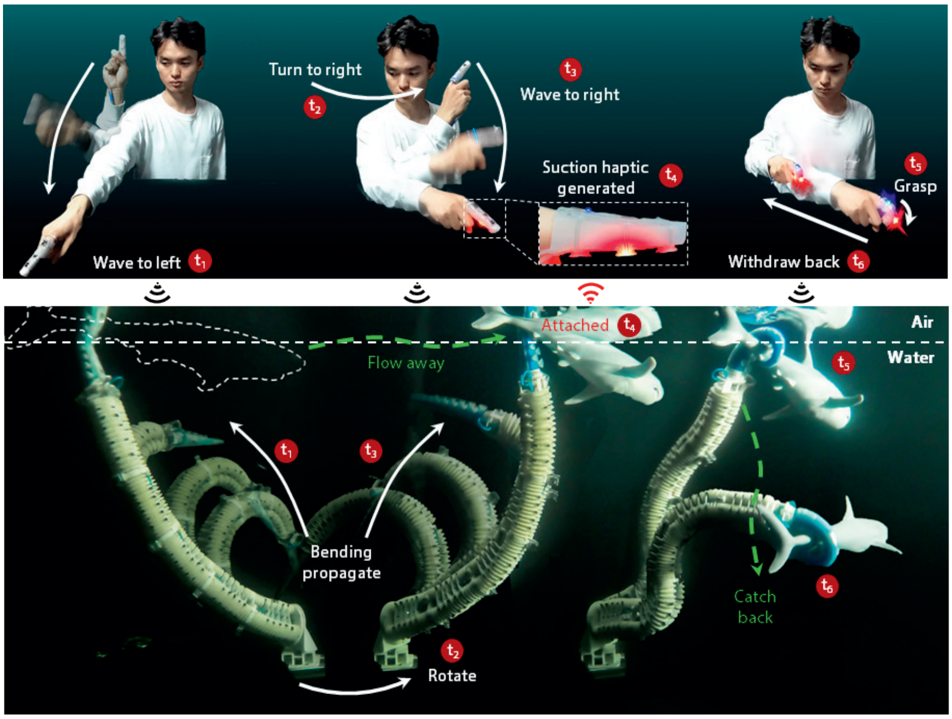



Figure 3-1-43 Human interactively controlled manipulation of octopus inspired arm in underwater environment.

## Research on the on-chip T-LEDs

Chiral photon sources, whose quantum states can be manipulated by modulating the spin angular momentum of photons, are a strategic frontier technology in fields such as quantum technology, three-dimensional display, and biological imaging. The existing methods mainly utilize the inherent spin polarization of materials to manipulate the spin angular momentum of electrons and photons. These approaches usually require an external magnetic field or low-temperature environment and possess low polarization ratio, poor stability, and susceptibility to electromagnetic signal interference. Breaking through the stability bottleneck of spin-polarized materials and further improving their polarization has become a key challenge in developing high-performance chiral photon sources.

Supported by the National Natural Science Foundation of China (Special Program 61227009, Excellent Young Scientists Fund 62022068, General Program 62274139), Professor Junyong Kang, Academician Rong Zhang, Professor Yaping Wu, et al. from the semiconductor research team in Xiamen University have achieved significant progress on the proposal of new principles for topological spin protection, the development of high-magnetic-field (HMF)-assisted growth equipment, the construction of topological spin structures, and the development of on-chip topology-induced spin light-emitting diodes (T-LEDs)(Figure 3-1-44). The main innovative achievements are as follows:

(1) A new principle of orbital-regulated topological protection was proposed. It was predicted that a strong magnetic field in crystal growth can enhance the coupling effect of d, s, and p orbitals. On this basis, a HMF-assisted molecular beam epitaxy (HMF-MBE) equipment was designed and built, and independent intellectual property rights for high-end equipment were obtained.

(2) By utilizing the HMF-MBE equipment, the bottleneck of topological spin structure growth has been overcome. For the first time, a large-area, long-range ordered topological spin structure (Meron) lattice has been grown. A high stability was achieved at room temperature and without an external magnetic field, which opens up a new path for the practical application of topological spin structures.

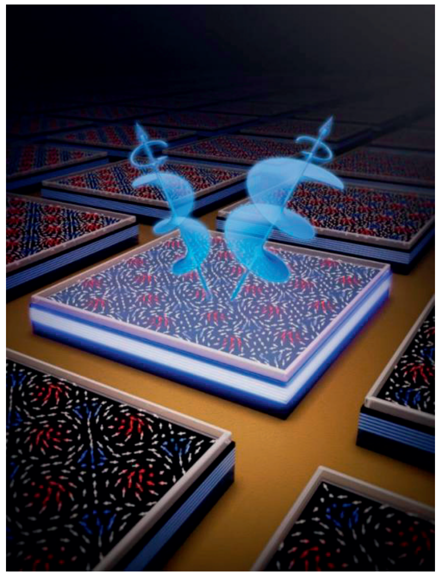


Figure 3-1-44 Schematic of the on-chip T-LEDs

(3) The regulation mechanisms of Meron lattice on the transport trajectories and spin polarization of conducting electrons were revealed. By further utilizing the radiation transition selection of spin-polarized electrons in quantum wells, chirality transfer from topologically protected quasi-particles to electrons and then to photons was achieved. A wafer-scale on-chip T-LED with high polarization, high electro-optical conversion rate, and high output optical power was developed (Figure 3-1-45).

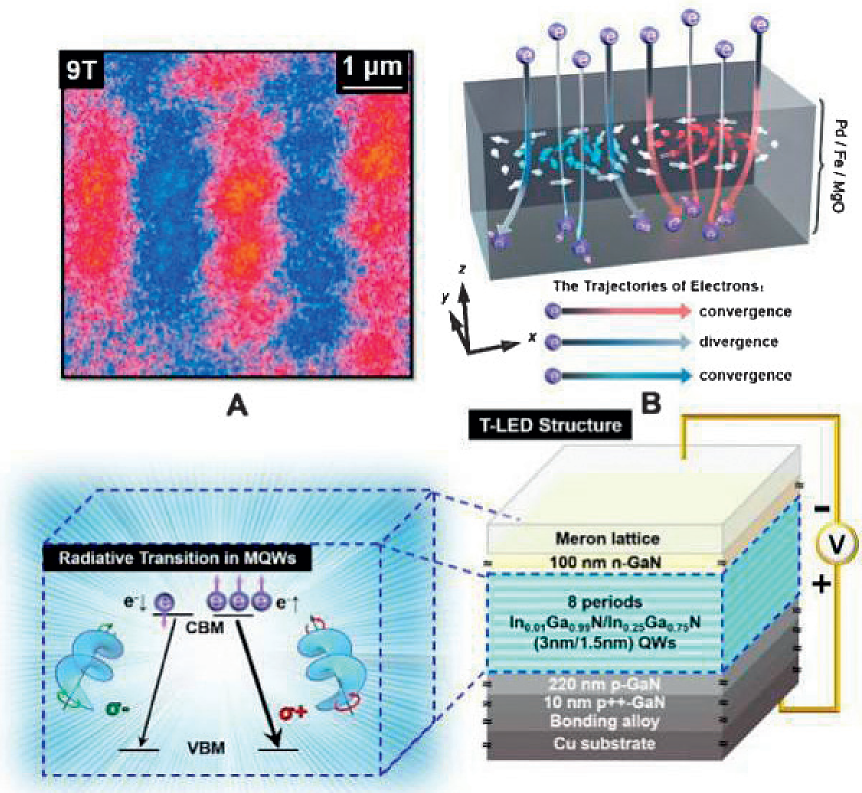



Figure 3-1-45 Characterization of the topological spin structures and the T-LEDs
A. The meron lattice characterized by magnetic force microscopy; B. The trajectories of electrons when injected into the meron lattice; C. The structure and optical transition in the LED.

The above results were published in *Nature Electronics* on July 13, 2023, with the title of "Topology induced chiral photon emission from a large scale meron lattice". A research briefing was published in *Nature Electronics* at the same time, evaluating the research as "Semiconductor applications of large-scale meron lattices". This achievement has also been widely reported by domestic and international professional media such as "*Science and Technology Daily*", *Compound Semiconductor, TechXplore*, and *EurekAlert!*. This work has opened up new paths for quantum state manipulation and transmission, represented a new breakthrough in topological materials from theoretical connotations to real applications, opened up a new field of interdisciplinarity between optoelectronics and topological spintronics, and made new contributions to promoting the development of future quantum information and other technologies.

## Context-aware Data Mining and Its Applications

Context-aware data mining is one of the adaptive artificial intelligence technologies aimed at recognizing human intention and predicting future behavior. It stands as a key technology in elevating the intelligent level of applications in national strategic scenarios and national welfare and livelihood scenarios, such as military operations, intelligent education, and the digital economy. Traditional data mining methods have always been limited by the level of modeling and utilization for context data, severely limiting their situational adaptability and decision-making efficiency. Context-aware data mining seeks to reveal the inherent computational mechanisms of modeling and utilizing contextual data, holding significant academic leadership value in driving the development of artificial intelligence.

Under the support of the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars 61325010, Excellent Young Scientists Fund 62022077, 61922073), the research team led by Prof. Enhong Chen at the University of Science and Technology of China conducted in-depth research on the basic theories and methods of context-aware data mining. Focusing on context-aware statistical learning, context data modeling and utilization, and large-scale efficient inference, the team revealed the operational mechanism of context data in optimization objectives, model design, and predictive reasoning, establishing foundational theories and methods for context-aware data mining. Firstly, they proposed a context-aware statistical learning method, uncovered the ranking principles of different behaviors under the same context, and discovered that context-conditioned behaviors follow a super long-tail distribution. They then derived the optimization objectives for context-aware data mining from adversarial generation networks on discrete data and proved the generalizability of the context-aware statistical learning method. Secondly, they established the mechanisms for modeling and utilizing context data. In particular, they first proposed a novel autoencoder-based representation method for context data based on the recovery of semantic structure, which reveals the modeling mechanism for removing complex noise in the representation of context data, and then introduced a personalized intent recognition method in the representation space of context data. They built a context-aware decision model from "personalized intent space, group consensus space" to "individual behavior space," improving the expressive power of data mining models by incorporating context. Lastly, they revealed that historical behavioral contexts satisfy the low-rank property, and then proposed a linear-time self-attention model based on low-rank decomposition, achieving constant-time computation of intent recognition. They expounded that the independence between model learning and index construction is the intrinsic reason for generalization degeneration resulting from sub-linear inference for context-aware models. They established a new paradigm for learning search indexes directly from behavioral data(Figure 3-1-46), which strikes a better balance between inference efficiency and accuracy of context-aware models by aligning the model learning space with the index construction space (Figure 3-1-47).

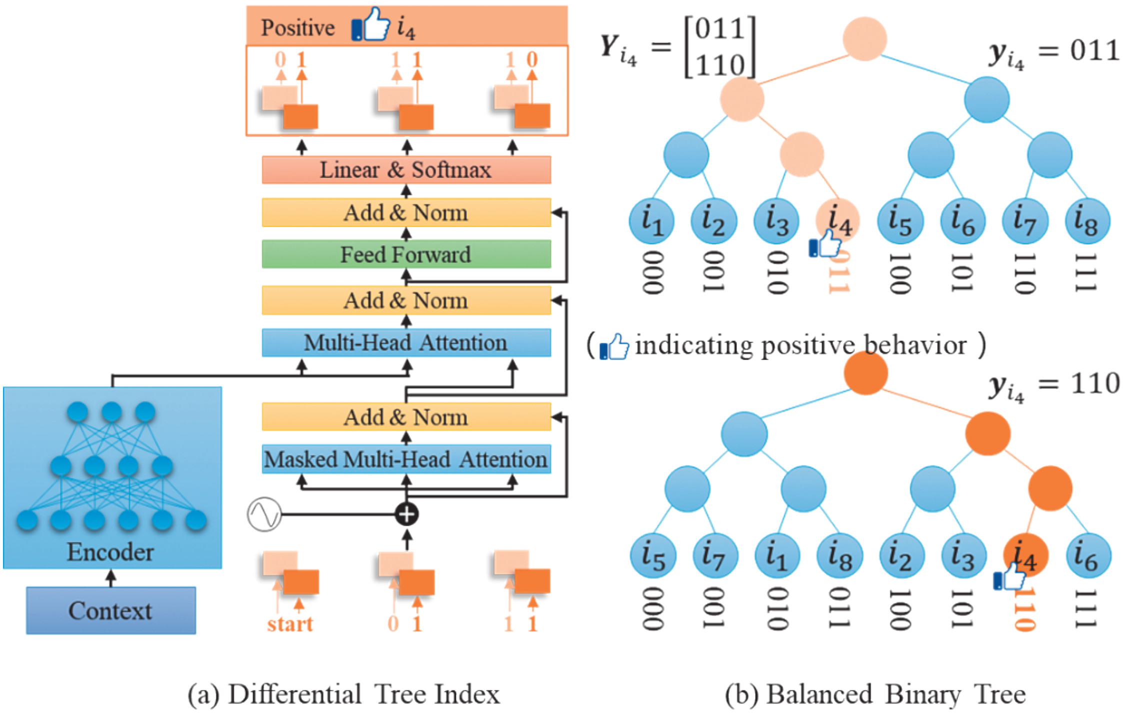



Figure 3-1-46 The framework of learning an index from behavior data (RecForest)

| | | NDCG@20 | NDCG@40 | Memory | Time | NDCG@20 | NDCG@40 | Memory | Time |
|---|---|---|---|---|---|---|---|---|---|
| | Method | Movie | | | | Amazon | | | |
| | DIN | **0.5440** | 0.5473 | - | 193.87 | **0.2766** | **0.3039** | - | 492.64 |
| | YoutubeDNN | 0.5329 | **0.5484** | - | **29.38** | 0.2195 | 0.2491 | - | **120.91** |
| Alibaba's method | JTM | 0.5149 | 0.5075 | 10.80 | 12.05 | 0.1533 | 0.1683 | 75.99 | 6.64 |
| | TDM | 0.4684 | 0.4651 | 10.80 | 9.33 | 0.0856 | 0.0949 | 75.99 | 6.61 |
| | SCANN | 0.4665 | 0.4695 | 3.64 | 18.64 | 0.1529 | 0.1780 | 14.66 | 4.48 |
| | IPNSW | 0.5330 | 0.5486 | 10.08 | 15.52 | 0.2255 | 0.2548 | 66.46 | 10.28 |
| Our method | RecForest | **0.5580** | **0.5682** | **3.21** | **8.33** | **0.2339** | **0.2576** | **7.32** | **3.79** |
| | 方法 | Gowalla | | | | Tmall | | | |
| More accurate | DIN | **0.2798** | **0.3095** | - | 186.41 | **0.2275** | **0.2491** | - | 4057.69 |
| | YoutubeDNN | 0.2312 | 0.2637 | - | **53.55** | 0.1736 | 0.1975 | - | **1086.75** |
| | JTM | 0.2595 | 0.2484 | 77.56 | 2.64 | 0.0749 | 0.0849 | 151.19 | 30.11 |
| | TDM | 0.1723 | 0.1775 | 77.56 | 2.55 | 0.0257 | 0.0272 | 151.19 | 29.42 |
| Lighter | SCANN | 0.1839 | 0.2083 | 15.48 | 1.86 | 0.1105 | 0.1226 | 28.10 | 20.88 |
| | IPNSW | 0.2464 | 0.2805 | 70.39 | 4.73 | 0.1696 | 0.1902 | 132.72 | 52.90 |
| | RecForest | **0.3783** | **0.3963** | **7.39** | **1.82** | **0.2059** | **0.2261** | **9.29** | **18.88** |
| Faster | 方法 | MIND | | | | Yelp | | | |
| | DIN | **0.7399** | **0.7399** | - | 62.98 | **0.2825** | **0.3117** | - | 170.25 |
| | YoutubeDNN | 0.7349 | 0.7336 | - | **52.14** | 0.2518 | 0.2850 | - | **48.51** |
| | JTM | 0.5956 | 0.5505 | 6.62 | 5.48 | 0.1014 | 0.1300 | 39.47 | 4.21 |
| | TDM | 0.5615 | 0.5198 | 6.62 | 5.51 | 0.1547 | 0.1515 | 39.47 | 4.34 |
| Google's method | SCANN | 0.5987 | 0.5713 | 3.20 | 19.51 | 0.1729 | 0.2012 | 8.44 | 3.58 |
| | IPNSW | 0.7346 | 0.7331 | 6.95 | 8.99 | 0.2562 | 0.2906 | 34.74 | 8.92 |
| | RecForest | **0.7583** | **0.7579** | **3.18** | **4.61** | **0.2766** | **0.3031** | **6.81** | **3.57** |

Figure 3-1-47 Comparison with the SOTA methods from Google and Alibaba in terms of efficiency, accuracy, and memory, indicate that the proposed method is lighter, faster, and more accurate.

The representative achievements titled "Fundamental Theories and Methods in Data Mining for Recommender Systems" won the first prize of the Natural Science Award of China Computer Federation (CCF) in 2023, being the sole recipient that year. This work received positive reviews from renowned scholars including academicians from China, the United States, and the United Kingdom, and has sparked follow-up and extension efforts among many international peers. In recognition of his contributions to context-aware data mining and recommender systems, Prof. Enhong Chen was elected as an IEEE Fellow in 2023. Upon this work, his team developed an open-source recommender system and a vector retrieval system. With the help of these systems, his team has repeatedly won championships and runner-up in international competitions like the KDD Cup. The developed techniques have been successfully applied in scenarios such as advertisements, product recommendations, and news recommendations, generating significant economic and social benefits.

## Operation Optimization and Coordination in a Mixed Duopoly Public Service System

Due to budget constraints, countries usually face capacity issues in public services like education, healthcare, and transportation. Introducing private service providers is one effective method to enhance public service capabilities. However, the entrance of private service providers leads to a two-tier public service system, resulting in a mixed duopoly market of public and private competition. Practical observations show that such markets often experience overutilization in public service providers and underutilization in private ones, reducing the efficiency of the two-tier system and posing challenges to public service management.

Under the support of the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars 71925002 and Key Program 71731006), the research team led by Professor Zhou Wenhui at the South China University of Technology has studied the optimization and coordination of the two-tier public service system from a competitive perspective and achieved the following innovative results.

1. In the mixed duopoly market, the optimal pricing strategy for public service providers remains based on the negative externality cost, which, however, can lead to system overutilization. This finding challenges the classical theory that externality cost pricing by public institutions prevents overutilization.

2. Although public institutions aim to maximize system-wide social welfare, transforming a purely private competitive market into a mixed public-private market (i.e., by converting one private institution to a public one) can paradoxically decrease overall social welfare. We refer to this counterintuitive phenomenon as the "public-private competition paradox".

3. The emergence of the public-private competition paradox is due to the increased structural imbalance of service flow in the system. The research further reveals the conditions under which this paradox occurs: only when the competitiveness of public institutions is weak.

4. Transforming public institutions into a stock-share-based public-private partnership (PPP) joint venture can alleviate the structural imbalance of service flow, thus avoiding the public-private competition paradox and enhancing overall social welfare. This provides a theoretical guideline and scientific mechanism for the government to improve the two-tier public service system.

These research findings, titled "On the Benefit of Privatization in a Mixed Duopoly Service System", were published in *Management Science* in March 2023. Unlike methods dependent on financial subsidies or capacity expansion, this study suggests stock-share reform to coordinate the two-tier public service system. This helps deepen the understanding of the role of private capital in public services and provides guidance for competition and pricing strategies for public and private service institutions. It also offers theoretical support for how to introduce private capital and manage the two-tier public service system for the government.

Optimal Dynamic Contract Design Considering "Suspension" Punishment

How to design a dynamic contract to incentivize an agent is a classical problem in the principal-agent theory. In the operational scenarios such as retail product sales, company customer service, and innovative product R&D, the agent's effort level is a significant factor that impacts the outcome of his work. A scientific and effective contract mechanism of reward and punishment can induce the agent to increase his effort level, boost his work output, thereby improving the firm's performance and operations efficiency. However, the characteristics such as the unobservability of the agent's effort level and the dynamics and randomness of the agent's work outcome bring challenges to the optimal contract design.

Supported by the National Natural Science Foundation of China (Excellent Young Scientist Fund 72122019 and General Program 71771202), the team of Prof. Ping Cao from University of Science and Technology of China utilized the principal-agent models in economics to study an optimal dynamic contract designing problem for the operational scenario, where the agent's outcome follows a counting process with rate depending on his effort level. They obtained the following innovative results:

(1) They proposed to use suspension as a punishment tool in dynamic contract to incentivize the agent who has a bad performance. In comparison with the punishment tool of terminating the contract, suspension can better incentivize the agent to increase his effort level.

(2) Taking the switching cost from suspension to work into account, they fully characterized the optimal dynamic contract structure with suspension punishment. When the switching cost is large, the optimal contract is not to hire the agent; and when the outcome revenue is large, the optimal contract is to pay the agent a fixed reward for each outcome. In other cases (Figure 3-1-48), the optimal contract takes a "control-band" structure, in which the agent's promised utility will change continuously according to a deterministic trajectory, and will jump when an outcome occurs or the working state changes, and the agent will be paid a reward only when his promised utility is above a threshold. This contract has a simple structure, and is easy to understand and implement for the agent and the company.

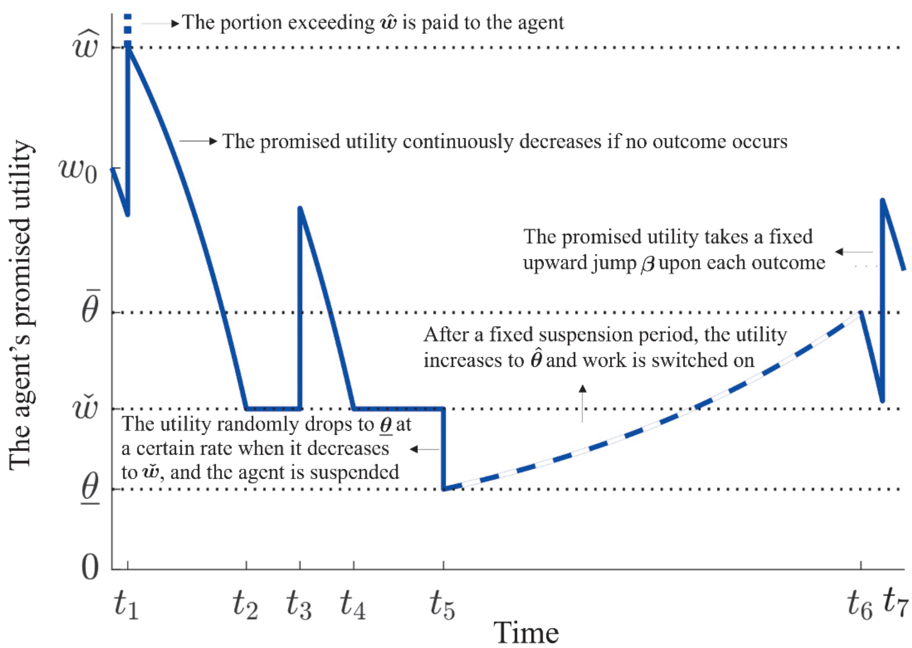



Figure 3-1-48 A Sample Trajectory for the Agent's Promised Utility under the Optimal Contract Considering Suspension Punishment

(3) They reformulated the optimal dynamic contract problem with suspension as an optimal control model, and provided a scientific method of solving this kind of optimal dynamic contract problems. This method also can apply in solving optimal control models with switching cost which are built on counting processes.

A relevant work, entitled "Punish Underperformance with Suspension: Optimal Dynamic Contracts in the Presence of Switching Cost", has been published online in June 2023 at *Management Science*. This work considers the operational setting in which the agent's outcome follows a counting process whose rate depends on the effort level, and provides a theoretical underpinning as well as a practical and scientific scheme for the optimal dynamic contract design, which will be helpful in improving the agent's work performance and increasing the company's operational efficiency.

## Research on Intelligent Recommendation Approach Considering Psychological Dynamics Identification

Supported by the National Natural Science Foundation of China (Major Research Plan 72172070 and Young Scientist Fund 72302153), Professor Qiang Wei's team at Tsinghua University, in collaboration with Assistant Professor Yao Mu at Shanghai International Studies University, has made progress in research on intelligent recommendation approach considering psychological dynamics identification. The study entitled "Dynamic Bayesian Network-Based Product Recommendation Considering Consumers' Multistage Shopping Journeys: A Marketing Funnel Perspective" was published online on October 3, 2023 in *Information Systems Research*.

On e-commerce platforms, recommender systems are extensively used by online merchants to surface products that appeal to consumers, so as to promote product sales and enhance consumers' shopping experience with accurate recommendations. Although dynamic recommendations that take into account interest shifts over time have been validated to achieve better performance, there remain challenges encountered by existing methods. First, consumer behaviors are naturally diversified, leading to difficulties in the effective extraction of generalizable regularity at the behavioral level. Second, consumers' interest shifts vary greatly in form, which require sufficiently flexible modeling to be accurately captured. Third, the implicit psychological dynamics of consumers are difficult to identify and thus cannot support targeted marketing decisions.

This study proposes a multistage dynamic Bayesian network approach (Figure 3-1-49), which models the psychological stage transitions, interest shifts, and behavior generation of consumers in shopping journeys from the marketing funnel perspective, and then provides targeted personalized recommendations based on the identification of consumers' implicit psychological dynamics. Enlightened by the marketing funnel theory, the proposed approach tackles the challenge of consumers' diverse behaviors by extracting the frequent and underlying regularity with regard to psychological dynamics. The approach innovatively models two dependent latent layers to capture the driving relationship and dynamic evolution of consumers' *stage—interest—behavior* patterns, thereby flexibly accommodating the variability in interest shifts. In addition, this study incorporates identification strategies of latent layers into the approach design, which not only optimizes the learning efficiency of the model but also explicitly detects consumers' psychological stages and interests. Extensive real-world data experiments indicate that the proposed approach significantly outperforms baseline methods in terms of product recommendation accuracy and ranking, effectively identifies and differentiates consumers' underlying psychological stages and interests, and exhibits good applicability and generalizability across various data scenarios. This work can generate more accurate and immediate product recommendations and provide valuable insights into consumer

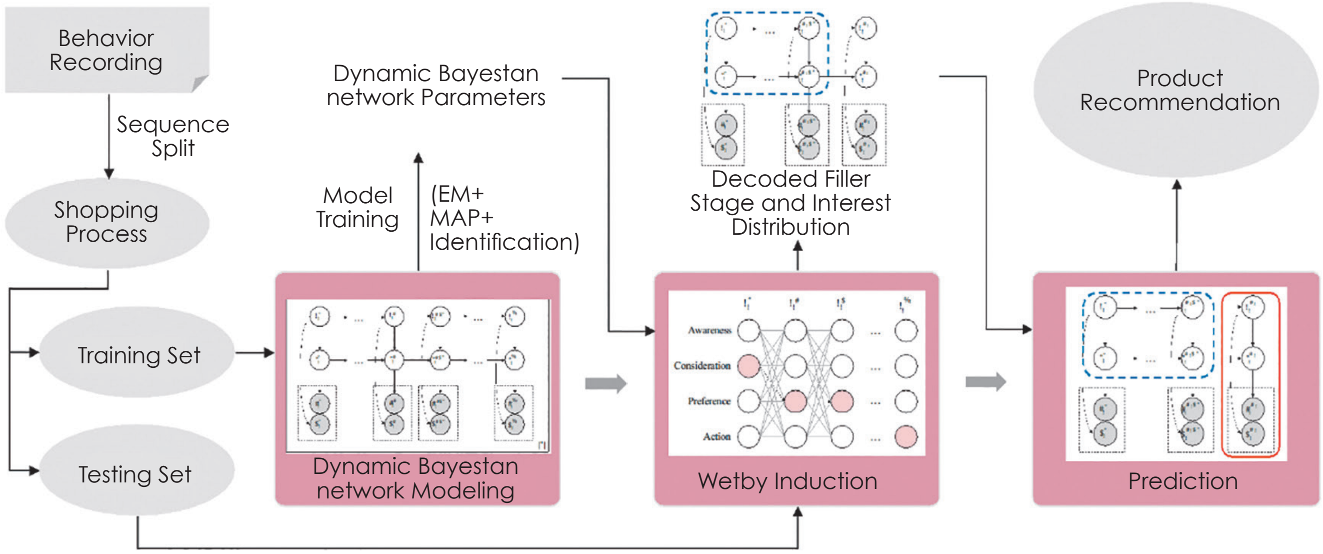



Figure 3-1-49 Multistage Dynamic Bayesian Network Approach Framework

shopping journeys, thereby facilitating sophisticated managerial practices such as advanced targeted marketing.

## Social Network with Unobserved Links

Under the support of the National Natural Science Foundation of China (General Program 71973097 and Excellent Young Scientists Fund 72222007), Professor Xi Qu from Shanghai Jiao Tong University, in collaboration with Professor Arthur Lewbel from Boston College and Professor Xun Tang from Rice University, has conducted original research on the identification and estimation of peer effects in social networks with unobserved links. The fruits of their research, titled "Social Network with Unobserved Links", were published in the *Journal of Political Economy* in April 2023.

Traditional spatial econometric models that investigate peer effects, where individuals influence one another within social networks, have expanded from geographical space to encompass socioeconomic spaces. However, real-world social networks are often difficult to observe accurately, plagued by missing links, misreporting, and other errors, with the most extreme scenario being networks that are entirely unobservable. Estimating and identifying peer effects under such conditions, where specific social network connections are unseen, stands as a cutting-edge issue of global scholarly interest.

The study, grounded in a model of endogenous and exogenous peer effects within social networks, leverages the distributional characteristics of these networks to innovatively construct linking equations between reduced form regression coefficients and the structural parameters of a system of equations. This approach addresses the identification problem of social network structural equations, giving rise to a novel method for estimating peer effects in social networks. The primary innovations of this method lie in two aspects: firstly, the conventional rank conditions are usually not met, so the paper lists additional exclusivity constraints that can be imposed through data structures to ensure the identification conditions; secondly, it offers a means for parameter estimation and hypothesis testing of peer effects when conventional estimation methods such as two-stage least squares, maximum likelihood estimation, and generalized method of moments fail. Empirical analyses revealed that the proposed method for identifying and estimating peer effects significantly reduces the need for observed social network data, thereby vastly expanding the application scenarios for studying peer effects in social networks.

## Economic Intervention Policies in Markets for Indivisible Goods

Supported by the National Natural Science Foundation of China (Key Program 72033004 and General Program 72073072), Professors Sun Ning (Southern University of Science and Technology) and Yu Ning (Nanjing Audit University) carried out original research on economic intervention policies in markets for indivisible goods. Their research paper "Job Matching with Subsidy and Taxation" was published online by the journal *Review of Economic Studies* in February 2023.

Studying intervention policies in the form of fiscal transfer in markets for indivisible goods not only lies on the frontier of scientific field of market design internationally, but also supports the need of high-quality economic growth domestically. Factors of production are usually indivisible when traded on markets, but existing market design theories have not thoroughly examined relevant aspects, so it is imperative that researchers systematically examine the complex intervention policies in such environments using mathematical models and analyzing their impacts.

The key policy design question is how to ensure the existence and stability of market equilibrium and the Pareto efficiency of allocative mechanisms such as auction. The team focuses on "market for indivisible resources," and studies which fiscal transfer policies are associated with benign market functionality. Its main theoretical contributions include the following: (1) In a standard "job matching" model (which nests a standard commodity market model), it provides a unifying framework for modeling innumerous complex policy options. For example, "complex transfer functions" allows the amount of fiscal transfer to vary depending on the set of employees and their salaries. (2) It discovers and proves a series of characterization theorems for "preserving the substitutes condition". For example, a complex transfer function always preserves the substitutes condition if and only if it is the sum of a "C-additively separable function" and a "C-cardinally concave transfer function". These results can be translated into the field of "discrete convex analysis," solving unresolved fundamental questions of which two discrete functions can be added while preserving or reestablishing the core concept of M#-Concavity. (3) It investigates how to utilize intervention policies to "reestablish" the substitutes condition. Practically, the team provides policymakers with references for how to better design market rules. The result shows that when "complementarity" among indivisible resources is problematic, the policymakers should avoid those policies which cannot preserve the substitutes condition; when the policies cannot be changed, cautions and ameliorations are recommendable.

## Comprehensive Assessment and Improvement Strategies for Universal Health Coverage in China

Universal health coverage (UHC) ensures access to essential quality health services for all without suffering from financial hardship, making it a top priority in the national strategic goal of building a "Healthy China" and achieving global sustainable development. However, there is a lack of reliable information about the comprehensive assessment of UHC in China. Supported by the National Natural Science Foundation of China (Excellent Young Scientist Fund 72122007), Prof. Zhou Ying's team at Huazhong

University of Science and Technology provided the most up-to-date and comprehensive assessment of UHC in China. They revealed the mechanisms between macroeconomic and health resource characteristics and UHC, providing decision-making support for optimizing the allocation of medical resources and improving the country's comprehensive health service capabilities. The related findings, titled "Universal Health Coverage in China: A Serial National Cross-Sectional Study of Surveys from 2003 to 2018", were published in *The Lancet Public Health*.

Based on cross-sectional health data of nearly one million Chinese individuals over a 15-year period, the team first proposed an evaluation framework for UHC in China. Through big data analysis, they found that China has made historic achievements in UHC, but showed lagging performance in the prevention domain compared to treatment domain.

During rapid development of China, safe drinking water, sanitation facility construction, and the accessibility of medical facilities are crucial for enhancing UHC's preventive service capacity. Over the past 15 years, substantial improvement has been observed in safe drinking water in both urban and rural areas, while there is still much room for progress in the construction of adequate sanitation facilities and accessibility of medical facilities. Despite the rapid increase in hospital construction with urbanization, the results indicate that the accessibility of healthcare facilities in urban areas is continuously decreasing, which is not keeping pace with the rapid urbanization process.

Increasing the government financial investment and healthcare resources is considered a key initiative to improve UHC. The results show that GDP per capita and government health expenditure exhibit significant diminishing marginal returns when UHC exceeds 80%, indicating that increasing financial investment alone has a limited contribution to UHC improvement (Figure 3-1-50). Thus, in the context oflimited resources, exploring how to improve efficiency in resource allocation in achieving UHC is urgently needed, which would be important to deal with the large chronic disease burdens with accelerated population aging in China. The team constructed panel data containing population health and healthcare resource indicators, and first provided solid evidence of the associations between UHC indicators and macroeconomic and healthcare resource characteristics. The findings highlight that, apart from medical personnel and bed resources, the construction of medical infrastructure plays an equally crucial role in enhancing health service capacity. Notably, primary health care institutions were closely and positively related to UHC indicators, especially in prevention domain. Therefore, optimizing resource allocation, enhancing primary health care, and investing healthcare resources in building capacity for primary healthcare services are considered key points to achieving UHC goals in China.

This study provides a solid theoretical foundation for the development of public health and health service policies in China. *The Lancet Public Health* published an invited comment by Dr. Pan Jie, Dean of West China School of Public Health and West China Fourth Hospital, School of Public Administration, Sichuan

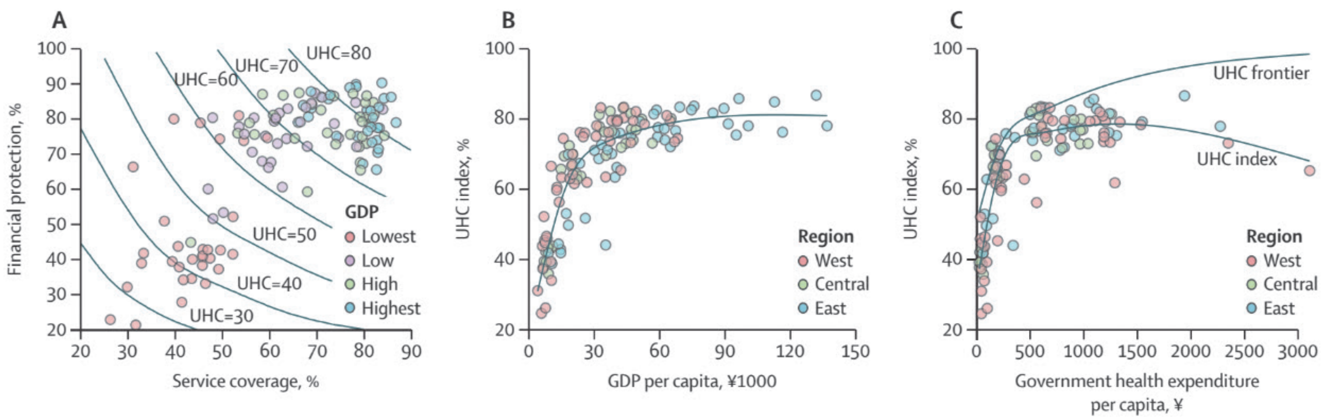



Figure 3-1-50 UHC index relative to pooled GDP per capita and government health expenditure per capita

University, in the same issue. Dr. Pan highly valued the study's contribution to UHC progress in China, and concluded that the main findings are of great significance in guiding the policy-making for the rational and effective allocation of healthcare resources at the national and regional levels.

## Jmjd4 Facilitates Pkm2 Degradation in Cardiomyocytes and Is Protective Against Dilated Cardiomyopathy

There are approximately 2.5 million cases of cardiomyopathy worldwide, with a 27% increase over the past decade. Dilated cardiomyopathy (DCM) stands out as the most prevalent subtype, characterized by ventricular enlargement and compromised systolic function. Without effective treatment option, a significant proportion of DCM patients progress to end-stage heart failure, highlighting the urgency for understanding the molecular mechanism of the disease to identify functional drug targets.

Supported by the National Natural Science Foundation of China (General Program 81770391 and 31771613), Professor Xu, Dachun's and Professor Wei, Ke's teams at Tongji University have made significant advancements in understanding the pathogenesis of dilated cardiomyopathy and identifying potential therapeutic targets. Their research uncovered a significant upregulation of Jmjd4 expression in both human and murine heart diseases. Cardiac-specific knockout of *Jmjd4* in mice resulted in the spontaneous development of dilated cardiomyopathy and subsequent heart failure. Transcriptome sequencing and functional analysis revealed mitochondrial metabolic defects caused by *Jmjd4* deletion. Metabolome analysis indicated abnormalities in pyruvate metabolism, with accumulated upstream substrate and depleted downstream product, suggesting a metabolic blockage of pyruvate production. The research team discovered the interaction between Jmjd4 and pyruvate kinase M2 (Pkm2), an ineffective enzyme for pyruvate production which is normally absent in cardiomyocytes but accumulated in heart diseases. Through a series of experiments, they demonstrated that Jmjd4 facilitates Pkm2 degradation via the chaperone-mediated autophagy pathway (CMA). Importantly, the study identified K66 residue on Pkm2 which can be hydroxylated by Jmjd4 and is necessary for CMA degradation of Pkm2. By using TEPP-46, an allosteric agonist Pkm2, the researchers successfully rescued the dilated cardiomyopathy phenotype in *Jmjd4* cardiac-specific knockout mice. Notably, this agonist also showed promise in mitigating heart failure induced by pressure overload in mice, suggesting Pkm2 could potentially be a universal pharmacological target for cardiometabolic intervention (Figure 3-1-51).

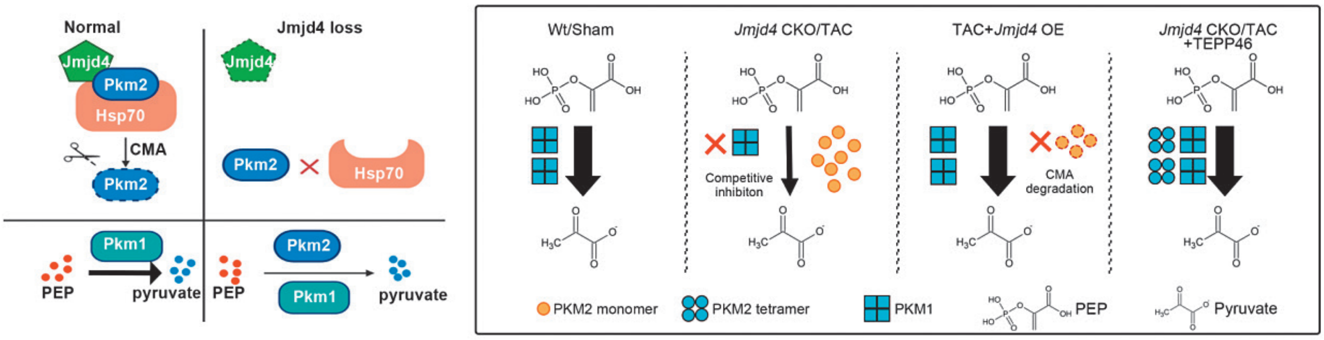



Figure 3-1-51 Jmjd4 promotes the degradation of Pkm2 through the chaperone (HSP70) -mediated autophagy pathway; the Pkm2 agonist TEPP-46 can restore pyruvate metabolism and cardiomyocyte metabolic homeostasis in Pkm2-accumulated cardiomyopathy

The groundbreaking findings of this study, titled "Jmjd4 Facilitates Pkm2 Degradation in Cardiomyocytes and Is Protective Against Dilated Cardiomyopathy," were published online on April 17, 2023, in *Circulation*. The research illuminates Jmjd4's role in regulating Pkm2 degradation via molecular chaperone-mediated autophagy, thus playing a crucial role in maintaining cardiomyocyte metabolic homeostasis and cardiac function. Moreover, it identifies Pkm2 as a promising target for dilated cardiomyopathy treatment and other metabolic heart diseases, offering new insights into the pathogenesis of dilated cardiomyopathy and providing a novel therapeutic avenue for its management.

## Study on the Efficacy of Thalidomide in Treating Small Intestinal Angiodysplasia Bleedings

Recurrent gastrointestinal bleeding caused by small intestinal angiodysplasia (SIA) has always been a clinical challenge. The histological characteristics of these SIA lesions are thin walls of the mucosa and submucosa, lack of smooth muscle layer, accompanied by immature abnormal blood vessel growth and focal accumulation and dilation of capillaries. About 50% of patients require repeated hospitalization/ blood transfusions, and some patients even experience life-threatening bleeding. Lesions are often hidden, multiple, and easy to regenerate, which brings unprecedented difficulties and challenges to clinical diagnosis and treatment. Currently, there is a lack of recognized effective and safe treatments and drug interventions.

With funding from the National Natural Science Foundation of China (General Program 81270474, 81670505, 82070573), the trial led by Professor Ge Zhizheng and Deputy Chief Physician Chen Huimin of Renji Hospital Affiliated to Shanghai Jiao Tong University School of Medicine filled a gap in the treatment in this disease field. The results of this study confirmed that thalidomide can significantly reduce the number of bleeding episodes in recurrent small intestinal bleeding caused by SIA, and it still has a relatively long-lasting effective effect after discontinuation of the drug.

The team's preliminary research shows that thalidomide may reduce angiogenesis by reducing the expression of pro-angiogenic factors (including vascular endothelial growth factor, angiopoietin 2, Notch1 and Dll4, etc.), thereby exerting its long-lasting effect on angiodysplasia bleeding. The team then collaborated with 10 large tertiary hospitals in the country to conduct the world's first prospective, multi-center, randomized, double-blind, placebo-controlled clinical study to explore the effectiveness of thalidomide in the treatment of recurrent gastrointestinal bleeding caused by SIA. The study included 150 SIA patients with ≥4 bleeding times per year, who were randomly assigned to the 100 mg/d thalidomide group, the 50 mg/d thalidomide group and the placebo group in a 1:1:1 ratio (Figure 3-1- 52). The primary endpoint of treatment effectiveness is defined as the patient's average annual bleeding frequency reduced by more than 50% within one year of follow-up after four months of treatment compared with the year before treatment. The definition of effective treatment for secondary endpoints includes changes in total blood transfusions, total number of hospitalizations for bleeding, average annual hospitalizations for bleeding, average length of stay, average number of bleedings, average bleeding duration, and average hemoglobin level before and after treatment. The results showed that compared with the control group (16.0%), the effective rates of sustained hemostasis in the treatment group were 68.6% and 51.0% respectively ($p<0.001$). In addition, the total blood transfusion volume, the total number of hospitalizations due to bleeding, the average number of hospitalizations for bleeding per year, and the average length of hospitalization were all significantly reduced in the thalidomide treatment group, and the changes in other secondary endpoints were also consistent with the direction of the primary endpoint.

The research results were titled "Thalidomide for Recurrent Bleeding Due to Small-Intestinal

Angiodysplasia" and were published in the *New England Journal of Medicine* on November 2, 2023. The journal also published a review by peer experts at the same time. Director of the Department of Gastroenterology at Yale University in the United States Loren Laine commented that " Chen et al. provide evidence supporting thalidomide for persistent or recurrent bleeding due to small intestinal angiodysplasias that is of higher quality than evidence that is available for any other therapy for this indication." This study focuses on the current pain points of clinical treatment, that is, paying full attention to the relatively long-term sustained effective effect after stopping the drug, rather than being limited to the short-term effect during the medication period, avoiding the unfavorable treatment situation of increased adverse reactions and decreased compliance caused by long-term medication, is expected to change the global treatment status of SIA bleeding.

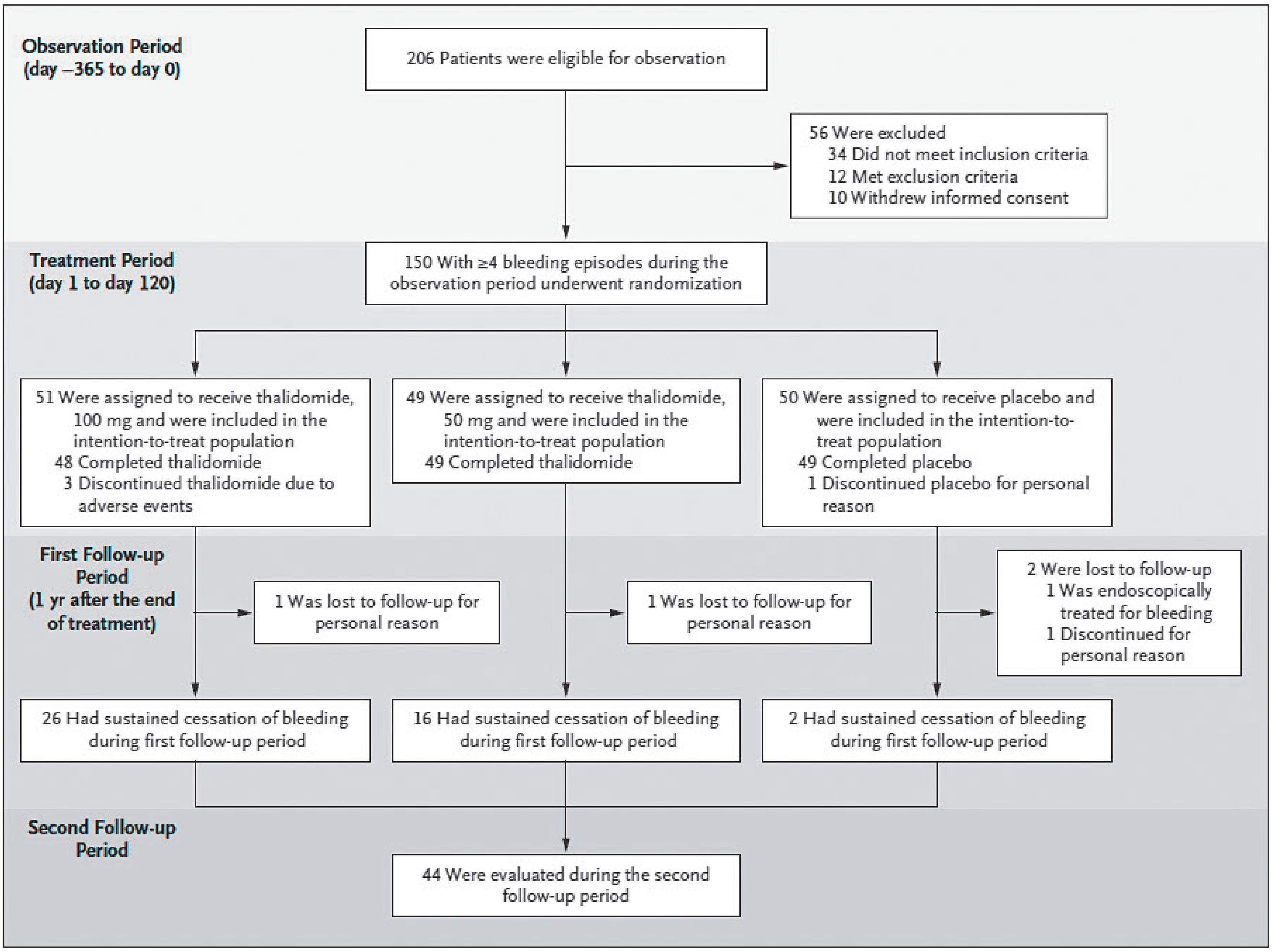



Figure 3-1-52 Enrollment of SIA, Randomization, and Follow-up.

## Uncovering the Pathogenic Mechanism of Charcot-Marie-Tooth Neuropathies

Charcot-Marie-Tooth neuropathies (CMT) diseases are the most common inherited peripheral neuropathies in the clinic. According to various causal genes, CMT can be further classified into over 100 different subtypes. Despite similar clinical presentation among different CMT subtypes, their causal proteins are highly varied in their cellular localizations and functions. The molecular mechanism underlying their genetic heterogeneity was poorly understood.

With the support of the National Natural Science Foundation of China (Special Program 82150003, Major Research Plan 91949104, General Program 31871022), the joint research team of Professor Ge Bai in School of Brain Science and Brain Medicine, Zhejiang University, together with Professor Jinsong Li in CAS Center for Excellence in Molecular Cell Science, Chinese Academy of Sciences, made an important progress on uncovering the pathogenic mechanism of CMT neuropathies.

This study used CMT2D-causing mutant protein, glycyl-tRNA synthetase (GlyRS), as the entry point. A combination of approaches was employed, including live-cell imaging, proximity labeling, quantitative MS-based proteomics, super-resolution imaging (STORM), etc. The researchers found that, upon exposure to environmental stressors, GlyRS adopted a new cellular location in stress granules (SGs), distinct from its normal cytoplasmic location. In SGs, mutant GlyRS perturbed the G3BP-centric core SG network by aberrantly binding to G3BP, causing the over-sequestration of non-SG molecules in SGs, thereby disturbing the cellular stress response and leading to an increased stress-vulnerability in motor neurons. Disrupting their aberrant interaction eliminated the impact of mutant GlyRS on SGs, improved the stress-vulnerability of motor neurons, and alleviated motor deficits in CMT2D mouse models. Moreover, the similar mechanism was largely shared by many other CMT2 subtypes.

In summary, this study identified SG abnormality as an important pathogenic mechanism underlying CMT pathogenesis, established a conceptual framework for developing uniform treatment of different CMT subtypes, and provided a new clue for understanding the genetic heterogeneity of complex diseases. This study was published online in *Cell* on February 3rd, 2023, as the cover article entitled "Diverse CMT2 Neuropathies are Linked to Aberrant G3BP Interactions in Stress Granules". The paper reviewer evaluated the findings of this paper as "important and novel that will change the way the field thinks ". The related results have also been positively cited in multiple high-impact papers published in journals such as the Journal of the American Chemical Society and JCI Insight.

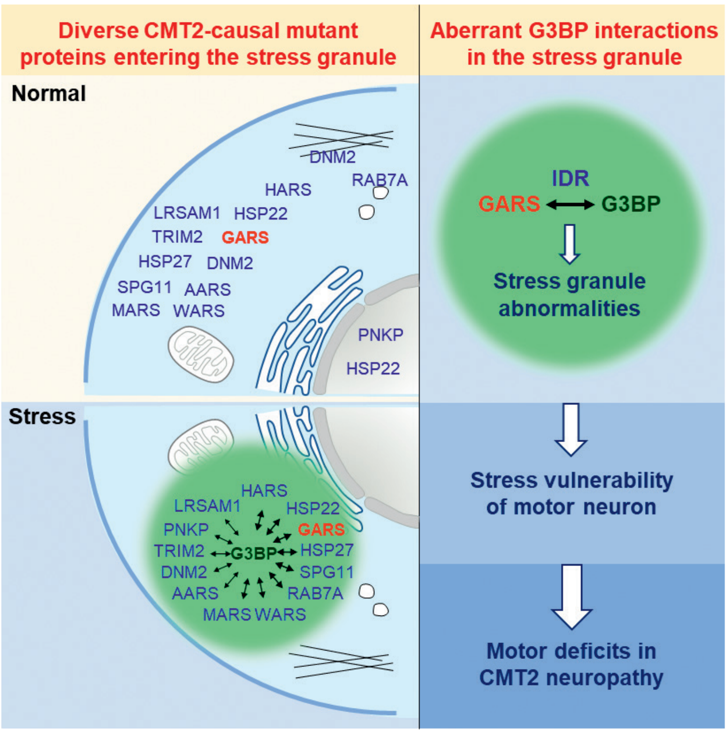



Figure 3-1-53 The mechanistic commonalities of diverse CMT2 proteins

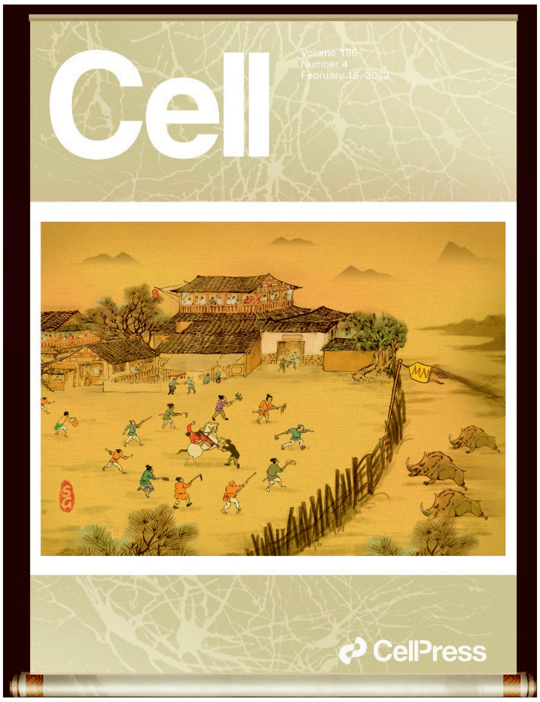



Figure 3-1-54 The cover designed by the team

Upon environmental stress (beast attack), these CMT2 mutant proteins (man in black) adopt similar activities by entering the stress granule (crowd annotated with the "SG" seal) and aberrantly interacting with SG core protein, G3BP (horse rider), thereby disrupting the stress response in motor neurons (fenced village annotated with the MN flag). The cover image design is inspired by the ancient Chinese painting (Riverside Scene at Qingming Festival); the background is adapted from the drawing of Santiago Ramón y Cajal (motor neurons in the spinal cord).

## Unlocking the Potential of *γδ* T Cells: Progress by Chinese Scientists

T cells are crucial components of the immune system, providing protection against infections and maintaining immune balance. They are classified into two main types: *αβ* T cells and *γδ* T cells. *αβ* T cells recognize antigens, primarily peptides, presented by major histocompatibility complex (MHC) molecules through their receptors (TCRs), playing a central role in cellular immunity and laying the groundwork for vaccine development and cell therapies. In contrast, the mechanism by which *γδ* T cells recognize antigens is less understood. V*γ*9V*δ*2 T cells, a major subtype of circulating human *γδ* T cells, exhibit MHC-independent activation and respond to various cancers and infectious diseases. Their activation is triggered by small non-peptidic diphosphate metabolites known as phosphoantigens. However, the precise mechanism by which these phosphoantigens activate *γδ* TCR remains poorly explored. At present, significant challenges hinder the progress of TCR therapies, which predominantly target *αβ* T cells. Additionally, vaccine development has yet to fully leverage the diverse responses of *γδ* T cells. Therefore, further exploration of the intricacies of *γδ* T cell immune recognition mechanisms holds the promise of unveiling novel avenues for innovative immunotherapeutic interventions and vaccine formulations.

Supported by the National Natural Science Foundation of China (Major Program 81991492 and General Program 82271887), researchers Yonghui Zhang from Tsinghua University and Ruiting Guo from

Hubei University have made significant progress in elucidating the mechanisms underlying the recognition of antigens by γδ T cells. In cancer and infections alike, aberrant cells engage human Vγ9Vδ2 T cells through an intricate signaling cascade, wherein diverse phosphoantigen molecules are detected by the intracellular domain of butyrophilin BTN3A1. Acting as "molecular glues," these phosphoantigens facilitate the interaction between the intracellular domains of BTN3A1 and the structurally akin butyrophilin BTN2A1, inducing outward fluctuations in BTN3A1 in a thermodynamically favorable manner. Consequently, BTN3A1 disengages from the BTN2A1 ectodomain, initiating T cell receptor-mediated activation of γδ T cells.

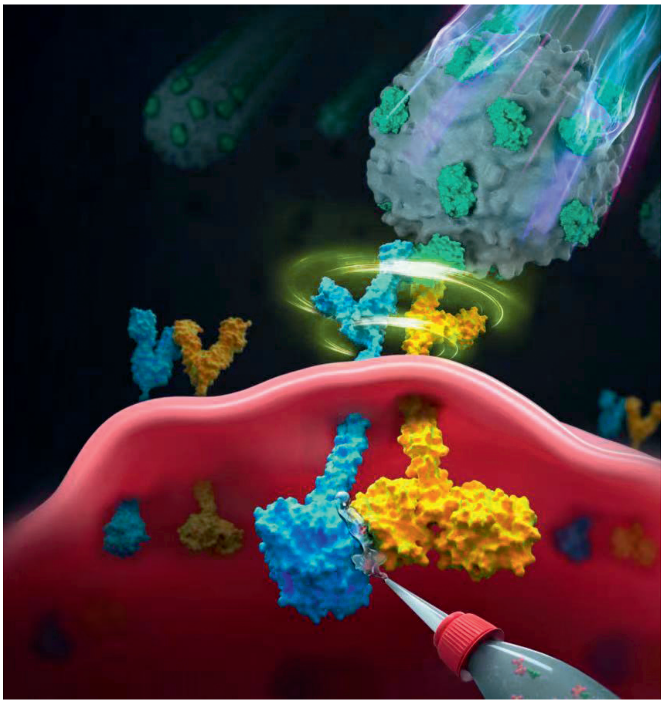


Figure 3-1-55 The diagram illustrates how phosphoantigens act as "molecular glue," connecting BTN3A1 and BTN2A1 to activate γδ T cells.

This mechanism diverges from αβ T cell activation pathways, offering avenues for therapeutic advancement. Targeting BTN3A1 and BTN2A1 shows potential as a therapeutic approach for addressing cancers and infectious diseases. Small-molecule drugs mimicking phosphoantigens as molecular glues provide a convenient pathway for γδ TCR-based immunotherapies. Additionally, this research provides novel strategies for developing vaccine adjuvants that elicit multiple immune responses. The findings were published on September 6, 2023 in *Nature,* titled "Phosphoantigens glue butyrophilin 3A1 and 2A1 to activate Vγ9Vδ2 T cells".

## A Hepatocyte-targeting Nanoparticle Contrast Agent for Magnetic Resonance Imaging Diagnosis of Early Hepatocellular Carcinoma

Hepatobiliary cancers including hepatocellular carcinoma (HCC) and intra/extrahepatic cholangiocarcinoma are highly lethal cancers, with the characteristics of insidious onset and rapid progression. Unlike most cancers, which require a confirmatory biopsy before therapy, hepatobiliary magnetic resonance imaging (MRI) has been advocated by clinical guidelines as the most sensitive method for non-invasive diagnosis of liver tumors in patients. Hepatocyte-specific contrast agents (CAs) are used to selectively modulate MR signals to improve tumour visibility. Currently, the clinical use of gadoxetate disodium (Gd-EOB-DTPA) for MRI diagnosis of hepatic tumors is limited by its low relaxivity and poor specificity. As a result, it is difficult to qualitatively diagnose small early HCC with a diameter of less than 1 cm, which fails to meet the clinical needs of early imaging diagnosis.

With the support of the National Natural Science Foundation of China (Special Program 82150301), Prof. Hai Ming Fan's group from Northwest University designed an innovative dual-targeting hepatocyte-specific pseudoparamagnetic ultrasmall manganese ferrite nanoparticle CAs ($MnFe_2O_4$-EOB-PEG) (Figure 3-1-56). In this study, the T1 relaxivity of $MnFe_2O_4$-EOB-PEG was found to be two times higher than that of the clinically utilized Gd-EOB-DTPA, leading to improved imaging sensitivity. Furthermore, the results revealed that the incorporation of a 3 nm $MnFe_2O_4$ core and the PEG-EOB ligand in $MnFe_2O_4$-EOB-PEG promoted the synergistic targeting of SLC39A14 and OATP1B1/B3 on hepatocytes, enhancing the specificity and affinity. Consequently, the hepatocyte-specific distribution reached a level as high as 70.59%. Hepatobiliary MRI in large animals showed that the contrast-to-noise ratio of the liver for $MnFe_2O_4$-EOB-PEG was 5.8 times higher than that of Gd-EOB-DTPA, and the hepatic duct with a diameter of 0.5 mm can be clearly distinguished. The optimal imaging time for hepatic parenchyma was shortened from 15 minutes to 5 minutes, thereby improving imaging efficiency. The high specificity of $MnFe_2O_4$-EOB-PEG for hepatocytes resulted in significantly improved detection sensitivity (92% versus 48%) for sub-5 mm liver tumors in rabbits, as well as more accurate assessment of biliary obstruction in macaques, compared to the clinically used Gd-EOB-DTPA. Additionally, results from preclinical safety evaluation in pigs showed that $MnFe_2O_4$-EOB-PEG is highly biocompatible. The $MnFe_2O_4$-EOB-PEG was excreted quickly in the form of intact nanoparticles *via* hepatic clearance (88.26%) and renal clearance (11.59%) pathways, with only < 1% of administered $MnFe_2O_4$-EOB-PEG retention after 7 days, indicating the excellent clinical translation potential of $MnFe_2O_4$-EOB-PEG.

The safe and efficient hepatocyte-targeting nanoparticle CAs $MnFe_2O_4$-EOB-PEG not only provides a new imaging diagnostic tool for the early detection of HCC, but also offers a new strategy for the design of highly specific imaging CAs. This research was published as a cover article in *Nature Biomedical Engineering* in March 2023, entitled "A Hepatocyte-targeting Nanoparticle for Enhanced Hepatobiliary Magnetic Resonance Imaging" (Figure 3-1-57). The chief editor of Nature Biomedical Engineering, Pep Pàmies, wrote a special editor's note, stating that "the nanoparticles CAs make MRI increasingly useful." The relevant work on ultrasmall ferrite nanoparticles has also been positively evaluated by peer experts: "Pseudoparamagnetic nanoparticles CAs can be used as highly sensitive MRI probes for non-invasive detection of clinically important biological targets *in vivo*".

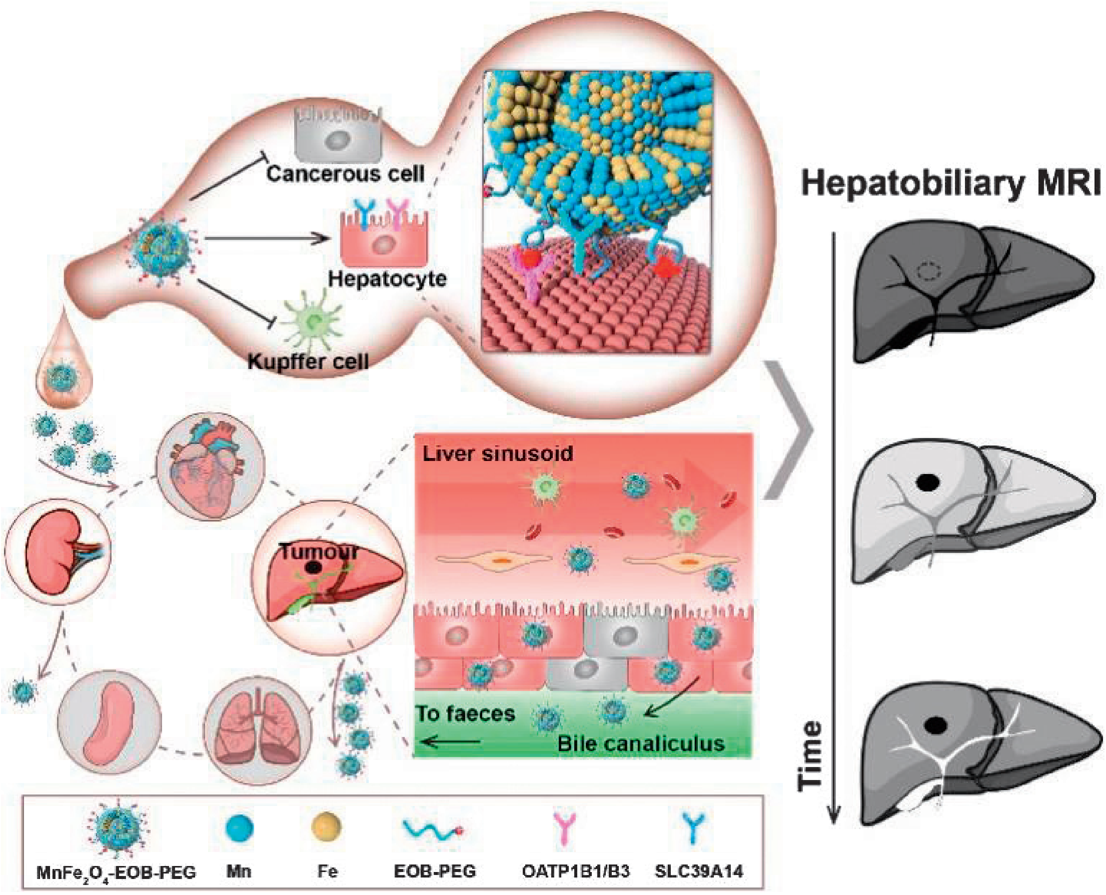



Figure 3-1-56 Design of hepatocyte-specific $MnFe_2O_4$-EOB-PEG nanoparticle-based CAs for hepatobiliary MRI.


Figure 3-1-57 The cover image of the Nature Biomedical Engineering (Volume 7 Issue 3, March 2023).

## A Novel Potential Drug Target for Treating Inflammatory Bowel Disease

Inflammatory bowel disease (IBD) is an etiologically unclear, chronic, and recurrent gastrointestinal inflammatory disease including ulcerative colitis (UC) and Crohn's disease (CD). Damage to the intestinal mucosal barrier plays a crucial role in both the occurrence and recurrence of IBD. Current IBD medications, such as aminosalicylates, corticosteroids, immunosuppressants, or biological agents are effective in combating inflammation, but have very limited efficacy on intestinal mucosal damage. Medications that enhance mucosal healing are highly sought after. The leucine-rich repeat-containing G-protein-coupled receptor 5 (LGR5) positive cells located at the base of the crypts possess the potential as adult stem cells, which are regulated by niche signaling and are critical for both self-renewal and differentiation into mature absorptive and secretory lineages to maintain the integrity of mucosal barrier. Current studies indicate that the impairment of intestinal stem cell (ISC) stemness is a significant factor contributing to recurrent inflammation in both IBD patients and mouse models. Therefore, discovering innovative drug targets that can restore ISC stemness is crucial for the treatment of IBD.

With the funding support of the National Natural Science Foundation of China (Key Program 82130108, General Program 82174044 and 81773744), a collaborative research team led by Professor Xiaoyan Shen and Daofeng Chen from Fudan University, Dr. Peng Du from Xinhua Hospital affiliated to Shanghai Jiao Tong University School of Medicine, and Xiaomin Luo from the Shanghai Institute of Materia Medica, Chinese Academy of Sciences, has successfully identified sorting Nexin 10 (SNX10) as a potential therapeutic target for IBD. This newly discovered target plays a crucial role in cholesterol synthesis and the maintenance of ISC stemness. Clinical data analysis and animal experiments revealed a positive correlation between SNX10 expression in ISCs and the severity of CD in both humans and murine colitis models. Specific knock-out of the *SNX10* gene in intestinal epithelial cells or ISCs facilitated mucosal healing in mouse colitis models induced by Dextran sulfate sodium (DSS) or 2,4,6-trinitrobenzenesulfonic acid (TNBS) by restoring ISC stemness. Gene Set Enrichment Analysis (GSEA) of sorted epithelial cells indicated that SNX10 inhibition-induced stemness restoration is associated with the activation of the mevalonate pathway in cholesterol biosynthesis. Utilizing organoid models, it was confirmed that SNX10 deficiency accelerates cholesterol biosynthesis, increases the sensitivity of ISCs to WNT ligands, and ultimately enhances ISC stemness. Further investigation through live-cell fluorescence imaging and immunoprecipitation experiments unveiled that the deletion of SNX10 gene disrupts the binding of endoplasmic reticulum lipid raft-associated protein 2 (ERLIN2) with sterol regulatory element binding protein cleavage activating protein (SCAP), thereby enhancing the transport, cleavage and activation of sterol regulatory element-binding protein 2 (SREBP2) from the endoplasmic reticulum to the Golgi apparatus. The team also validated these mechanisms by using the previously discovered SNX10 protein-protein interaction (PPI) inhibitor DC-SX029. The results showed that this compound can enhance ISC stemness and promote the recovery of the intestinal mucosal barrier, confirming the substantial anti-IBD efficacy of DC-SX029 (Figure 3-1-58).

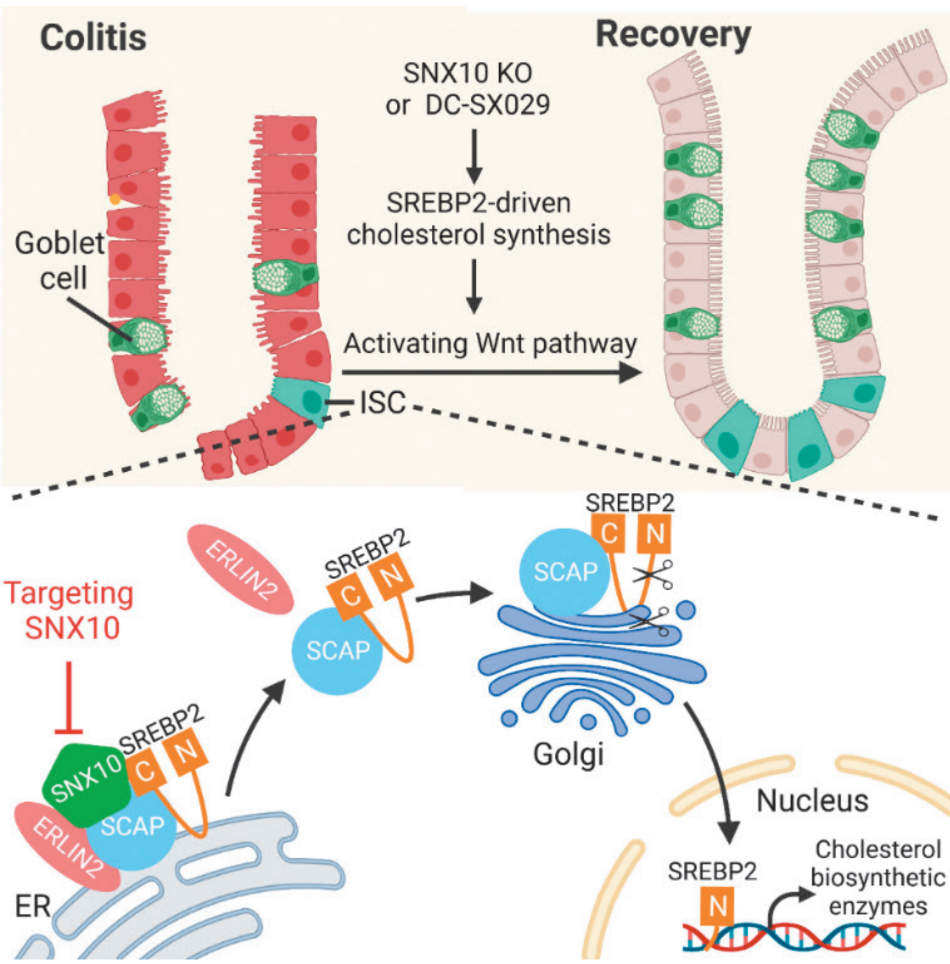



Figure 3-1-58 Targeting SNX10 promotes mucosal healing through SREBP2-mediated restoration of intestinal stem cell stemness in IBD.

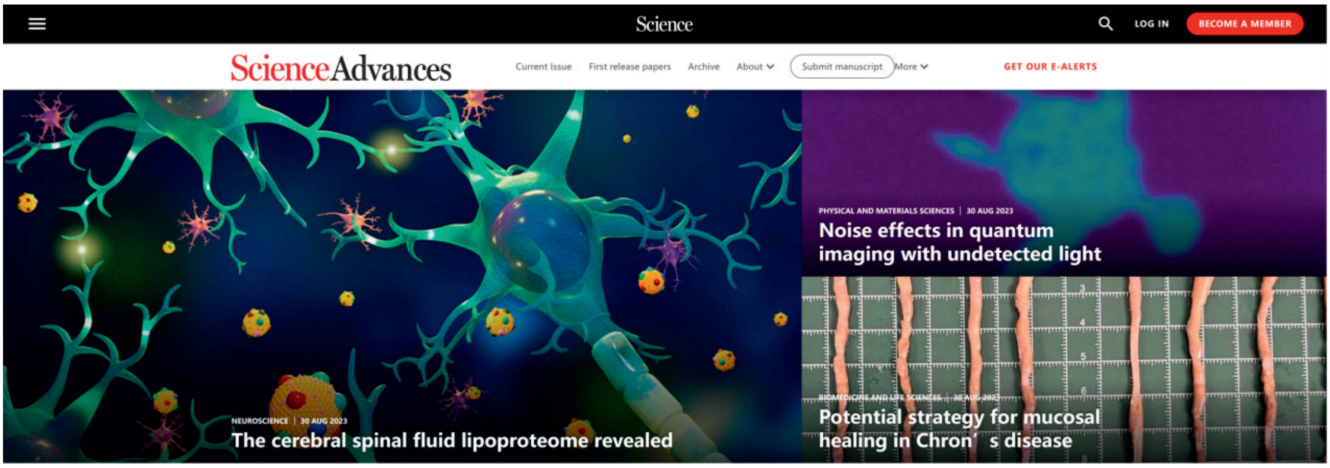



Figure 3-1-59 *Science Advances* on the front page

This study suggests that targeting SNX10 or the key factors in cholesterol metabolism regulated by SNX10 may provide a novel approach for promoting mucosal healing in IBD. The research, titled "Inhibiting sorting nexin 10 promotes mucosal healing through SREBP2-mediated stemness restoration of intestinal stem cells", was published in *Science Advances* on August 30, 2023, and was featured on the front page as a "potential strategy for mucosal healing in Crohn's disease" (Figure 3-1-59).

## DNA-based Programmable Gate Arrays General-purpose DNA Computing

In 1994, Turing Award winner Leonard Adleman introduced the concept of bio-computing taking advantages of base pairing principle of DNA molecules. Since then, liquid-phase DNA molecular computing, which is based on the interactions between DNA molecules, has demonstrated remarkable potential in high-parallel coding and algorithm execution.

With the support from the National Natural Science Foundation of China (Basic Science Center T2188102, etc.), a team led by Chunhai Fan and Fei Wang from Shanghai Jiao Tong University recently developed DNA-based programmable gate arrays (DPGAs) that allows general-purpose digital computing. Using DPGAs, they demonstrated general-purpose digital DNA computing through programming with molecular instructions and achieved the construction of large-scale liquid-phase molecular circuits without attenuation. The research results were published in *Nature* on September 13, 2023, with the title "DNA-based programmable gate arrays for general-purpose DNA computing".

Using DNA molecular reaction networks, researchers have realized diverse computing functions, such as cellular automata, logic circuits, decision making machines and neural networks. However, existing DNA computing systems are mainly limited to hardware customization for specific functions. In the field of electronic computing, general-purpose integrated circuits (e.g., FPGA) can execute various computational functions through software programming without de novo designing and manufacturing hardware, providing a higher-level platform for developing computing devices. Therefore, how to develop general-purpose DNA computing units and realize their programming and integration has become a bottleneck restricting the development of the field of DNA computing.

To address this challenge, the research team first demonstrated that using single-stranded DNA as a uniform transmission signal (DNA–UTS) can achieve signal transmission similar to that of electrons in electronic circuits. They further developed a DPGA that supports general-purpose digital computing and established a method for multi-DPGA integration at the device level, achieving intra-device programmability and inter-device integrability. When the complexity of a circuit exceeds the executable scale of a single DPGA, the circuit can be divided into subcircuits and corresponding molecular instructions can be generated. The molecular instructions for each sub-circuit call and connect the participating DNA units through their logical addresses, realizing the programming of DPGA. Signal transmission between sub-circuits and further multi-DPGA routing is mediated by DNA origami registers, thereby achieving device-level multi-DPGA integration.

Leveraging the programmability and high integration of DPGAs, this study broke through the bottleneck in circuit scale and circuit depth of DNA molecular computing. For the first time, they experimentally demonstrated a circuit scale with up to 30 logic gates, 500 DNA strands, and 30 layers of DNA strand displacement reactions, representing a new breakthrough in the field of DNA computing.

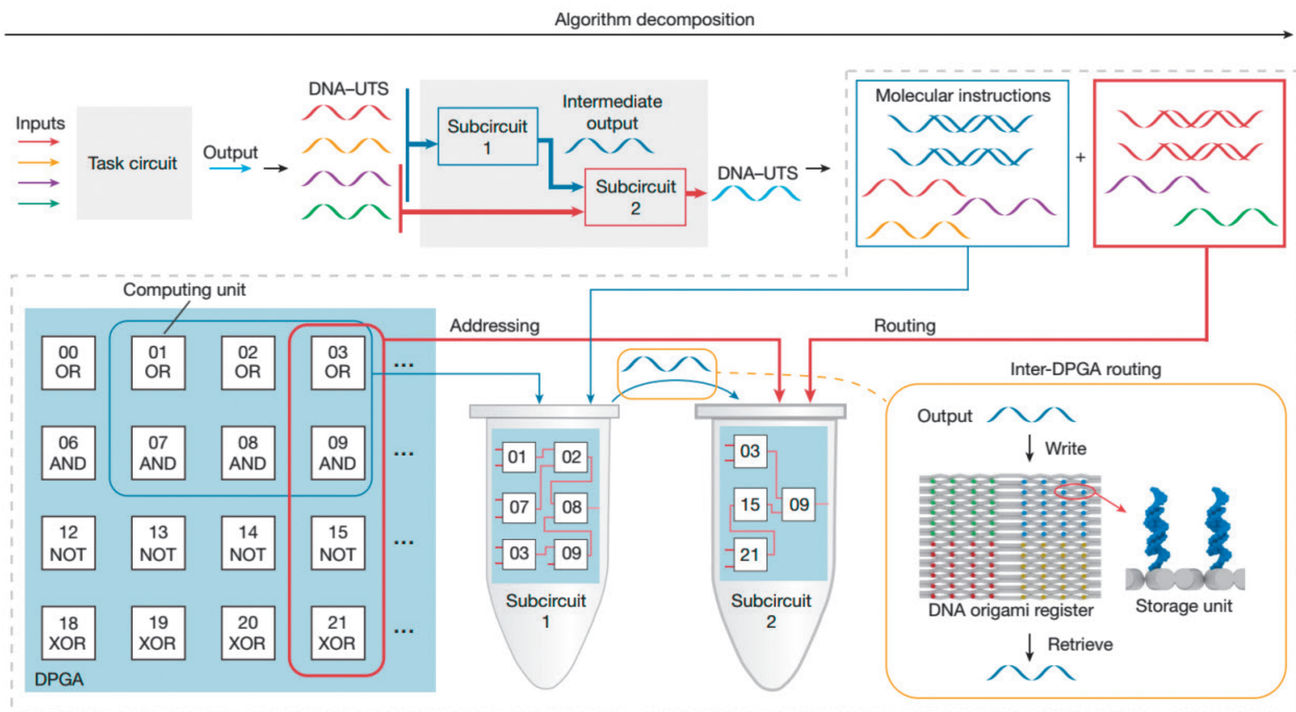



Figure 3-1-60 Programming workflow of DNA-based programmable gate arrays for general-purpose computing.

## Research on Quantum Key Distribution over One Thousand Kilometers Fiber Distance without Relays

Under the Support of the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars T2125010), Professor Qiang Zhang from University of Science and Technology of China, in collaboration with Jinan Institute of Quantum Technology, Shanghai Institute of Microsystem and Information Technology of the Chinese Academy of Sciences, and Tsinghua University, has achieved point-to-point long-distance quantum key distribution (QKD) over a fiber distance of 1002 km. This not only sets a world record for the distance of fiber-based QKD without relays but also provides a scheme for high-rate backbone links in intercity quantum communications. The related finding entitled “Experimental Twin-Field

Quantum Key Distribution over 1,000 km Fiber Distance" was published in *Physical Review Letters* on May 25, 2023.

QKD, based on the fundamental principles of quantum mechanics, enables secure key distribution among users. Combined with "one-time pad" encryption, it ensures the highest level of secure communications in principle. However, the distance for QKD has been limited mainly by the inherent loss of communication fibers and detector noise. The twin-field QKD(TF-QKD) protocol utilizes the properties of single-photon interference to elevate the rate-distance relationship from  linear to  square root thus achieving a much longer distribution distance than conventional QKD schemes.

The team adopted the "sending-or-not-sending" TF-QKD protocol to effectively increase the distance of the QKD experimental system under practical conditions, as showed in Figure 3-1-61. In collaboration with relevant company, the team used ultra-low-loss fibers based on "pure silica core" technology, achieving a quantum channel fiber link with a loss below 0.16 dB/km. By developing ultra-low-noise superconducting single-photon detectors, the team reduced the noise of single-photon detectors to 0.02 counts per second; and by developing a time multiplexed dual-wavelength phase estimation scheme, they minimized the impact of scattering and other noise, reducing the link noise below 0.01 Hz.

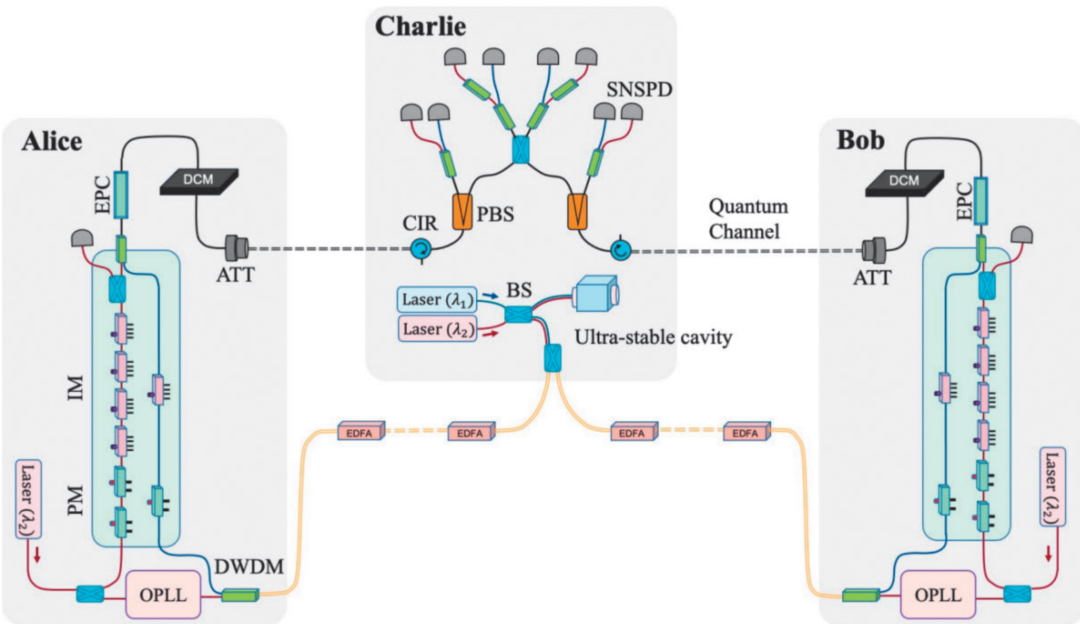



Figure 3-1-61　Experimental Setup of Long-Distance Quantum Key Distribution.

Based on these technologies, the team implemented TF-QKD over a distance of 1002 km, achieving a key rate of 0.0034 bit/s. After optimizing system parameters, they achieved a key rate of 47.06 kbit/s at a fiber distance of 202 km, and at 300 km and 400 km fiber distances, the key rates obtained were six orders of magnitude higher than the original "measurement-device-independent" QKD. This work not only verifies the feasibility of the TF-QKD scheme over extremely long distances but also demonstrates that this protocol can achieve high-rate QKD in intercity fiber distances, making it suitable for use in intercity quantum communication backbone links.

# Development of Cryogen-Free Low-Temperature Scanning Probe Microscope

As liquid helium resources become increasingly scarce, technology for cryogen-free refrigeration has been continuously advancing. Equipment based on cryogen-free refrigeration is gradually becoming the mainstream in low-temperature scientific research instruments. However, scanning probe microscope (SPM) systems with sub-atomic resolution capabilities require extremely stringent vibration levels. Achieving cryogen-free closed-cycle refrigeration technology in the field of low-temperature SPM presents significant challenges.

With support from the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars T2125014), the team led by Prof. Qing Huan from the Institute of Physics, Chinese Academy of Sciences, proposed a novel remote liquefaction cryogen-free closed-cycle refrigeration scheme. In collaboration with partners, they developed an SPM system based on this scheme, achieving high-resolution imaging and spectroscopic characterization in temperature regions below 3 K. The team revolutionized the existing method of proximal installation of the refrigerator in cryogen-free SPM systems. They installed the low-frequency, high-amplitude vibrating refrigerator in a remote independent refrigeration chamber and innovatively eliminated the vibration of the refrigerator through a three-stage self-balancing welded bellows. Using only about 10 liters of helium gas, they achieved a base temperature of approximately 2.8 K and a noise level of about 1 pm. The system can operate continuously for several months at low temperatures, with technical specifications superior to existing foreign products (Figure 3-1-62). The system's performance in non-contact atomic force microscopy atomic-resolution imaging, scanning tunneling spectroscopy, and inelastic electron tunneling spectroscopy is comparable to that of international commercial wet SPM systems.

This method overcomes the shortcomings of existing cryogen-free SPM schemes, such as the inability to bake, magnetic field sensitivity, installation angle limitations, gas permeability and icing of rubber bellows, and difficulties in upgrading. It not only allows for the convenient upgrade of existing wet SPM systems to cryogen-free SPM systems but also is well compatible with other physical environments such as high magnetic fields and optical accesses. The research results, titled "Development of a Cryogen-Free Sub-3K Low-Temperature Scanning Probe Microscope by Remote Liquefaction Scheme," were published in the *Review of Scientific Instruments* on September 6, 2023.

The comprehensive performance specifications of this equipment are at the international leading level, with temperature stability close to ±0.1 mK, a vibration level of about 1 pm, and temperature drift of less than 10 pm/h. It achieves continuous variable temperature imaging from low temperatures (2.8 K) to room temperature and has reached Technology Readiness Level 8 (TRL8). Multiple sets of SPM systems based on this technology have been transferred and produced by ACME (Beijing) Technology Co., Ltd. This technology is also expected to be applied in other fields requiring low temperatures and sensitive to vibrations, such as precision spectroscopy measurements and weak electrical information characterization of quantum materials, aiding in significant breakthroughs in condensed matter physics research, materials science, biomedicine, and other fields in China.

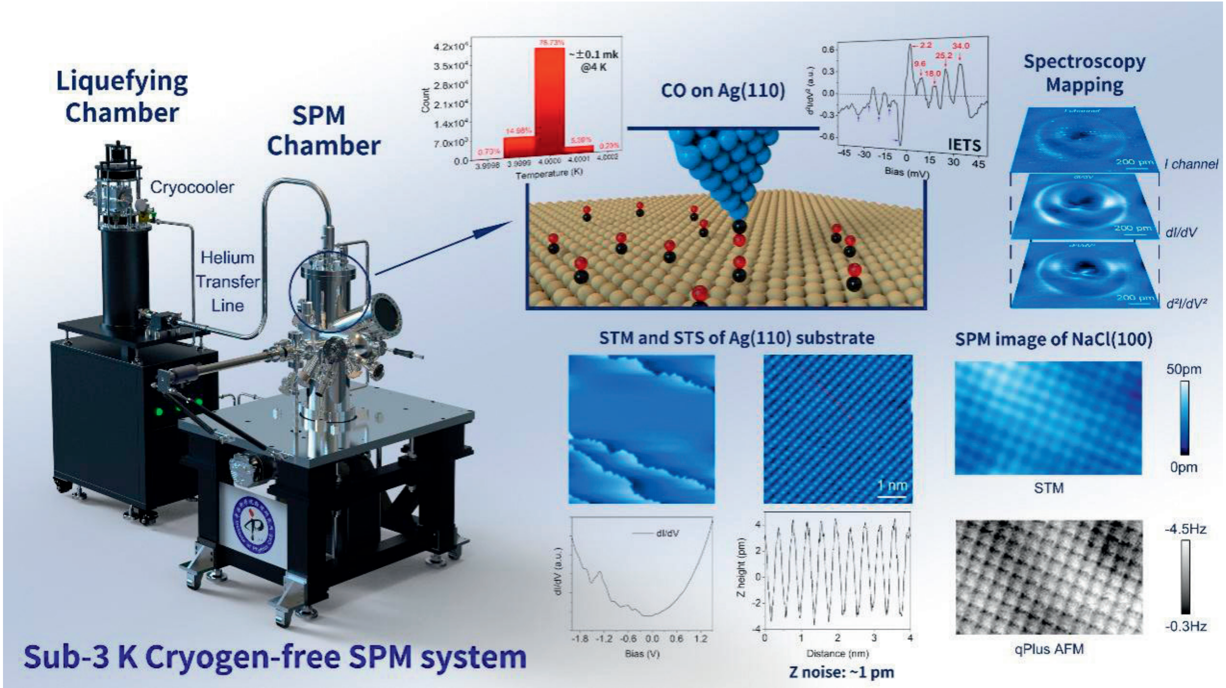



Figure 3-1-62 The photo and function characterizations of Cryogen-Free Low-Temperature Scanning Probe Microscope.

## Fundamental Research on Carbon-free Power System with Ammonia-Hydrogen Synergy Fuel for Heavy Duty Commercial Vehicles

Carbon neutrality technology is a significant demand for automotive powertrains to meet the dual carbon target of China. The annual carbon dioxide emitted by automobiles in China is approximately 0.9 billion tons, in which heavy-duty vehicles account for 50%, but there is currently no global solution for them. Ammonia as a zero-carbon fuel and efficient hydrogen carrier is attractive as potential zero carbon fuel in world wide, but utilizing it in powertrain systems faces three key challenges : fuel inertia, combustion inertia, and power inertia. Conducting relevant fundamental research can provide new solutions for achieving carbon neutrality goals and open up new international frontier technologies.

Under the support of the National Natural Science Foundation of China (Special Program T2241003), Professor LI Jun's team from Tsinghua University, in collaboration with BeiHang University, TongJi University, Wuhan University of Technology, and Foshan Xianhu Laboratory, has launched the fundamental researches on zero carbon emission powertrain system with ammonia-hydrogen synergy fuel for heavy duty commercial vehicles. The team has made several breakthroughs in the fields of fundamental scientific problems and key technologies, and successfully achieved the success of ignition for heavy-duty commercial vehicle engines using ammonia-hydrogen synergy fuel, which is the first time internationally for heavy duty truck engine.

The team proposed innovative methods for enhancing mass transfer and heat transfer in ammonia decomposition and electrochemical hydrogen separation, effectively addressing the challenges of large volume, high energy consumption, and low efficiency inherent in traditional ammonia decomposition systems and conventional hydrogen separation methods. This fills the gap in theoretical and fundamental materials for efficient ammonia-hydrogen synergy fuel reactions in confined spaces (Fig.3-1-63). The team developed a liquid ammonia spray simulation model, studied the effects of injection speed, turbulence, and cavitation on spray characteristics, and proposed a new combustion method for liquid ammonia combustion in-cylinder direct injection of ammonia to produce hydrogen, solving the problems of difficult ignition, slow combustion, and detonation of ammonia under heavy load conditions. They conducted in-depth researches on the generation rules and mechanisms of combustion pollutants in ammonia-hydrogen fuel in cylinders, obtaining the variation rules of exhaust pollutants under different conditions.

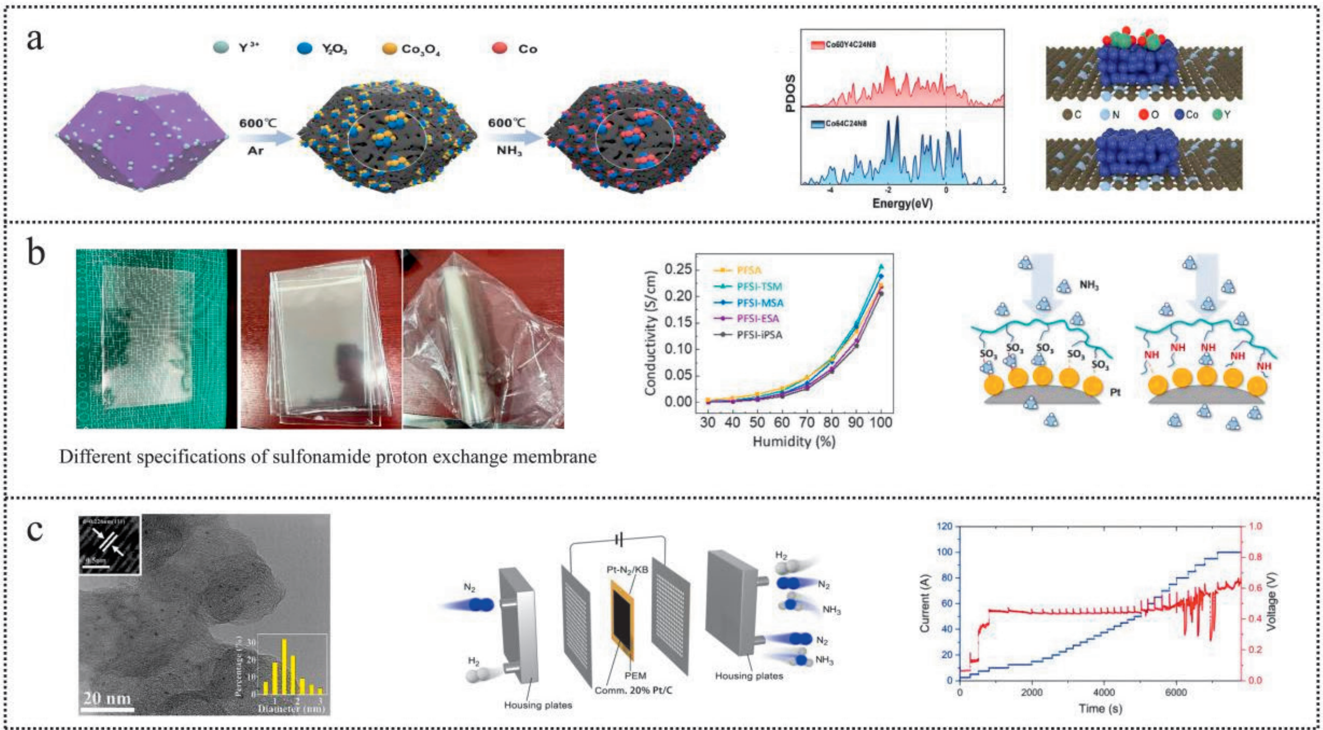



Fig.3-1-63 Key Materials and Mechanisms for Ammonia-Hydrogen Fuel Reforming.

The team, in collaboration with FAW Jie Fang Automotive Co., Ltd., jointly developed China's first ammonia-hydrogen direct injection zero carbon emission heavy-duty commercial vehicle internal combustion engine (Fig. 3-1-64), which was successfully ignited and operated on June 28, 2023. This engine employs liquid ammonia direct injection in-cylinder and an active pre-chamber hydrogen flame jet ignition technology for ammonia-hydrogen mixture. With a displacement of 13 liters and a power output of 400 kW, it fully meets the high-power demands of heavy-duty commercial vehicles. This achievement marks a significant step forward in the design and development of liquid ammonia internal combustion engines, the construction of combustion systems, and the development of key components for electronic control and ammonia-hydrogen fuel supply systems. The breakthrough of this powertrian technologies provide a new technical path for achieving the " Carbon Peak& Carbon Neutrality" goals for heavy-duty vehicles, playing a crucial role in leading and promoting national innovation in ammonia-hydrogen new energy technology.

Fig. 3-1-64 Ammonia-Hydrogen Synergy Fuel Direct Injection Zero-Carbon Internal Combustion Engine System.

## Enhanced Detection of Fluorescence Fluctuations for High Throughput Super-Resolution Imaging

Supported by the National Natural Science Foundation of China (Excellent Young Scientists Fund T2222009, Special Fund for Research on National Major Research Instruments 32227802), Professor Haoyu Li and Professor Weisong Zhao's group at Harbin Institute of Technology, collaborating with Professor Liangyi Chen's group at Peking University, developed a high-throughput super-resolution method based on auto-corelation with two-step deconvolution (SACD). This super-resolution technology has been published in *Nature Photonics* with the title of "Enhanced detection of fluorescence fluctuations for high-throughput super-resolution imaging", and the paper has been selected as the cover article on September 1, 2023.

Super-resolution (SR) imaging methods offered the analysis of cells over Abbe diffraction limit, which typically require stringent photochemical environments or additional optical devices. These limitations prevent SR techniques from becoming a customary method for high throughput live-cell analysis in medicine. They developed a super-resolution method based on auto-correlation with two-step deconvolution (SACD) reducing the frame number of SR optical fluctuation imaging (SOFI) by orders of magnitudes. SACD only needs 20 frames to achieve a twofold 3D resolution improvement, compared to the ~1,000 frames required in conventional SOFI, enabling the highest throughput SR imaging that covers millimeter-level area in just 10 minutes. To achieve long-term live-cell SR imaging and the visualization of transient cellular dynamics, this study introduced previously developed Sparse deconvolution after autocorrelation calculation, improving both throughput and robustness. The research group captured a super-resolved 3D mitochondrion network during stretching over ten minutes of imaging, revealing the mitochondrial fission and fusion occurring across 4D in whole-cell. SACD achieves the highest-throughput imaging currently and enables the visualization of transient cellular dynamics with no need for additional optical devices.

Professor David Baddeley from University of Auckland specially published a corresponding review article on News&Views section of the same volume in *Nature Photonics,* in which he praised this work as "immensely valuable" (https://doi.org/10.1038/s41566-023-01275-0).

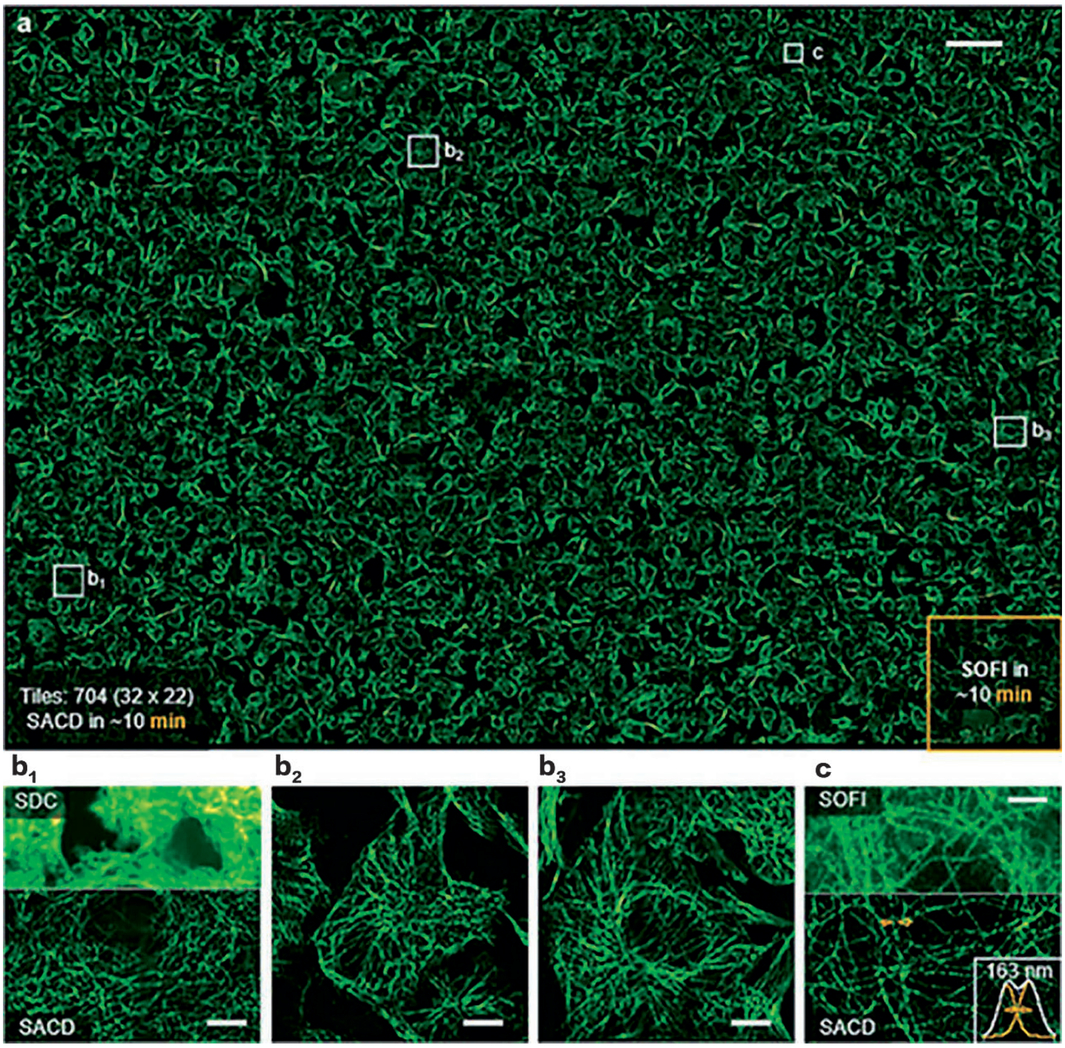



Figure 3-1-65 Live four-dimensional super-resolution imaging

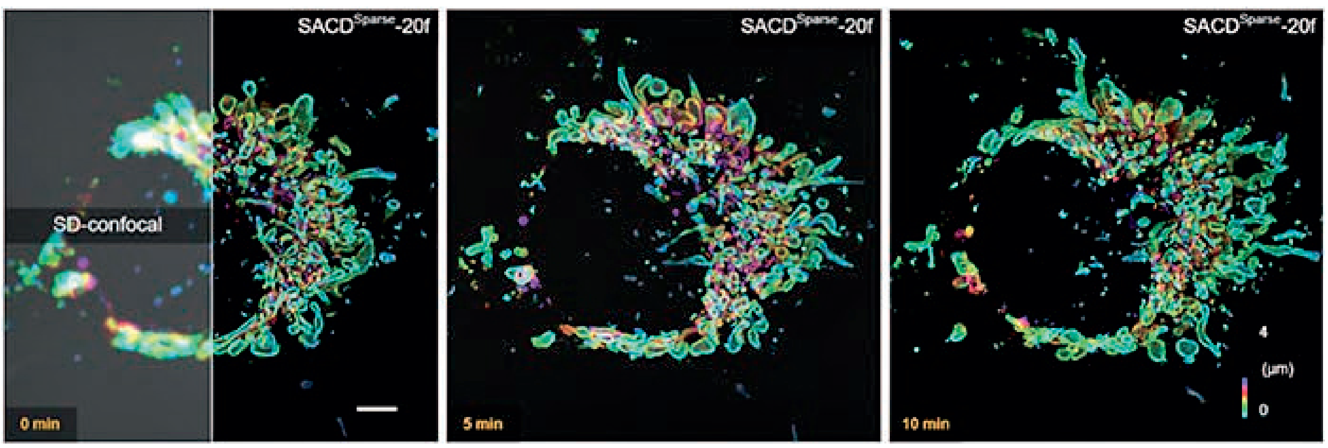



Figure 3-1-66 Live four-dimensional super-resolution imaging

# Exosome-loaded Degradable Polymeric Microcapsules for the Treatment of Vitreoretinal Diseases

Supported by the National Natural Science Foundation of China (National Science Fund for Distinguished Young Scholars T2225021) etc., Prof. Ma Guanghui and Prof. Wei Wei from the Institute of Process Engineering, Chinese Academy of Sciences, in collaboration with Prof. Tao Yong from Beijing Chaoyang Hospital, Capital Medical University, have made a new progress on intravitreal sustained-release exosome based on self-healing microcapsules. The research, titled “Exosome-loaded degradable polymeric microcapsules for the treatment of vitreoretinal diseases”, was published online in *Nature Biomedical Engineering* on October 23, 2023.

In recent years, cell therapy has shown some efficacy in clinical trials for the treatment of ocular diseases, but still faces a series of challenges, such as low in vivo cell survival rates, unstable cell phenotypes in pathological environments, and strict storage conditions for cell products. To address these issues, the researchers created a novel system using self-healing microcapsules (Cap) loaded with exosomes (Exo). This ExoCap system can simulate functional cells in terms of size, internal structure, and secretion behavior. Once injected into the vitreous cavity, ExoCap can settle and remain at the inferior of the vitreous cavity, avoiding the problem of active cells floating in the vitreous cavity and affecting the line of sight. As ExoCap slowly degrades, it sustainably releases the active exosomes, which is conducive to exert a therapeutic effect over an extended period. This system can be loaded with exosomes from various cell sources according to different therapeutic needs (as shown in the Figure 3-1-67).

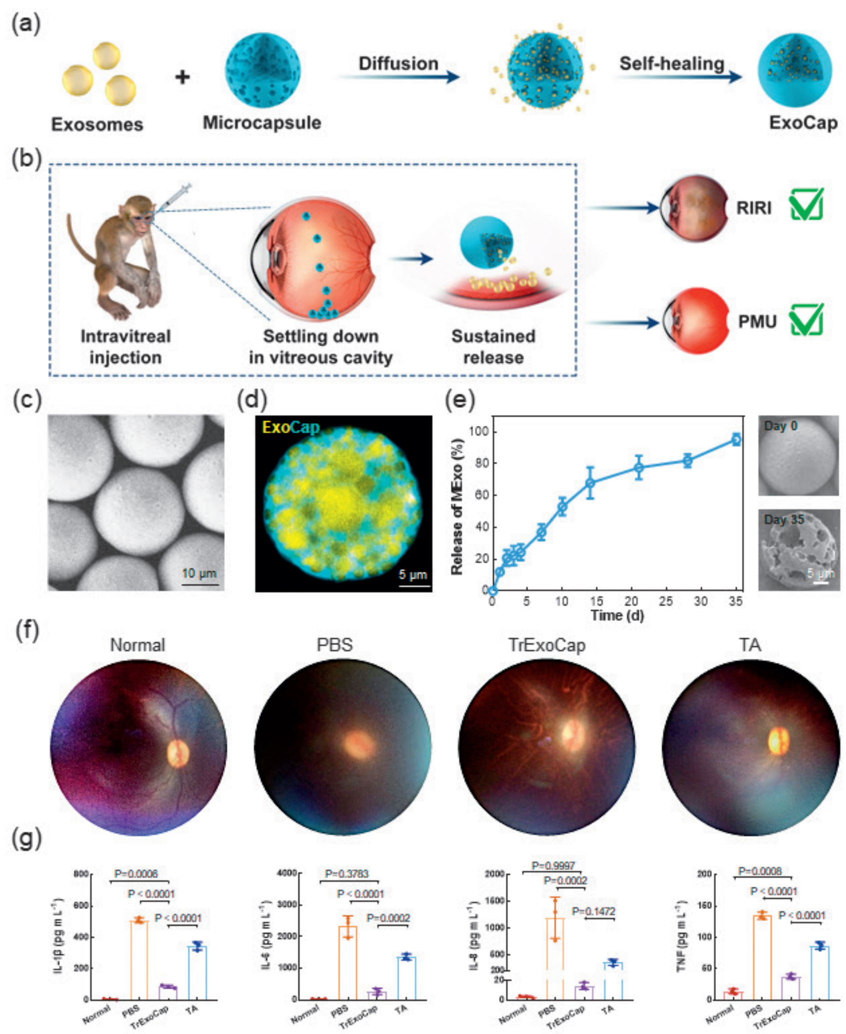



Figure. 3-1-67 Construction of ExoCap and its therapeutic effect in the non-human primates with primed mycobacterial uveitis

# 3D Optical Microscopic Measurement Instrument for Complex Microstructures

Harbin Institute of Technology, National Institute of Metrology of China and other research teams, funded by a special project (2021YFF0700400) "Research and Development of Basic Scientific Research Conditions and Major Scientific Instrument Equipment" and the National Natural Science Foundation of China (General Program 5197050993), cooperated to propose a technical method for confocal microscopic measurement of orbital angular momentum in dark field to achieve 3D optical ultra-high sensitivity surface and subsurface defect detection smaller than 100 nm, and presided over the revision of the international standard ISO 8785 (Surface Imperfections), which is the first time that Chinese representatives in the field of geometrical product specifications take the lead in the international development of ISO standards.

Microdefects are extremely destructive to the performance of micro-devices/micro-systems such as high-performance detectors and high-power optical components, and are complex in types and difficult to be defected and quantitatively characterized, thus becoming a critical bottleneck hindering the improvement of product yield. The front surface reflection of the sample leads to dramatic increase of photon noise, and subsurface defects are more difficult to be detected than surface defects. The characterization method for defects is still 2D evaluation in the international standard system. Harbin Institute of Technology proposed a technical method for confocal microscopic measurement of orbital angular momentum in dark field, carried out research on the characterization method for defect properties based on multi-order vortex component extraction, provided an effective technical means for subsequent research on the correlation between damage and defect morphology, solved the problem of low-order diffraction noise separation, and developed a multi-modal bright-field/dark-field/photothermal integrated measurement instrument, which was proved by preliminary experiments to be able to distinguish 3D geometric polarity characteristics of surface and subsurface defects smaller than 100 nm. At the same time, during the implementation of the project, Professor Liu Jian from Harbin Institute of Technology was hired as the person responsible for the revision of ISO 8785-1998 (Surface Imperfections).

The breakthrough of the 100-nm 3D optical ultra-high sensitivity surface and subsurface defect detection technology and the revision of ISO 8785-1998 mean that optical non-contact 3D micro-measurement instruments may be used for 3DIC preorder defect detection, the system of surface defects in international standards has been improved, the concept of surface defects has extended from the traditional surface to the shallow surface, and the quantitative characterization method has entered the development stage from 2D discovery to 3D property identification. Figure 3-1-68 is a physical photo of an engineering prototype, and Figure 3-1-69 shows examples of defect detection results.

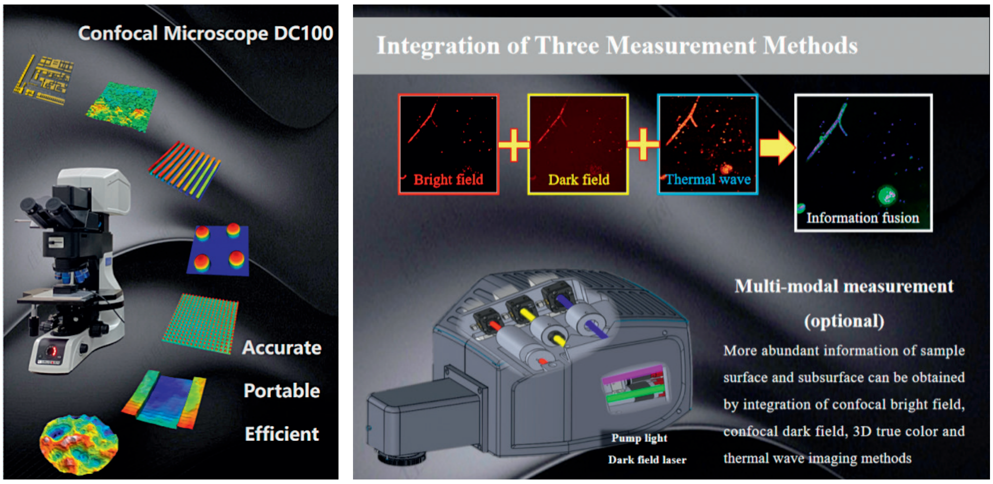



Figure 3-1-68 Physical Photo of Engineering Prototype of 3D Optical Microscopic Measurement Instrument for Complex Microstructures

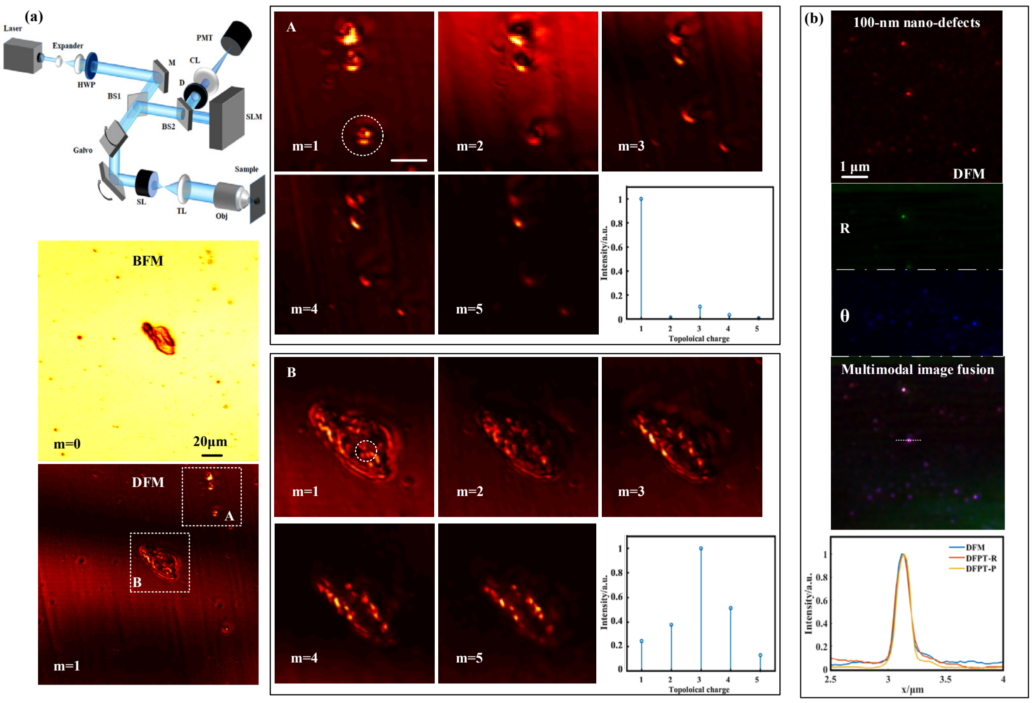



Figure 3-1-69 Examples of Defect Detection Results. (a) Characterization for defect properties based on multi-order vortex component extraction. (b) Multimodal detection of defects with 100-nm scale

## Centiliter-scale Compact Cold Atoms Physical Package

Magneto-optical trap (MOT) is a general and robust approach for cooling and trapping atoms and is widely applied in quantum standards and sensors, such as cold atoms clocks, atomic gravimeters, magnetometers, and microwave sensing. With more and more quantum systems integrated into real-world applications, the size, weight, and power (SWaP) of the quantum systems need to be reduced. However, the application of conventional MOT in mobile and compact systems is still challenging because of their relatively complicated and large architecture, where its volume is generally at the level of m3.

Funded by the National Key Research and Development Program of China under Grant No.2021YFF0603700, the National Institute of Metrology and its collaborators, including the Innovation Academy for Precision Measurement Science and Technology, University of Science and Technology of China and China Jiliang University, have designed and fabricated a high-diffraction-efficiency grating chip, a planar coil chip, and a passively pumped compact vacuum chamber, which is shown in Figure. 3-1-71. All the components were combined to demonstrate a centiliter-scale compact cold atoms physical package (Figure. 3-1-72). Atoms were cooled and trapped in this system with a single incident cooling beam (Figure. 3-1-72a). This compact cold atoms-based system was implemented to a coherent population trapping (CPT) experimental setup, and a contrast up to 50 % CPT resonance signal was obtained (Figure. 3-1-72b). This result validated the feasibility of the cold atoms system for the CPT atomic clock. Furthermore, the grating chip-based idea was extended to more cooling atom technique. A dipole trap structure with a grating chip was proposed. With this design, a MOT and a dipole trap could be realized with a single laser beam on a single grating chip. This study was published in Joc. Opt. Soc. Am. B with the title "Concept of a miniature dipole trap system based on a simple architecture grating chip".

In summary, this work had demonstrated a compact cold atoms physical package for a CPT system. The results demonstrate impressive progress toward reducing the power consumption and volume of a compact cold-atom system. It holds great potential for application in portable cold-atom sensors and quantum devices.

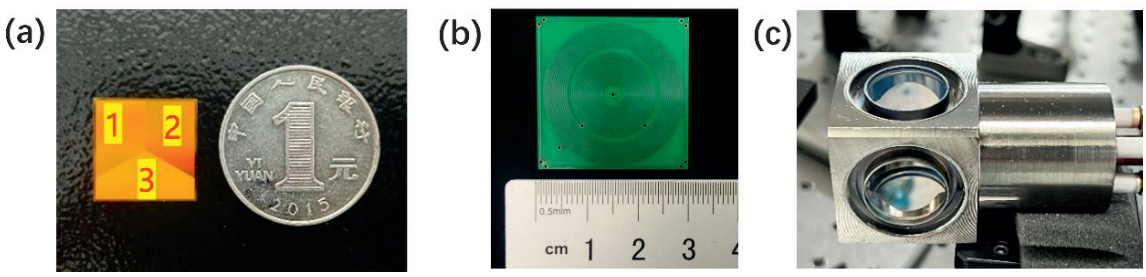



Figure 3-1-70 (a) Grating chip; (b) Planar coils chip; (c) Compact vacuum chamber.

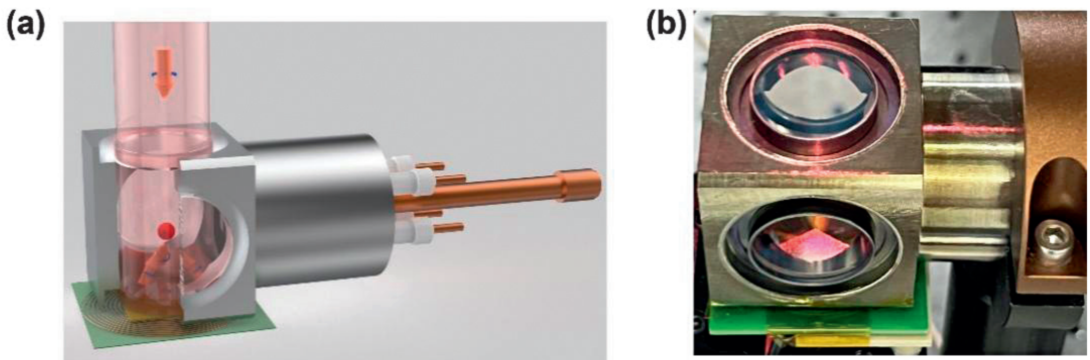
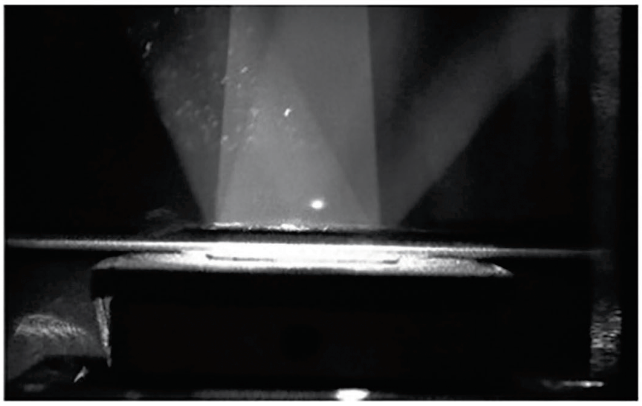



Figure 3-1-71 (a) Architecture and (b) photo of the compact cold physical package.



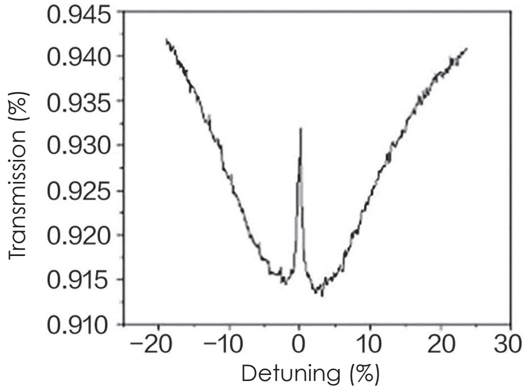



Figure 3-1-72 (a)　Fluorescence of the cold atoms; (b) CPT resonance signal.

## Research on Remote Sensing Technology and Aapplication of Trace Gases by Domestic Hyperspectral Satellites

Hyperspectral satellite remote sensing is an indispensable observation technology for comprehensively capturing the spatial and temporal characteristics of pollution/greenhouse gases and supporting China's "co-reduction of pollutant and carbon emissions" strategy (Figure 3-1-73). However, China's hyperspectral remote sensing of the atmospheric environment has long relied on satellite payloads from Europe and the United States such as OMI and TROPOMI, which has not favored the development of the remote sensing of atmospheric environment in China.

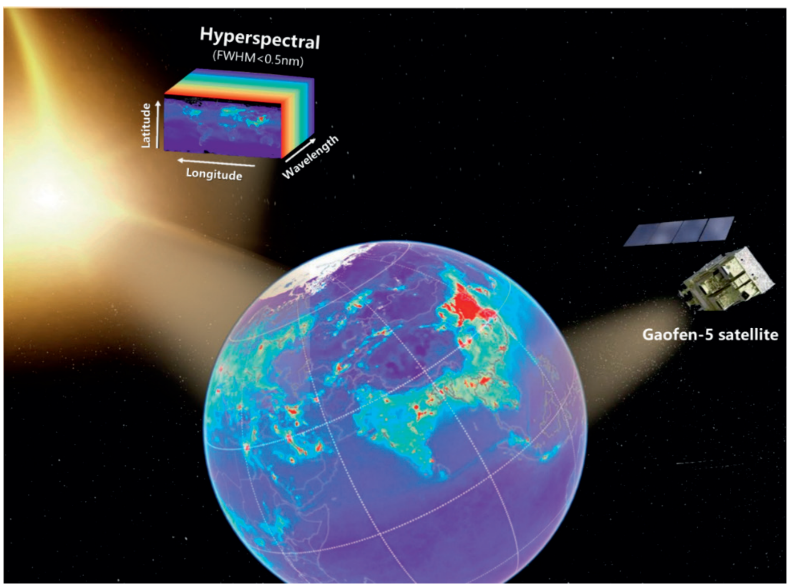



Figure 3-1-73　Schematic of remote sensing of atmospheric pollution components by national hyperspectral satellites

Funded by the National Key Research and Development Program (2022YFC3700100), Prof. Cheng LIU's team at the University of Science and Technology of China, and the collaborators at Hefei Institutes of Physical Science, Chinese Academy of Sciences, Anhui University and other institutes, has developed the pre-launch calibration algorithm and post-launch hyperspectral distortion correction technology for

China's first UV-visible hyperspectral satellite payload EMI (Figure 3-1-74). This algorithm has been used for on-orbit testing of Chinese satellites by the Satellite Application Center for Ecology and Environment, Ministry of Ecology and Environment, and provided a long-term stable observation foundation for Chinese satellites with drastic changes in their performance in the space environment. A multi-species pollutant and greenhouse gas retrieval algorithm for hyperspectral satellites has been developed, which approached the inversion accuracy of the latest satellites of a similar type in Europe and the United States.

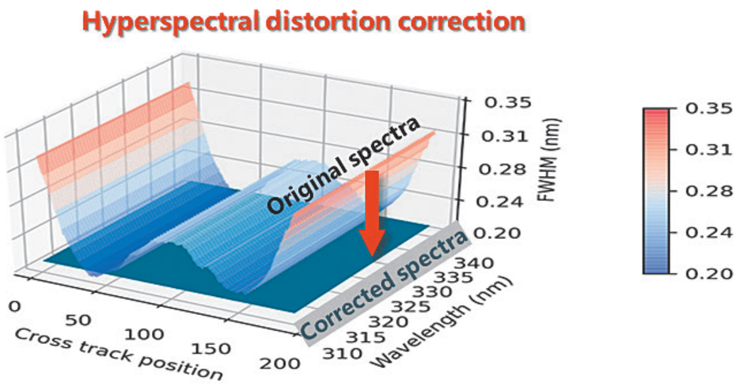



Figure 3-1-74 Post-launch hyperspectral distortion correction technology for correcting the spectral deformation of the EMI payload after launch

The results of domestic hyper-spectral satellite remote sensing have been used by the Satellite Application Center for Ecology and Environment, Ministry of Ecology and Environment as official standard products, and have been popularized and applied in the practical work of the "Beautiful China" ecological civilization construction by more than 20 governmental departments, including the China National Environmental Monitoring Center and the National Joint Center for Air Pollution Prevention and Control. It has realized the use of domestic satellite remote sensing to support air quality assurance for major national events such as the China International Import Expo and the Chengdu Universiade, breaking the situation of high dependence on foreign satellite payloads over the years, and the research findings has been awarded the Xplorer Prize of the New Cornerstone Science Foundation (2023).

## Metallogenic Theory and Exploration Demonstration of Lithium Deposits in Western China

Lithium, a strategic and scarce mineral resource in China, is abundant in Western China, yet the precise extent of these resources and their strategic development is not fully understood. Supported by the "Strategic Mineral Resource Development and Utilization" key project of the National Key R&D Program, the Institute of Mineral Resources, Chinese Academy of Geological Sciences has undertaken the project of "Study on the Metallogenic Regularity and Prospecting Techniques of Pegmatite-type Lithium and Other Rare Metals in Western China" (Project Number: 2021YFC2901900).This project focuses on crucial scientific issues, including the "heterogeneous and synchronous explosive metallogenesis" of lithium mines in Western China, as well as quantitative evaluation techniques for lithium and other rare metal resources. It aims to elucidate the metallogenic conditions of lithium mines, swiftly assess resource potential, identify new mining sites, augment reserves and production of lithium resources, and fortify national resource security through comprehensive research efforts. Preliminary findings have shed light on the regional metallogenic conditions for lithium mines in Western China, identifying four new major metallogenic belts for lithium and other rare metals including Altyn, Gangdise, Himalayas, and the northern margin of Qaidam Basin, providing decision-making basis for the national new round of exploration breakthrough strategy.

The project has made seminal contributions to the understanding of lithium ore metallogenesis and the development of exploration methods and technologies. Firstly, it has advanced and refined the "multi-cycle deep circulation integrating endogenic and exogenic processes" metallogenesis theory, revealing the metallogenic regularity of pegmatite-type lithium mines and identifying five key mining areas including Shaligou and Tamaqi in Xinjiang, Shinaier in Qinghai, Jiada in Sichuan, and Loza in Tibet. Secondly, lithium mine prospecting technology has become more systematic and comprehensive. Techniques such as isotopic methods for lithium prospecting, combinations of audio-frequency magnetotelluric sounding with high-density resistivity methods, and the use of high-resolution remote sensing imagery have been developed for lithium mine exploration and resource potential evaluation, gaining valuable experiential insights. Additionally, the application of new mineral prediction technologies based on deep machine learning, particularly for clay-type and other novel forms of lithium mines, has pioneered new frontiers in mineral prediction research.

This research has also set a benchmark for the rapid translation of scientific findings into practical applications. Around Jiada in Ma'erkang, Sichuan, new lithium ore veins like Mana have been discovered (Figure 3-1-75), leading to the successful auction of exploration rights for the Jiada Lithium Mine, yielding

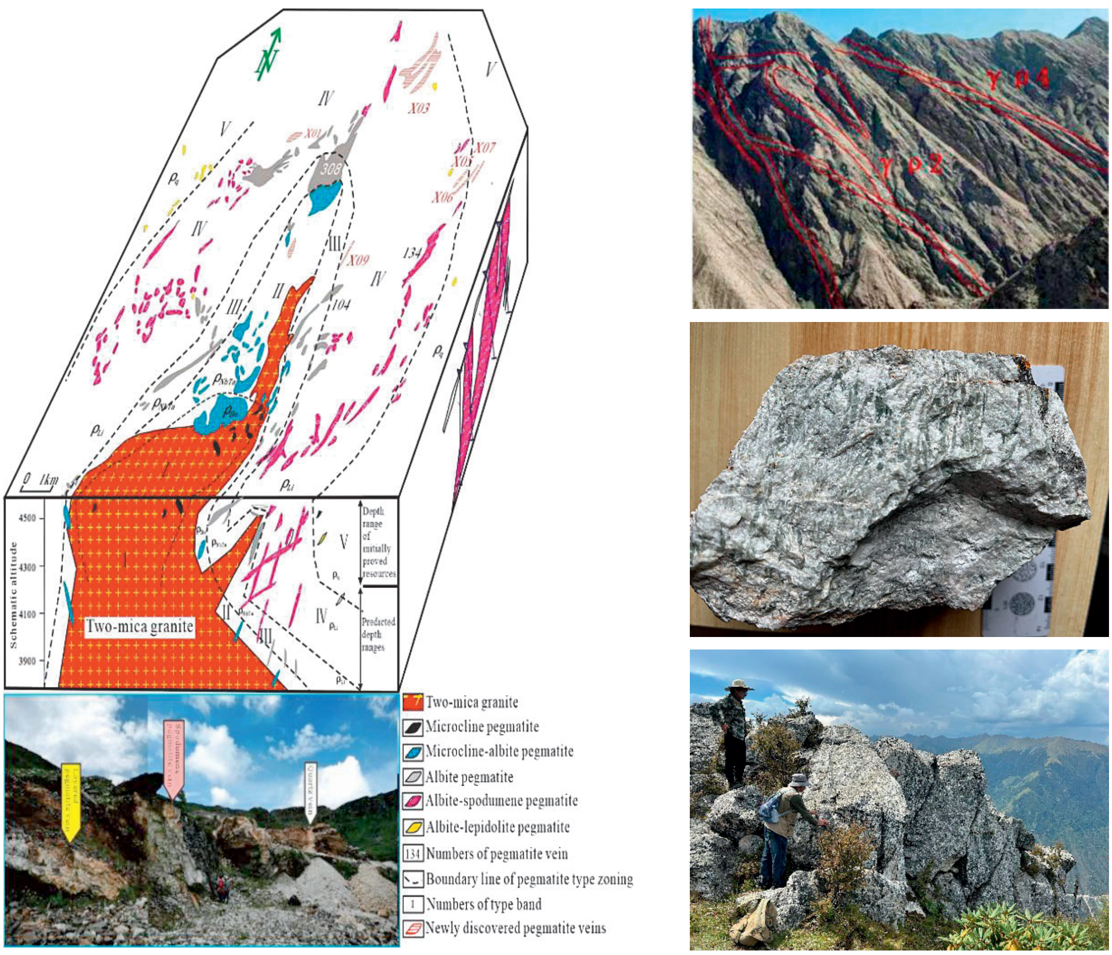



Figure 3-1-75 Pegmatite-type lithium ore metallogenesis model and new discoveries in lithium mine prospecting projects
a—Pegmatite-type lithium ore metallogenesis model; b—Surface outcrop of lithium-bearing pegmatite veins in Altyn Tagh, Tamuqi, Xinjiang; c—Pegmatite specimen of lepidolite from the Gabo Lithium Mine in Loza, Tibet; d—Ore-bearing pegmatite vein outcrop in Jiada Lithium Mine, Ma'erkang, Sichuan.

significant financial benefits (4.2 billion RMB) for national and local governments. This discovery provides a solid foundation for the establishment of a major lithium mining base in Western Sichuan, and it is poised to serve as an exemplary model of commercial follow-up, rapid breakthrough, and expansion in reserves and production for National Key R&D Program projects.

## Key Technologies for Acoustic Detection of Floating and Sinking Intelligent Networking

Ocean seismic acoustic observation has been a long-standing gap in the field of ocean observation, resulting in a lack or absence of seismic ray coverage in large areas of the ocean, which greatly affects the deep structure and dynamics of the marine Earth system, and hinders further understanding of the mechanism and dynamic process of earthquake occurrence.

Under the special funding of the National Key R&D Program, Academician Li Jiabiao from the Second Institute of Oceanography of the Ministry of Natural Resources organized the "Key Technologies for Acoustic Detection of Floating and Sinking Intelligent Networking (2021YFC3101400)" project. The project follows the technical route of "online observation → land-based integration → demonstration application", focusing on solving two key scientific issues: the impact of the deep structure of the Earth and the marine environment on the propagation of major event signals in water. We have developed intelligent ocean acoustic buoys and fiber optic three-dimensional composite array acoustic submarines, and constructed a dynamic- static integrated ocean seismic acoustic observation system. It has the ability to monitor natural seismic P-waves of level 6 or above within 6000km and locate underwater event sound sources (within 500 Hz, sound source level ≥ 235 dB) within 500km of water(Figure 3-1-76 and Figure 3-1-77).

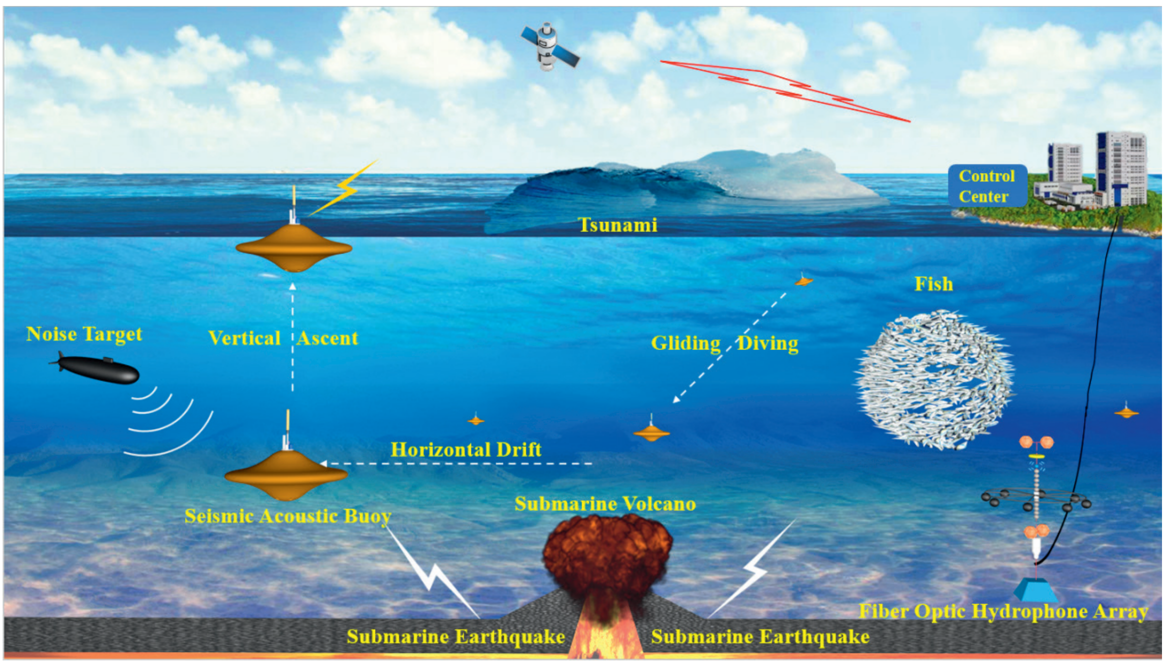



Figure 3-1-76 Demonstration of marine seismic acoustic observation system

The marine seismic acoustic observation system can achieve large-scale, long-term, and quasi real-time observation on hardware, and online accurate classification and recognition of underwater acoustic signals on software. It achieved breakthroughs in three aspects.

(1) During the development process, key technologies such as the streamline structure, attitude control, and collaborative networking of intelligent acoustic buoys were breakthroughs, overcoming the limitations of the lack of mobility and inability to intelligently network existing technologies internationally. For the first time, a new type of seismic acoustic buoy with both mobility and intelligence has been developed, possessing the capability of global ocean seismic acoustic network observation technology.

(2) The high-sensitivity, low-frequency, low-noise deep-sea optical fiber hydrophone technology has been broken through, and a high-gain and high-precision acoustic direction-finding method for three-dimensional composite optical fiber hydrophone arrays has been proposed. For the first time, a remote observation and positioning system for underwater acoustic signals based on dual three-dimensional composite arrays acoustic submerged buoys has been constructed, enabling the simultaneous detection of major events and underwater targets in water.

(3) Breakthrough the multi-scale feature extraction and long-short term memory deep neural network detection technology of seismic and underwater major event signals under various interference conditions, establish a data-driven deep learning recognition algorithm, and solve the problem of low online recognition accuracy of existing MERMAID buoys.

The project results can be used to construct an earthquake acoustic observation system with independent intellectual property rights, fill the gap in global ocean seismic observation, obtain global-scale tomography, and clarify the Earth's multi-layer system. It can also form an international cooperation plan dominated by China, allowing China to maintain its outstanding leadership in international cooperation.

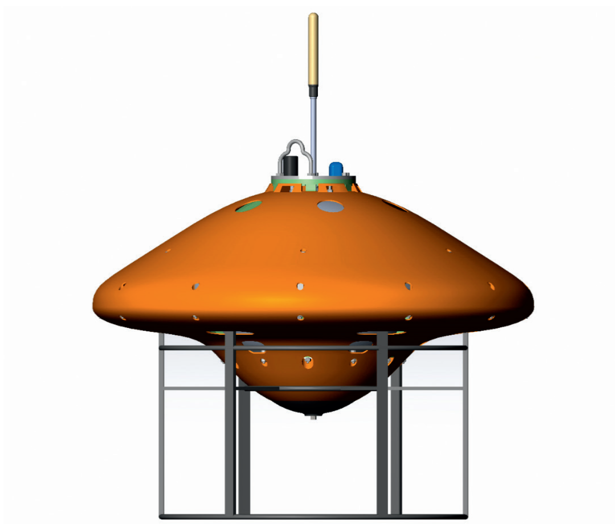


Figure 3-1-77　Prototype of marine seismic acoustic buoy

## Research on Earthquake Monitoring and Prediction Technology Based on Big Data and Artificial Intelligence

Under the support of the Key Special Project "Major Natural Disaster Prevention and Control and Public Safety" of the National Key Research and Development Program, the Institute of Earthquake Prediction, China Earthquake Administration, has undertaken the project of "Research on Earthquake Monitoring and Prediction Technology Based on Big Data and Artificial Intelligence" (Project Number: 2021YFC3000700). The project has developed an artificial intelligence real-time earthquake monitoring technology and system, intelligent monitoring of temporal and spatial changes in crustal stress and medium parameters, comprehensive acquisition of earthquake anomaly information. The team conducted demonstration applications of earthquake monitoring and prediction in experimental areas to improve the level of intelligent processing of seismic data and the accuracy of medium- and short-term predictions.

The research team has established the world's largest artificial intelligence earthquake monitoring dataset, including waveform data of more than 1.3 million earthquakes recorded by the China Seismic Network since 2009, with a total of over 45 million labels. It is the most extensive dataset containing the most earthquake events and standards, the widest magnitude range, the broadest epicentral distance range, and the richest types of seismic phases and earthquake types in the world. It provides critical data support for the development of artificial intelligence in earthquake monitoring in China.

Our team has developed and refined the world's first artificial intelligence real-time earthquake monitoring system (EarthX), an artificial intelligence seismic auxiliary cataloging system (RISP) (Figure 3-1-78), and an artificial intelligence automatic classification system, which have achieved demonstration applications. These systems can process earthquakes occurring in the experimental field in real-time and effectively distinguish between artificial earthquakes and natural earthquakes, significantly enhancing the monitoring capability of microearthquakes. During the implementation of the project, multiple aftershocks of several moderate-strong earthquake sequences were detected in real-time, all exceeding twice the number analyzed manually. At present, demonstration applications have been carried out in multiple regions such as Sichuan, Yunnan, and Fujian, gradually replacing the tedious repetitive work done by humans; the team's artificial intelligence monitoring system for source parameters and underground stress changes can obtain source parameters in real-time for earthquakes above magnitude 2 and monitor underground stress changes in real-time. Moreover, the earthquake artificial intelligence prediction system based on graph neural networks has begun demonstration operations in the Sichuan-Yunnan region.

Figure 3-1-78　Realization of business operation of the Intelligent Cataloging System

The team innovatively designed a series of machine learning experiments, classified and analyzed the correlation of more than 3,000 earthquakes worldwide, proving that the differences in deep and shallow earthquake rupture processes are controlled by the rigidity of the Earth and unrelated to their specific generation mechanisms, correcting a long-standing research misconception, improving the self-similar definition proposed by Aki in 1967 and used until now, establishing a new earthquake scaling law, and predicting systematic changes in earthquake parameters with depth (Figure 3-1-79). This achievement was published in the internationally renowned journal *Nature Geoscience*.

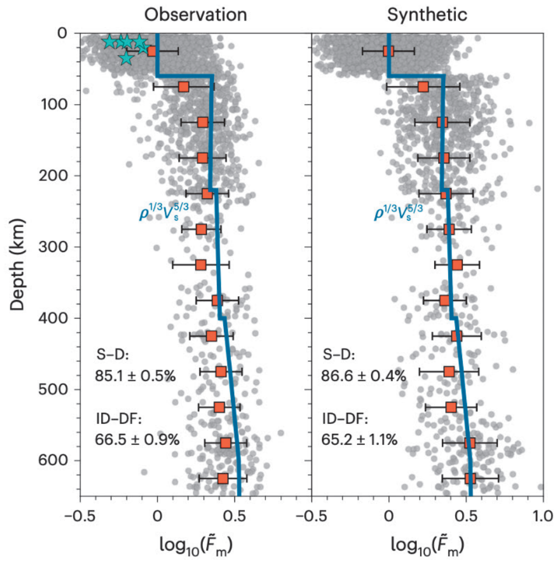



Figure 3-1-79　Machine Learning Reveals Deep Earthquake Mechanisms

## Large-area Reflective Static Exposure Interferometer Assists Breakthrough of the World's Largest Pulse Compression Grating

The pulse compression grating is the core component of the ultra-short super-intensity laser equipment, which plays the bottleneck role in narrowing the laser pulse width and transmitting energy of the laser system, and its area is proportional to the energy load of the laser equipment. Therefore, the large grating fabrication has a big challenge in the world. At present, large-aperture pulse compression gratings are mainly prepared by full-aperture transmission interference exposure, fine beam scanning interference exposure splicing and other technologies at home and abroad. It is regretful that more large-aperture high-quality lens materials or focused-spot sidelobes caused by seams has become an insurmountable "gap" to further expand the aperture of gratings by using existing technologies, however, led by development of 100PW even EW high peak power individual laser beam, there must be innovation in construction of more large interference exposure field.

With the support of the National Key R&D Program of China, a research team led by the Shanghai Institute of Optics and Mechanics (SIOM), Chinese Academy of Sciences (CAS) creatively proposed a large-aperture reflective exposure technology. The team constructs a holographic interference exposure system with an aperture of ~2m based on two large off-axis parabolic mirrors and a high coherence solid-state ultraviolet lithography laser. Spin coating has been the method of choice for depositing precise submicron-thick photoresist films onto the surface of large, heavy substrate and a ~2m level non-seam holographic grating mask can be formed through one-time interference exposure. This technology breaks through the limitations of high-quality large lens fabrication in the traditional full-aperture transmission interference and solves the possible problem of grating diffraction wave-front phase jump and greatly improves the aperture expansion ability, manufacturing efficiency and quality of pulse compression grating.

At present, the large-aperture reflective exposure technology has been preliminarily applied and verified. A series of innovative technologies, such as large-aperture high-precision off-axis parabolic mirror processing, surface defect detection and suppression, stable control of temperature and flow field in the exposure environment, large-area interference field control, high-uniform deposition of large-area photoresist submicro-thick coating, and high-precision development monitoring, have been broken through. A special R&D line for the development of ~2m large-area pulse compression grating has been constructed. The world's largest aperture of 1620mm × 1070mm non-slit pulse compression grating has been developed, this aperture area is 2.9 times that of the largest international grating element of the same kind, and the average diffraction efficiency within the 200nm spectral bandwidth is higher than 93% of the optical performance index. The technological breakthrough at this stage can solve the most important bottleneck in the single-channel 100 petawatt or even EW-level ultra-intensity ultra-short laser.

In the next stage, the research team will continue to carry out iterative optimization work on the processing technology of large-aperture off-axis mirrors' surface defects, the precision control of exposure environment and interference field, the exposure development process and the photoresist coating, etc. to further improve the surface quality of the large mask and the contrast of the exposure field and its controllability. On the basis of the above iterative process, the laser damage threshold, diffractive wave-front and other indicators of the large gating can reach the engineering application level, and this series of technique will make some contribution to the next generation of lasers development: delivering higher peak powers for fundamental research in the world.

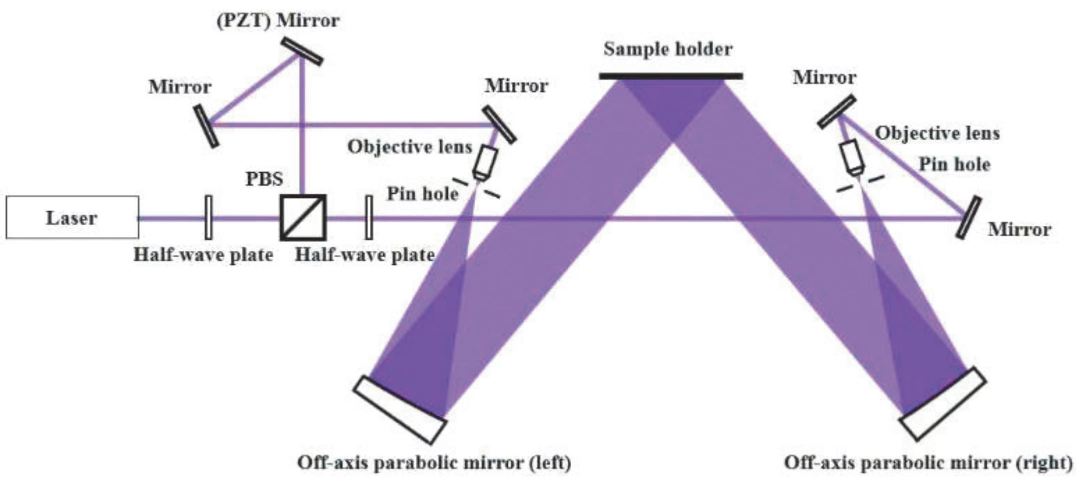



Figure 3-1-80 Schematic of Full-aperture reflective interference

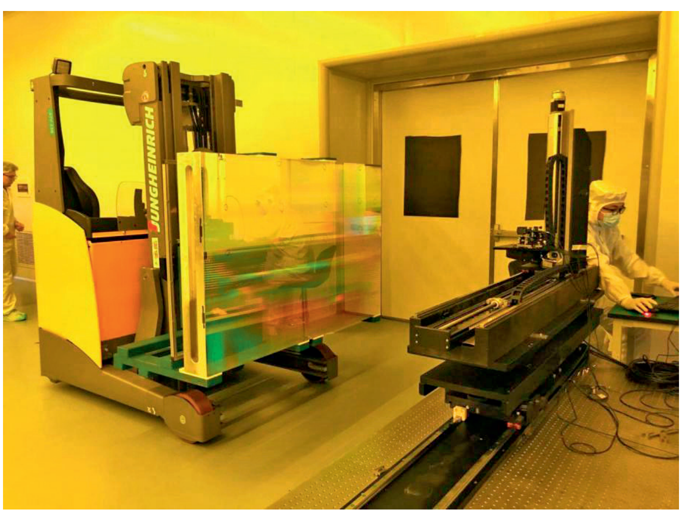



Figure 3-1-81 Photo of the largest grating with size of 1620mm×1070mm×160mm and 1400line density

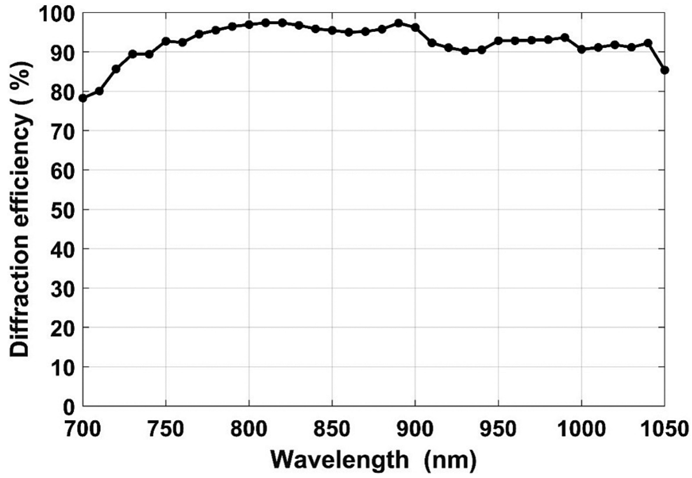



Figure 3-1-82 Diffractive efficiency of the largest grating measured at 45°

## Exploring Primate Early Embryonic Development: Insights from Ex utero Monkey Embryogenesis

The early embryonic development of primates, particularly gastrulation and organogenesis, represents a significant frontier in developmental biology and is crucial for understanding human reproductive development diseases. Our understanding of human early development is severely hampered by limited access to embryonic tissues. Due to their close evolutionary relationship with humans, non-human primates are often used as surrogates to understand human development, however, the cellular and molecular dynamics underlying the transition from gastrulation to early organogenesis in primates remain elusive, highlighting the need for an accessible model for tractable experimental perturbations.

With the support of the National Key R&D Program of China, a research team led by Kunming University of Science and Technology focuses on key scientific issues in primate embryonic development, such as the phylogenetic aspects of gastrulation, the origins of embryonic layers, and regional specialization. The research encompasses three main areas: 1) Construction of single-cell transcriptome atlas of cynomolgus monkey embryos; 2) The development of an embedded three-dimensional (3D) culture platform that supports the self-organization of monkey embryos ex utero; 3) Modeling embryogenesis with stem-cell-derived embryonic models(Figure 3-1-83).The mapping of single-cell transcriptomes of cynomolgus

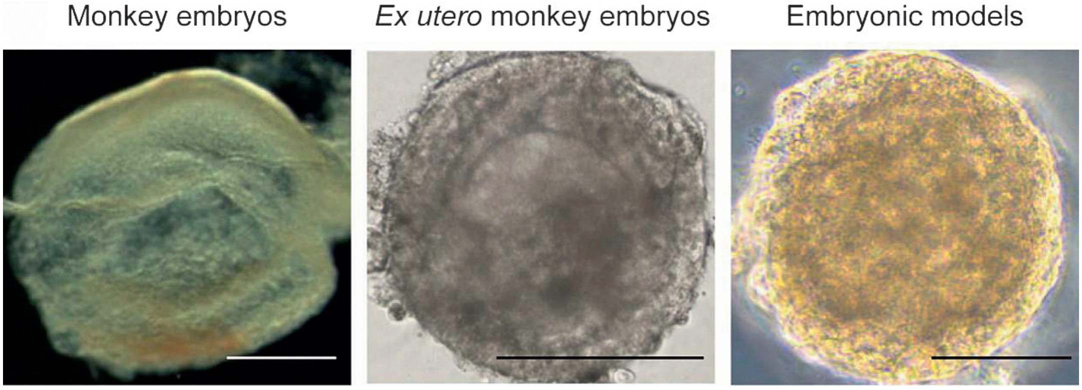



Figure 3-1-83 Natural monkey embryos, monkey embryos cultured *ex utero*, and embryonic models

monkey embryos, aged 20-29 days post-fertilization (2022, *Nature*), marked a first in the field. Additionally, two types of 3D embryonic culture systems, extending up to 25 days post-fertilization, were developed (2023a, Cell; 2023b, *Cell*) (Figure 3-1-84). By integrating *in vivo* and *in vitro* data, the project has systematically analyzed the phylogenetic specialization trajectories in primate gastrulation and explored the molecular evolution in early tissue and organ development, including neurogenesis and hematopoiesis. Moreover, the project has made strides by using monkey and human stem cells to construct models resembling primate blastocysts and gastrulas. These models are instrumental in revealing the mechanisms of per-implantation embryonic development in primates (2023, *Cell Research)*.

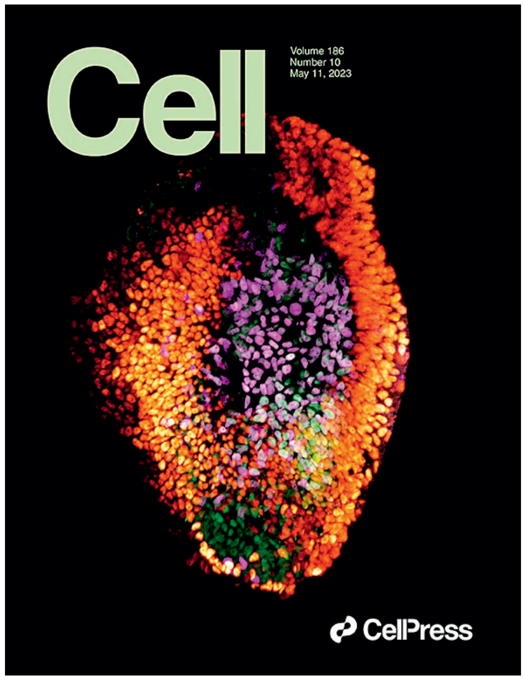



Figure 3-1-84 Research results published back-to-back in Volume 186, Issue 10 of the journal Cell, and selected as the cover article

For the first time, the ex-utero development of primate embryos has been achieved up to 25 days by the research team. *Nature* has featured a special report and provided positive feedback on the 3D embryo culture platform . The project systematically uncovers the cellular composition and molecular features of primate embryos from gastrulation to the early stages of organ development. It employs a synergistic approach, integrating in vivo, in vitro, and research on embryonic models to explore embryonic development in primates. This study delves deeper into the intricacies of cell lineage development and the associated molecular regulatory mechanisms. The findings of this research not only bridge the knowledge gap in primate embryonic development from gastrulation to early organogenesis but also help understand the etiology of developmental malformations and early pregnancy losses in humans.

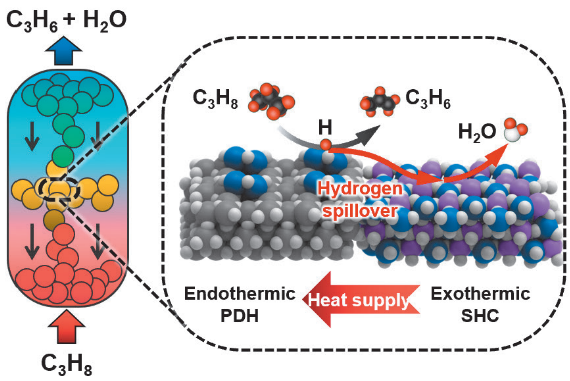
## Tandem Propane Dehydrogenation and Surface Oxidation Catalysts for Selective Propylene Synthesis

Propylene plays a pivotal role in the global petrochemical industry, which could exemplify the development of the economy of a nation. Notably, China stands as the unrivaled leader in both propylene demand and production capacity worldwide. The economic significance of propylene and its downstream products is underscored by its contribution of approximately 1% to the national GDP. Moreover, propylene production is responsible for roughly 8% and 5% of carbon emissions from the petrochemical industry in China and worldwide, respectively. According to the “14th Five-Year Plan”, there is a resounding call for the petrochemical and chemical industry to embrace a trajectory of green, low-carbon, and high-quality development. Consequently, the spotlight is cast on the pivotal role of green and low-carbon olefin production technology as the linchpin of core competitiveness, which attracts exceptional attentions from both domestic and international research endeavors in this field.

The propane dehydrogenation to propylene technology emerges as a beacon of economic efficiency in carbon resource utilization, representing a pivotal pathway toward achieving a paradigm shift in lightweight olefin production. However, China’s reliance on foreign imports for propane dehydrogenation technology is a notable gap in its self-sufficiency. The traditional propane dehydrogenation method as an endothermic reaction, characterized by its high-temperature profile and intense heat absorption, is restricted by thermodynamic equilibrium, resulting in suboptimal energy efficiency.

With the support of the National Key R&D Program of China, a research team led by Tianjin University discovered that the achievement of precise regulation of tandem reactions was governed by the order of catalytic active sites. The integrated oxygen carrier catalysts with tandem dehydrogenation sites and selective hydrogen combustion sites were successfully created. A novel process of hydrogen spillover-mediated tandem endothermic dehydrogenation reaction and exothermic selective hydrogen combustion reaction was established (Figure 3-1-85). It was demonstrated that the reaction temperature was reduced by about 50, and the thermodynamic equilibrium limitations of traditional direct propane dehydrogenation was broken by in-situ heating via selective hydrogen combustion within the reactor. The single-pass propylene yield in this novel process was increased by around 20%, and the energy consumption was reduced by about 35% compared to traditional processes. Taking a 600,000-ton propylene production unit as an example, carbon emissions could be reduced by over 30,000 tons. The research results have innovated the propylene production process, significantly improved the efficiency of propylene production and energy utilization, realized the energy-efficient dehydrogenation of propane to propylene, and laid the scientific foundation for the development of high-quality and low-carbon olefin production.


(a) Industrial plant for propane dehydrogenation




(b) Tandem propane dehydrogenation and selective hydrogen combustion

Figure 3-1-85

The research results were published in the *Science* journal in August 2023, and this research breakthrough has been highly praised by domestic and international scholars and experts. The application of this research achievement in industrial plants contributes to energy-saving and emission reduction in the olefin production sector and promotes the low-carbon transformation of the industry.

## All-analog Photoelectronic Intelligent Computing Chip

Moore's Law, the principle on which today's mainstream computing performance gains depends, has been slowing down for nearly a decade and even facing invalidation. The demand for computing speed in an AI society has increased by 300,000 times in five years. The improvement of computing speed and energy efficiency of computing architecture is urgent.

Funded by the National Natural Science Foundation of China (Basic Science Center Program and National Fund for Distinguished Young Scholars) and the National Key R&D Program of China, a R&D team led by Tsinghua University proposed an all-analog photoelectric fusion computing chip ACCEL. In intelligent vision tasks, it is the first time in the world for opto-electronic computing to reach more than 3,000 times in computing speed and more than 4 million times in energy efficiency than top GPUs at the system level experimentally. It proves the superiority of photon computation in many AI tasks, and opens a series of wide application prospects in the post-Moore's Law era.

This research is devoted to solving the three key technical bottlenecks: large-scale integration, nonlinearity and photoelectric interface in optoelectronic computing chips, and innovatively proposes an all-analog optoelectronic fusion computing framework. The large-scale diffraction neural network for visual feature extraction and the all-analog electronic calculation based on Kirchhoff's law are integrated in the same chip, realizing large-scale computing unit integration, efficient nonlinear and high-speed photoelectric interface on a single chip (Figure 3-1-86).

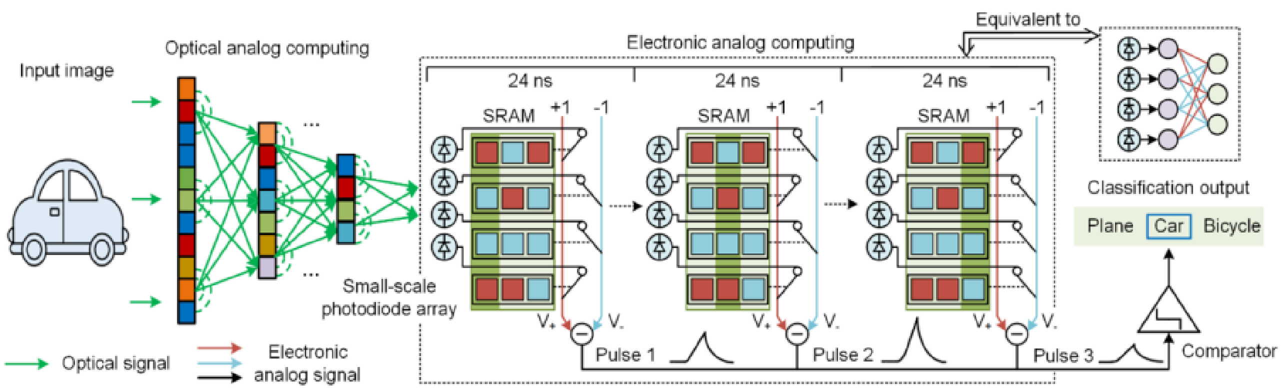



Figure 3-1-86 Architecture and principles of ACCEL

In addition, in view of the key difficulties that analog computing chips are sensitive to noise, ACCEL unsupervised learns the encoding mode of converging light intensity to some feature points while extracting features in high parallel, and improves local light intensity when the total light intensity is extremely low. This improves the signal-to-noise ratio of the corresponding photodiode and its robustness in high-speed vision tasks (Figure 3-1-87).

The above research results were published in *Nature*, in October, 2023." ACCEL might enable these architectures to play a part in our daily life much sooner than expected." *Nature* commented in a special commentary published in a research briefing. Cui Tiejun, an expert in the field of computational electromagnetics and academician of Southeast University, commented that the technology "breaks through the power-consumption and latency limitations of analog-to-digital converters in previous optical neural networks ". Xinhua News Agency, People's Daily, MIT Technology Review and other media also reported and highly praised the study as opening a new path for ultra-high performance computing architectures.

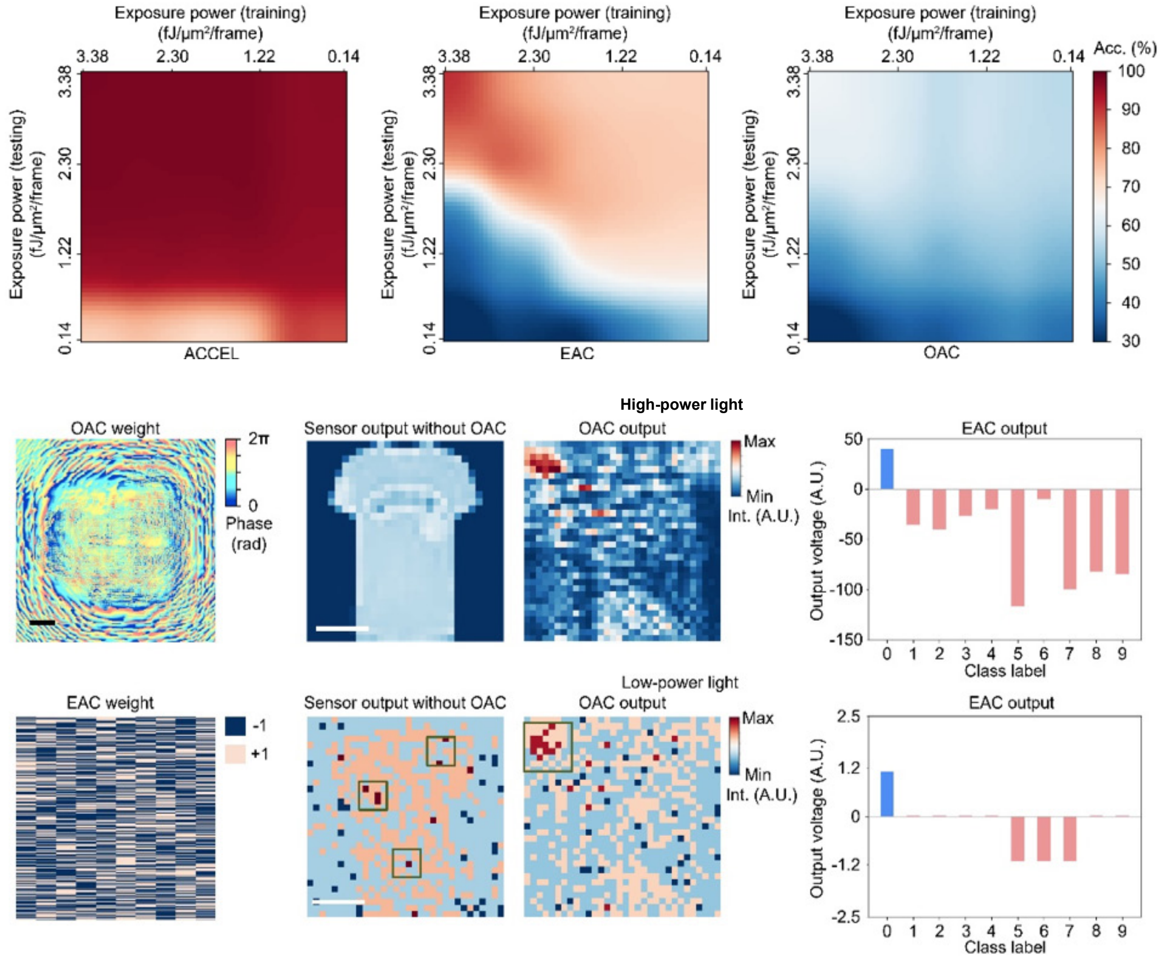



Figure 3-1-87 ACCEL under different exposure and tasks

## Research on Cadmium-free Quantum Dots and Photolithgraphic Patterning of Quantum Dots in QLEDs

Active matrix quantum dot light emitting display (AMQLED) is a strong competitor as the next generation display technology due to its advantages of high color gamut, low power consumption, and flexibility. Currently, this technology faces several key problems: cadmium-free and lead-free quantum dot materials suitable for electroluminescence industrialization are relatively immature; the efficiency and lifetime of the device have not yet met the industrialization requirements, the key mechanism restricting the stability of the device is not clear; high-resolution quantum dot light emitting layer patterning process and full-color flexible prototype preparation process were still not up to mass production standards.

With the support of the National Key R&D Program of China, a R&D team led by BOE Technology Group Co., LTD has conducted systematic and in-depth research based on the above issues, clarified the crystal growth kinetics of cadmium-free and lead-free quantum dot materials and their structure-function relationships with photoelectric properties, and explored the mechanism of carrier injection, transport, and recombination kinetics and their relationship between device optical structure and luminescence performance. This project also studied the key mechanisms of device failure. The impact of patterning

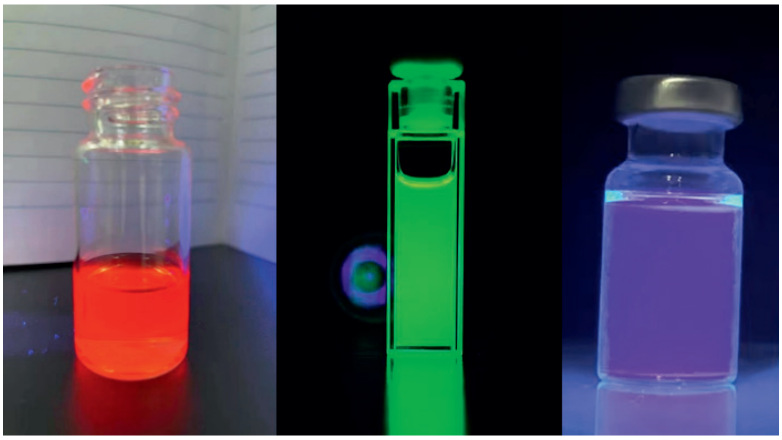


Figure 3-1-88 InP, ZnSe quantum dots with high PLQY

process on the physicochemical properties of quantum dots and devices has also been explored. The project has achieved the following breakthroughs:

Firstly, through the rational design of precursors and the fine tuning of shell structure, the photoluminescence quantum yield of red, green and blue quantum dots was increased to 71%, 60% and 50%, respectively, with the full width at half maximum controlled at 38 nm, 45 nm and 28 nm. Breakthroughs have been made in some restricting problems of materials of transporting layer, such as energy level, alcohol solubility and mobility, which lay a foundation for the realization of high-efficiency solution-processed QLEDs. The related results were published in *Small* in July 2023. Through the optimization of the surface of quantum dots, the energy level and mobility of functional layers, the current efficiency of red, green and blue devices was increased to 24 cd/A, 69 cd/A and 11.8 cd/A, respectively, which are among the highest results worldwide. In order to improve the device lifetime, Cd based quantum dots were used as a model system, long-life green devices have achieved by the transport layer doping and double layer structure to reduce injection barrier. The $T_{95}$ lifetime of the device under 1000 cd $m^{-2}$ reached 17,700 h, and the efficiency reached 21%.

Second, in order to achieve high-resolution quantum dot patterning, this project proposed the direct photolithgraphy pattering of quantum dots. After printing and coating process the quantum dot light-emitting layer is pixelated via photolithography by using photosensitive crosslinkable groups such as carbene, leading to a maximum resolution of 2,000 PPI, breaking through the resolution limitations of traditional evaporation and inkjet printing processes. This project developed the world's first direct photolithography of quantum dot patterning in QLEDs, which is the third process route with the potential for mass production other than evaporation and inkjet printing. This project successfully achieved a 4.7-inch, 650 PPI full-color AMQLED prototype by direct quantum dot lithography with a color gamut of 85% BT2020. This prototype achieved world debut in the 2023 SID Display week. To date, this is the highest resolution AMQLED display prototype worldwide, and it is highly praised by the display community.

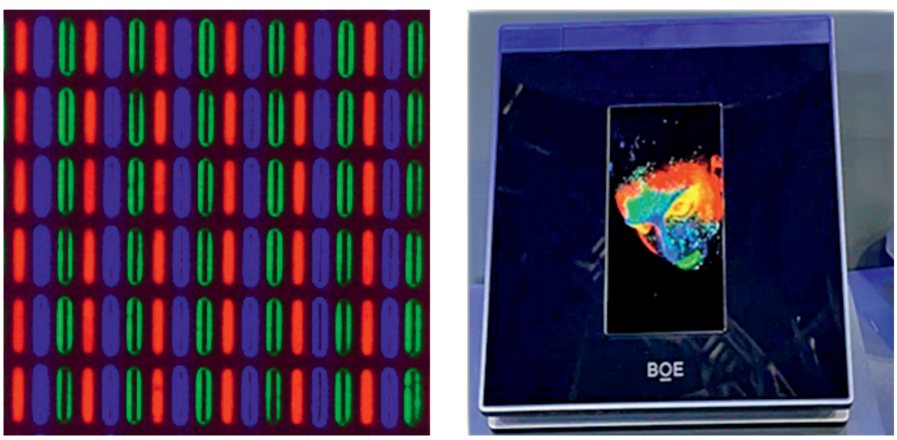



Figure 3-1-89 (a) Electroluminescence of R/G/B subpixels; (b) 4.7 inch 650PPI full-color AMQLED demo prepared by direct photolithography of quantum dots.

# Femtosecond Laser Manufacturing Based on Electrons Dynamics Control

The high-quality manufacturing of complex three-dimensional structures, micro-fine features, and large aspect ratios of difficult-to-process materials is a global challenge. For instance, drilling of target balls constitutes a critical determinant in the success of nuclear fusion ignition. The mass balancing and sensor micro-structuring in gyroscopes are key to the development of high-precision inertial navigation systems. Cutting hard and brittle materials is a bottleneck in the evolution and renewal of consumer electronics. Traditional manufacturing methods fail to meet these needs. Femtosecond (fs) lasers, with pulse peak powers exceeding a trillion watts within less than one trillionth of a second, uniquely address these manufacturing challenges. However, they still face issues like low processing efficiency, limited aspect ratio, and limited precision. These challenges underscore the urgent need for innovative breakthroughs in manufacturing methodologies.

With the support of the National Key R&D Program of China, a R&D team led by the Beijing Institute of Technology has proposed and realized novel methods of laser manufacturing based on Electrons Dynamics Control (EDC) of shaping fs laser pulses by designing and controlling the spatiotemporal distributions of ultrafast and ultrastrong light field. For the first time, electrons dynamics in laser manufacturing were actively controlled and the limits of laser manufacturing were significantly expanded. For instance, it has increased processing efficiency by 56 times, enhanced the aspect ratio by 260-fold, achieved repeatable minimum width precision of~56 nm (1/14 of the laser wavelength), and reached mass removal precision down to hundreds of femtograms (Figure 3-1-90).

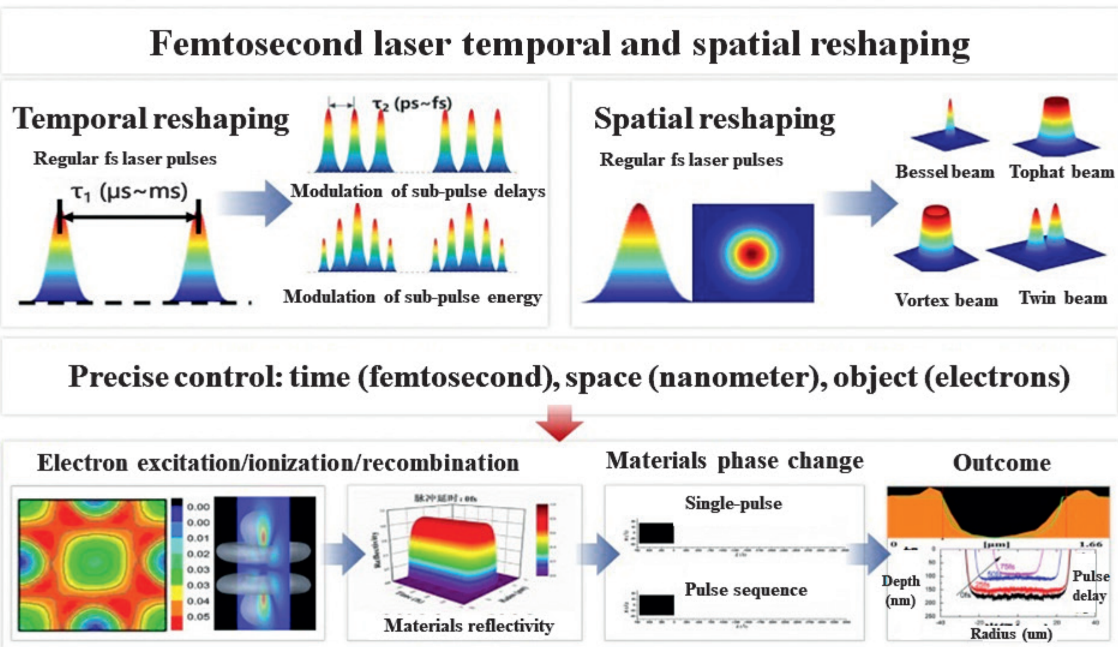



Figure 3-1-90

EDC-based techniques and equipment, such as EDC drilling, -cutting, -mass balancing, -engraving, have propelled the application of fs laser manufacturing globally, laying a pivotal foundation for 37 National Major Projects/Equipment. The gyroscopes and novel fiber optic micro-sensors processed have realized multiple important applications in aerospace fields, etc. In collaboration with Han's Laser, EDC cutting equipment was developed and have become the mainstream products internationally, securing 60% market share in the specially-shaped cutting of all screen display and OLED flexible screens with 1731 units sold.

The work received positive comments from 4 Nobel Laureates, 107 esteemed national academicians and 232 fellows in prestigious journals such as Nature and Science. For example, the news platform of the American Association for the Advancement of Science (AAAS) and its journal *Science* stated that the work "provides revolutionary contributions to high-end manufacturing, material properties manipulation, and chemical reactions control". An evaluation committee consisting of 11 academicians remarked that this work had "achieved active control of electrons dynamics during laser manufacturing, and achieved industrialization as well as significant engineering applications of fs laser manufacturing for the first time worldwide… reaching the leading level internationally."

# PART 4

# International (Regional) Cooperation and Exchange

NSFC

## I. Implementing the Pilot Program of the Science Fund for Global Challenges and Sustainability

NSFC established the Department of International Programs and carried out the Research Fund for International Scientists (RFIS) as the pilot implementation of the Science Fund for Global Challenges and Sustainability. A total of 277 projects for international young scientists (RFIS-I), excellent young scientists (RFIS-II) and senior scientists (RFIS-III, including PGP RFIS-III) were funded, with a direct cost of 250 million yuan. The RFIS has become one of the main supporting channels for attracting and retaining outstanding foreign young and senior scholars.

## II. Promoting Regional Innovation and International (Regional) Exchanges and Cooperation

By the end of 2023, NSFC has established stable partnerships with 103 funding agencies and international organizations in 54 countries (regions). The National Natural Science Fund, based on the globally accepted academic standards and operational mechanisms, has become an important guarantee for smooth international cooperation.

In terms of cooperation with the Americas and Oceania, NSFC implemented the important consensus reached between the Presidents of China and the United States, actively and prudently promoting exchanges and cooperation with the United States and making steady progress; established partnership with New Zealand’s Ministry of Business, Innovation and Employment (MBIE); and continuously deepened substantive cooperation with Latin America in areas of distinctive advantages.

In terms of cooperation with Europe, a balanced collaboration framework was built through a new pattern of cooperation. NSFC actively involved in outlining China-Europe basic science cooperation agenda; deepened mechanisms of high-level policy discussions with Europe; and participated in the intergovernmental Joint Committee Meetings on Scientific and Technological Cooperation with Italy, Russia, the Netherlands, Finland, Belgium and Bulgaria.

Regarding cooperation with Asia and Africa, NSFC comprehensively consolidated high-level exchanges and visits with funding agencies in these regions. Therein, NSFC further strengthened ties with Japan, South Korea and Israel; expanded cooperation with Sri Lanka; and participated in the meetings of China-Israel and China-Mongolia Joint Committees on Scientific and Technological Cooperation.

Regarding cooperation with international organizations and multilateral mechanisms, NSFC gave full play to the role of organizations and platforms of the Global Research Council (GRC), Science Europe (SE), the United Nations Environment Program (UNEP), the Consultative Group on International Agricultural Research (CGIAR), the International Institute for Applied Systems Analysis (IIASA), the Meeting of Heads of Research Councils in Asia (A-HORCs), and the Belmont Forum (BF); strengthened high-level policy discussions and strategic dialogues; supported joint research and talent projects addressing global challenges; and actively engaged in global science and technology governance and multilateral joint funding with a more proactive stance.

In terms of cooperation with Hong Kong, Macao and Taiwan, with the deep understanding of the central government’s major arrangements for Hong Kong, Macao and Taiwan, NSFC upholds the principle of “one country, two systems”, promotes the integration of Hong Kong and Macao’s scientific and technological strengths into the overall development of the country, and advances the cross-strait integrated development. We carefully arranged high-level visits; actively participated in the meetings of the “Mainland and Hong Kong” and “Mainland and Macao” Science and Technology Cooperation Committee meetings; gradually improved layouts of academic seminars with cooperating agencies in Hong Kong and Macao, with an increase in the number of grants and a focus on young scientific researchers; and continued to organize online academic seminars with cooperating agencies in Taiwan.

NSFC actively promoted the functional transformation of the Sino-German Center for Research Promotion and enhanced strategic cooperation between China and Germany. The Center played a unique role in the young talents training by piloting the funding for excellent Chinese undergraduate students' academic visits in Germany.

In the past year, NSFC welcomed 29 high-level official visits from funding agencies and scientific organizations in the United States, Germany, Canada, Switzerland, Sweden, Japan, South Korea, New Zealand, Malta and other countries, as well as from the China's Hong Kong and Macao, totaling 93 visits at all levels. Visits by leaders of the NSFC to the United Kingdom, Germany, France, Switzerland, Turkey, Belgium, the Netherlands, New Zealand, etc., as well as to China's Hong Kong and Macao, have greatly deepened the bilateral and multilateral partnerships and substantive cooperation in science and technology. NSFC further explored bilateral and multilateral cooperation channels and potentials; promoted the construction of an international cooperation platform for basic research; maintained interactions and exchanges with funding agencies and international organizations from the United States, Germany, the United Kingdom, Japan, Israel, BRICS countries, etc.; and carried out the funding work of International (Regional) Cooperation Research and Exchange Programs, with a total of 3987 received applications and 654 of them were funded.

## III. Focusing on Sustainable Development, Promoting Bilateral (Multilateral) International Exchanges and Cooperation

NSFC actively promoted the implementation of Sustainable Development International Cooperation (SDIC) plan, continuously focusing on top-level design to meet national strategic needs, clarifying strategic directions, emphasizing implementation mechanisms, and strengthening scenario-driven approaches. Initiate the second round of joint funding for the plan. A new cooperation model has been developed for strategic alignment and joint funding with international scientific organizations, expanding the funding areas from 'Surface Earth System Science' to 'Ecosystem Security'. NSFC received 200 applications and funded 40 capacity-building projects and key projects with direct costs totaling 58.63 million yuan.

Deeply involved in the negotiations under the United Nations Framework Convention on Climate Change (UNFCCC), the Administrative Center for China's Agenda 21 (ACCA21) focused on sustainable development, leading technical issue negotiations and serving as the coordinator for the Group of 77 and China, as well as a member of the UN Technology Executive Committee (TEC), contributing to the outcomes of the Dubai Climate Conference (COP28). ACCA21 also actively participated in multilateral exchanges, including the Clean Energy Ministerial (CEM) and the Mission Innovation Ministerial (MI), with a focus on Carbon Capture, Utilization, and Storage (CCUS) technology. Actively promoting China-U.S. CCUS technology exchange and cooperation, ACCA21 has designed the China-U.S. Climate Change bilateral cooperation mechanism, and organized a series of technical workshops on CCUS, methane emission reduction, and other topics. ACCA21 also advanced the establishment of the China-France Carbon Neutrality Center. In collaboration with the International Energy Agency (IEA) and the Global CCS Institute (GCCSI) to conduct joint research, ACCA21 co-authored the "CCS Progress in China - A Status Report (2023)". Moreover, ACCA21 actively promoted the establishment of a platform for South-South cooperation on sustainable development, by leading the establishment of the 'Belt and Road' Low Carbon Technology Innovation and Transfer Alliance and implementing the "China-Africa Renewable Energy Technology Transfer Cooperation Project", achieving fruitful results.

# IV. Typical results

## Pharmaco-proteogenomic Characterization of Liver Cancer Organoids for Precision Oncology

Genomic studies have uncovered the spectrum of genetic variation and extensive heterogeneity in liver cancer, but significant limitations exist. To further enable precise prediction of drug efficacy in liver cancer patients, establishing a preclinical model capable of reproducing the molecular typing characteristics of tumors and obtaining corresponding pharmaco-omics information is among the forefront issues in liver cancer translational medicine and drug development.

To address these scientific challenges, with the support of NSFC [Nos. 81961128025, 82130077], Prof. Qiang Gao from Fudan University, Prof. Hu Zhou from Shanghai Institute of Materia Medica, Chinese Academy of Sciences, and Prof. Bing Zhang from Baylor College of Medicine collaborated to establish 65 liver cancer patient-derived organoid models and conduct a comprehensive pharmaco- proteogenomic analysis. Through the integration of multi-omics data, the modeling has successfully reproduced the proteogenomic molecular subtypes observed in liver cancer patients, confirming the feasibility of using organoid models to drive the discovery of therapeutic targets, enable precise prediction of drug response, and evaluate potential drug combination treatment strategies. These findings provide guidance for clinical patient selection and drug combination treatments (Figure 4-1-1).

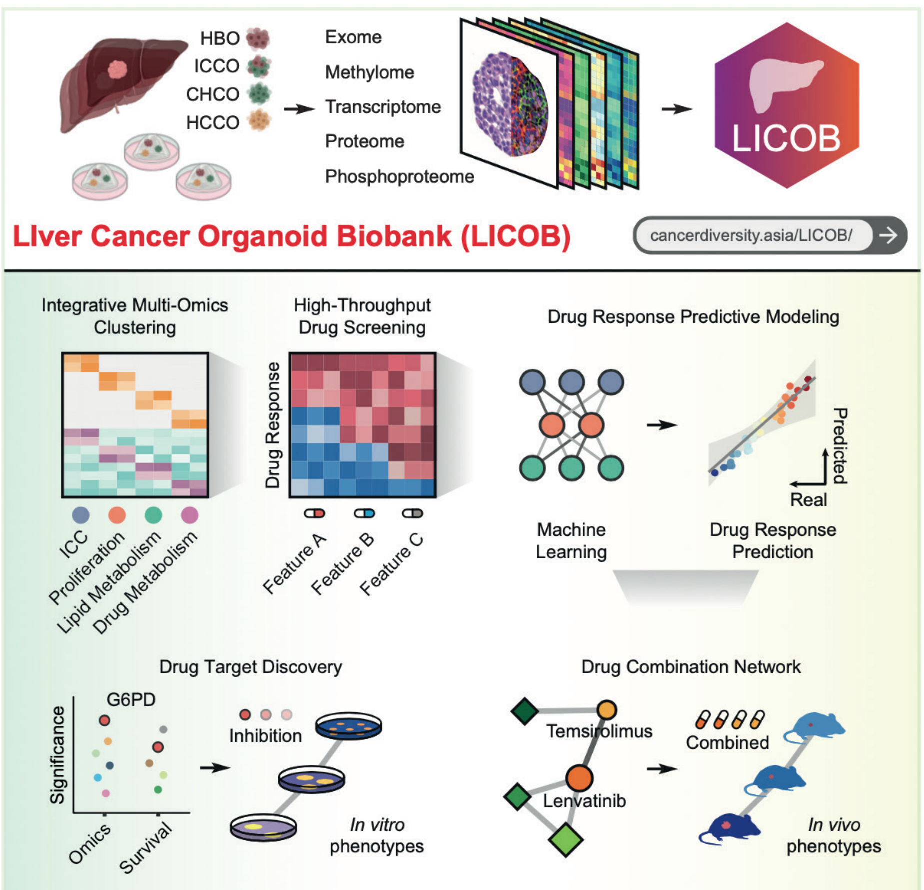



Figure 4-1-1 Establishment and pharmaco-proteogenomics analyses of liver cancer organoids.

The outcomes have been published in a research paper titled "Pharmaco-proteogenomic characterization of liver cancer organoids for precision oncology" in *Science Translational Medicine*. This study represents the first application of pharmaco-proteogenomics to liver cancer organoids on a large scale. The generated pharmaco-proteogenomic data will greatly contribute to biomedical, translational research, and clinical exploration, ultimately facilitating the clinical implementation of functional precision medicine.

## Cu-catalyzed Total-carbon Utilization of 1,3-dihydroxyacetone for Formamide Synthesis under Mild Conditions

Formamide is an important nitrogen-containing chemical with a wide range of applications in synthetical and medicinal chemistry, but its industrial production requires the use of highly toxic CO, which causes a serious safety concern in production. Therefore, the development of new, safe and sustainable method for formamide syntheis remains one of the main tasks in this field.

With the support of NSFC [No.21961132025], Prof. Feng Shi from Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, in collaboration with Prof. Angelika Brückner and Dr. Jabor Rabeah from Leibniz Institute of Catalysis, Germany, has successfully synthesized a series of secondary and tertiary formamides with different structures by the N-formylation of amines with biobased 1,3-dihydroxyacetone (DHA) as the carbonyl source and $H_2O_2$ as the oxidant at 50°C over CuZr/5A zeolite catalyst prepared by ion-exchange method, where all carbon atoms of DHA can be transferred into the desired formamide product. The research results has been published online in *Green Chemistry* on January 23, 2023 with the title of "Cu-Catalysed sustainable synthesis of formamide with glycerol derivatives as a carbonyl source via a radical-relay mechanism".

In situ construction of carbonyl-containing intermediates by the selective and successive cleavage of C-C bonds in DHA is vital in the N-formylation of amines with DHA. A series of monometallic Cu/5A and bimetal catalysts CuM/5A (M = Ni, Zr, Ag, Pd, Rh) were prepared by the same method and their activity were tested with the N-formylation of aniline and DHA. The results showed that CuZr/5A exhibited the best catalytic activity and 90% yield was obtained at 50°C after 24h with only 5 mg catalyst. Combined characterization results of XRD, XPS, $NH_3$-TPD, EPR and HAADF-STEM revealed that the copper species in the active catalyst CuZr/5A exists as isolated Cu(II) ions and Zr mainly as Zr(IV) ions. Operando ATR-FTIR of the model reaction observed glycolic acid and formic acid intermediates resulted from the C-C bond cleavage of DHA. EPR spin trapping experiments uncovered that •OH radical is responsible for the C-C bond cleavage of DHA into glycolic acid and formic acid. The $H_2O_2$ activation study over catalysts and control experiments showed that introduction of Zr can promote the selective formation of •OOH radical and the C-C bond cleavage of glycolic acid. Based the above results, the team speculated that the N-formylation of aniline and DHA proceeds via a radical-relay reaction mechanism co-mediated by •OH and •OOH radicals: first •OH radical attacks DHA to generate glycolic acid and formic acid intermediates by splitting the C-C bond, and then •OOH radical cut the C-C bond of in situ generated glycolic acid intermediate to form $C_1$ intermediate (Figure 4-1-2). Finally, the in situ generated $C_1$ intermediate reacts with aniline to form the desired formamide product.

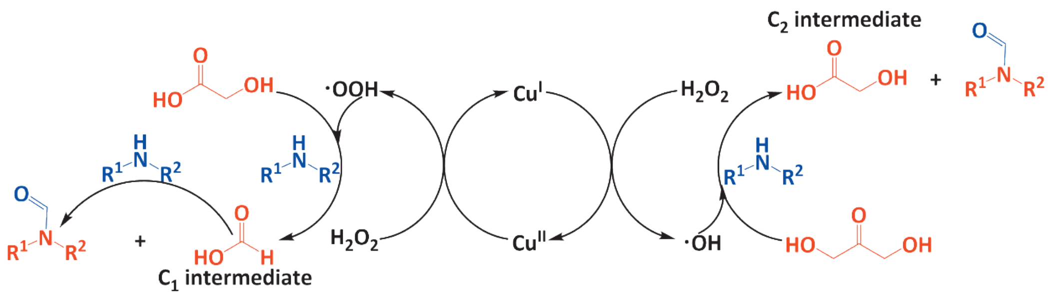



Figure 4-1-2 Cu-catalyzed total-carbon utilization of DHA for synthesis of formamides via a radical-relay mechanism.

## Synergizing Nitrogen Management in Agriculture to Achieve the United Nations 2030 Sustainable Development Goals

With the support of NSFC [No.42261144001], Professor Baojing Gu's team at Zhejiang University, in collaboration with international partners from the United Kingdom, Germany, the Netherlands, Austria and Australia, has made significant progress in the field of agricultural sustainability and nitrogen pollution mitigation, publishing their findings in two representative papers.

The first paper, titled "Cost-effective Mitigation of Nitrogen Pollution from Global Croplands", was published in *Nature* on January 4, 2023. This paper provides a deep analysis of global cropland nitrogen pollution and proposes a range of cost-effective mitigation strategies, such as improved fertilization methods and adjustments in planting structures, the main results of which are shown in Figure 4-1-3. It emphasizes the importance of technological innovation and global cooperation in addressing cropland nitrogen pollution issues and suggests feasible policy recommendations to promote nitrogen cycle management and environmental protection. The study identifies key measures that can significantly reduce nitrogen emissions from croplands while increasing crop yields and nitrogen use efficiency. Innovative policy suggestions like the Nitrogen Credit System (NCS) are proposed to facilitate the implementation of these measures. The findings of this paper are crucial for guiding global agricultural practices, reducing environmental pollution, enhancing food security, and maintaining ecological balance, thereby contributing significantly to global sustainable agriculture and environmental protection.

The second paper, titled "Ageing Threatens Sustainability of Smallholder Farming in China", was published in *Nature* on February 22, 2023. This study delves into the impact of population aging on the sustainability of smallholder farming in China, offering insights into the socio-economic and environmental challenges faced in this field. It identifies key issues confronting Chinese small-scale farmers, such as labor shortages and loss of agricultural knowledge due to aging, and reveals how these issues affect agricultural production efficiency and sustainability. The specific impact pathways are shown in Figure 4-1-4. The paper notes that aging leads to smaller farm sizes and reduced agricultural inputs, impacting farmers' income and the environment. It suggests transitioning to new agricultural models to reverse the negative impacts of aging and emphasizes the necessity of formulating adaptive policies, such as enhancing agricultural technological support and providing incentives for young farmers, to maintain agricultural vitality and promote eco-agriculture. The outcomes of this paper are enlightening for policymakers, agricultural support program designers, and agricultural science and technology development teams, aiding in addressing agricultural sustainability issues in China and other countries facing similar challenges.

Through these studies, the team not only demonstrates how to effectively address the impacts of agricultural nitrogen pollution and aging on agricultural sustainability but also highlights the necessity of integrated solutions from a global perspective, providing important theoretical support and practical guidance for tackling the challenges faced by global agriculture and the environment.

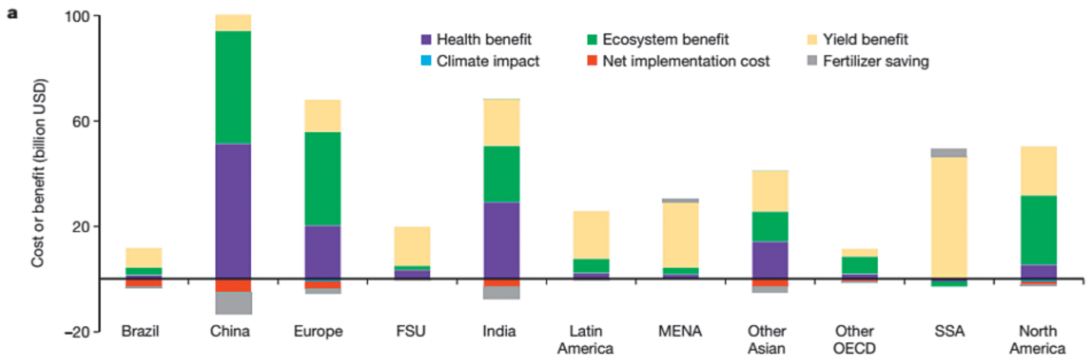



Figure 4-1-3 Cost and benefit of global nitrogen pollution abatement on cropland

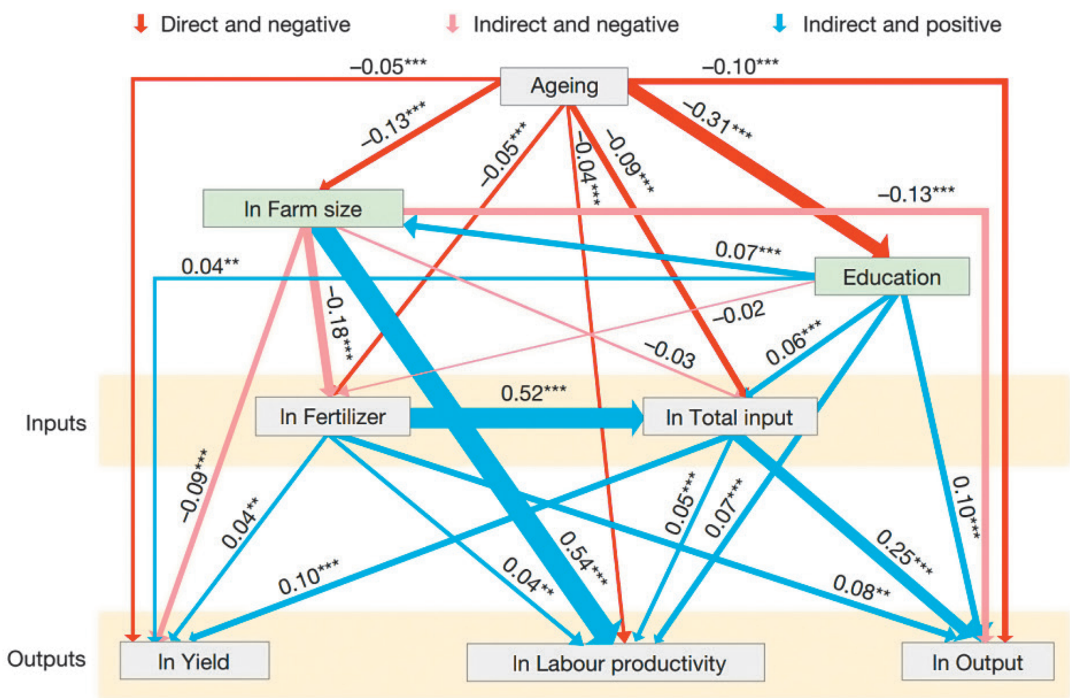



Figure 4-1-4 Pathways of aging on agricultural production

## Ultrafast Exciton Fluid Flow in an Atomically Thin MoS2 Semiconductor

With the support of NSFC [No. 12250710126], Professor Xiong Qihua's team from Tsinghua University, along with international collaborative teams from Nanyang Technological University and National University of Singapore, have discovered for the first time the ultrafast exciton fluid flows over long distances (at least 60 μm) at a speed of ~6% the speed of light in the atomically thin semiconductor MoS2. The research findings, titled "Ultrafast exciton fluid flow in an atomically thin MoS2 semiconductor" were published on July 31, 2023, in the journal *Nature Nanotechnology*.

Excitons in semiconductors refer to bound states of electron-hole pairs formed due to Coulomb interactions. These "hydrogen-like" quasi-particles exhibit typical absorption peaks below the band edge. Excitons also display surprising nonlinear properties due to their dipole moment characteristics and Coulomb interactions. $MoS_2$, as a novel two-dimensional semiconductor material, demonstrates unique optical and electrical properties as its electronic band structure transitions from a multilayer indirect band gap to a single-layer direct band gap. This results in distinctive features such as spin-valley locking, exciton effects, and high carrier mobility, making two-dimensional semiconductors widely applicable in photonics and optoelectronics. Excitons are typically generated through optical excitation (*i.e.*, exciton generated from semiconductor light absorption) and rapidly decay over time, with lifetimes generally in the picosecond to nanosecond range. Simultaneously, the high concentration of excitons at the laser spot can drive exciton diffusion outwards. Considering their limited lifetime and diffusion coefficients, the typical diffusion length of excitons is only on the order of hundreds of nanometers.The research reveals that the steady-state photoluminescence spectrum of a monolayer of two-dimensional $MoS_2$, encapsulated in hexagonal boron nitride, is primarily composed of neutral excitons and charged excitons. Typically, the fluorescence is observed only at the laser spot (see Figure 4-1-5a). When a negative back-gate voltage is applied, the emission of charged excitons is suppressed, while the neutral excitons dominate. At temperatures below 150 K, the fluorescence from the sample is not only localized at the excitation spot but also extends uniformly across the entire $MoS_2$ sample, producing bright and uniform fluorescence (see Figure 4-1-5b). Through pump-probe ultrafast spectroscopy measurements, the study finds that the exciton fluid in the hexagonal boron nitride-encapsulated $MoS_2$ monolayer propagates at a speed of approximately $1.8 \times 10^7$ m/s (about 6% of the speed of light) over an extremely long distance, exhibiting a collective behavior (see Figure 4-1-5c). Keeping the temperature constant, when the gate voltage gradually decreases from +20 V to -60 V, the entire sample suddenly "lights up", clearly indicating the power density (*i.e.*, exciton density) and "threshold" characteristics of the exciton fluid propagation. This suggests that excitons can rapidly propagate throughout the entire sample in a manner resembling a "ballistic transport" within their limited lifetime, distinct from the traditional exciton diffusion. Theoretical simulations indicate that momentum conservation and local equilibrium between excitons are possible, aligning with the fluid dynamics description of exciton transport. Spectroscopic experiments also reveal a blue shift in the resonance of excitons by 1-2 millielectronvolts, providing compelling evidence for the driving force behind the ultrafast transport of exciton fluid.

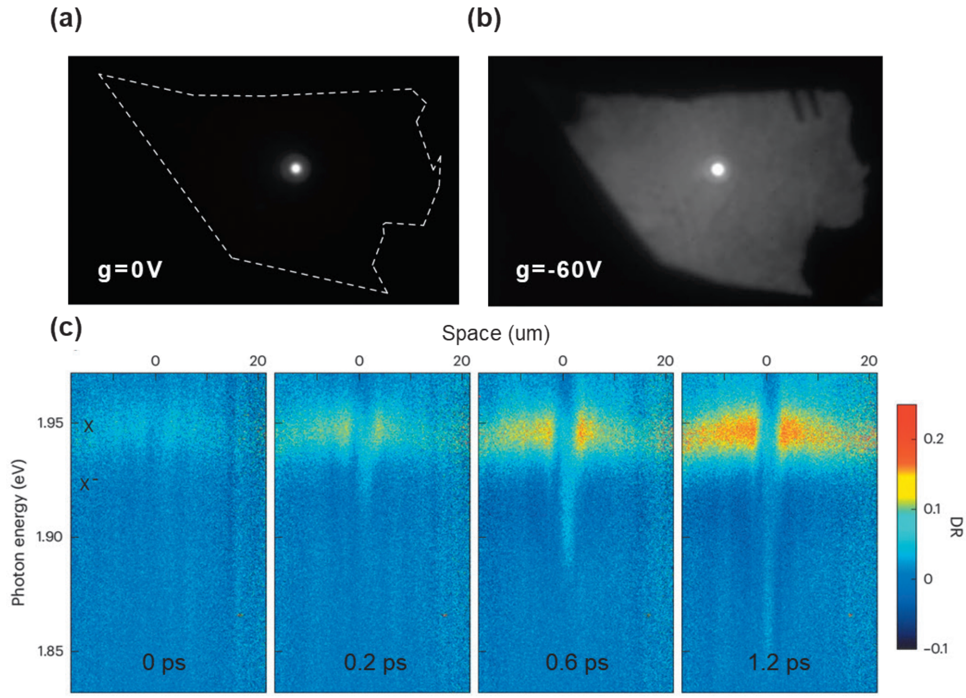



Figure 4-1-5 Steady-state and transient spectral responses under different gate voltages

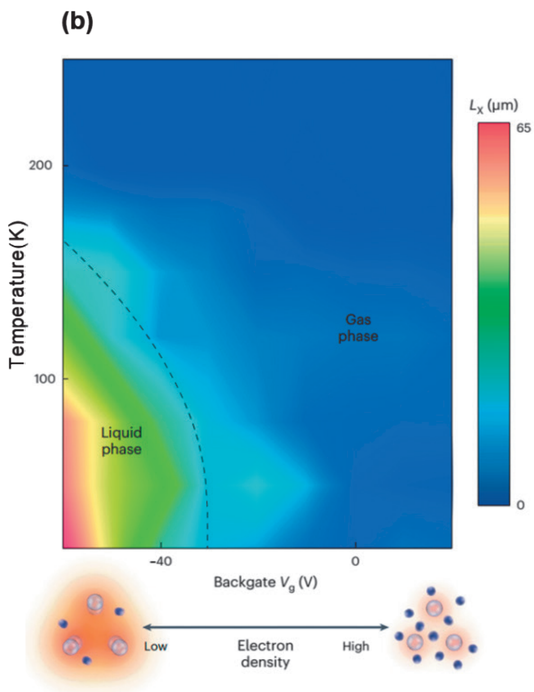



Figure 4-1-6 The propagation of exciton fluid and its phase diagram

The fluidic flow originates from strong many-body interactions within a mixed phase of excitons and free charge carriers (see Figure 4-1-6), controlled by laser power and gate voltage, and maintained stable until temperatures close to room temperature. Most experimental observations align with the fluid dynamics description supported by theoretical simulations. However, current research also indicates the need for further theoretical and experimental studies to quantitatively elucidate the physical mechanisms leading to the ultrafast and long-range propagation of exciton fluid. This represents a direction for future effort. Their findings hold significant implications for ultrafast exciton-mediated light switches, excitonic valley Hall devices, and on-chip excitonic circuits.

## Starlight and the First Black Holes: Researchers Detect the Host Galaxies of Quasars in the Early Universe

Observations of giant black holes have attracted attention of astronomers in recent years. The 2020 Novel Prize in Physics was awarded to stellar motion observations at the heart of the Milky Way. Whilst the existence of such giant black holes has become solid, no one knows their origin. Astronomers have reported that there exist billion-solar-mass black holes within the first billion years of the universe -- How could these black holes grow to be so large when the universe was so young? Even more puzzling, observations in the local universe show a clear relation between the mass of supermassive black holes and the much larger galaxies in which they reside. The galaxies and the black holes have completely different sizes, so which came first: the black holes or the galaxies?

With the support of NSFC [No.12150410307], an international team of researchers led by Masafusa Onoue from Peking University and Xuheng Ding, a research fellow at the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) and now a faculty member of Wuhan University, have started to answer this question with JWST (Figure 4-1-7), a 6.5-meter space telescope developed by an international collaboration among NASA, the European Space Agency (ESA), and the Canadian Space Agency (CSA), and launched in December 2021.

Quasars are luminous, while their host galaxies are faint, which has made it challenging for researchers to detect the dim light of the galaxy in the glare of the quasar, especially at great distances. The team observed two quasars with the JWST, HSC J2236+0032 and HSC J2255+0251, at redshifts 6.40 and 6.34 when the Universe was approximately 860 million years old. These two quasars were originally discovered by a wide-field survey of the 8.2m-Subaru Telescope, with which the research team has identified more than 160 quasars up to date . The relatively low luminosities of these quasars made them prime targets for measurement of the host galaxy properties, and the successful detection of the hosts represents the earliest epoch to date at which starlight has been detected in a quasar.

The images of the two quasars were taken at infrared wavelengths of 3.56 and 1.50 micron with JWST's NIRCam instrument, and the host galaxies became apparent after carefully modeling and subtracting glare from the accreting black holes (Figure 4-1-8). The stellar signature of the host galaxy was also seen in a spectrum taken by JWST's NIRSpec for J2236+0032, further supporting the detection of the host galaxy. The team found that the ratio of the black hole mass to host galaxy mass is similar to those seen in the more recent Universe. The result suggests that the relationship between black holes and their hosts was already in place within the first billion years after the Big Bang.

This work titled "Detection of Stellar Light from Quasar Host Galaxies at Red Shifts Above 6" was published in the journal *Nature* on June 28, 2023.

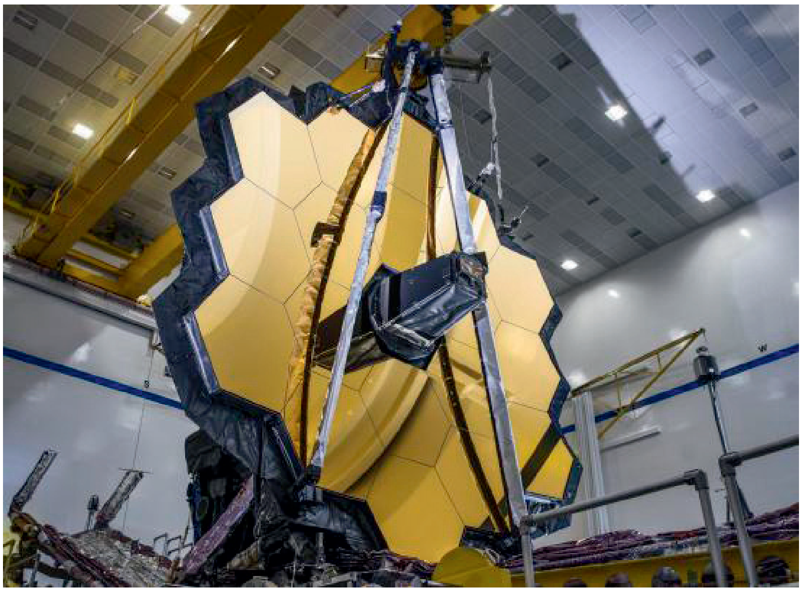


Figure 4-1-7 NASA's James Webb Space Telescope

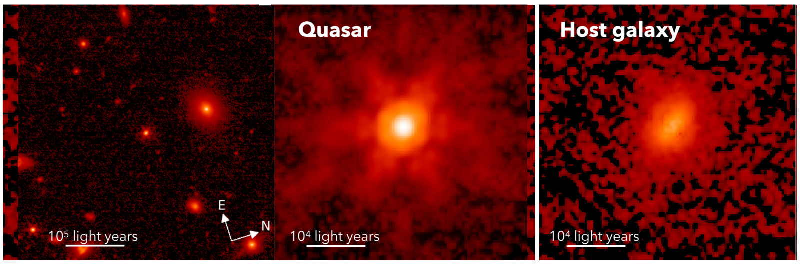



Figure 4-1-8 JWST NIRCam 3.6 μm image of HSC J2236+0032. The zoom-out image, the quasar image, and the host galaxy image after subtracting the quasar light (from left to right).

## CCUS PROGRESS IN CHINA - A STATUS REPORT

With the increasingly severe global climate crisis, controlling and reducing greenhouse gas emissions has become an urgent global task. Carbon Capture, Utilization and Storage (CCUS), as a key technology to mitigate global warming and ensure energy security, has been attracting widespread attention both domestically and internationally. The Administrative Center for China's Agenda 21 (hereinafter referred to as "ACCA21") has actively implemented the Memorandum of Understanding (MOU) signed with the Global Carbon Capture and Storage Institute (GCCSI), and jointly carried out the compilation of *CCUS PROGRESS IN CHINA - A STATUS REPORT* (hereinafter referred to as "the Report"). The writing team conducted in-depth research and analysis on the domestic and international maturity of CCUS technologies, as well as the deployment of CCUS in key industries such as power, steel, cement, chemical, petroleum, etc., thereby highlighting application characteristics and emerging trends of CCUS technology across diverse sectors. Through expert interviews, data analysis and literature research, the Report provides a systematic assessment of China's CCUS policy environment and illuminates the policy framework for CCUS development in China at the current stage. The Report provides estimates of the demand and potential of CCUS technology to contribute to the "Dual carbon" goals, and puts forward targeted policy recommendations for the promotion and application of CCUS technology, which are scientifically sound, systematic and forward-looking. It fully leveraged GCCSI's profound knowledge and research resources as a leading global think tank in CCUS, as well as ACCA21's extensive expertise in strategic research and international cooperation on CCUS technologies. The Report, launched officially on the 14th of July, 2023, offers valuable insights to facilitate China's advancement towards its "Dual carbon" goals.

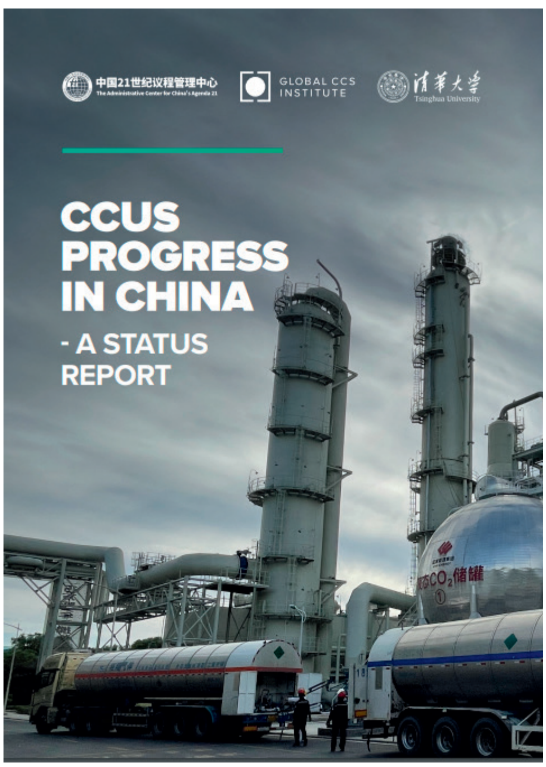



Figure 4-1-9 Cover of *CCUS PROGRESS IN CHINA - A STATUS REPORT*

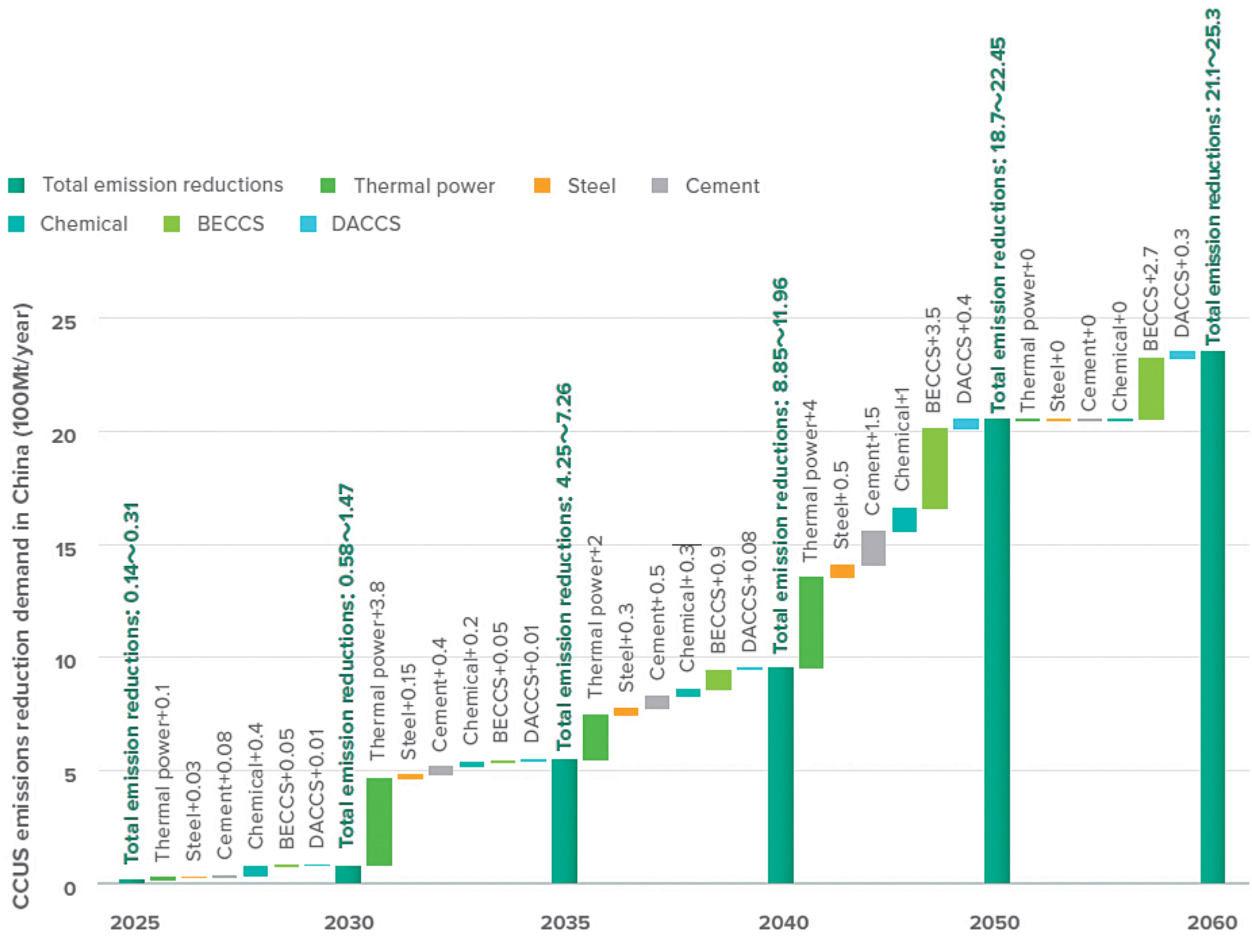


Figure 4-1-10 CCUS emissions reduction demand in China

# PART 5

## Research Integrity

NSFC

In accordance with the work arrangements of *The Opinions on Further Strengthening the Construction of Scientific Integrity*, *The Opinions on Further Carrying Forward the Spirit of Scientists and Strengthening the Construction of Work Style and Academic Atmosphere*, and *The Opinions on Strengthening the Ethical Governance of Science and Technology* issued by the General Office of the CPC Central Committee in tandem with the General Office of the State Council, NSFC has been committed to fostering an environment of ethical academic practices and promoting research integrity and ethics by implementing the Action Plan for Improving the Academic Atmosphere of the National Natural Science Fund, which is systematically deployed in five aspects: education, motivation, regulation, supervision and punishment. NSFC has carried out special initiative to tackle the persistent issue of string-pulling which jeopardizes the impartiality of peer reviewers to promote a clean and upright research environment.

## I. Strict Punishment for Typical Cases of String-pulling

First, strengthening positive guidance. NSFC has issued the *List of Prohibited Behaviors for String-pulling in the Review of National Natural Science Foundation Projects*, specifying 24 prohibited acts for researchers, host institutions, review experts, and NSFC staff. Resisting string-pulling has been included in the core content of research integrity education, and an animated film alerting such behaviours were produced. Various methods were adopted to ensure the fairness and impartiality of peer reviews. NSFC strengthened the interpretation of relevant rules and regulations by publishing the revised interpretation of the *Measures for Investigation and Handling of Scientific Research Misconduct of NSFC Projects* on the front page of *Science and Technology Daily*, and reprinted and publicized it on the website of the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection and the National Supervisory Commission stationed at the Ministry of Science and Technology to release strong signals of resolutely and seriously investigating and punishing misconduct such as "probing, seeking personal connections, requesting favors, bribery and exchange of interests. Second, improving the defense against research integrity violations. At the introduction of the panel meeting, emphasis was placed on the special rectification work requirements of preventing string-pulling targeting the review experts. The pull-up banners with the "*List of Prohibited Behaviors for String-pulling in the Review of National Natural Science Foundation Projects*" were placed at all the panel meeting sites, and promotional videos were on loop playback during meeting intervals. Third, strictly punishing "string-pulling" cases. Under the guidance of the Discipline Inspection and Supervision Group of the Central Commission for Discipline Inspection and the National Supervisory Commission stationed at the Ministry of Science and Technology, the clues of scientific research misconduct reporting involving "string-pulling" were listed as key cases for investigation and handling. Nearly a hundred reported cases of "string-pulling" have been verified, and for confirmed cases, a zero-tolerance attitude has been adopted to impose severe punishments on those responsible, effectively exerting a deterrent effect.

## II. Comprehensive Implementation of Research Integrity Education and Promotion

First, diversifying publicity forms. NSFC organized the publication and compilation of *the Handbook of Scientific Research Integrity Standards* and *the Introduction to Scientific Research Standards and Scientific Research Integrity Education*. In response to common occurrences of plagiarism, duplicate applications, falsification, third-party services, dissemination of misinformation, string-pulling, six warning education animations have been released. Second, 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, strengthening warning education. On the official website of NSFC, severe violations of 34 individuals who have been criticized and dealt with were published, and warning education was carried out through typical cases of scientific research misconduct. Fourth, enhancing exchanges and collaboration. NSFC jointly issued the *Key Points for Publicity and Education of National Scientific Ethics and Style of Study Construction in 2023* with eight departments including China Association for Science and Technology, and actively participated in the promotion of scientific ethics and the development of academic conduct. NSFC promoted the innovative measures and achievements of NSFC in the construction of scientific research integrity in China-Switzerland Scientific Research Integrity Seminar and other academic exchanges at home and abroad. Fifth, NSFC further strengthened the responsibility of affiliated units. The main responsibility and key role of the host institutions in the development of scientific research integrity of NSFC were emphasized in the National Natural Science Fund Guide to Programs and research integrity lectures.

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

First, conscientiously conducting similarity checks on project applications. Based on the results of similarity checks, NSFC investigated cases of high similarity in applications. In 2023, a total of 94 cases of high similarity were investigated, and serious action was taken against relevant individuals. Second, strengthening the review discipline. Before panel review, the *Reminder Letter of the Respondent of the Project Review Meeting of National Natural Science Foundation of China* and *the Reminder Letter of the Review Experts of the Project Review Meeting of National Natural Science Foundation of China to Perform Their Duties* are sent to remind the respondent and the review experts to fulfill the commitments in the Letter of Commitment. A mobilization and deployment meeting for the review of NSFC projects were also held before the panel meetings, emphasizing the scientificity and impartiality of NSFC with rigorous and earnest work style, and solidly carrying out project review work to continuously improve the efficiency of science funding. Third, strengthening on-site supervision. NSFC completed on-site supervision of programs including National Science Fund for Distinguished Young Scholars, Excellent Young Scientists Fund, Key Program, General Program, Young Scientist Fund, Fund for Less Developed Regions, Special Fund for Research on National Major Instrument, and some Programs of Joint Funds in nine scientific departments, totaling 38 panel meetings covering 354 review panels. An impartiality survey among participating experts was conducted after the panel meeting and results demonstrated that the impartiality of the panel review experts was widely acknowledged and highly regarded. Fourth, rigorously implementing joint integrity review of the projects to be funded. Prior to the approval of NSFC projects, the applicants, participants, host institutions and cooperative institutions of the projects to be funded shall be subject to joint disciplinary integrity review. Individuals and institutions found to have integrity issues and are within the punishment period will be vetoed, ensuring that entities recorded in the serious misconduct database of research integrity do not undertake or participate in scientific fund projects during the punishment period. Fifth, regularly conducting the integrity audit of the science fund review expert pool. In 2023, after the centralized acceptance period for proposal submissions and in the third quarter, two integrity audits were carried out on the review expert pool to ensure that individuals with records of serious misconduct such as illegal activities, plagiarism, falsification, and tampering are barred from participating in the review for science fund projects.

## IV. Continuously Increase Efforts to Combat Research Misconduct

In 2023, NSFC received a total of 575 complaints and reports related to research misconduct, and convened two full committee meetings of the Supervisory Committee to review the investigation status of complaint and report leads. Following the Committee's approval, a total of 331 individuals and 6 host institutions in 199 cases were subject to disciplinary measures. Among the cases, 48 respondents received official criticism, while 45 were subject to internal criticism. 1 host institution was notified of public criticism, 3 were issued warnings, and 2 received criticism and education. The qualifications of 2 individuals for reviewing and applying for NSFC projects were permanently revoked. Application and review qualifications of 162 individuals were suspended for 1 to 7 years. Fifty-one grants and 90 applications were revoked.

## V. Effectively Promoting Science and Technology Ethics

NSFC thoroughly implemented the *Opinion on Strengthening the Ethics and Governance in Science and Technology* issued by the Central Office of the Communist Party of China and the Office of the State Council by formulating work plans and clarifying the division of responsibilities and work requirements for each department. To further enhance the publicity of science and technology ethics of the science fund, NSFC guided Principal Investigators to strictly adhere to the scope approved by science and technology ethics review, and strengthened the overall ethical management of research projects and team members. To further strengthen the supervision of science fund technology ethics, NSFC stressed ethical requirements in project guideline formulation, review, and supervision, cooperating with host institutions for joint management to prevent technology ethics risks.

## VI. Thoroughly Conducting Supervision and Inspection of Project Funds

Firstly, *Implementation Plan for the Supervision and Inspection of NSFC Projects for the Year 2023* was formulated based on research and analysis. The supervision and inspection meeting of NSFC projects were held in Guangdong Province, Sichuan Province, and Hebei Province respectively. Fund supervision and inspection on 889 projects were randomly selected from 102 host institutions in three provinces, involving a total amount of 739.455 million RMB. A report was formulated upon the completion of the on-site supervision and inspection. Secondly, the "second part" of the supervision and inspection of NSFC project funds was effectively carried out. In response to the supervision and inspection of NSFC project funds conducted in Guizhou Province in 2022, with the goal of "finding and rectifying," responsibilities for rectification were enforced. Approximately 1.5 million RMB of improperly used funds were recovered. Fifteen host institutions in Guizhou Province were issued letters of rectification opinions, specifying rectification requirements and deadlines. By advancing rectification efforts, the results of supervision and inspection were effectively improving the efficiency of scientific funds. Thirdly, reported issues and clues related to project funds were investigated and handled. In 2023, a total of 50 complaints and reports related to project funds were received. With a strengthened sense of review deadlines and efficiency, approximately 831,200 RMB of improperly used funds were recovered. Three institutions received warnings, two individuals received internal criticisms, two received warnings, and two received criticism and education. The application and participation qualifications of three individuals were revoked for 1-5 years. Fourthly, the investigation of special issues identified through "economic responsibility audit" were completed. In response to the matters uncovered through the "economic responsibility audit" of eight host institutions referred by the Audit Office, each case was meticulously verified and confirmed with the relevant institutions. As a result, a total of 8 host institutions, with improperly utilized funds amounting to 8.0403 million RMB, were identified and the funds were successfully recovered. Among them, five received warnings, and all the eight received rectification letters. They all subsequently implemented the necessary corrective measures within the designated time frame.

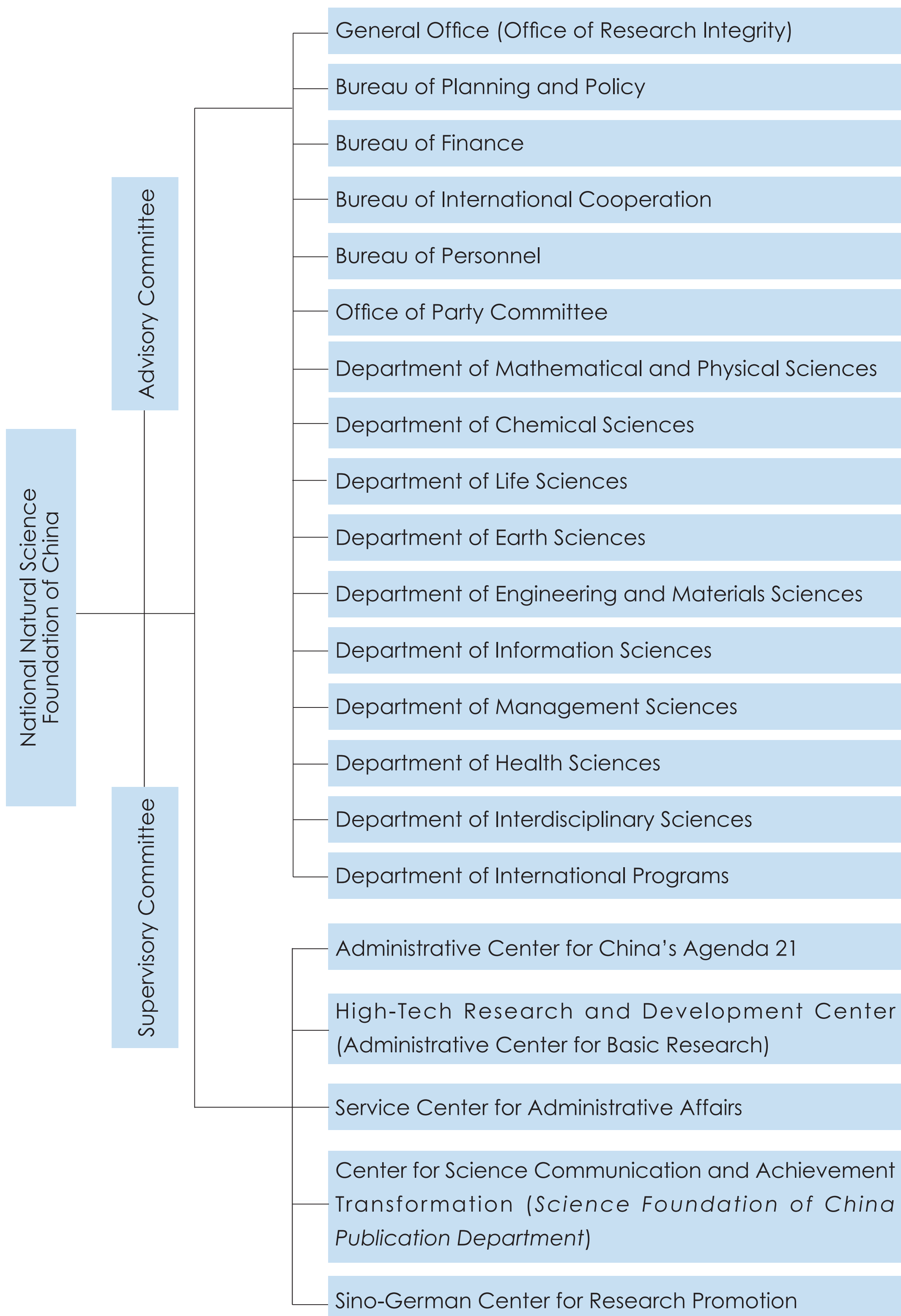
# PART 6

## Organization

NSFC

# Organizational Structure

## 1. Chart of Organization Structure



## 2. Members of The 9th Council of the National Natural Science Foundation of China

President: Dou Xiankang

Vice Presidents: Wang Xiqin, Lu Jianhua, Zhang Xuemin, Jiang Song, Yu Jihong, Han Yu (concurrently Secretary General), Lan Yujie

Members: Ma Hongbing, Wang Enge, Bian Xiuwu, Zhu Rixiang, Liu Changsheng, Liu Zejin, Wu Yan, Wu Manqing, Shen Zhulin, Chen Jie, Luo Hui, Xi Zhenfeng, Huang Haijun, Cao Xiaofeng, Chang Jin, Xie Yi, Pan Aihua

## 3. Members of the 6th Supervisory Committee of the National Natural Science Foundation of China

Director: Chen Yiyu

Deputy Directors: He Minghong, Shao Feng, Sun Changpu

Members: Wang Hongyan, Wang Junhong, Wang Jiancheng, Wang Guoyu, Wang Yuefei, Tian Zhixi, Liu Ming, Qi Hai, Yan Jinghua, Yang Xiao, Wu Fuyuan, Zhang Hongbing, Chen Xinyuan, Zhou Xiang, Zheng Yongfei, Zhao Dongliang, Yao Zhujun, Gao Xiang, Guo Jianquan, Cui Xiang

## 4. NSFC Staff

### A. Permanent staff

The budgeted staff quota at NSFC is 309. By December 31, 2023, NSFC has 239 permanent staff, of whom 137 are males and 102 are females; and 224 hold a professional technical position (title). The average age of the permanent staff is 43.6. 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

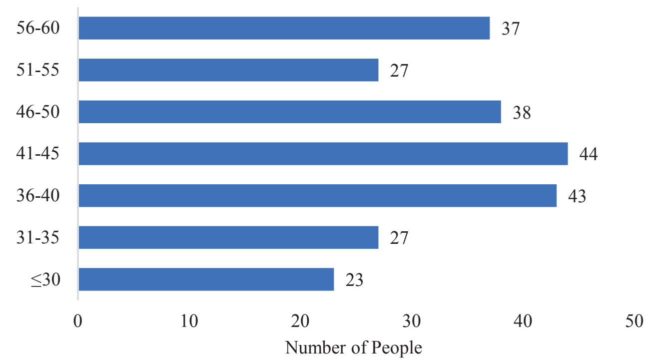



Figure 6-1-2 Age distribution of NSFC staff

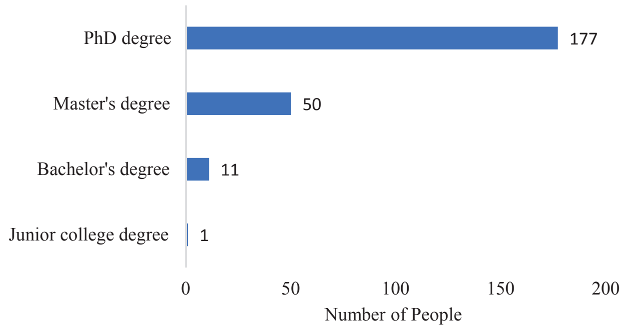



Figure 6-1-3 Academic degrees of NSFC staff

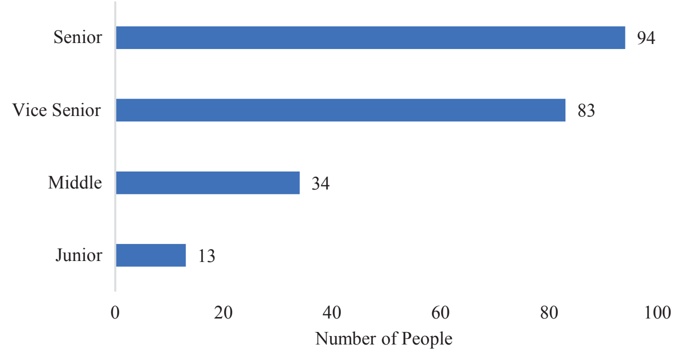



Figure 6-1-4 Professional titles of NSFC staff

### B. Rotational Program Directors

By December 31, 2023, there are 135 Rotational Program Directors on duty at NSFC, of whom 99 are males and 36 are females; 126 have a Ph.D. degree; 66 have a senior professional technical position (title) and 60 have a vice senior professional technical position (title).

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

**Leaders of NSFC's Bureaus and Departments**

(As of December 31, 2023)

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

**Leaders of NSFC's Subordinate Units**

(As of December 31, 2023)

| Unit | Leaders |
|---|---|
| Administrative Center for China's Agenda 21 | Ke Bing, Chen Qizhen |
| High-Tech Research and Development Center (Administrative Center for Basic Research) | Zhang Honggang, Bian Shuguang |
| 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 2023

## January

On January 3, the signing ceremony of the "NSFC-CMA Joint Fund Agreement" was held in Beijing. Present at the ceremony were Dou Xiankang, Secretary of the Party Leadership Group; Li Jinghai, President; Hou Zengqian and Gao Ruiping, Vice Presidents and members of the Party Leadership Group; and Zhuang Guotai, Secretary of the Party Leadership Group and Director of CMA; and Bi Baogui, Deputy Director of CMA.


On January 4, the 16th plenary session of the Fifth Supervisory Committee of NSFC was held in Beijing, chaired by Chen Yiyu, Director of the Supervisory Committee. Chen Yiyu and He Minghong, Deputy Directors, respectively chaired the meetings of the Life and Medical Sciences Professional Committee and the General Professional Committee. Han Yu, member of the Party Leadership Group and Secretary-General, attended the meeting and delivered a speech. Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection and the National Supervisory Commission at the Ministry of Science and Technology, and Mu Yatian, Director of the Third Discipline Inspection and Supervision Office, attended the meeting online.

## February

On February 20, Xie Xincheng, Vice President, met with the visiting delegation led by Chen Yunxi, Chairman of the Administrative Committee of the Macao Science and Technology Development Fund.


On February 21, the Party Leadership Group reviewed and approved the special rectification work plan for the persistent issue of "contacting" review experts and launched the special rectification work.

On February 23, Dou Xiankang, Secretary of the Party Leadership Group, presided over a special meeting of the Party Leadership Group to convey and implement the important speech of General Secretary of CPC Xi Jinping during the third collective study session of the Political Bureau of the CPC Central Committee. The meeting discussed and deployed continuous improvement of the efficiency of scientific funding.

On February 24, the mid-term evaluation meeting of the 2022 Major Research Program was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group, attended the meeting and delivered a speech. Gao Ruiping, Vice President and member of the Party Leadership Group, presided over the opening ceremony. The comprehensive evaluation expert group of the Major Research Program, some members of the advisory expert group, the management working group, and relevant staff from NSFC departments participated in the meeting.


## March

On March 1, the review meeting for the continued funding of the 2022 Basic Science Center Projects was held in Beijing. The meeting reviewed projects from the second batch of the 2017 pilot implementation that received excellent grades upon expiration. Dou Xiankang, Secretary of the Party Leadership Group, and Gao Ruiping, Vice President, attended the meeting and delivered speeches.

On March 1, Li Jinghai, President of NSFC, met with Professor Bernd Sachweh, Vice President of BASF Research Institute.

From March 2 to 3, the final evaluation meeting of the 2022 Major Research Program was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group, attended the meeting and delivered a speech. Gao Ruiping, Vice President, presided over the meeting. The comprehensive evaluation expert group of the Major Research Program, some members of the advisory expert group, the management working group, and relevant staff from NSFC departments participated in the meeting.

On March 14, NSFC held a meeting to convey the spirit of the First Session of the 14th National People's Congress and the First Session of the 14th National Committee of the Chinese People's Political Consultative Conference. Dou Xiankang, Secretary of the Party Leadership Group, presided over the meeting. Li Jinghai, member of the 14th National People's Congress Standing Committee and President of NSFC, conveyed the spirit of the First Session of the 14th National People's Congress. Lu Jianhua, member of the National Committee of the Chinese People's Political Consultative Conference and Vice President of NSFC, conveyed the spirit of the First Session of the 14th National Committee of the Chinese People's Political Consultative Conference.


On March 16, the 2023 NSFC Project Fund Management Seminar was held in Beijing. Gao Ruiping, Vice President, attended the meeting and delivered a speech. Li Xiaonan, Second-level Inspector of the Technology Audit Bureau of the National Audit Office, Gao Hui, Director of the Science and Technology Division of the Ministry of Finance, and nearly 50 scientific research and financial management heads from institutions in the Beijing-Tianjin-Hebei region attended the meeting.


On March 17, the Strategic Seminar on Interdisciplinary Science Based on Quantum Information Technology was held in Hefei. Dou Xiankang, Secretary of the Party Leadership Group, attended the meeting and delivered a speech.

On March 30, NSFC held the 2023 Comprehensive Strict Party Governance Work Conference. Dou Xiankang, Secretary of the Party Leadership Group, attended the meeting and delivered a speech. Li Jinghai, President, Gao Ruiping, Vice President, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection and the National Supervisory Commission at the Ministry of Science and Technology, attended the meeting.

On March 31, NSFC and BASF signed a letter of intent for cooperation in Beijing. Dou Xiankang, Secretary of the Party Leadership Group, attended the meeting and delivered a speech. Li Jinghai, President, and Detlef Kratz, President of BASF Research Institute, signed the letter of intent and delivered speeches on behalf of their respective sides.


## April

On April 4, the Party Leadership Group of NSFC held a special meeting to convey and implement the spirit of the Thematic Education Work Conference on Xi Jinping's Thought on Socialism with Chinese Characteristics for a New Era. Dou Xiankang, Secretary of the Party Leadership Group, presided over the meeting and delivered a speech. Members of the Party Leadership Group and leadership team attended the meeting.

On April 12, the Party Leadership Group of NSFC held a mobilization and deployment meeting to study and implement Xi Jinping's Thought on Socialism with Chinese Characteristics for a New Era. Li Xiuling, Head of the 38th Central Guidance Group for Thematic Education, attended the meeting and delivered a speech. Dou Xiankang, Secretary of the Party Leadership Group and Leader of the Thematic Education Leading Group, delivered a mobilization speech. Li Jinghai, President and Deputy Leader of the Thematic Education Leading Group, attended the meeting. Wang Bingnan, Deputy Leader of the 38th Central Guidance Group for Thematic Education, and other relevant personnel, members of the Party Leadership Group and leadership team, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection and the National Supervisory Commission at the Ministry of Science and Technology, attended the meeting. Gao Ruiping, Vice President and Deputy Leader of the Thematic Education Leading Group, presided over the meeting.


On April 19, the Thematic Education Leading Group of the Party Leadership Group of NSFC held its first meeting. Dou Xiankang, Secretary of the Party Leadership Group and Leader of the Thematic Education Leading Group, presided over the meeting and delivered a speech. Members of the Thematic Education Leading Group and its office attended the meeting.

On April 24, the Party Leadership Group of NSFC held the opening ceremony of the Theoretical Study Reading Class for Studying and Implementing Xi Jinping's Thought on Socialism with Chinese Characteristics for a New Era. Dou Xiankang, Secretary of the Party Leadership Group, presided over the opening ceremony and delivered a speech. Members of the Party Leadership Group and leadership team attended the study session.


On April 28, the State Council appointed Dou Xiankang as the President of the 9th NSFC. Lu Jianhua, Zhang Xueming, Jiang Song, Yu Jihong, Han Yu, and Lan Yujie were appointed as Vice Presidents of the 9th NSFC.

## May

From May 4 to 21, NSFC held seminars on the needs and policies of medical research funding in Shanghai, Beijing, and Wuhan. Dou Xiankang, Secretary of the Party Leadership Group and President, attended and presided over the seminars. Zhang Xueming, Vice President, and Gao Ruiping, member of the Party Leadership Group, participated in the seminars. Over 170 experts from various universities and research institutes across the country engaged in in-depth discussions on key funding directions in the medical field, improving medical talent cultivation mechanisms, enhancing the effectiveness of scientific funding, scientific research funding management policies, and mechanisms for refining major scientific issues.

On May 5, NSFC held an internal seminar on the special rectification of the persistent issue of "contacting" review experts. Dou Xiankang, Secretary of the Party Leadership Group and President, presided over the meeting and delivered a speech. Han Yu, Vice President and Secretary-General, Gao Ruiping, member of the Party Leadership Group, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection and the National Supervisory Commission at the Ministry of Science and Technology, attended the meeting.


On May 5, NSFC held a Youth Cadre Exchange and Sharing Meeting. Dou Xiankang, Secretary of the Party Leadership Group and President, attended the event and delivered a speech. Han Yu, Vice President and Secretary-General, attended the meeting.

On May 8, NSFC and the Ministry of Education held a working meeting. Dou Xiankang, Secretary of the Party Leadership Group and President, and Wu Yan, Deputy Minister of Education, attended the meeting and delivered speeches. Gao Ruiping, member of the Party Leadership Group, attended the meeting.

On May 12, the Theoretical Study Reading Class for Studying and Implementing Xi Jinping's Thought on Socialism with Chinese Characteristics for a New Era of the Party Leadership Group of NSFC conducted a special study and research activity at the China Aviation Materials Research Institute. Dou Xiankang, Secretary of the Party Leadership Group and President of NSFC, and Cao Jianguo, Secretary of the Party Leadership Group and Chairman of China Aviation Materials Research Institute, participated in the activity and delivered speeches.

On May 16, NSFC held the 2023 Scientific Fund Project Review Work Mobilization and Deployment Meeting in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, attended the meeting and delivered a speech. Lu Jianhua, Vice President, presided over the meeting. Han Yu, Vice President and Secretary-General, outlined the responsibilities of the "four parties" in implementing their respective duties. Gao Ruiping, member of the Party Leadership Group, provided an overview of the 2023 scientific fund project review work. Zhang Xueming, Jiang Song, Yu Jihong, Lan Yujie, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection and the National Supervisory Commission at the Ministry of Science and Technology, attended the meeting.


On May 19, Dou Xiankang, President of NSFC, met with Keith Tanti, Secretary of State for Youth, Research, and Innovation of the Republic of Malta. Lan Yujie, Vice President, and John Busuttil, Ambassador of the Republic of Malta to China, attended the meeting.

On May 19, Lan Yujie, Vice President of NSFC, met with Kim Yungchul, Secretary-General of the National Research Foundation of Korea.

On May 25, Han Yu, Vice President and Secretary-General of NSFC, met with Frank Vrancken Peeters, CEO of Springer Nature.

On May 25, the 7th meeting of the 8th Expert Advisory Committee of the Chemistry Division of NSFC was held in Beijing. Yu Jihong, Vice President, and Yang Xueming, Director of the Chemistry Division and Chair of the Expert Advisory Committee, attended the meeting and delivered speeches.

On May 26, the launch ceremony of the "China Discipline and Frontier Field 2035 Development Strategy Series" was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President of NSFC, and Chang Jin, member of the Party Leadership Group and Vice President of the Chinese Academy of Sciences, jointly unveiled the first 18 volumes of the series. Gao Ruiping, member of the Party Leadership Group, presided over the ceremony.


On May 26, the 7th plenary (expanded) meeting and the scientific center review meeting of the 8th Expert Advisory Committee of the Information Science Division of NSFC was held in Beijing. Lu Jianhua, Vice President, attended the meeting and delivered a speech.

On May 26, the closing ceremony of the Theoretical Study Reading Class for Studying and Implementing Xi Jinping's Thought on Socialism with Chinese Characteristics for a New Era of the Party Leadership Group of NSFC was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, presided over the closing ceremony and delivered a summary speech.

On May 29, the first special meeting of the 2023 Advisory Committee of NSFC was held in Shanghai. Yang Wei, Director of the Advisory Committee, presided over the meeting. Gao Ruiping, member of the Party Leadership Group, attended the meeting and delivered a speech.


From May 29 to June 2, Lan Yujie, Vice President of NSFC, led a delegation to The Hague, Netherlands, to attend the 11th Annual Meeting of the Global Research Council (GRC).

On May 31, NSFC and the State-owned Assets Supervision and Administration Commission of the State Council (SASAC) held a working meeting. Dou Xiankang, Secretary of the Party Leadership Group and President of NSFC, and Zhang Yuzhuo, Secretary of the Party Leadership Group and Director of SASAC, attended the meeting and delivered speeches. Gao Ruiping, member of the Party Leadership Group, attended the meeting.


## June

On June 1, NSFC issued the "Notice on the Promotion and Release of Basic Researcher Identification (BRID) Arrangements", officially launching the Basic Researcher ID (BRID).

On June 2, a policy research meeting on funding female researchers was held in Beijing. Zhang Xiaolan, Vice President and Secretary of the Secretariat of the All-China Women's Federation, and Wang Hongyang, President of the China Women's Science and Technology Association, attended the meeting and delivered speeches. Gao Ruiping, member of the Party Leadership Group, presided over the meeting.

On June 3, the 6th meeting of the 1st Expert Advisory Committee of the Interdisciplinary Science Division was held in Beijing. Yu Jihong, Vice President, attended the meeting and delivered a speech. Tang Chao, Director of the Interdisciplinary Science Division and Chair of the Expert Advisory Committee, presided over the meeting.


On June 13, the Party Leadership Group of NSFC and the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology held the 1st 2023 special meeting on comprehensive strict Party governance. The theme was "Thoroughly Studying and Implementing the Spirit of the 20th National Congress, the Second Plenary Session of the 20th Central Committee, and the National 'Two Sessions'; Earnestly Implementing the 'Party and State Institutional Reform Plan'; and Ensuring the Reform Tasks Are Fully Implemented." Gao Bo, Head of the Discipline Inspection and Supervision Team, attended the meeting and delivered a speech. Dou Xiankang, Secretary of the Party Leadership Group and President, presided over the meeting and delivered a speech. Xu Minzhen, Director of the Comprehensive Office of the Second Supervisory Inspection Office of the Central Commission for Discipline Inspection, attended the meeting for guidance. Members of the Party Leadership Group and leadership team, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team, attended the meeting.

On May 30, June 8, and June 14, supervision and inspection meetings on NSFC project funding were held in Guangzhou, Chengdu, and Shijiazhuang, respectively. Han Yu, Vice President and Secretary-General of NSFC, attended the meetings and delivered speeches. Leaders from the science and technology departments of the three provinces and representatives from the host institutions delivered speeches.

On June 19, a seminar on the diversified investment mechanism for basic research and the management of joint funds was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, attended the meeting and delivered a keynote report. Gao Ruiping, member of the Party Leadership Group, presided over the meeting.


On June 28, Dou Xiankang, President of NSFC, met with Andreas Göthenberg, Executive Director of the Swedish Foundation for International Cooperation in Research and Higher Education (STINT). Lan Yujie, Vice President, attended the meeting.


On June 29, Dou Xiankang, Secretary of the Party Leadership Group and President, met with Rocky S. Tuan, President of the Chinese University of Hong Kong. Lan Yujie, Vice President, and Gao Ruiping, member of the Party Leadership Group, attended the meeting.

On June 30, the first plenary meeting of the 9th NSFC Committee was held in Beijing. Wang Zhigang, Secretary of the Party Leadership Group and Minister of Science and Technology, attended the meeting and delivered a speech. The meeting reviewed and approved the work report delivered by Dou Xiankang, titled "Continuously Improving the Funding System and Enhancing Funding Efficiency to Strongly Support High-level Scientific and Technological Self-reliance and Self-improvement," the report by Chen Yiyu, Chair of the Supervisory Committee, titled "Vigorously Creating a Clean and Upright Research Environment to Provide Solid Support for Improving the Funding Efficiency of the Scientific Fund," the draft amendments to the "NSFC Charter," and the "2022 Budget and Funding Plan Execution and the 2023 Budget and Funding Plan."


## July

On July 4, the Party Leadership Group of NSFC reviewed and approved recommendations to further support female researchers, deciding to extend the age limit for female researchers applying for the National Science Fund for Distinguished Young Scholars from 45 to 48 years starting in 2024.

On July 6, Dou Xiankang, Secretary of the Party Leadership Group and President, delivered a thematic education lecture titled "Adhering to and Strengthening the Party's Comprehensive Leadership and Fully Undertaking the New Mission Assigned by the Central Committee in the New Era" to all Party members and cadres. Li Xiuling, Head of the 38th Central Guidance Group for Thematic Education, Wang Bingnan, Deputy Leader, and all members of the guidance group, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology, attended the meeting for guidance. Members of the Party Leadership Group and leadership team attended the event. Han Yu, Vice President and Secretary-General, presided over the event.


From July 12 to 14, the review meeting for the 2023 Excellent Young Foreign Scholars Research Fund and the Senior Foreign Scholars Research Fund was held in Beijing. Lan Yujie, Vice President, attended the meeting and delivered a speech.

On July 19, Dou Xiankang, President of NSFC, met with Roger Glass, the new Chairman of the China Medical Board.


On July 25 and 28, the joint working meeting of the 2023 Enterprise Innovation Development Joint Fund was held in Beijing. Gao Ruiping, member of the Party Leadership Group, presided over the meetings.

On July 27, NSFC held a briefing on the special rectification of the persistent issue of "contacting" review experts, reporting the related work to the 38th Central Guidance Group for Thematic Education. Dou Xiankang, Secretary of the Party Leadership Group and President, attended the meeting and introduced the situation. Li Xiuling, Head of the 38th Central Guidance Group for Thematic Education, and group members Wang Shengxue, Zhao Huaiqian, and Zhu Chen attended the meeting. Han Yu, Vice President and Secretary-General, presided over the meeting.


From July 27 to 28, the inaugural meeting of the 6th NSFC Supervisory Committee and the first plenary meeting of the 6th Supervisory Committee were held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, Chen Yiyu, Chair of the 6th Supervisory Committee, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology, attended the inaugural meeting and delivered speeches. Han Yu, Vice President and Secretary-General, presided over the meeting.

On July 28, Lan Yujie, Vice President, met with Sylvain Charbonneau, Vice President of the University of Ottawa, Canada.


From July 30 to 31, the review meeting for the 2023 National Major Scientific Instrument Development Projects (departmental recommendations) was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, attended the meeting and delivered a speech. Gao Ruiping, member of the Party Leadership Group, presided over the meeting.


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

## August

On August 3, the thematic education rectification work promotion meeting of NSFC was held in Beijing. Han Yu, Vice President and Secretary-General, and Deputy Leader of the Thematic Education Leading Group, attended the meeting and delivered a speech.

From August 16 to 17, Dou Xiankang, Secretary of the Party Leadership Group and President, led a delegation to Inner Mongolia for targeted assistance and to research scientific and technological support for rural revitalization. Bao Xianhua, Vice Chairman of Inner Mongolia Autonomous Region, and Sun Junqing, Vice Chairman of the CPPCC and Director of the Department of Science and Technology of Inner Mongolia, attended the relevant research activities. Han Yu, Vice President and Secretary-General, participated in the research activities.


On August 18, the thematic education research results exchange meeting of the Party Leadership Group of NSFC was held in Beijing. Li Xiuling, Head of the 38th Central Guidance Group for Thematic Education, Wang Bingnan, Deputy Leader, and guidance group members Zhou Shanshan, Wang Shengxue, and Zhu Chen attended the meeting for guidance. Members of the Party Leadership Group and leadership team of NSFC, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology, attended the meeting. Han Yu, Vice President and Secretary-General, presided over the meeting on behalf of Dou Xiankang, Secretary of the Party Leadership Group and President.


From August 22 to 25, the first review meeting of the NSFC Basic Research Program for Undergraduate Students was held in Beijing and Hefei. The meeting interviewed outstanding undergraduate applicants from eight pilot universities, including Tsinghua University and Peking University. Dou Xiankang, Secretary of the Party Leadership Group and President, attended the meeting and delivered a speech. Wu Yan, Vice Minister of Education, attended the meeting. Gao Ruiping, member of the Party Leadership Group, presided over the meeting.

On August 23, Dou Xiankang, President of NSFC, met with Ingrid Krümann, Deputy Director of the International Cooperation Bureau of the German Research Foundation and German Director of the Sino-German Science Center.


On August 24, the first National Industrial Internet Innovation Competition, jointly hosted by the Information Science Division of NSFC and the Anhui Provincial Department of Science and Technology, was held in Hefei. Lu Jianhua, Vice President, attended the award ceremony and delivered a speech.


## September

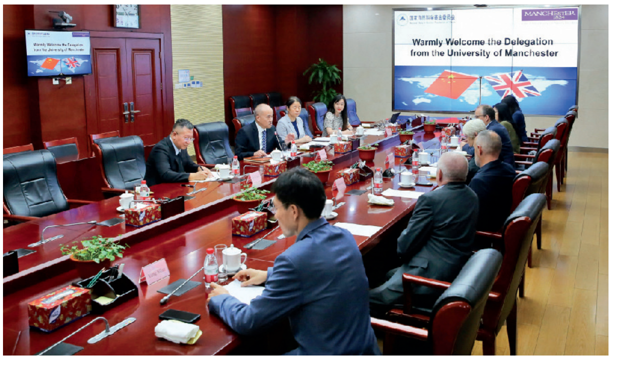
From September 4 to 8, Jiang Song, Vice President, led a delegation to Turkey and held bilateral talks with Hasan Mandal, President of the Scientific and Technological Research Council of Turkey (TÜBiTAK).

On September 4, Dou Xiankang, President, met with Dr. Luis Velázquez, President of the Cuban Academy of Sciences.

On September 8, Dou Xiankang, President, met with Professor Quarraisha Abdool Karim, President of The World Academy of Sciences (TWAS). Gao Ruiping, member of the Party Leadership Group, and Yang Wei, Director of the Advisory Committee, attended the meeting.

On September 8, the summary meeting of the thematic education on studying and implementing Xi Jinping Thought on Socialism with Chinese Characteristics for a New Era was held in Beijing. Wang Bingnan, Deputy Leader of the 38th Central Guidance Group for Thematic Education, attended the meeting and delivered a speech. Dou Xiankang, Secretary of the Party Leadership Group, President, and Leader of the Thematic Education Leading Group, presided over the meeting and delivered a summary report. Li Xiuling, Head of the 38th Central Guidance Group for Thematic Education, and relevant personnel from the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology, attended the meeting.


On September 12, Dou Xiankang, President, met with Nancy Rothwell, President of the University of Manchester.




On September 13, Dou Xiankang, President, met with Kumsal Bayazit, CEO of Elsevier.

On September 14, a welcome meeting for the staff transferred due to institutional reforms was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, attended the meeting and delivered a speech. Yu Jihong, Vice President, Gao Ruiping, member of the Party Leadership Group, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology, attended the meeting. Lan Yujie, Vice President, presided over the meeting. Principal leaders of various departments and directly affiliated units, and all staff of the Administrative Center for China's Agend 21 and the High Technology Research and Development Center (Administrative Center for Basic Research), attended the meeting.


On September 14, Lan Yujie, Vice President, met with Pema Gyamtsho, Director General of the International Centre for Integrated Mountain Development (ICIMOD).


On September 19, Dou Xiankang, President, met with a delegation of university presidents from the UK. Lan Yujie, Vice President, attended the meeting.


On September 28, Wu Weihua, Vice Chairman of the Standing Committee of the National People's Congress and Chairman of the Central Committee of the Jiusan Society, led a team to visit NSFC for research. Dou Xiankang, Secretary of the Party Leadership Group and President, attended and presided over the research meeting. Cong Bin, member of the Standing Committee of the National People's Congress, Deputy Director of the Constitution and Law Committee, Vice Chairman of the Central Committee of the Jiusan Society, and

Academician of the Chinese Academy of Engineering, Liu Zhengkui, member of the Standing Committee of the National Committee of the Chinese People's Political Consultative Conference (CPPCC), Deputy Secretary-General, and Vice Chairman of the Central Committee of the Jiusan Society, Lai Ming, member of the Standing Committee of the CPPCC, former Vice Chairman of the Central Committee of the Jiusan Society, Gao Ruiping, member of the Party Leadership Group, and relevant department heads and staff of the Central Committee of the Jiusan Society, attended the research activities.

## October

On October 9, the 10th meeting of the Joint Leading Group for Strategic Research on Discipline Development between NSFC and the Chinese Academy of Sciences (CAS) was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President of NSFC, and Chang Jin, member of the Party Leadership Group and Vice President of CAS, attended the meeting and delivered speeches. Gao Ruiping, member of the Party Leadership Group, presided over the meeting.


On October 13, the 30th anniversary seminar of the "Special Fund for Theoretical Physics" was held in Beijing. Jiang Song, Vice President of NSFC, and Chang Jin, Vice President of CAS, attended the meeting.

On October 16, the 20th Anniversary Seminar of the Shuangqing Forum was held in Beijing. Gao Ruiping, member of the Party Leadership Group, presided over the meeting.

From October 16 to 25, Dou Xiankang, President, led a delegation to France, Germany, and Switzerland. They visited nine institutions, including the French National Centre for Scientific Research (CNRS), the German Research Foundation (DFG), the Swiss National Science Foundation (SNSF), Université Paris Cité, the University of Bonn, the Alexander von Humboldt Foundation, the International Energy Agency, CERN, and Science Europe.

On October 17-18, a training and seminar meeting on the management of the National Major Scientific Instrument Development Projects was held in Changchun. Gao Ruiping, member of the Party Leadership Group, attended the meeting and delivered a speech.


From October 23 to 28, Gao Ruiping, member of the Party Leadership Group, led a delegation to Hong Kong and Macao for research activities.

On October 30, NSFC High-tech Research and Development Center organized the panel meeting for 2023 National Key R&D Program-Special Projects. President Dou Xiankang attended the meeting and gave opening remarks, Vice President Lan Yujie and the leadership of the Center were present.

On October 31, the Party Leading Group of NSFC approved the "Work Plan for Post-evaluation and Continued Funding of National Science Fund for Distinguished Young Scholars". From 2024, National Science Fund for Distinguished Young Scholars projects that concluded in the previous year will go through post-evaluation. Those rated excellent will receive continued funding of 5 years. And after another five years, some of the projects will be given a third term of 5-year support based on merit-based selection. The maximum funding amount for each project will reach nearly 30 million yuan through 15 years. By doing so, NSFC intends to allocate the best resources to top-notch talents.

## November


From November 1 to 2, the 2023 Annual Work Conference of the Party Leadership Group of NSFC was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, presided over the meeting. The meeting focused on themes such as "Optimizing the Diversified Investment Mechanism to Enhance the Efficiency of Joint Fund Support" and "Improving the Mechanism for the Initiation, Review, and Management of Major Projects." Members of the Party Leadership Group and leadership team, leaders from the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology, and leaders from the Advisory Committee and Supervisory Committee, as well as directors (part-time) of various scientific departments and all bureau-level cadres, attended the meeting.


From November 3 to 4, the 2023 Training Class for Female Cadres was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, attended the meeting and delivered a speech. Gao Ruiping, member of the Party Leadership Group, attended the opening ceremony.

From November 5 to 12, Lan Yujie, Vice President, led a delegation to the UK and Sweden to attend the 5th Biennial Strategic Meeting between NSFC and UK Research and Innovation (UKRI). The delegation also visited seven institutions, including the Royal Society, the Swedish Foundation for International Cooperation in Research and Higher Education (STINT), the Swedish Research Council (VR), University College London, the Royal Institute of Technology (KTH), the Karolinska Institute, and the University of Manchester.

From November 8 to 10, the 2023 Training Class on Party Affairs and Business Capabilities was held in Beijing. Han Yu, Vice President and Secretary-General, and Secretary of the Party Committee, attended the meeting and delivered the opening speech. Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology, gave a special report.

On November 15, the NSFC Excellent Achievements Promotion Conference was held in Chongqing. Han Yu, Vice President and Secretary-General, attended the meeting and delivered a speech.

On November 17, the 5th Meeting of the Joint Leading Group for the "China Engineering Science and Technology Development Strategy for the Next 20 Years" project was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, and Li Xiaohong, Secretary of the Party Leadership Group and President of the Chinese Academy of Engineering, attended the meeting and delivered speeches. Wu Manqing, member of the Party Leadership Group and Vice President of the Chinese Academy of Engineering, presided over the meeting. Gao Ruiping, member of the Party Leadership Group, attended the meeting.

On November 17, a special lecture on Scientific and Technological Innovation and Basic Research Development was held in Beijing. The meeting invited Wu Hanming, Dean of the School of Micro-Nano Electronics at Zhejiang University and Academician of the Chinese Academy of Engineering, to deliver a special report. Yu Jihong and Jiang Song, Vice Presidents, Han Yu, Vice President and Secretary-General, and Gao Ruiping, member of the Party Leadership Group, attended the lecture.

From November 20 to 22, the 20th Annual Meeting of the Asian Heads of Research Councils (A-HORCs) was held in Guangzhou. Dou Xiankang, President, Lee Kwang Bok, President of the National Research Foundation of Korea (NRF), and Sugino Tsuyoshi, President of the Japan Society for the Promotion of Science (JSPS), each led delegations to attend the meeting.

On November 22, Dou Xiankang, President, met with a delegation from the Faculty of Science at Université Paris Cité.

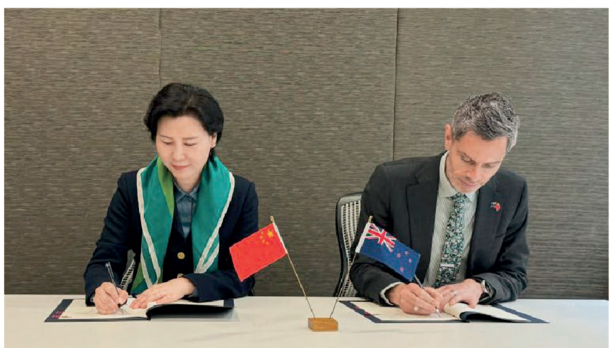
On November 23, Dou Xiankang, President, met with Dr. Stefan von Holtzbrinck, CEO of Holtzbrinck Publishing Group and Chairman of the Supervisory Board of Springer Nature.

On November 24, Dou Xiankang, President, met with Nicholas Burns, US Ambassador to China. The two sides exchanged in-depth views on implementing the San Francisco Vision and promoting cooperation and personnel exchanges in basic research between China and the US. Yu Jihong, Vice President, attended the meeting.


On November 25, the Strategic Cooperation Agreement Signing Ceremony between the Science Communication and Achievement Transformation Center of NSFC and the Science Park Management Committee of Xiong'an New Area was held in Xiong'an New Area. Han Yu, Vice President and Secretary-General, attended the ceremony and delivered a speech.

On November 27, the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology and the Party Leadership Group of NSFC held the 2nd 2023 special meeting on comprehensive strict Party governance. The theme was "Thoroughly Studying and Implementing the Important Instructions of General Secretary Xi Jinping on Party Building and Organizational Work and Vigorously Strengthening the Leadership Team and Cadre Team of the Science Fund." Gao Bo, Head of the Discipline Inspection and Supervision Team, attended the meeting and delivered a speech. Dou Xiankang, Secretary of the Party Leadership Group and President, presided over the meeting and delivered a speech. Fan Shuzhi, Director of the Comprehensive Office of the Second Supervisory Inspection Office of the Central Commission for Discipline Inspection, attended the meeting for guidance. Members of the Party Leadership Group and leadership team, and Lan Chijun, Deputy Leader of the Discipline Inspection and Supervision Team, attended the meeting.

On November 28, the Party Leadership Group of NSFC decided that starting from 2024, the application conditions and review processes for the National Science Fund for Distinguished Young Scholars, Excellent Young Scientists Fund, and Young Scientists Fund projects will be consistent across institutions in Hong Kong, Macao, and mainland China, competing on the same platform and awarding funding based on merit.



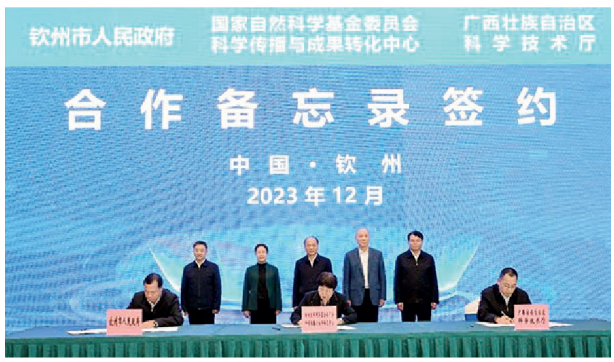
From November 28 to December 2, Yu Jihong, Vice President, led a delegation to New Zealand and signed the "Memorandum of Arrangement on Scientific Cooperation" with Nic Blakeley, Deputy Secretary of the Ministry of Business, Innovation and Employment of New Zealand, in Wellington.

## December

From December 3 to 5, Dou Xiankang, President, led a delegation to Macao to visit the Macao Science and Technology Development Fund, the University of Macao, and the Macao University of Science and Technology. They also participated in the second Academic Committee meeting of the State Key Laboratory of Lunar and Planetary Science.

On December 5, the first meeting of the 9th Expert Advisory Committee of the Mathematical and Physical Sciences Division was held in Beijing. Jiang Song, Vice President, and Chen Xianhui, Director of the Mathematical and Physical Sciences Division, awarded appointment letters to the new members of the Expert Advisory Committee and delivered speeches.


On December 5, the Science Communication and Achievement Transformation Center of NSFC signed a memorandum of cooperation with the Department of Science and Technology of Guangxi Zhuang Autonomous Region and the People's Government of Qinzhou City. Han Yu, Vice President and Secretary-General, and Liao Pinhu, Vice Chairman of Guangxi Zhuang Autonomous Region, attended the signing ceremony.




On December 11, the inaugural meeting of the 9th Expert Advisory Committee of the Life Sciences Division was held in Beijing. Zhang Xueming, Vice President, awarded appointment letters to the new members of the Expert Advisory Committee and delivered a speech. Zhong Kang, Director of the Life Sciences Division, presided over the meeting.

On December 11, the first meeting of the 6th Expert Advisory Committee of the Medical Sciences Division was held in Beijing. Dou Xiankang, Secretary of the Party Leadership Group and President, awarded appointment letters to the new members of the Expert Advisory Committee and delivered a speech. Zhang Xueming, Vice President, attended the meeting and delivered a speech.

From December 13 to 14, the second plenary meeting of the 6th Supervisory Committee was held in Beijing. Chen Yiyu, Chair of the Supervisory Committee, presided over the plenary meeting and the Life and Medical Sciences Professional Committee meeting. He Minghong, Deputy Chair, presided over the General Professional Committee meeting. Liu Yao from the Discipline Inspection and Supervision Team of the Central Commission for Discipline Inspection at the Ministry of Science and Technology attended the meeting.

On December 14, the 26th Joint Committee Meeting of the Sino-German Science Center was held in Jena, Germany. Han Yu, Vice President, led a delegation to Germany to attend the meeting. Chinese members of the Joint Committee, including Xie Xincheng, Chair Professor at Peking University, Zhang Xi, President of Jilin University, and German members, including Axel Brakhage, Vice President of DFG and German Chair of the Joint Committee, Heide Ahrens, Secretary General of DFG and German member of the Joint Committee, Ursel Fantz, Professor at the Max Planck Institute for Plasma Physics and Augsburg University, and Mathias Göken, Professor at the University of Erlangen-Nuremberg, attended the meeting.

On December 18, the 2023 NSFC Management Work Conference was held in Beijing. The meeting reviewed and summarized the work on scientific fund support and management in 2023, introduced reform ideas and measures for the new period, and deployed related work for 2024. Dou Xiankang, Secretary of the Party Leadership Group and President, attended the meeting and delivered a speech. Members of the Party Leadership Group and leadership team attended the meeting. Han Yu, Vice President and Secretary-General, presided over the opening ceremony.

On December 28, the first plenary meeting of the 9th Expert Advisory Committee of the Engineering and Materials Sciences Division was held in Beijing. Lu Jianhua, Vice President, awarded appointment letters to the new members of the Expert Advisory Committee and delivered a speech.


On December 28, the first 2023 meeting of the 9th Expert Advisory Committee of the Management Sciences Division was held in Beijing. Jiang Song, Vice President, awarded appointment letters to the new members of the Expert Advisory Committee and delivered a speech.

## II. Shuangqing Forum

In 2023, the Shuangqing Forum studied and implemented the spirit of the 20th National Congress of the Communist Party of China and the important speech of General Secretary Xi Jinping during the third collective study session of the Political Bureau of the CPC Central Committee. Adhering to the requirements of the "Four Orientations" and focusing on the 14th Five-Year Plan for the development of the Science Fund, the forum coordinated basic research, applied basic research, and talent cultivation. It maintained a goal-oriented and problem-oriented approach, strengthened the construction of the strategic research platform, and enhanced the strategic research function of the forum. The forum discussed and refined important scientific issues that lead the development of scientific frontiers and serve major national needs. It also explored ideas and measures to deepen the reform of the Science Fund and improve its funding efficiency, supporting the forward-looking, strategic, and systematic layout of basic research. Throughout the year, the Shuangqing Forum held a total of 37 sessions (see Table 2-1), with more than 1,600 experts participating.

2023 marked the 20th anniversary of the founding of the Shuangqing Forum. By organizing high-level scientists to jointly discuss and propose forward-looking, comprehensive, and interdisciplinary scientific issues, the forum played an important role in the development of basic research and the funding work of the Science Fund (see Table 2-1 and 2-2). To implement the new mission and requirements assigned to the Science Fund by the Central Committee in the new era, NSFC launched research to strengthen the construction of the Shuangqing Forum in 2023, promoting the optimization of the forum's organization and management, and improving the quality and effectiveness of the entire process. First, the forum focused on innovating the discussion mode to enhance the effectiveness of discussions. According to thematic settings, it standardized and piloted on-site research and exchange discussions, helping participating experts better understand scientific issues in technology and engineering and enhancing interdisciplinary communication and interaction. Second, the forum invited experts from relevant ministries, commissions, and enterprises more widely to better discuss and refine scientific issues in major applied research, promoting the integration of government, industry, academia, and research. Third, it emphasized talent cultivation by further increasing the proportion of young experts, piloting the "Integrated Circuit" Youth Shuangqing Forum. This leveraged the proactive, pragmatic, lively thinking, and enthusiastic characteristics of young experts, fostering more "dream builders" and "dream chasers" in scientific and technological innovation. Fourth, it improved the forum management model in line with scientific laws, focusing on theme selection and agenda design. This fully utilized the forum's macro grasp and strategic guidance role, encouraging participating experts to focus on themes and core issues throughout the process and engage in multiple


Figure 2-1 "Strategic Seminar on the Structure and Layout of Medical Science Research in China" Shuangqing Forum


Figure 2-2 "Key Fundamental Scientific Issues and Countermeasures for New Pollutant Control" Shuangqing Forum discussions and interactions, ensuring sufficient discussion time and improving discussion effectiveness, thereby supporting the production of high-level discussion outcomes.

In 2023, the Shuangqing Forum placed a greater emphasis on promoting its achievements. A coordinated mechanism was established for disseminating results through internal publications such as Fundamental Research, Bulletin of National Natural Science Foundation of China, and external publications like National Science Review, Chinese Science Bulletin, and Science China. The quality of the forum's discussion outcomes and the effectiveness of their dissemination have significantly improved. The Shuangqing Forum also focused more on serving the national science and technology strategic advisory function, actively offering suggestions and proposals. Based on the discussion outcomes, reports were submitted to the central government, supporting the construction of a strong science and technology nation.

**Table 2-1 2023 Shuangqing Forum Themes**

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| Session 316: Research on Space-Time Benchmarks in the Era of Precision (Quantum) Measurement (March 15-16, 2023) | Session 337: Frontiers and Challenges in RNA Research (April 29-30, 2023) |
| Session 326: Key Fundamental Scientific Issues in Building Carbon Neutrality (February 23-24, 2023) | Session 338: Behavioral Science and Economic Policy Design (May 5-6, 2023) |
| Session 327: Strategic Seminar on the Structure and Layout of Medical Science Research in China (March 21-22, 2023) | Session 339: Scientific Issues in Expanding the Intrinsic Functions of Magnesium (May 8-9, 2023) |
| Session 328: Frontier in Disease Diagnosis and Treatment with Nano-Synthetic Biology (March 6-7, 2023) | Session 340: Rare Earth Resources and Their Green and Efficient Utilization (May 9-10, 2023) |
| Session 329: Precise Characterization and Regulation of Novel Single-Molecule Physical and Chemical Phenomena (March 21-22, 2023) | Session 341: Basic Science of Electroplating Surfaces and Interfaces in Chip Manufacturing (May 27-28, 2023; December 9-10, 2023) |
| Session 330: Fundamental Scientific Issues in Atomic-Scale Manufacturing (March 23-24, 2023) | Session 342: Life Movements from a Mathematical Perspective (July 10-11, 2023) |
| Session 331: Interpreting Traditional Chinese Medicine Principles with Modern Science (March 27-28, 2023) | Session 343: Technology of Two-Dimensional Information Materials and Devices (August 21-22, 2023) |
| Session 332: Paradigm Shift and Interdisciplinary Innovation in Rehabilitation Medicine Research (March 29-30, 2023) | Session 344: Statistical Management Theory in Large-Scale Business Scenarios (September 14-15, 2023) |
| Session 333: Anthropocene Science (April 3-4, 2023) | Session 345: Integrated Layout of Education, Science, Technology, and Talent Development Strategy (August 30-31, 2023) |
| Session 334: Frontiers and Prospects in High-Precision Quantum Control and Detection (April 9-10, 2023) | Session 346: Frontier Technologies and Key Fundamental Scientific Issues in High-Speed Maglev Transportation (September 14-15, 2023) |
| Session 335: Theories and Methods in Digital and Intelligent Service Operations Management (April 20-21, 2023) | Session 347: Future Development and Key Issues in Integrated Circuits (September 25-26, 2023) |
| Session 336: Deciphering the Glycan Code of Life (April 24-25, 2023) | Session 348: New Technologies and Strategies in Materials Biology (September 26-27, 2023) |

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| Session 349: Separation of Strategic Element Natural Isotopes and Their Significant Roles (October 15-16, 2023) | Session 356: Interdisciplinary Laboratory Medicine (November 16-17, 2023) |
| Session 350: Key Scientific Issues in the Prevention and Control of Major Livestock and Poultry Diseases (October 19-20, 2023) | Session 357: RNA and Major Disease Diagnosis and Treatment (November 21-22, 2023) |
| Session 351: Basic Research on Exploration and Utilization of Deep Geothermal Resources (October 21-22, 2023) | Session 358: Scientific Issues in Energy Conversion and Utilization under the "Dual Carbon" Goals (November 27-28, 2023) |
| Session 352: New Theories, Methods, and Key Applications in Privacy Computing (October 24, 2023) | Session 359: Key Scientific Issues in Multidisciplinary Food Science (December 7-8, 2023) |
| Session 353: Fundamental Scientific Issues in Hydropower Development under Complex Adverse Conditions (October 25-26, 2023) | Session 360: Key Processes and Complex System Dynamics Determining Decadal Changes in the Climate and Environmental Systems of the Asian Monsoon Region (December 9-10, 2023) |
| Session 354: Low-Carbon Science Fundamentals in Mining and Metallurgical Engineering (October 26-27, 2023) | Session 361: Key Fundamental Scientific Issues and Countermeasures for New Pollutant Control (December 27-28, 2023) |
| Session 355: Challenges and Opportunities in Mathematical Software (October 27-28, 2023) | |

## III. NSFC Policy Files

According to the Regulations of the National Natural Science Foundation, as of December 31, 2023, 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.

**Administrative Normative Document System of NSFC**

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