2021—2022 年报 Bi-annual Report

北京大学 物理学院

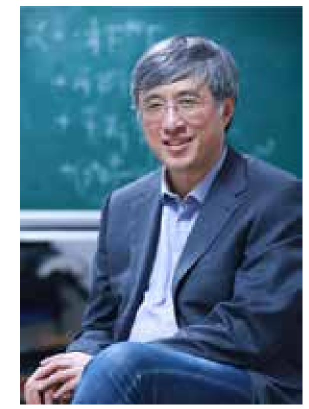
School of Physics, Peking University

年报

BI-ANNUAL REPORT

2021 / 2022

院长寄语
Message from the Dean



从 1913 年北京大学物理学门的设立，开启中国物理高等教育之先河，历经上世纪五十年代北京大学物理系的调整，群贤毕至、少长咸集，又经历本世纪初叶北京大学物理学院的整合，教研并进、争创一流，北大物理学科从未停下读书救国、教育兴国、科学强国的脚步，跨越了 110 年的风雨兼程。

从红楼南渡长沙，西征昆明，再北归燕园，一代代北大物理人从未停止用科学知识刻写青春华章、用科学思想挺拔精神脊梁、用“刚毅坚卓”砥砺理想信念，为我国高等教育与科学技术事业铸就了世纪荣光。

这里是加快造就卓越人才、培厚创新沃土的北大物理。我们组织实施物理学科卓越人才培养计划、物理学领域本科教育教学改革试点工作计划，创设物理学院博士研究生培优计划，引导学生探索未知、追求真理、服务国家急需、赶超国际标杆。

这里是持续加强基础研究、策源创新突破的北大物理。我们推进战略导向的体系化基础研究和目标导向的应用型基础研究，瞄准战略性、关键性领域，着力解决影响制约国家发展全局和长远利益的重大科技问题。

这里是弘扬“两弹一星”精神、践行“强国有我”誓言的北大物理。我们面向世界科技前沿、国家战略需求、国民经济主战场、人民健康，勇闯创新“无人区”，抢占国际竞争制高点，自觉坚守北大物理人至诚报国、助推复兴的初心。

这里是融汇全球创新资源、塑造国际发展动能的北大物理。我们完善“近者悦、远者来”的育人聚才环境，引进高层次智力资源，推动大科学国际合作，以对外开放的主动育先机、开新局，自觉履行北大物理人面向世界、面向未来的责任。

北大物理，百年成林，十年新绿。

我们理当首先向老一辈北大物理人重教乐育的优秀传统和格物穷理的执着追求致敬——这是血脉的赓续、力量的汲取，蕴藏着绿叶对根的情意。我们更应在围绕高层次领军人才培养、高素质师资队伍建设、高水平科技创新与学科交叉融合的中国特色世界一流学科建设进程中，诠释新一代北大物理人品格无私、学术无畏的正气风骨和实干争先、培优增效的时代担当，无愧于学生、家长、校友、国家和世界对北京大学物理学科的瞩目与期盼。

北京大学物理学院院长

高原宁

Welcome to the School of Physics at Peking University!

Physics delves into the study of the universe at both its smallest and largest scales. The discoveries in physics form the foundation for numerous technological advancements and contribute significantly to addressing global challenges.

It is both an honor and a privilege to have the opportunity to lead the School where I was exceptionally fortunate to pursue my education during the 1970-80s.

As we celebrate our 110th anniversary, we take pride in the achievements of our founders. The School boasts an illustrious historical record of remarkable accomplishments. Our tradition of excellence has been established by numerous distinguished professors, lecturers, and the multitude of baccalaureate and doctoral degrees we have conferred over the decades. As a result, the School consistently ranks among the top in the nation.

Our teaching programs and research interests are diverse, spanning from theoretical to experimental disciplines. With over 224 affiliated faculty members, 1296 graduate students, 988 undergraduate physics majors, and 182 postdoctoral fellows, the School fosters a vibrant intellectual environment where everyone can thrive. We place particular emphasis on inspiring and encouraging our students to become leaders in the next generation of physicists or to excel in the science-driven, high-tech industrial world. In addition to our continuous degree programs, our students' horizons are broadened through co-curricular initiatives and activities.

The School has attracted a cadre of distinguished scientists with international acclaim, drawn by the recognition of their scientific backgrounds. Cutting-edge research is conducted by a dynamic community in state-of-the-art facilities and laboratories. These endeavors bring transformative and interdisciplinary perspectives to address fundamental questions, satisfy human curiosity, promote public understanding, and enhance the quality of our lives.

Motivated by a strong commitment to ensuring that the School remains as creative and inclusive as ever, I eagerly anticipate working with everyone who is enthusiastic and highly capable in the years to come. Together, we will enhance and realize the full potential of the School, poised to reach greater heights and amplify the major impacts it can make on science and our ever-changing society.

Dean of the School of Physics,
Peking University

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发展进程
Developments

2021 年 1 月，物理学院被中共北京大学委员会评为北京大学抗击新冠肺炎疫情先进集体
January 2021
The School of Physics was awarded as an Advanced Group in the Anti-COVID-19 Campaign of Peking University；

2021 年 3 月
物理学院天文学专业入选国家级一流本科专业建设点
物理学院两项合作研究成果入选 2020 年中国重大科学、技术和工程进展
March 2021
Astronomy major in School of Physics selected as a national first-class undergraduate major construction site；
Two collaborative research results from the School of Physics were selected in the Important Advances of Science, Technology and Engineering in China in 2020;

2021 年 4 月
物理学院举办"两弹一星"功勋郭永怀事迹报告会暨物理学院与山东荣成郭永怀事迹陈列馆党建共建签约仪式
April 2021
The School of Physics held a symposium on "Two Bombs and One Satellite" awardee Guo Yonghuai's heroic deeds and a signing ceremony of the school's joint construction of the Exhibition Hall of Guo Yonghuai's stories in Rongcheng, Shandong;

2021 年 5 月
组织北京大学物理学院成立二十周年庆祝活动
May 2021
Organized the 20th anniversary celebration of the founding of the School of Physics of Peking University;

2021 年 10 月
纪念"与党同龄的物理教育家沈克琦先生"百年诞辰
October 2021
Commemorated the centenary of the birth of Mr. Shen Keqi, a physics educator of the same age as the Party;

2021 年 11 月
"燕园有李" 庆祝北京现代物理研究中心成立三十五周年暨庆贺李政道先生九十五岁华诞研讨会隆重举行
北京论坛（2021）"科学照亮世界"分论坛成功举办
November 2021
Organized the seminar to celebrate the 35th anniversary of the establishment of Beijing Institute of Modern and the 95th birthday of Mr. Tsung-Dao Lee ;
Beijing Forum (2021) "Science Illuminates the World" Sub-forum was successfully held;

2021 年 12 月
启动北京大学物理学科卓越人才培养计划
December 2021
Launch of the Physics Extraordinary Talent Program at Peking University;

2021 年学院师生作为第一作者或通讯作者发表 SCI 论文约 750 篇，其中在 Science 及其子刊、Nature 系列子刊、PRL、PNAS 等顶级杂志发表文章 60 余篇。
In 2021, about 750 SCI papers were published by faculty and students of the School of Physics as the first author or corresponding author; more than 60 papers were published in international leading journals such as Science series, Nature series, PRL, PNAS, etc.;

获批国家重点研发计划重点专项项目 4 项、课题 9 项，国家自然科学基金重大项目 1 项，重点项目 4 项，重大研究计划集成项目 1 项，联合基金重点支持项目 1 项，专项科学部综合研究项目 1 项，原创探索计划项目 2 项。
4 programs and 9 projects of national key research and development plan were approved. 1 major programs, 4 key programs, 1 major research program (integrated), 1 joint-fund key support program and 1 comprehensive research program of the Special Science Department and 2 original exploration programs of National Natural Science Foundation were approved.

2022 年 3 月
现代光学所党支部入选"第三批全国党建工作样板支部培育创建单位"
March 2022
The Party Branch of Institute of Modern Optics was selected as the "Third Batch of National Party Building Work Model Branch Cultivation and Creation Unit";

2022 年 6 月
北京大学物理学院核物理专业入选国家级一流本科专业建设点
June 2022
Nuclear physics major in School of Physics selected as a national first-class undergraduate major construction site;

2022 年 9 月
北京大学物理学科卓越人才培养计划 2022 级开班式举行
September 2022
Opening Ceremony of the Class of 2022 of the Outstanding Talent Training Program in Physics at Peking University;

2022 年 10 月
经校学位评定委员会审议，同意"物理学"一级学科下自主设置"复杂与生命系统物理"目录外二级学科，同意"电子信息"专业学位类别下自主设置"光电信息工程"等目录内专业领域。
October 2022
The Academic Degree Evaluation Committee of the university agreed to independently set up a second-level discipline "Physics of Complex and Living Systems" outside catalog under the first-level discipline "Physics"; and a major "Optoelectronic Information Engineering" inside catalog under the degree category "Electronic Information".

2022 年 10-12 月
深入学习贯彻落实党的二十大精神
October-December 2022
In-depth study and implementation of the spirit of the 20th Party Congress;

2022 年 11 月
获批中国气象局龙卷风重点开放实验室
November 2022
Approved the key open laboratory of tornado by China Meteorological Administration;

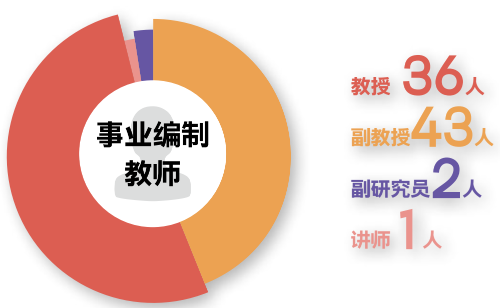
发展进程 | *Developments*

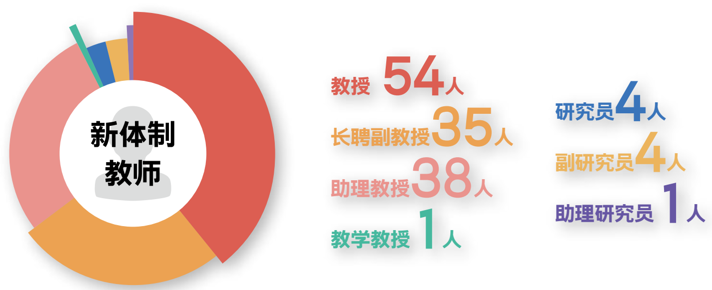
2022 年 11 月
赵凯华、陈佳洱、甘子钊、赵光达教授及周光召、王乃彦、杨国桢、杜祥琬校友获颁中国物理学会终身贡献奖
November 2022
Professors Zhao Kaihua, Chen Jiaer, Gan Zizhao, Zhao Guangda and alumni Zhou Guangzhao, Wang Naiyan, Yang Guozhen and Du Xiangwan were awarded the Lifetime Contribution Award of the Chinese Physical Society;

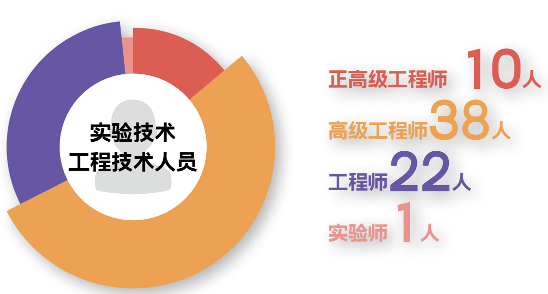
2022 年，学院师生作为第一作者或通讯作者发表 SCI 论文约 690 篇，其中在 Science 及其子刊、Nature 系列子刊、PRL、PNAS 等顶级杂志发表文章 68 篇；
In 2022, about 690 SCI papers were published by faculty and students of the School of Physics as the first author or corresponding author; 68 papers were published in international leading journals such as Science series, Nature series, PRL, PNAS, etc.;

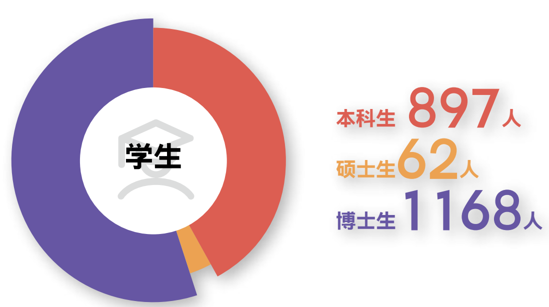
获批国家重点研发计划项目 10 项、课题 18 个，国家自然科学基金重大项目 2 项、重点项目 8 项、重大研究计划项目（集成）2 项、国家重大科研仪器研制项目 1 项、理论物理专款研究项目（重点）1 项、原创探索计划项目 3 项。
10 programs and 18 projects of national key research and development plan were approved. 2 major programs, 8 key programs , 2 major research program (integrated), 1 national major program of research instrument development, 1 research project (key) dedicated to theoretical physics, and 3 original exploration programs of National Natural Science Foundation were approved.

人员概况
General View of Personnel









下属机构
Divisions

普通物理教学中心 Teaching Center for General Physics
基础物理实验教学中心 Teaching Center for Experimental Physics

理论物理研究所 Institute of Theoretical Physics
现代光学研究所 Institute of Modern Optics
凝聚态物理与材料物理研究所 Institute of Condensed Matter and Material Physics
技术物理系 Department of Technical Physics
重离子物理研究所 Institute of Heavy Ion Physics
天文学系 Department of Astronomy
大气与海洋科学系 Department of Atmospheric and Oceanic Sciences
电子显微镜实验室 Electron Microscopy Laboratory
量子材料科学中心 International Center For Quantum Materials
科维理天文与天体物理研究所 The Kavli Institute for Astronomy and Astrophysics

基础物理国家级实验教学示范中心
National Experimental Teaching Demonstrating Center for Experimental Physics
人工微结构和介观物理国家重点实验室
State key Laboratory of Artificial Microstructure and Mesoscopic Physics
核物理与核技术国家重点实验室
State key Laboratory of Nuclear Physics and Technology

北京现代物理研究中心（北京大学高能物理研究中心）
Beijing Institute of Modern Physics (Peking University Center for High Energy Physics)
北京大学纳光电子前沿科学中心
Frontiers Science Center for Nano-Optoelectronics, Peking University

北京大学东莞光电研究院
Peking University Dongguan Institute of Optoelectronics
北京大学长三角光电科学研究院
Peking University Yangtze Delta Institute of Optoelectronics
广东省新兴激光等离子体技术研究院
Guangdong Institute of Laser Plasma Accelerator Technology

系所中心研究亮点
Highlights

01 理论物理研究所 Institute of Theoretical Physics

理论物理研究所现有教职工 21 人，其中教员（含教授、副教授、研究员等）20 人，办公行政人员 1 人。主要研究领域包括：超弦与宇宙学、粒子物理、强子物理、核物理、凝聚态理论与统计物理等，涉及自然界从宇观到介观直至微观基本粒子的各个尺度。

There are 21 members in the Institute of Theoretical Physics, consisting of 20 faculty members and one administrative staff. The research fields include string and cosmology, particle physics, hadron physics, nuclear physics, condensed matter and statistical physics，and cover from the scale of the universe down to microscopic scales of elementary particles.

一、暗物质的本质及其探索

暗物质占据了宇宙大部分的质量，其存在不仅可以解释星系旋转速度和宇宙微波背景辐射的起源，还可以为大尺度结构的形成提供关键支持。暗物质的本质仍然不为人所知，但是对理解宇宙及其演化非常重要。另外，暗物质可能由某种尚未发现的基本粒子构成，并且由于残余丰度的来源而可能与标准模型粒子具有微弱的相互作用。因此，暗物质的本质可以为粒子物理学中超越标准模型的新物理提供线索，并有助于推动物质和宇宙的基本本质的理解。

刘佳研究员课题组提出，暗光子暗物质可以在太阳日冕层中通过共振方式转化为光子，该光子的能量约等于暗光子的质量，同时其频谱峰宽非常窄，是良好的单频光谱信号。该光子信号适合目前主流射电望远镜的探测频段，其所能达到的探测精度将会优于宇宙背景辐射的间接限制，同时与地球暗物质直接探测具有极好的互补效果。该项工作发表于《物理评论快报》（Phys. Rev. Lett. 2021, 126, 181102）。

朱守华教授课题组提出了一种新的暗物质残余丰度来源的催化机制，为暗物质的理论探索和实验探测提供了新的思路和候选目标。他们的研究发现，引入新的催化机制后，暗物质与普通物质之间的相互作用比原来设想的更弱，但仍然能够得到正确的暗物质丰度。这一新机制适用于质量在 1 MeV 至 100 TeV 之间的暗物质，并伴随着独特的现象学，未来的实验观测将有助于判断其是否可行。该项工作发表于《物理评论快报》（Phys. Rev. Lett. 2021, 127, 061101）。

I. The nature and exploration of dark matter

Dark matter makes up most of the mass in the universe and its existence not only explains the rotation speeds of galaxies and the origin of cosmic microwave background radiation, but also provides crucial support for the formation of large-scale structures. The true nature of dark matter is still unknown, but it is crucial for our understanding of the universe and its evolution. Additionally, dark matter may be composed of one or more yet-to-be-discovered fundamental particles and may have weak interactions with Standard Model particles due to the source of its relic abundance. Therefore, the nature of dark matter can provide clues for new physics beyond the Standard Model of particle physics and help to push our understanding of the fundamental nature of matter and the universe.

Prof. Jia Liu's team proposed that dark photons of dark matter can be converted to photons in resonance in the solar corona, where the energy of the converted photon is approximately equal to the mass of the dark photon, and the spectral peak is very narrow, providing an excellent single-frequency spectral signal. This photon signal is suitable for the detection frequency band of the current mainstream radio telescope, and its detection accuracy can surpass the indirect limit of cosmic background radiation while having excellent complementary effects with direct detection of dark matter on Earth. This work was published in Physical Review Letters (Phys. Rev. Lett. 2021, 126, 181102).

Prof. Shouhua Zhu's team proposed a new catalysis mechanism for the relic abundance of dark matter, which provides new ideas for theoretical exploration and new candidate targets for experimental detection of dark matter. Their research found that even though the interaction between dark matter and ordinary matter is much weaker than previously assumed, the correct relic abundance of dark matter can still be obtained by introducing a new catalysis mechanism. This new mechanism is applicable to dark matter with masses between 1 MeV and 100 TeV, accompanied by unique phenomenology, and future experimental observations will help to determine its viability. This work was published in Physical Review Letters (Phys. Rev. Lett. 2021, 127, 061101).

二、 解决持续 40 余年的重要世界难题——费曼圈积分计算

北京大学强子物理团队经过 7 年努力，提出并发展“辅助质量流方法”用以计算费曼圈积分，最终把该问题彻底转换为线性代数问题，首次给出了多圈费曼积分计算这一持续了 40 余年重要世界难题的系统解决方案。最新结果发表在物理评论快报（Phys. Rev. Lett. 2022, 129, 222001），北京大学博士研究生刘志峰为第一作者，马滟青副教授为通讯作者。

辅助质量流方法在传播子分母中引入辅助质量 η，当 η 趋于无穷大的时候一般性费曼积分变为了较容易的单质量真空费曼积分。利用费曼积分之间的线性关系，可以建立起费曼积分关于 η 的线性常微分方程组；再结合上述 η 趋于无穷大时的边界条件可求解得到 η 趋于零时的值，即得到了原始费曼积分的值。数值求解线性常微分方程组是一个早已解决的数学问题，能够完全系统化且效率极高。因此，只要有了相对简单的单质量真空费曼积分的输入，即可系统化地计算一般性的费曼积分。

而单质量真空费曼积分与有两条外线但少了一个圈的费曼积分等价。而为了计算有两条外线的费曼积分，利用辅助质量流把它转化为相同圈数的单质量真空费曼积分问题。由此可见，为了计算给定圈数的单质量真空费曼积分，除了线性代数信息外只需要把少一圈的单质量真空费曼积分作为输入；

不断地循环利用这一关系，最终只需要线性代数信息作为输入。因此，一般性费曼积分计算问题被简化为线性代数问题。

基于上述方法已撰写并开源程序 AMFlow，可自动化计算任意费曼积分，程序发布一年以来已被国内外同行用于数十个前沿微扰场论物理问题的计算。2022 年 11 月 30 日，《科学》(Science) 杂志长篇专题报道了这一进展（http://doi.org/10.1126/science.adg0720），文中指出费曼圈积分是持续了几十年的重要世界难题，而该团队的方法给出了解决方案；受采访的微扰场论国际著名专家美因茨大学 Stefan Weinzierl 教授指出，该方法原则上普适于任何场景，可用以处理任意费曼积分，运用效果好得令人惊讶。

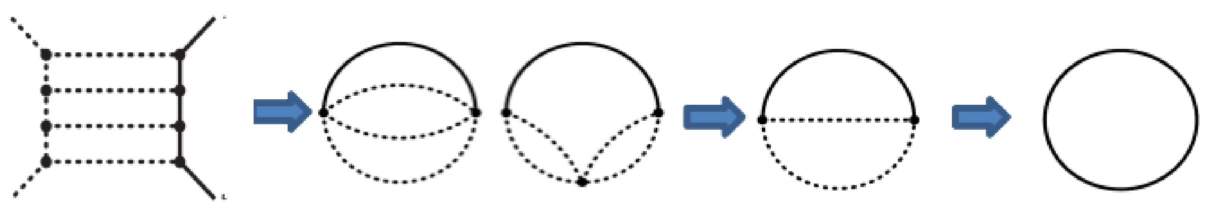


图 1. 方法示意图。

Fig 1. Schematic diagram for the method.

II. The long-standing world problem of multi-loop Feynman integral calculations resolved

After seven years of effort, the Peking University team on hadron physics has proposed and developed the "Auxiliary Mass Flow Method" to calculate Feynman loop integrals. Ultimately, the team transformed the problem into a linear algebraic problem and provided a systematic solution to the long-standing world problem of multi-loop Feynman integral calculations, which had lasted for more than 40 years. The latest results were published in Physical Review Letters (Phys. Rev. Lett. 2022, 129, 222001) , with Zhi-Feng Liu, a Ph.D. candidate at Peking University, as the first author and Associate Professor Yan-Qing Ma as the corresponding author.

The auxiliary mass flow method introduces an auxiliary mass η into the propagator denominator. As η approaches infinity, the general Feynman integral becomes a relatively easy single-mass vacuum Feynman integral. By establishing a system of linear differential equations for the Feynman integrals with respect to η, based on the linear relations between Feynman integrals, and combining the boundary conditions when η tends to infinity, the value of the original Feynman integral as η tends to zero can be achieved by solving the differential equations. Numerically solving the linear differential equations is a well-established mathematical problem that can be completely systematized and highly efficient. Therefore, general Feynman integrals can be systematically calculated once single-mass vacuum Feynman integrals are known.

Single-mass vacuum Feynman integrals are equivalent to Feynman integrals with two external lines but one fewer loop. To calculate Feynman integrals with two external lines, the auxiliary mass flow is used to transform it into a single-mass vacuum Feynman integral problem with the same number of loops. Therefore, to calculate a given number of loops for single-mass vacuum Feynman integrals, besides linear algebraic information, only single-mass vacuum Feynman integrals with one fewer loop are required as input. By recursively utilizing this relationship, the general Feynman integral calculation problem is ultimately simplified into a linear algebraic problem.

Based on the above method, the team has written and open-sourced the program AMFlow, which can automate the calculation of any Feynman integral. Since its release a year ago, the program has been used by domestic and foreign peers to calculate dozens of cutting-edge perturbative field theory physics problems. On November 30, 2022, Science magazine reported on this development in a lengthy article (http://doi.org/10.1126/science.adg0720), stating that Feynman loop integral calculation is a long-standing world problem and that the team's method provides a solution. Professor Stefan Weinzierl, an internationally renowned expert in perturbative field theory at the University of Mainz, who was interviewed for the article, pointed out that the method is general enough and can be used to handle any Feynman integral, with surprisingly good results.

三、准晶和非晶体中的拓扑物态研究进展

拓扑物态具有独特的体 - 边对应关系，即在比体态低一维的边缘或表面上受拓扑保护的边界态。作为拓扑晶体绝缘体概念的扩展，高阶拓扑绝缘体具有受晶体对称性保护的无能隙角模或铰链模态。通常来说，描述高阶拓扑态的基本理论框架是在倒易空间中的特殊动量点建立的。然而，动量在准晶和非晶体等非周期体系中不再是好量子数，且准晶具有与晶体不相容的旋转对称性，使得传统理论框架难以被推广到非周期体系。

黄华卿研究员与合作者利用新型傅里叶变换且考虑长波近似，构建了适用于准晶的低能有效模型来描述准晶赝布里渊区中心的拓扑电子结构。基于该有效模型，联合研究团队发现，在二维准晶拓扑绝缘体中，面内塞曼场可以诱导出相邻边缘的质量扭结并产生具有分数电荷的拓扑角模态。该研究将质量扭结导致的高阶拓扑态扩展到准晶，同时提供了研究准晶体低能物理的一个通用的理论框架。该成果发表于《物理评论快报》（Phys. Rev. Lett. 2022, 129, 056403）。

此外，为了揭示结构无序诱导的拓扑相变机理，黄华卿研究员与合作者利用准晶格模型与紧束缚模拟相结合的方法，发现在适当条件下结构非晶化可以在拓扑平庸的晶体中诱导出非平庸的电子拓扑态，并以非晶化锡烷为例证实了其中结构无序导致的拓扑相变，将传统材料工程中的非晶化方法拓展到实现拓扑态的新领域。该项工作发表于《物理评论快报》（Phys. Rev. Lett. 2022, 128, 056401）。

III. Research progress on topological states in quasicrystalline and amorphous systems

The topological state of matter has a unique bulk-boundary correspondence, that is, a topologically protected gapless state exists on the boundary that is one dimension lower than the bulk. As an extension of the topological crystalline insulator, higher-order topological insulators have gapless corner or hinge modes protected by crystalline symmetry. In general, the basic theoretical framework for describing higher-order topological states is established at special momenta in the reciprocal space. However, momentum is no longer a good quantum number in aperiodic systems such as quasicrystals and amorphous ones, and quasicrystals have rotational symmetry that is incompatible with crystals, making it difficult for traditional theoretical frameworks to be generalized to aperiodic systems.

Huaqing Huang and collaborators used the novel Fourier transform and considered the long-wave approximation to construct a low-energy effective model suitable for quasicrystals to describe the topological electronic structure of quasicrystalline pseudo-Brillouin zone centers. Based on this effective model, the joint research team found that in two-dimensional quasicrystalline topological insulators, the in-plane Zeeman field can induce mass kinks of adjacent edges and generate topological angular modes with fractional charges. This study extends the higher-order topological states caused by mass kinks to quasicrystals and provides a general theoretical framework for studying the low-energy physics of quasicrystals. The results were published in Physical Review Letters (Phys. Rev. Lett. 2022, 129, 056403).

In addition, to reveal the mechanism of topological phase transition induced by structural disorder, Huang Huaqing and collaborators used the combination of a quasi-lattice model and tight-binding simulation to find that structural amorphization can induce topologically nontrivial electronic states in normal crystals under appropriate conditions and confirmed the topological phase transition caused by structural disorder by taking amorphous stannane as an example, expanding the amorphous method in traditional materials engineering to a new field of topological state. The work was published in Physical Review Letters (Phys. Rev. Lett. 2022, 128, 056401).

02 凝聚态物理与材料物理研究所 Institute of Condensed Matter and Material Physics

凝聚态物理与材料物理研究所现有教职工 60 人，其中，教授 21 人，副教授 18 人，预聘制助理教授 6 人， 研究技术人员 2 人，工程技术人员 13 人。 研究队伍中包括院士 6 人，长江特聘教授 6 人，国家杰出青年 13 人。研究领域包括宽禁带半导体物理和器件，凝聚态理论，纳米半导体与半导体光子学，微纳光子学及近场微区光谱，高温超导材料、物理与器件，纳米结构和低维物理，软凝聚态物理和生物物理，以及磁性物理和新型磁性材料。

There are 60 faculty members in the Institute of Condensed Matter and Material Physics, consisting of 21 professors, 18 associate professors, 6 tenure-track assistant professors, 2 research technicians and 13 engineering technicians. Among the senior researchers are 6 academicians of the CAS, 6 Chang Jiang scholar professors，and 13 national distinguished young scholars. The research fields cover a wide range include wide bandgap semiconductor physics and devices, theoretical condensed matter physics, nanosemidonductors and semiconductor photonics, nanophotonics and near-field optics, high-temperature superconducting physics, materials and devices, nanostructures and low-dimensional physics, soft condensed matter physics and biophysics, and magnetism physics and advanced magnetic materials.

一、二维半导体面内外延的新制备方法

二维层状半导体材料在具有几个原子层厚度的同时能够保持较高载流子迁移率，因而成为抑制短沟道效应、进一步缩小晶体管尺寸的重要备选材料。基于大面积集成电路对于半导体器件性能以及均一性的要求，在器件基底上直接制备晶圆尺寸连续的二维半导体单晶材料是产业界、科研界亟待解决的科学和技术问题。为此，叶堉课题组与合作者提出了一种利用相变和重结晶过程制备晶圆尺寸单晶半导体相 2H-$MoTe_2$ 薄膜的新方法（Science 2021, 372, 195-200）。首先，通过定向转移技术将机械剥离的单晶 2H-$MoTe_2$ 纳米片作为诱导相变的籽晶转移到 1T'-$MoTe_2$ 晶圆的正中央，通过面内二维外延实现了单一成核相变生长的单晶 2H $MoTe_2$ 薄膜（图 1）。整个相变过程伴随着以异质界面处 2H-$MoTe_2$ 为模板的重结晶过程，使得相变后的整个薄膜的晶格结构和晶格取向与籽晶完全一致，最终得到晶圆尺寸的单晶 $MoTe_2$ 薄膜。该工作入选“2021 年度中国半导体十大研究进展”。

由于平面内的二维外延技术打破了晶格匹配和结构对称性对单晶半导体制备的限制，由此我们开发了一种新的异质外延范式，即一种在任意结构（高度晶格失配的基底或任意三维架构）上直接异质外延单晶二维半导体的方法（图 2），从而有望发展前所未有的集成技术与器件功能（Nature Synth. 2022, 1, 701-708）。该工作被推荐参评“2022 年度中国半导体十大研究进展”。

I. New synthesis paradigm of two-dimensional semiconductor in-plane epitaxy

Two-dimensional (2D) layered semiconductors can maintain high carrier mobility while having a thickness of several atomic layers, so they become important candidates for suppressing short-channel effects and further scaling the size of transistors. Based on the requirements of large-area integrated circuits for the high performance and uniformity of semiconductor devices, it is a scientific and technical problem to be solved urgently to directly synthesize continuous wafer-scale 2D single-crystal semiconductors on the device substrate. Thus, Yu Ye's research group and collaborators proposed a new method to prepare wafer-sized single-crystal semiconductor 2H-$MoTe_2$ thin films using phase transition and recrystallization processes (Science 2021, 372, 195-200). First, the mechanically exfoliated single-crystal a 2H-MoTe2 nanoflake was transferred to the center of the 1T'-$MoTe_2$ wafer as seeds for induced phase transition by directional transfer technique, and a single-nucleation phase-transition-grown single crystal was achieved by in-plane 2D epitaxy of 2H-$MoTe_2$ thin film (Fig 1). The entire phase transition process is accompanied by the recrystallization process using the 2H-$MoTe_2$ at the hetero-interface as a template so that the lattice structure and lattice orientation of the entire film after phase transition are consistent with the seed crystal. Finally, a wafer-sized 2H-$MoTe_2$ single crystal is obtained. This work was selected as one of the " Top Ten Research Progresses in China's Semiconductors in 2021".

Since the in-plane 2D epitaxy technology breaks the constraints of lattice matching and structural symmetry on the preparation of single-crystal semiconductors, we have developed a new heteroepitaxy paradigm, that is, directly heteroepitaxial single-crystal 2D semiconductor on arbitrary structures (including highly lattice-mismatched substrates and arbitrary 3D architectures, Fig 2), which is expected to develop unprecedented integration technology and device functionalities (Nature Synth. 2022, 1, 701-708). This work is recommended to the "Top Ten Research Progresses in China's Semiconductors in 2022".

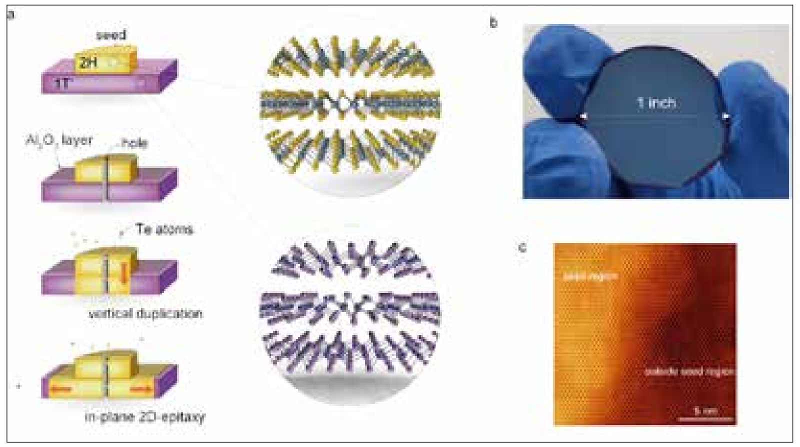


图 1. 晶圆级二维半导体单晶。a，晶圆尺寸单晶 $MoTe_2$ 薄膜的制备过程示意图。b，制备的 $MoTe_2$ 薄膜的光学照片。c，种子区域的 STEM 表征。

Fig 1. Wafer-scale 2D semiconductor single crystal. a, Schematic diagram of the fabrication process of wafer-sized single-crystal $MoTe_2$ thin films. b, Optical photograph of the prepared $MoTe_2$ thin film. c, STEM characterization of the seed region.

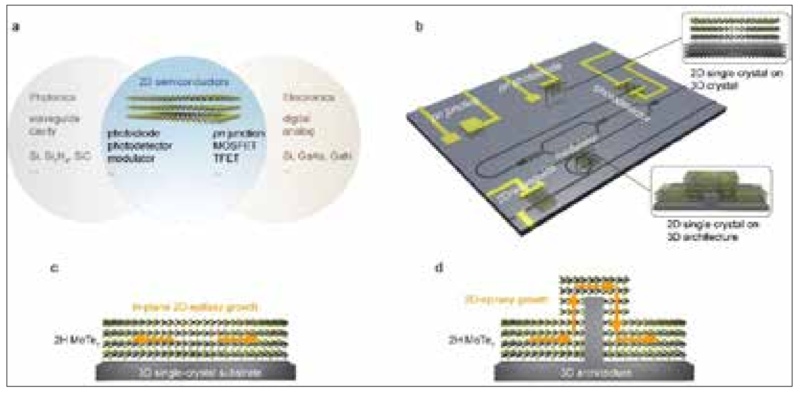


图 2. 与任意架构集成的半导体 2H-$MoTe_2$ 异质外延技术。a，二维半导体与传统电子和光子学集成以增强功能。b，在平面和 3D 架构上直接制备的二维半导体集成光电芯片示意图。c、d，单晶 2H-$MoTe_2$ 在 3D 单晶基底和 3D 架构上的外延示意图。

Fig 2. 2H-$MoTe_2$ semiconductor heteroepitaxially integrated with arbitrary architectures. a, 2D semiconductors integrated with conventional electronics and photonics for enhanced functionality. b, Schematic diagram of a 2D semiconductor-integrated optoelectronic chip directly fabricated on planar and 3D architectures. c, d, Schematic diagram of epitaxy of single-crystal 2H-$MoTe_2$ on 3D single-crystal substrate and 3D architecture.

二、量子蒙特卡洛方法的发展及凝聚态物理前沿交叉应用

量子蒙特卡洛是一种用于解决复杂系统的薛定谔方程的数值方法。它涉及使用蒙特卡洛方法对波函数空间进行采样，通过最小化试波函数的能量来计算量子力学体系的基态或激发态性质。该方法广泛应用于凝聚态物理，量子化学和材料科学及其交叉体系的研究中。近期，陈基课题组与合作者结合机器学习方法提出了一系列新的量子蒙特卡洛算法，大大提升了传统量子蒙特卡洛的精度、效率和适用范围，（1）提出了新的适用于周期性体系的 DeepSolid 神经网络波函数模型（Nat. Commun. 2022, 13, 7895）；（2）将神经网络波函数引入扩散量子蒙特卡洛，开发了新的量子蒙特卡洛计算框架 JaQMC（图 1）（arXiv:2204.13903, 2022, Nat. Commun. In press）；（3）在机器学习量子蒙特卡洛中发展了原子有效核势方法（Phys. Rev. Research 2022, 4, 013021）；（4）首次实现了机器学习量子蒙特卡洛中原子间作用力的计算（J. Chem. Phys. 2022, 157, 164104）。

基于先进的计算方法，陈基课题组在水、冰和碳等前沿交叉领域取得重要进展。主要包括:（1）与合作者对高纯单晶立方冰的生长机制进行了深入的探索，为立方冰与六角冰的竞争生长机理和立方冰的缺陷结构及动力学提供了理论描述（Nature 2023, 617, 86–91）；(2) 与理论合作者共同重构了二维冰的温压相图（Nature 2022, 609, 512）；(3) 与实验合作者共同发现了核量子效应诱导的二维冰氢键对称化（Science 2022, 377, 315）；(4) 与实验合作者共同揭示了二维非晶碳中存在一种特有的无序度，并首次建立了二维非晶碳中无序度和导电性的构效关系（Nature 2023, 615, 56）。

II. Developments and applications of quantum Monte Carlo methods in frontier and interdisciplinary research of condensed matter physics

Quantum Monte Carlo (QMC) is a numerical method used to solve the Schrödinger equation for complex systems. It involves minimizing the energy of a trial wave function by sampling configurations of particles using Monte Carlo methods. This allows for the calculation of ground state properties and excited states of quantum mechanical systems. QMC is widely used in condensed matter physics, quantum chemistry, and materials science research. Recently, Ji Chen's group and their collaborators have proposed a series of new QMC algorithms based machine learning technology, which greatly improve the accuracy, efficiency and applicability of quantum Monte Carlo methods. The main progresses include: (1) proposing the DeepSolid periodic neural network wave function model (Nat. Commun. 2022, 13, 7895); (2) introducing neural network wave function into the diffusion quantum Monte Carlo method and developing a new QMC package (JaQMC) (arXiv:2204.13903, 2022, Nat. Commun. In press); (3) developing the effective core potential method in machine learning quantum Monte Carlo (Phys. Rev. Research 2022, 4, 01302); (4) achieving for the first time the calculation of inter-atomic force in machine learning QMC (J. Chem. Phys. 2022, 157, 164104).

Based on the advanced computational methods, Ji Chen's group have made important breakthroughs in the study of interdisciplinary areas of water, ice and carbon. The main progresses include, (1) carrying out deep analyses of the growth mechanism of highly pure single-crystalline cubic ice and providing new theoretical description to the competing growth of cubic ice and hexagonal ice and the dynamics of defects in cubic ice (Nature 2023, 617, 86–91); (2) establishing the temperature-pressure phase diagram of two-dimensional ice with other theoreticians

(Nature 2022, 609, 512); (3) finding symmetric hydrogen bonds in two-dimensional ice due to nuclear quantum effects in collaboration with experimental researchers (Science 2022, 377, 315); (4) revealing a new type of disorder in two-dimensional amorphous carbon and establishing the structure-property relationship with experimental researchers (Nature 2023, 615, 56).

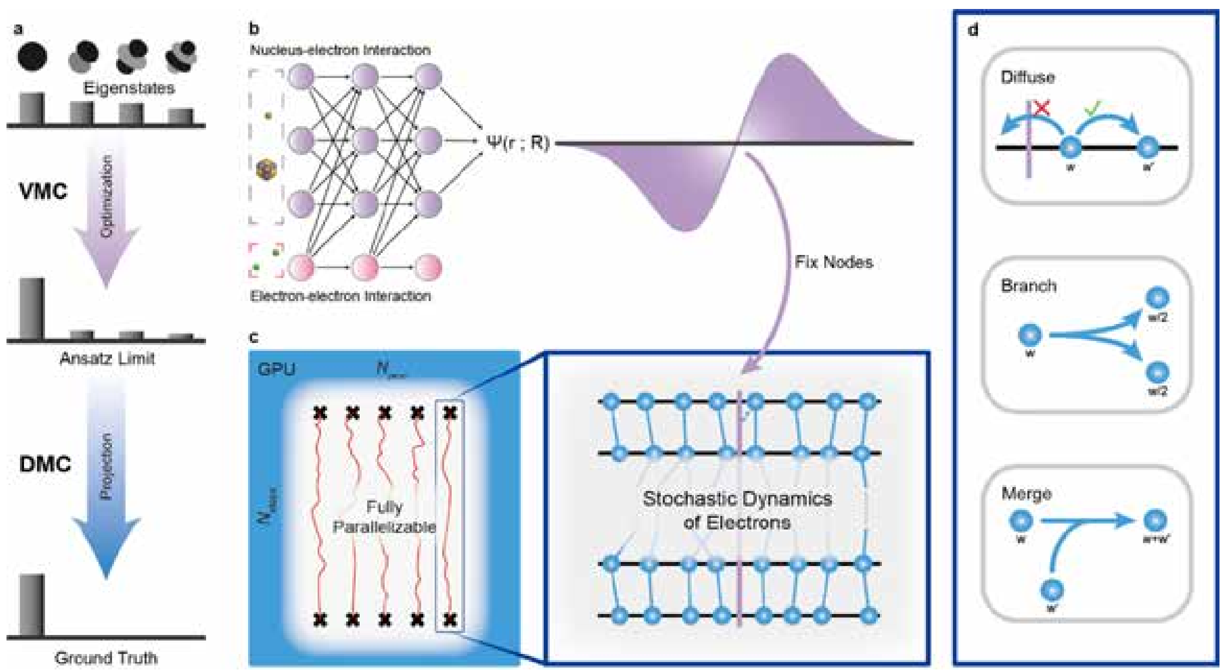


图 1. 基于神经网络的机器学习量子蒙特卡洛框架 JaQMC 示意图。

Fig 1. The JaQMC framework of machine learning quantum Monte Carlo based on neural network.

三、人工智能助力时间分辨冷冻电镜发现重大药物靶点动力学调控机制

生命分子机器通过高度复杂的非平衡动力学过程和结构变化来实现其特殊功能，如蛋白酶体通过一系列复杂的构象变化介导真核细胞内约 80% 蛋白质的降解，对于维持细胞内蛋白质稳态和正常的细胞功能至关重要，蛋白酶体的功能失调与癌症和神经退行性疾病的发生发展密切相关。因此，精准观察蛋白酶体的功能复合动力学为靶向药物的设计提供了传统技术难以获取的复合物动态标底，将推动新一轮原研药重大创新。

在人体细胞中，蛋白酶体的功能受到多个水平的严格调控。去泛素化酶 USP14 是最主要的蛋白酶体调控分子，被认为是一个潜力巨大的治疗癌症和神经退行性疾病的重要靶标，其小分子抑制剂曾进入过美国一期临床研究，但围绕 USP14 功能机制的一系列悬而未决的关键问题极大限制了其靶向药物分子的开发和临床应用。USP14 通过结合蛋白酶体而被激活，然后以毫秒的时间尺度剪切底物上的泛素链。它是如何被蛋白酶体激活并调控蛋白酶体功能的，一直是全球研究机构和生物制药界期待解决的关键科学问题。毛有东课题组利用自主研发的深度学习高精度四维重建技术，发展并应用时间分辨冷冻电镜技术，捕获了 USP14- 蛋白酶体复合物降解多泛素化底物过程的 13 种不同功能中间状态的高分辨率（3.0~3.6 埃）非平衡构象，通过时间分辨冷冻电镜分析，重建了受控蛋白酶体的完整动力学工作周期（图 1），并结合分子生物学功能和基因突变研究，阐明了 USP14 和蛋白酶体相互调控活性的原子结构基础和非平衡动力学机制。相关研究工作发表于《自然》杂志（Nature, 2022, 605, 7910）。

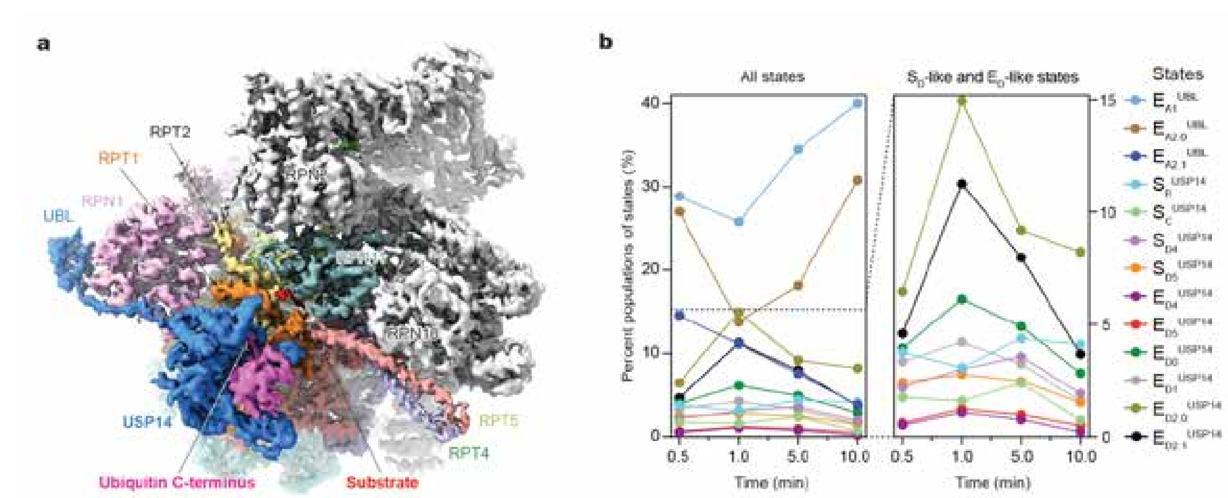


图 1. (a) USP14 调控下蛋白酶体复合体降解多泛素化底物的原子结构模型之一。(b) 时间分辨率冷冻电镜解析 13 种中间态的统计分布随蛋白质降解进程的时间演化。

Fig 1. (a) One of the atomic structure models for the degradation of polyubiquitinated substrates by USP14 regulated proteasome complexes. (b) Analysis of the statistical distribution of 13 intermediate states with time-resolved cryo-electron microscopy and its time evolution in protein degradation process.

III. Artificial intelligence assists time-resolved Cryo-EM to discover the mechanism of dynamic regulation of major drug targets

The life molecular machine achieves its specific functions through highly complex non-equilibrium kinetic processes and structural changes. For example, proteasomes mediate about 80% proteins degradation in eukaryotic cells through a series of complex conformational changes, which is essential for maintaining intracellular protein homeostasis and normal cellular functions. Dysfunction of proteasomes is closely associated with the occurrence and development of cancer and neurodegenerative diseases. Therefore, precise observation of the complex kinetics of functional proteasome can provide a composite dynamic substrate for design of targeted drugs that is difficult to obtain by traditional techniques, and will drive a new round of major innovation in prodrugs.

In human cells, proteasome function is tightly regulated at multiple levels. The deubiquitinating enzyme USP14 is the predominant proteasome regulatory molecule and

系所中心研究亮点 | *Highlights*

is considered an important target with great potential for the treatment of cancer and neurodegenerative diseases, whose small molecule inhibitors have entered phase I clinical studies in the U.S. However, a series of unresolved key questions surrounding the functional mechanism of USP14 have greatly limited the development and clinical application of its targeted drug. USP14 is activated by binding to the proteasome, which then shears the ubiquitin chain on the substrate on a millisecond time scale. How it is activated by the proteasome and regulates proteasome function has been a key scientific question expected to be addressed by research institutions and the biopharmaceutical community worldwide. Using the self-developed deep-learning high-precision four-dimensional reconstruction technique, Youdong Mao's group developed and applied time-resolved cryo-electron microscopy to capture the high-resolution (3.0~3.6 Å) nonequilibrium conformations of 13 different functional intermediate states of the USP14-proteasome complex during degradation of polyubiquitinated substrates, and reconstructed the complete kinetics work cycle of the regulated proteasome by time-resolved cryoelectron microscopy analysis. Combining molecular biological function and gene mutation studies, the group has also elucidated the atomic structural basis and non-equilibrium kinetic mechanism of interaction between USP14 and proteasome. The related work was published in Nature (Nature, 2022, 605, 7910).

四、 基于界面原子架构的石墨烯上准范德华外延氮化镓薄膜晶格极性调控机制

“界面即器件”，界面是器件设计的基础，也是材料生长控制的核心。一直以来，在半导体研究中金属 / 半导体界面、异质半导体之间的界面始终是研究的重点。近年来，基于以石墨烯为代表的二维材料上的半导体外延技术，可以规避来自衬底的晶体学限制，制备出不依赖于衬底的、可剥离转印的薄膜材料，及新结构、新功能光电器件。到目前为止，单晶氮化物，如氮化铝 (AlN) 和新型薄膜器件，已经通过远程外延或准范德华外延在具有石墨烯缓冲层的衬底上实现。

但是，目前关于“二维材料与半导体材料界面耦合机制及调控方法”这一关键科学问题的认知尚不充分，导致氮化物外延薄膜主要具有金属晶格极性。氮极性外延薄膜制备困难及极性调控机理不清晰阻碍了薄膜外延、器件工艺范式的建立，不利于氮化物半导体准范德华外延体系的产业化发展进程。针对这一关键科学问题，宽禁带半导体研究中心王新强课题组联合李新征课题组和刘开辉课题组通过氧原子辐照 graphene 上 GaN 外延的界面成键机制研究，发展了一种 GaN 外延层晶格极性界面原子构型调控模型。基于分子束外延原位氧辐照技术及原子优先供给方法，通过形成 C-O-N-Ga(3) 界面原子构型的方法在单晶 graphene/ 蓝宝石模板上成功制备出易剥离转印的金属晶格极性 GaN 薄膜，通过形成 C-O-Ga-N(3) 界面原子构型的方式制备出氮晶格极性 GaN 薄膜，验证了界面原子构型调控模型的正确性。通过球差矫正透射电子显微镜证明在含氧环境中制备 AlN 中间层时，自然形成的 AlON 晶格极性反转层将屏蔽界面原子构型的调制效果，锁定上层 GaN 薄膜的金属晶格极性，回答了“二维材料上采用 AlN 作为成核层时倾向得到金属极性氮化物薄膜”这一问题。上述工作可为二维材料上氮化物半导体准范德华外延体系的发展提供界面理论指导，推动新型垂直结构氮化物光电器件等研发工作。相关研究成果发表于《先进材料》（Adv. Mater. 2022, 34, 2106814），并作为当期扉页文章（Frontispiece）做简要介绍。

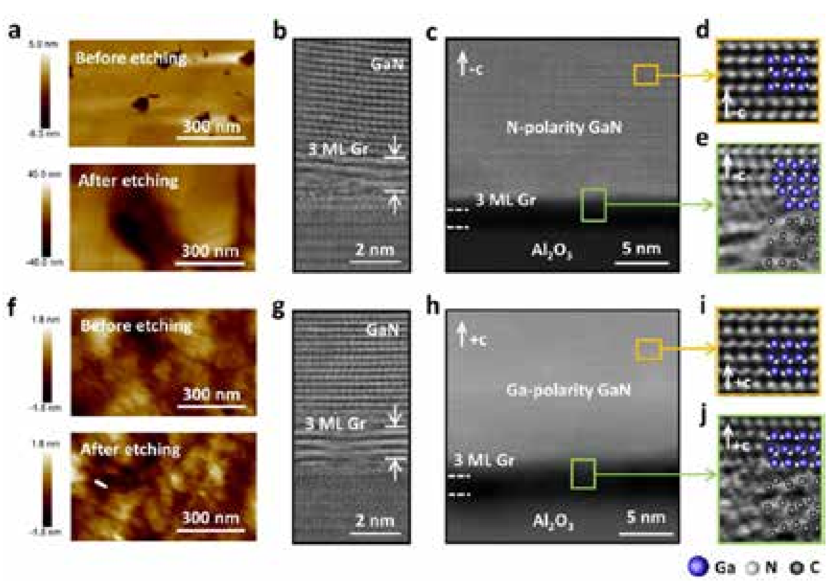


图 1. (a-e) 基于 C-O-Ga-N(3) 界面原子构型，在三原子层厚单晶 graphene/ 蓝宝石模板上实现氮晶格极性 GaN 薄膜；(f-j) 基于 C-O-N-Ga(3) 界面原子构型，在三原子层厚单晶 graphene/ 蓝宝石模板上成功实现金属晶格极性GaN薄膜。

Fig 1. (a-e) Based on the C-O-Ga-N(3) interfacial atom configuration, a nitrogen lattice polarity GaN film is realized on the 3-ML-thick single crystal graphene/sapphire template; (f-j) Based on the C-O-N-Ga(3) interfacial atom configuration, a metal lattice polarity GaN film is realized on the 3-ML-thick single crystal graphene/sapphire template.

IV. Lattice polarity manipulation of quasi-vdW epitaxial GaN films on graphene through interface atomic configuration

The interface is the device, which is the foundation of device design and the core of material growth. The metal/semiconductor interface and the interface between heterostructure of semiconductors have always been the focus in semiconductor research. In recent years, the semiconductor epitaxy technology, based on two-dimensional materials represented by graphene, provides a way, in principle, to achieve single-crystal epilayers with preferred atom configurations that are free of substrate, which promotes the development of transferable thin films, as well as novel structure and functional optoelectronic devices. So far, single crystal nitrides, such as aluminum nitride (AlN) and novel thin film devices, have been achieved through remote epitaxy or quasi van der Waals epitaxy on substrates with graphene buffer layers.

Unfortunately, this has not been experimentally confirmed in the case of the hexagonal semiconductor III-nitride epilayer until now. The difficulty in preparing nitrogen polar epitaxial films and unclear polarity control mechanisms hinder the establishment of film epitaxy and device process, which is not benefit for the industrialization of quasi van der Waals epitaxy of nitride semiconductors. Xinqiang Wang's group at Research Center for Widegap Semiconductor in School of Physics, collaborated with Xizhen Li's group and Kaihui Liu's group in School of Physics, in School of Physics have demonstrated the epitaxy of gallium nitride (GaN) on graphene can tune the atom arrangement (lattice polarity) through manipulation of the interface atomic configuration, where GaN films with gallium and nitrogen polarity are achieved by forming C-O-N-Ga(3) or C-O-Ga-N(3) configurations, respectively, on artificial C-O surface dangling bonds by atomic oxygen pre-irradiation on trilayer graphene. Furthermore, an aluminum nitride buffer/interlayer leads to unique metal polarity due to the formation of an AlON thin layer in a growth environment containing trace amounts of oxygen, which explains the open question of why those reported wurtzite III-nitride films on 2D materials always exhibit metal polarity. The reported atomic modulation through interface manipulation provides an effective model for hexagonal nitride semiconductor layers grown on graphene, which definitely promotes the development of novel vertical optoelectronic devices. The work was published in Advanced Materials (Adv. Mater. 2022, 34, 2106814) and shown as a Frontispiece article for the current issue.

五、轨道 Rashba-Edelstein 磁电阻效应研究

电流诱导力矩可以高效实现电流驱动的畴壁移动及磁矩翻转，在自旋电子学领域具有重要的研究意义，有望实现新型高效的磁存储器件。目前，大多数研究局限于具有强自旋轨道耦合的重金属体系中，重金属中的电流通过自旋霍尔效应产生自旋流，自旋流与铁磁矩交换角动量进而诱导自旋轨道力矩。然而，不具备强自旋轨道耦合的轻金属体系一般并不会产生自旋霍尔效应，因此轻金属材料中很难产生自旋轨道力矩效应。通常来讲，自旋流的产生强烈依赖于自旋轨道耦合，而轨道角动量的积累并不依赖于体系的自旋轨道耦合。虽然在基态下轨道流会快速淬灭，但是在电场的作用下轨道角动量的积累依然可能存在，这表明相较于自旋流，轨道流在材料体系中会更加本征。此外，理论研究表明在强自旋轨道耦合的体系中，轨道流可以有效的转换为自旋流，所以实验上如何利用轨道流进一步提高自旋流的转换效率成为研究的关键。

近日，北京大学物理学院杨金波课题组，在自旋电子学领域取得了重要进展。该工作针对氧化铜体系中的轨道 Rashba-Edelstein 效应展开研究，首次观察到轨道 Rashba-Edelstein 效应诱导的新型磁电阻效应，表明不具备强自旋轨道耦合的体系中仍可以利用电流诱导产生力矩。2022 年 2 月 10 日相关成果以“Observation of the Orbital Rashba-Edelstein Magnetoresistance”为题，发表在《物理评论快报》（Phys. Rev. Lett. 2022, 128, 067201），并被选为编辑推荐文章 (Editors'

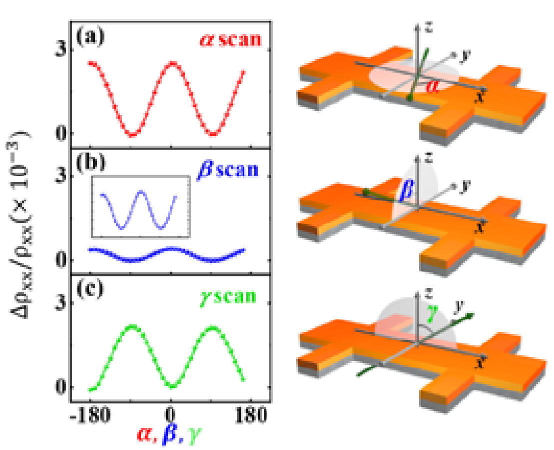


图 1. (a)-(c) CuO_x(3 nm)/Py(5 nm) 异质结构在三个旋转平面 (α, β, γ) 内的磁电阻效应 (300 K, 6 T)，右侧为霍尔结构示意图以及旋转角度的定义。其中，γ 平面内的磁电阻为各向异性磁电阻效应，β 平面内的磁电阻为轨道 Rashba-Edelstein 磁电阻效应，α 平面内的磁电阻为 β 与 γ 平面内磁电阻效应之和。

Fig 1. (a)-(c) The angular dependent MR measurements in Py(5) / Cu*(3) heterostructure at 300 K and 6 T in the three -rotation planes (). The schematics on the right show the sample Hall bar and the definition of the axes, angles, and measurement configuration. is the MR ratio collected in different -rotation planes. The inset in (b) shows a zoom for the MR signal in the yz plane.

Suggestion)。

该论文研究了氧化铜 (CuO_x) / 坡莫合金 (Py) 体系中的电流诱导力矩效应，研究团队发现该体系中存在类似于自旋霍尔磁电阻（Phys. Rev. Lett. 2013, 110, 206601）的磁电阻效应，如图 1 所示。CuO_x/Py 体系在 yz 平面内的磁电阻效应被认为是轨道 Rashba-Edelstein 磁电阻效应，通过改变 Py 的厚度，CuO_x/Py 体系中的磁电阻效应相对于 Pt/Py 体系呈现出更加缓慢的衰减趋势 (如图 2 所示)。利用自旋模型对数据进行拟合分析，结果表明 CuO_x/Py 体系中具有较长的有效自旋散射长度，说明自旋流不是引起磁电阻的主要因素，进一步证明体系中的轨道 Rashba-Edelstein 效应的存在。该工作表明部分轻金属 (氧化物) 可以通过轨道霍尔效应和轨道 Rashba-Edelstein 效应来诱导电流力矩的产生，进而研发高效率、低成本的自旋轨道力矩器件。

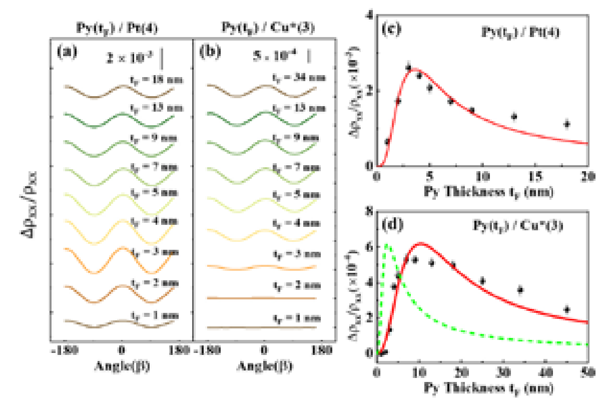


图 2. (a)-(b) 6 T 磁场下，Pt(4 nm)/Py(t_F) 和 CuO_x(3 nm)/Py(t_F) 在 β 平面内的磁电阻效应。(c)-(d) 两个体系中磁电阻比率随 Py 厚度的变化关系。其中，红色曲线是数据的拟合曲线， 绿色虚线曲线表示将 Py 的自旋散射长度带入公式后获得的磁电阻与 Py 厚度的变化关系，表明体系中的磁电阻效应不来自于自旋流。

Fig 2. (a) and (b) The ORMR measurements in the scan for Py(t_F) / Pt(4) and Py(t_F) / Cu*(3) at 6 T. (c) and (d) plots of the Py thickness dependence of the MR ratio taken from (a) and (b), respectively. The red curves are the fitting curves of the data. The green dashed curve in (d) is the fitting by forcing the effective relaxation length of Py to match the value taken from the Py/Pt samples, which shows a significant deviation from the obtained data.

V. Study on the magnetoresistance of orbital Rashba-Edelstein effect

Current-induced torque can efficiently achieve current-driven domain wall movement and magnetic moment reversal, which has essential research significance in spin electronics and is expected to achieve new and efficient magnetic storage devices. However, most studies are limited to heavy metal systems with strong spin-orbit coupling. The current in heavy metals generates a spin current through the spin Hall effect, which exchanges angular momentum with ferromagnetic moments to induce spin-orbit moments. However, light metal systems that do not have strong spin-orbit coupling generally do not generate spin-Hall effects, so it is challenging to generate spin-orbit torque effects in light metal materials. Generally speaking, the generation of spin current strongly depends on spin-orbit coupling, while the accumulation of orbital angular momentum does not depend on the spin-orbit coupling of the system. Although the orbital current rapidly quenches in the ground state, the accumulation of orbital angular momentum may still exist under an electric field, indicating that orbital current is more intrinsic in material systems than spin current. In addition, theoretical studies have shown that in systems with strong spin-orbit coupling, orbital currents can be effectively converted into spin currents. Therefore, how to use orbital currents to further improve the conversion efficiency of spin currents in experiments has become the key to research.

系所中心研究亮点 | *Highlights*

Recently, the Yang Jinbo's Group of the School of Physics of Peking University has made significant progress in spintronics. This work focuses on studying the orbital Rashba-Edelstein effect in copper oxide systems. A novel magnetoresistance effect induced by the orbital Rashba-Edelstein effect has been observed for the first time, indicating that current induction can still generate torque in systems without strong spin-orbit coupling. On February 10th, 2022, related achievements were published in the Physical Review Letters (Phys.Rev.Lett. 2022,128.067201), and was selected as Editor's Suggestion.

This paper studied the current-induced torque effect in the copper oxide (CuO_x)/permalloy (Py) system. The research team found a spin Hall magnetoresistance similar to that in the system (Phys. Rev. Lett. 2013,110, 206601). The magnetoresistance effect is shown in Fig 1. The magnetoresistance effect of the CuOx/Py system in the y-z plane is considered to be the orbital Rashba Edelstein magnetoresistance effect. By changing the thickness of Py, the magnetoresistance effect in the CuO_x/Py system exhibits a slower attenuation trend than the Pt/Py system (as shown in Fig 2). Using a spin model to fit and analyze these data, the results show that the CuO_x/Py system has a longer effective spin scattering length, indicating that spin current is not the main factor causing magnetoresistance, further proving the existence of the orbital Rashba Edelstein effect in the system. This work shows that some light metals (oxides) can generate current torque through the orbital Hall effect and the orbital Rashba-Edelstein effect, thereby can be used to develop high-efficiency and low-cost spin-orbital torque devices.

六、新颖量子输运效应

电输运测量是重要的材料表征方法，电输运性质也是材料的电学应用的基础。磁电阻和霍尔效应是最常见的电输运研究对象。霍尔效应来源于磁场或者贝里曲率对载流子的横向偏转，通常认为当磁场平行于霍尔测量平面时不存在霍尔效应。另外，根据著名的昂萨格对易关系可以推出，霍尔效应是磁场的奇函数，而磁电阻则是偶函数。这种关于磁场的奇偶性的差别，也成为实验上区分两种效应的标准方法。

吴孝松课题组和国内国际的研究者合作，在异维超晶格材料 V_5S_8 中发现了一种新颖的面内霍尔效应，即使磁场平行于霍尔测量平面，依然观察到显著的霍尔效应。该效应源于材料中特殊形式的自旋轨道耦合。在面内磁场和自旋轨道耦合的作用下，能带产生了具有面外分量的贝里曲率。贝里曲率可以被视为动量空间的虚拟磁场，因此载流子在该虚拟磁场作用下发生偏转，产生了面内霍尔效应。相关研究工作发表于《自然》（Nature 2022, 609, 46），并获得 2022 中国十大半导体进展提名奖。

课题组还研究了磁性拓扑外尔半金属 $Co_3Sn_2S_2$ 电学输运性质，发现了一种新奇的线性磁电阻效应。这种磁电阻效应类似反常霍尔效应，是磁化强度的奇函数，进一步地，它也和磁场呈奇函数关系，打破了磁阻是磁场的偶函数这一普遍对称性。分析发现该磁阻效应来源于贝里曲率和外尔手性的共同作用，从而也为探究外尔体系提供了一种新的输运探测方法。这一成果发表于《物理评论快报》（Phys. Rev. Lett. 2021, 126, 236601）。课题组还发现了具有类似磁场和磁化强度奇偶对称关系的热电效应，揭示了该效应中轨道磁化的重要影响，相关研究结果发表于《物理评论快报》（Phys. Rev. Lett. 2021, 129, 056601）。

VI. Novel quantum transport effects

Electrical transport measurement is an important material characterization method. Transport properties are also the basis for electrical applications. The most widely studied transport phenomena are the magnetoresistance and Hall effect. The Hall effect is originated from the deflection of charge carriers by a magnetic field or a Berry curvature. It is generally believed to vanish when the magnetic field is in the Hall measurement plane. The Hall resistance is an odd function of magnetic field. In contrast, the magnetoresistance is an even function of magnetic field. This distinction is rooted in the celebrated Onsager's reciprocal relations. A standard technique to separate these two effects in experiments is based on this parity difference.

Xiaosong Wu's group, through international collaboration, has discovered a novel in-plane Hall effect in a heterodimensional superlattice materials, V_5S_8. The Hall resistance is substantial even if the magnetic field is in the plane of the electrical current and Hall field. This unexpected Hall effect results from the peculiar form of spin-orbit coupling in the material. The in-plane magnetic field generates an out-of-plane Berry curvature, which acts as a fictitious magnetic field in the momentum space. Deflection of carriers by the fictitious field gives rise to the Hall effect.. The discovery is published in Nature (Nature, 2022, 609, 46) and nominated as "China's Top 10 Breakthroughs in Semiconductor 2022".

The group has studied the quantum transport in a magnetic topological Weyl semimetal, $Co_3Sn_2S_2$, which led to the observation of an unconventional linear magnetoresistance. Similar to the anomalous Hall effect, this magnetoresistance is an odd function of magnetization. Moreover, it is also an odd function of the magnetic field, which violates the common belief that the magnetoresistance is an even function of the magnetic field. It is found that the Berry curvature and the chirality of Weyl cones are responsible for the effect. Therefore, the linear magnetoresistance offers a characterization tool for Weyl physics. The results are published in Phys. Rev. Lett. 2021, 126, 236601. Furthermore, the group has also found a thermoelectric effect that shares the same parity symmetry with the unconventional magnetoresistance. It is revealed that the orbital magnetization plays an important role. The results are reported in Phys. Rev. Lett. 2021, 129, 056601.

03 现代光学研究所 Institute of Modern Optics

1933 年饶毓泰先生就职北京大学物理系，同期开创了光学及原子分子结构这一研究方向，并长期保持着良好的发展态势。2001 年 5 月，在北京大学原物理系光学专业的基础上，成立了北京大学现代光学研究所，首任所长为龚旗煌教授。2021 年刘运全教授任新一届所长。截止到 2022 年底，现代光学研究所有固定人员 29 人（2 人为 2021-2022 年度引进），其中教授 15 人（含博雅讲席教授 1 人、博雅特聘教授 9 人），博雅青年学者 8 人，副教授 2 人，教授级高级工程师 1 人，高级工程师 2 人，工程师 1 人。

现代光学研究所现拥有光学和原子分子物理两个二级学科，重点布局介观光学与微纳光子学、超快光学和原子分子强场物理、物理光学与非线性光学和光电功能材料与器件物理等研究方向。面向科技前沿、国家重大需求开展有组织科研，注重在信息、能源、生命等领域的应用研究和成果的转移转化。是“人工微结构和介观物理国家重点实验室”及“纳光电子教育部前沿科学中心”的重要支撑力量，也是北京大学长三角光电科学研究院的主要依托建设单位。

2021-2022 年度，现代光学研究所累计发表论文超过 160 篇，其中包括 Nature Photonics 4 篇、PNAS 2 篇、Physical Review Letters 10 篇等顶级期刊文章。现代光学研究所成果荣获多项奖励。2021 年项目“原子分子动力学超快光场成像和调控”获高等学校科学研究优秀成果奖（科学技术）自然科学一等奖、项目“双倍频程展宽的芯片级光频梳”入选中国光学十大进展、论文“mixed-cation perovskite solar cells in space”（SCIENCE CHINA Physics, Mechanics & Astronomy, 2019, 62, 974221）被评为《中国科学：物理学 力学天文学》期刊年度优秀论文；2022 年项目“超快强场激光场下量子隧穿理论和实验研究”获中国光学学会科技奖基础研究类一等奖、项目“钙钛矿半导体多晶薄膜‘埋底界面’的创新研究方法”获第二届中国半导体十大研究进展提名奖励等。

现代光学研究所在人才培养方面成效显著。现代光学研究所现有中科院院士 1 人，长江特聘教授 4 人，杰出青年基金获得者 9 人（新增 2 人），万人计划领军人才 3 人，国家级优秀青年人才计划获得者 11 人（新增 3 人）。2021 年现代光学研究所极端光学创新研究团队荣获第六届全国专业技术人才先进集体表彰，2022 年龚旗煌、刘运全、肖云峰、胡小永、古英、吴成印、何琼毅、朱瑞等荣获北京市优秀研究生指导教师团队。许秀来荣获中国物理学会饶毓泰物理奖（2022）、《物理学报》推荐入选优秀审稿人案例（2022）；朱瑞（2021）和何琼毅（2022）分别荣获王大珩光学奖中青年科技人员光学奖；肖云峰获得北京市杰出青年中关村奖（2022）、当选中国光学学会会士（2021）、获选《中国科学》优秀编委（2021）；王剑威获亚太物理学会联合会 - 亚太理论物理中心“杨振宁奖”（2022）；杨起帆入选《麻省理工科技评论》“35 岁以下科技创新 35 人”中国区榜单（2021）；彭良友获选美国物理学会 2021 年度杰出审稿人（2021）。多位研究生也获得了重要奖励。2021 年李耀龙获得中国光学学会第十七届王大珩光学奖学生奖、韩猛《强激光场原子电离中的相位问题》获中国光学学会郭光灿光学优秀博士学位论文；2022 年方一奇获得中国光学学会第十八届王大珩光学奖学生奖。

In 1933, Professor Rao Yutai joined the Department of Physics of Peking University and then started the research direction of optics and atomic-molecular structure, which has been keeping up good development until now. In May 2001, the Institute of Modern Optics was established on the basis of the former Department of Optics, and its first director was Professor Gong Qihuang. 2021 Professor Liu Yunquan was appointed as the new director. By the end of 2022, the Institute of Modern Optics has 29 permanent staff (2 were introduced in 2021-2022), including 15 professors (including 1 Boyer Chair Professor and 9 Boyer Distinguished Professors), 8 Boyer Young Scholars, 2 associate professors, 1 professorial senior engineer, 2 senior engineers, and 1 engineer.

The Institute of Modern Optics has two secondary disciplines including optics and atomic-molecular physics. Especially we Focus on the research directions such as mesoscopy and micro- and nano-photonics, ultrafast optics and strong field physics of atoms and molecules, physical optics and nonlinear optics, and physics of optoelectronic functional materials and devices. We always put the major needs of the country in the first, and follow the frontiers of science and technology in the world. In addition, we focus on application and transfer of our research in the fields of information, energy and life. It is an important supporting force of the State Key Laboratory of Artificial Microstructure and Mesoscopic Physics and the Frontier Science Center of the Ministry of Nanophotonics, and is also the main supporting unit of the Yangtze River Delta Institute of Optoelectronic Science of Peking University.

From 2021 to 2022, We have published more than 160 papers, including 4 articles in Nature Photonics, 2 articles in PNAS, and 10 articles in Physical Review Letters and other top journals. In 2021, the project "Ultrafast optical field imaging and modulation of atomic and molecular dynamics" won the first prize of natural science in the prize of excellent achievements in scientific research (science and technology) of higher education institutions, and the project "Chip-level optical frequency comb with double frequency spreading" was selected as one of the top ten advances in optics in China. The paper "mixed-cation perovskite solar cells in space" (SCIENCE CHINA Physics, Mechanics & Astronomy, 2019, 62, 974221) was selected as one of the top ten advances in optics in China, and the paper "Mixed-cation perovskite solar cells in space" (SCIENCE CHINA Physics, Mechanics & Astronomy, 2019, 62, 974221) was awarded as one of the annual "Science in China: Physics, Mechanics, Astronomy". In 2022, the project "Theoretical and experimental study of quantum tunneling in ultrafast strong-field laser fields" won the first prize of the Science and Technology Award of the Optical Society of China in the category of basic research, and the project "Innovative research method of 'buried bottom interface' in polycrystalline thin films of chalcogenide" was nominated for the Second China Top Ten Research Progress Award in Semiconductor, etc.

The Institute of Modern Optics has achieved remarkable results in the cultivation of talents. There is one academician of Chinese Academy of Sciences, four Cheung Kong Distinguished Professors, nine Distinguished Youth Fund recipients (two new ones), three leading talents of the Ten Thousand Talents Program, and eleven national outstanding young talents program recipients (three new ones). 2021, the Extreme Optics Innovation Research Team of the Institute of Modern Optics was awarded the Sixth National Advanced Group of Professional and Technical Talents, and 2022, Gong Qihuang, Liu Yunquan, Xiao Yunfeng, Hu Xiaoyong, Gu Ying, Wu Chengyin, He Qiongyi, and Zhu Rui were awarded the Beijing Outstanding Graduate Student Mentor Team. Xu Xulai was awarded the Rao Yutai Physics Award of the Chinese Physical Society (2022) and recommended by the Journal of Physics to be selected as an excellent reviewer case (2022); Zhu Rui (2021) and He Qiongyi (2022) were awarded the Wang Daheng Optics Award for Young Scientists in Optics; Xiao Yunfeng was awarded the Zhongguancun Award for Outstanding Youth in Beijing (2022), elected as a Fellow of the Optical Society of China (2021), and selected as a member of the (2021); Wang Jianwei received the Asia-Pacific Union of Physics Societies - Asia-Pacific Centre for Theoretical Physics "Chen-Ning Yang Award" (2022); Yang Qifan was selected as one of the MIT Technology Review "35 Under 35 in Science and Technology Innovation" (2021). (2021); Peng Liang-You was selected as the American Physical Society's Outstanding Reviewer of the Year 2021 (2021). Several graduate students have also received important awards. In 2021, Li Yao-Long received the Student Award of the 17th Wang Daheng Optics Prize of the Optical Society of China, and Meng Han's thesis "Phase Problem in Atomic Ionization in Strong Laser Fields" was selected as the Outstanding Doctoral Thesis in Optics by Guo Guangcan of the Optical Society of China; In 2022, Fang Yiqi received the Student Award of the 18th Wang Daheng Optics Prize of the Optical Society of China.

一、强激光光子的自旋 - 轨道相互作用研究

微观粒子的自旋角动量和轨道角动量是描述粒子复杂动力学行为中最基本的两个物理量，这两个角动量之间的耦合普遍存在于自然界之中。光子的自旋 - 轨道相互作用，在光与物质相互作用的研究以及应用中具有举足轻重的意义。光子的自旋 - 轨道相互作用可以分为自旋 - 轨道转换和轨道 - 自旋转换。光子的自旋 - 轨道转换在近十年来得到广泛的研究，然而它的逆过程——轨道 - 自旋转换至今仍未在实验中得到很好的观测和调控。

随着超短脉冲激光技术的飞速发展，超强飞秒激光的光场能量在时空中的高度集中，使得聚焦后的激光场强度可以远远超过原子内部库仑场（I>1016W/cm2）。对于如此强的激光场的自旋态 - 轨道态及其耦合，可以调控强光与物质的许多非线性相互作用过程。但由于巨大的光子能量密度，传统的光学方法，譬如近场重构技术，在强场领域已经完全失效，揭示强激光场中光子的自旋 - 轨道相互作用是一个没有解决且非常重要的问题。

刘运全教授课题组结合高分辨光电子成像技术以及光场调控对强激光场中光子自旋轨道相互作用进行了开创性研究。他们利用超结构波片和螺旋相位板将平面波制备成径向偏振的光涡旋（图 1），并借助狭缝控制光场的空间形状，在此过程中，光子始终只具有轨道角动量而不具有自旋角动量。进一步，将得到的合成结构光场进行聚焦，通过理论模拟，他们发现焦点的光场会耦合出自旋角动量。他们借助光电离这一非线性过程对超强激光光场的轨道角动量和自旋角动量转换进行表征。通过冷靶反冲离子电子动量成像谱仪（COLTRIMS）实验装置，测量结构光场与 Xe 原子相互作用的光电子动量分布。实验发现，通过控制狭缝间距，Xe 原子电离产生的光电子动量分布会随着狭缝间距的减小发生明显变化，光电子动量分布逐渐从类似于圆偏光场作用形成的光电子动量分布（M. M. Liu et al.，Phys. Rev. Lett. 120, 2018，043201），逐渐变成了类似线偏光作用下形成的光电子动量分布（M. Li et al.，Phys. Rev. Lett. 111, 2013，023006）。实验结果直接证明了结构光场发生了轨道自旋转化，转化得到的自旋角动量通过光电子动量得到了非常直观的体现。实现强激光场光子轨道角动量 - 自旋角动量的转换，可以广泛应用于产生具有高轨道态、自旋态可控的极紫外光子束和电子束等。相关研究发表在《自然·光子学》上。

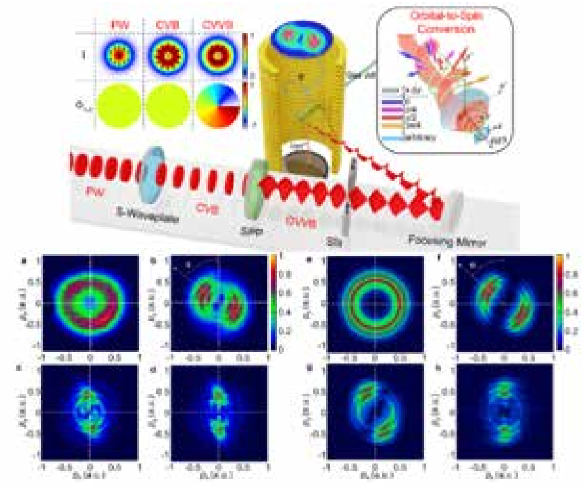


图 1 上：光场的轨道 - 自旋相互作用及光电子成像实验示意；下：实验结果及理论模拟。

Fig 1. Upper panel: Schematic illustration of orbit-spin interaction of intense laser field and experimental scheme of photoelectron mapping. Lower panel: Experimental results and the corresponding simulations.

I. Research on photon spin-orbit interaction in intense laser fields

The spin angular momentum and orbital angular momentum serve as the most fundamental physical quantities in describing the complex dynamics of microparticles. Their coupling is ubiquitous in nature. It is shown that the spin-orbit interaction of photons plays an important role in the fundamental studies of light-matter interaction and accompanied applications. The photon spin-orbit interaction can be sorted into two categories, i.e., the spin-to-orbit conversion and the orbit-to-spin conversion. During the past decade, the former has been extensively studied, whereas the orbit-to-spin conversion has not been directly observed in experiment yet.

With the development of ultrashort laser techniques, the field intensity of strong laser pulses can be highly concentrated in time and space. This causes the fact that the field intensity after focusing (I>1016W/cm2) far exceeds the internal Coulomb field of atoms. Under such intense laser fields, the photon spin-orbit coupling can be employed to control the nonlinear processes in laser-matter interaction. However, due to the high photon energy density, the traditional optical methods which aim at investigating the spin-orbit interaction, such as the near-field reconstruction technique, are totally invalid in strong-field community. How to reveal the spin-orbit interaction of intense light fields is an important but still challenging task.

The group led by Prof. Yunquan Liu carried out pioneering research on the photon spin-orbit interaction of intense laser fields by combining high-resolution photoelectron imaging technology with spatial light modulation. They used q-plate and spiral phase plates to shape plane wave into radially polarized optical vortices, whose spatial shape are further controlled with the help of slits. In this process, photons have orbital angular momentum but no spin angular momentum. Then, they focused the obtained synthetic structured light field into cold target recoil ion momentum spectroscopy (COLTRIMS). Through theoretical simulation, they found that the light field after focusing possesses the spin angular momentum. They characterized the orbital-spin conversion of ultra-intense laser light field by means of the nonlinear process of photoionization. The photoelectron momentum distribution of Xe atoms ionized by structured light field was measured by COLTRIMS. The experiment revealed that by controlling the slit width, the photoelectron momentum distribution of photoionization of Xe atom changes significantly. The photoelectron momentum distribution gradually changes from a typical distribution caused by circularly polarized light fields (M. M. Liu et al.，Phys. Rev. Lett. 120, 2018，043201) to that caused by a linearly polarized light (M. Li et al.，Phys. Rev. Lett. 111, 2013，023006). This experiment provides a direct evidence for the orbit-to-spin conversion of structured light field, and the spin angular momentum obtained from the conversion manifests itself intuitively with the photoelectron momentum distribution. The conversion between spin angular momentum and orbital angular momentum in intense laser field has promising implications for generating extreme ultraviolet photon beams and electron beams which have highly controllable orbital states and spin states. This work has been published in Nature Photonics.

二、微腔光场调控与超高灵敏传感应用

光学微腔可以将光子长时间局域在很小的空间内，极大地增强了光和物质的相互作用，是光物理基础与前沿应用的重要平台之一。微腔光场调控从物理上研究微腔结构及其光场特性之间的联系，能为新颖微纳光场生成、高维度激光调控、高灵敏度传感、超分辨光学成像等诸多光学问题及应用提供解决及优化方案。肖云峰课题组通过调控光学模式动能与微腔传感界面的势垒相对大小，首次揭示了界面回音壁模式（图 1）。该界面模式的电磁场峰值刚好位于回音壁微泡腔传感内表面，从物理上提高了传感器的光学响应强度。通过与表面等离激元共振结合，传感灵敏度能够达到单分子水平。该成果发表于干《美国国家科学院院刊》（PNAS 2022, 119, e2108678119），入选了“2022 中国光学十大进展”。

此外，肖云峰课题组利用回音壁光学微腔中指数衰减的倏势场，在光学微腔 - 悬臂梁微光纤耦合体系中，构建了耗散型光声相互作用，并证明其在声波检测中的重要潜力。这种耗散型机制对声波的响应比传统色散型机制提高 2 个数量级，且具有宽频响应特性。该成果发表于于《物理评论快报》（Phys. Rev. Lett. 2022, 129, 073901）。

肖云峰课题组也在相空间探索微腔光场调控新方法。他们首次提出并实验证明了裁剪相空间的微腔光场调控新机制，通过在非对称微腔内引入特定的局域结构，实现了对相空间中动力学轨道的精确“裁剪”。该成果发表于《物理评论快报》（Phys. Rev. Lett. 2021, 127, 273902）。

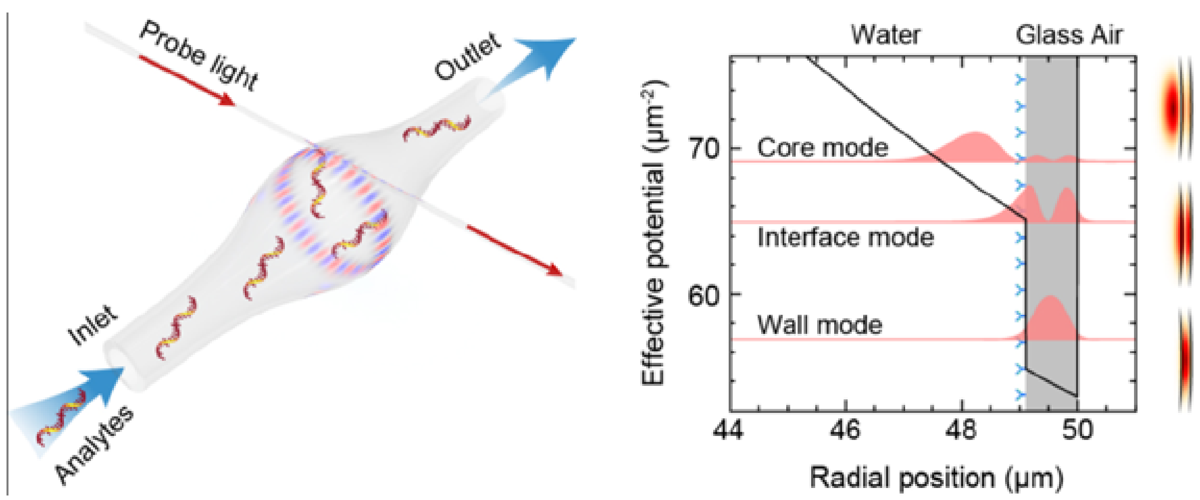


图 1. 基于界面回音壁模式的生物分子表面探测。

Fig 1. Interface whispering gallery modes for interfacial molecular detection.

II. Microcavity light field manipulation and applications in sensing

Optical microcavities can confine photons in a small space for a long time, greatly enhancing the light-matter interaction, making them an important platform for fundamental studies and frontier applications. The field manipulation of optical microcavities involves studying the connections between the microcavity structure and its optical field characteristics, providing strategies for novel optical field generation, high-dimensional laser control, high-sensitivity sensing, super-resolution optical imaging, etc. The research group led by Yunfeng Xiao has revealed, for the first time, the interface whispering gallery modes by manipulating the relative magnitude of the kinetic energy of optical mode and the potential barrier at the cavity sensing surface. (Fig 1). The electromagnetic field peak of this interface mode is exactly located at the inner surface of the whispering gallery microbubble cavity, which enhances the optical response of the microcavity sensor from a physical perspective. By combining with plasmonic resonance, the sensitivity reaches single-molecules level. This work was published in Proceedings of the National Academy of Sciences of the United States of America (PNAS 2022, 119, e2108678119), and was selected as one of the "Top Ten Progresses in Chinese Optics" in 2023.

Besides, the research group led by Yunfeng Xiao proposed a strong dissipative acousto-optic interaction between a whispering-gallery microresonator and a suspended vibrating microfiber, for the first time, utilizing the exponentially decaying evanescent field of optical modes. This dissipative acousto-optic interaction is observed experimentally to be stronger than the conventional dispersive interaction by two orders of magnitude and shows broadband response to acoustic waves. This work was published in Physical Review Letters (Phys. Rev. Lett. 2022, 129, 073901).

This group has also explored light field manipulation in phase space. They proposed and experimentally demonstrated the light field manipulation of optical microcavity by "tailoring" its phase space for the first time. By introducing specific local structures in an asymmetric cavity, the precise "tailoring" of dynamical orbits in the phase space was achieved. This work was published in Physical Review Letters (Phys. Rev. Lett. 2021, 127, 273902).

三、量子光学和量子信息理论研究进展

1）微纳光子结构中的腔量子电动力学

微纳尺度单光子源是集成量子信息和可扩展量子网络的基础构建模块。而实现单光子源的关键原理之一，就是腔量子电动力学框架下的自发辐射增强（或珀塞尔效应），即通过腔模的改变来调控量子体系自发辐射的速率。微纳光子结构中特有的局域场增强或者光学模式体积减小，给腔量子电动力学和片上量子信息过程带来了巨大的优势。根据集成光量子信息的发展趋势，在微纳尺度上实现单光子发射速率的增强及其调控变得越来越重要。

拓扑光子晶体的拓扑态具有光子无散射传播和免疫缺陷的拓扑保护特点，被越来越多地运用在微纳光子学和量子光学器件上，成为重要的光学新兴领域。微纳尺度的单光子源是利用微纳光子器件结构的局域场增强来改善单光子自发辐射，但无法避免散射和吸收造成的损耗，且在传输中单光子收集效率低。2021 年，古英教授和龚旗煌教授领导的团队提出了拓扑保护下边界态主导的模式耦合机制，在此基础上，发现了腔量子电动力学弱耦合体系在拓扑保护下的珀塞尔增强的吸收减少效应，并实现了高光子收集效率（图 1）。这种拓扑态主导的模式耦合机制和相应的吸收减少效应，可以拓展到更高维度的光子结构中，对以后的拓扑光子晶体和微纳尺度腔量子电动力学的研究产生重要影响。

同时，无散射的珀塞尔增强可以应用在片上量子光源。相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2021, 126, 023901）。

由于研究团队多年来在微纳光子结构中珀塞尔效应的研究积累，受邀在《PhotoniX》上发表综述文章。微纳尺度下自发辐射增强的研究（如在回音壁腔、光子晶体、表面等离激元、超材料等微纳光子结构中），已经取得了诸多研究成果，给人们提供了多种调控和收集单光子的方法和选择。我们主要综述了这些光子结构在自发辐射方面的理论、实验以及最新的应用（如表一所示）。这些研究表明了微纳尺度自发辐射在单光子源、光子回路、片上量子信息方面的重要影响。相关综述发表于《PhotoniX》（PhotoniX 2021, 2:21）。

2）具有量子计量能力的量子态的远程制备与操控

在相距遥远的用户间远程制备与操控量子态是构建量子网络的核心问题之一，量子纠缠是实现的重要手段。Wigner 函数具有负值的非高斯态具有优越的量子计量能力，在量子计算和量子精密测量中都有重要应用，在探索经典 - 量子边界等量子力学基本问题方面也有重要物理意义。近两年，何琼毅教授和龚旗煌教授领导的团队提出了利用量子导引这类特殊类型的量子纠缠在远距离用户间远程制备和调控非高斯量子态的新型方案与资源分配机制，并与实验组合作完成了验证，为实现远程量子信息处理任务提供了新思路。

研究团队首先提出了利用量子导引与本地非高斯操作实现远程制备与操控薛定谔猫态的新方案，并基于腔磁系统中的磁光耦合进行了结果展示（图 2）。利用激光脉冲可以实现磁子与光学模式间的量子导引，进而对传输到遥远距离处的光学模式进行单光子操作与投影测量，可以使得磁子量子态坍缩到奇宇称猫态或偶宇称猫态，从而实现了磁子猫态的远程制备与调控。在实验可实现参数下，对远程制备的磁子猫态性质进行了详细的分析，提出了实现高保真度和高非经典性磁子猫态的参数要求，在考虑了实验上投影测量误差以及非高斯操作中暗计数的影响后，磁子猫态的寿命依然可以达到微秒量级。相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2021, 127, 087203）。在取得理论研究进展之后，研究团队随即与山西大学光电研究所苏晓龙教授实验组展开合作，结合了连续变量量子纠缠资源和离散变量光子探测技术实现了光学猫态的远程制备与调控，实验观察到远程制备的猫态对施加单光子操作的被导引方的损耗具有更高的鲁棒性。相关研究工作发表于《激光与光子学评论》（Laser Photonics Rev. 2023, 2300103）。

面向构建量子网络的实际需求，研究团队进一步提出了多用户场景中具有 Wigner 负性量子态的远程制备方案，并揭示出资源在用户间的分配机制，进而与实验组合作完成方案验证。Wigner 负性的强弱反映了量子态在量子计算与量子精密测量中超越经典系统的能力。研究团队针对多模连续变量系统，从定量的角度研究了多用户场景中 Wigner 负性的远程制备和分配机制，展示了量子导引在方案中不可替代的作用，严格证明了产生的集体 Wigner 负性总是大于等于个体资源的和；此

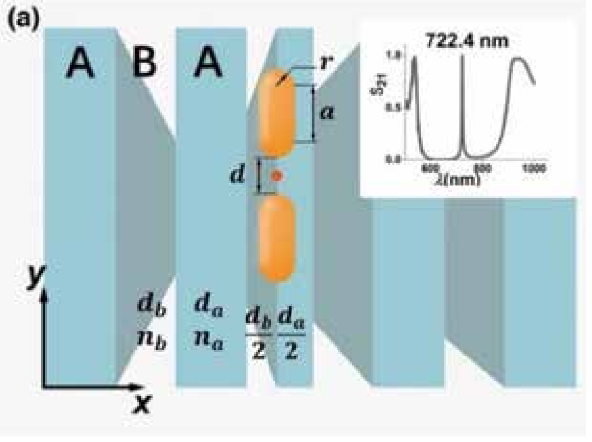


图 1. 拓扑保护下的珀塞尔增强中吸收部分减少的结构示意图。

Fig 1. Schematic diagram of Purcell enhancement under topological protection.

外，对于减光子这类典型的非高斯操作，研究结果指出远程产生的 Wigner 负性大小可以完全由系统初始量子态的纯度刻画，提供了一种更便捷的度量方法。相关研究成果发表于《自然合作期刊　量子信息》（npj Quantum Inf. 2022, 8, 21）。在理论方案提出后，研究团队与山西大学苏晓龙教授实验组进一步合作，基于双模 EPR 纠缠光场首次实现了远程制备具有 Wigner 负性的非高斯态，验证了量子导引和产生的 Wigner 负性之间的定性、定量关系，展示了远程产生的 Wigner 负态在量子精密测量中具有优越的计量能力，为量子技术提供了丰富的即用型量子资源。相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2022, 128, 200401）。

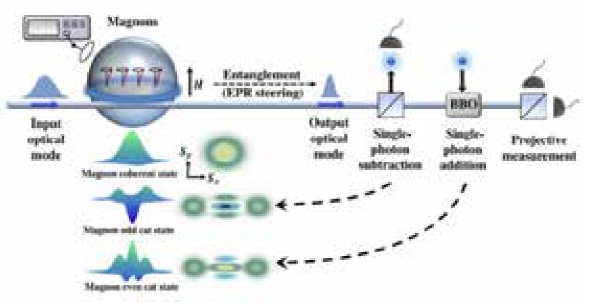


图 2. 基于磁 - 光纠缠远程制备磁子薛定谔猫态的方案设计示意图。

Fig 2. Schematic diagram of remote generation of a magnon cat state.

III. Research progress of quantum optics and quantum information

1）Cavity quantum electrodynamics in micro/nano photonic structures

Micro/nano scale single photon source is the building block of integraded quantum information and scalable quantum networks. One of the key principles of realizing a single photon source is the spontaneous emission enhancement (or Purcell effect) under the cavity quantum electrodynamics, that is, spontaneous emission rate of quantum emitter can be modulated by the change of density of cavity modes. The local field enhancement or optical mode volume reduction existing in micro/nano photonic structures brings huge advantages to cavity quantum electrodynamics and on-chip quantum information process. According to the development of integrated optical quantum information, it is becoming more and more important to realize the enhancement and manipulation of single photon emission at micro/nano scale.

The topological photonics, as an important emerging field of optics, has the characteristics of non-scattering propagation of photons and the topological protection of immune defects, which are increasingly used in micro-nano photonics and quantum optical devices. Micro/nano scale single photon source utilizes the local field enhancement of micro/nano photonic structures to improve the single photon emission, but the loss caused by scattering and absorption cannot be avoided and the single photon collection efficiency is still low. In 2021, the team of Profs. Gu Ying and Gong Qihuang proposed a boundary state-dominated mode coupling mechanism under topological protection. Based on this mechanism and using the cavity quantum electrodynamics, they found the absorption reduction effect of Purcell enhancement under topological protection and achieved the high efficiency of photon collection (as shown in Fig 1). This topological state-dominated mode coupling mechanism and corresponding absorption reduction effect can be extended to higher dimensional photonic structures, which will have an important influence on the future study of topological photonic crystals and quantum electrodynamics in micro/nano scale cavity. Meanwhile, the non-scattering Purcell enhancement can be applied to on-chip quantum light sources. This work is published in Physical Review Letters (Phys. Rev. Lett. 2021, 126, 023901).

Due to the research work on the Purcell effect in micro/nano photonic structures over the years, the research team was invited to publish a review article in PhotoniX. The enhancement of spontaneous emission at the micro/nano photonic structures, such as whispering gallery microcavities, photonic crystals, plasmon nanostructures, metamaterials, and their hybrids, has been studied extensively. By foucusing on these structures (as shown in Tab. 1), we mainly reviewed the theoretical and experimental works in the field of spontaneous emission as well as their applications. These studies indicate the important effect of micro/nano scale spontaneous emission on single photon source, photonic circuits, on-chip quantum information. This review is published in PhotoniX (PhotoniX 2021, 2:21).

2）Remote preparation and manipulation of non-Gaussian states with quntum advantage

How to remotely prepare and manipulate quantum states between remote users is one of the core issues in constructing quantum networks. Quantum entanglement can provide an efficient means to solve this problem. For some continuous-variable (CV) states, the Wigner function can reach negative values. This Wigner negativity can ensure superior metrological power in quantum metrology tasks, and offers insight into studying fundamental quantum mechanics, such as the classical-quantum boundary. In recent two years, the research team led by Prof. Qiongyi He and Prof. Qihuang Gong has made some progress on this topic, including proposing a series of novel theoretical schemes for remote generation and manipulation of non-Gaussian states based on quantum steering, and then collaborated with experimental groups to implement them. These results pave the way for exploiting Wigner negativity as a valuable resource for numerous quantum information protocols.

The research team first proposed a general theoretical scheme for the remote preparation and manipulation of Schrödinger's cat states, and showed the feasibility of this scheme based on the magnon-photon entanglement in cavity optomagnonic systems. The quantum steering between the magnons and the optical mode can be established with laser pulses. Then single-photon operations and projection measurements are performed on the optical mode transmitted to a distant node, which makes the magnon state collapse into an odd or even cat states. A detailed analysis of the remotely prepared magnon cat states has been provided under experimentally feasible parameters, showing the conditions for preparing high-fidelity magnon cat states. And the lifetime of magnon cat states is in the timescale of microseconds, with the measurement errors and the dark counts considered. This work has been published in Physical Review Letters (Phys. Rev. Lett. 2021, 127, 087203). With this theoretical progress, the research group immediately developed an experimental cooperation with the group of Prof. Xiaolong Su at Shanxi University. By combining the CV quantum entanglement resources and the discrete-variable photon detection technology, the experimental demonstration of remotely preparing and manipulating optical cat states has been reported. The results showed that the remotely prepared cat states have higher robustness to the losses in the steered party that the single-photon operations are applied, where the fidelity is always higher than 0.5. This work has been published in Laser & Photonics Reviews (Laser Photonics Rev. 2023, 2300103).

Towards the development of quantum networks, the research team further developed the scheme of remote preparation of Wigner-negative states in multipartite scenarios and quantitatively studied the distribution of generated Wigner negativities, then collaborated with the experiment group to realize such protocol between space-separated stations for the first time. In multi-mode CV systems, the research team demonstrated the indispensable role of quantum steering in preparing Wigner negativity among multiple users. By constructing a Coffman-Kundu-Wootters type monogamy constraint, it has been revealed that the generated Wigner negativity cannot be freely distributed among users, where the sum of the Wigner negativities generated in the individual modes cannot exceed their intergroup negativity. Additionally, for one of the commonly used non-Gaussian operations, photon subtraction, the results indicate that the remotely generated Wigner negativity can be fully characterized by the purity of the initial states and an intuitive measurement method is provided. This work has been published in npj Quantum Information (npj Quantum Inf. 2022, 8, 21). After making this theoretical progress, the research team then collaborated with the group of Prof. Xiaolong Su at Shanxi University and realized the remote preparation of Wigner-negative states between space-separated stations. Based on two-mode EPR entangled optical fields, the qualitative and quantitative relationship between quantum steering and generated Wigner negativity have been verified. Moreover, it is also demonstrated that the remotely generated Wigner negativity has superior metrological power in quantum precision measurement. These results present a significant advance in a concrete in-depth understanding of the connection between different quantum effects and provide abundant ready-to-use quantum resources for quantum technology. This work has been published in Physical Review Letters (Phys. Rev. Lett. 2022, 128, 200401).

04 重离子物理研究所 Institute of Heavy Ion Physics

北京大学重离子物理研究所创建于 1983 年 5 月，其顺应学科前沿发展和国家战略需求，一直致力于探索加速器科技前沿，聚焦能源、先进制造和生命健康等关乎人类生存与发展的重大问题，以建设成为国际顶尖的前沿应用科学研究和人才培养基地为目标，目前已在激光加速、超导加速、核物理及核磁共振技术等领域获得了多项重大突破。

重离子物理研究所现有核技术及应用、医学物理与工程、等离子体物理、高能量密度物理 4 个二级学科，各学科在充分发挥北京大学基础研究优势的基础上，交叉发展，推陈出新，各具特色，相得益彰，针对核能源、大科学装置、国防安全、先进制造和核医学等领域开展创新研究，勇于探索科学前沿，承接国家任务和重大需求，学科声誉不断提升。

这里精英汇聚，被誉为"核科学家摇篮"，包括两弹一星元勋朱光亚、西北核基地司令钱绍钧、核物理学家陈佳洱等 22 位院士。现由中科院院士 6 人（含双聘）、杰青 4 人、青千 4 人、优青 2 人等组成的年轻化、国际化团队。这里硕果累累，近 5 年来共承担了 50 多项国家重大科研项目，包括 10 项国家重点研发计划和重大科学仪器设备开发项目，在高端期刊发表论文 500 余篇，近年来多个教授团队荣获国际奖项，研究所的世界影响力快速提升。已经竣工的怀柔国家科学中心——北京激光加速创新中心未来将作为世界级原始创新承载区，将吸引聚集全球更多高端科学家，为新一代大科学装置立项奠定坚实的基础。

The Institute of Heavy Ion Physics at Peking University was founded in May 1983. Adhering to the forefront of disciplinary development and national strategic needs, it has been committed to exploring accelerator technology, focusing on major issues related to human survival and development such as energy, advanced manufacturing, and life and health. Its overall objective is to create an international top-level frontier application scientific and talent training base. The Institute has achieved significant breakthroughs in essential fields such as laser acceleration, superconducting acceleration, nuclear physics, and nuclear magnetic resonance technology.

The Institute of Heavy Ion Physics has four secondary disciplines: Nuclear Technology and Applications, Medical Physics and Engineering, Plasma Physics, and High Energy Density Physics. Each discipline gives full play to the advantages of Peking University's basic research and cross-develops to innovate, with each having its own characteristics. For instance， innovative research has been carried out for nuclear energy, major scientific devices, national defense security, advanced manufacturing, and nuclear medicine, etc. The academic reputation has been constantly improving.

The institute is a gathering place for elites and is known as the "cradle of nuclear scientists". It includes 22 academicians, including the two founders of China's nuclear weapons program, Zhu Guangya and Qian Shaojun, as well as the nuclear physicist Chen Jia'er. The current team boasts of being young and international, with six academicians of the Chinese Academy of Sciences (including double-hired), four winners of the National Science Fund for Distinguished Young Scholars, four winners of the National Youth Thousand Talents Program, and two winners of the Youth Elite Support Program.

In recent years, The Institute of Heavy Ion Physics has made significant strides. It has undertaken more than 50 major national scientific research projects in the past five years, including 10 national key R&D projects and major scientific instrument and equipment development projects.. It has published more than 500 research papers in high-end journals. Multiple professor teams at the Institute have won international awards, and the global influence of the Institute has rapidly increased. The Huairou National Science Center, the Beijing Laser Acceleration Innovation Center, which has been completed, will serve as a world-class original innovation bearing area in the future, attracting and gathering more top scientists from around the world and laying a solid foundation for the establishment of a new generation of major scientific devices.

系所中心研究亮点 | *Highlights*

一、建立一套全新的高质量中国人磁共振脑影像大数据开放资源

人类的脑与行为受到基因、环境和文化及其相互作用的塑造，而运用多模态脑影像大数据集进行融合性探索，可以推动深入探究人脑宏观结构与功能连接组架构及其与以上重要影响因素之间的关系。

高家红团队近年来启动并初步完成了「中国人脑连接组计划」(Chinese Human Connectome Project, 简称 CHCP)，为方便对照可比，该 CHCP 与美国「人类脑连接组计划」(Human Connectome Project, 简称 HCP) 的研究规程保持高度一致：包括磁共振成像扫描、数据采集参数、功能脑成像的任务范式、行为与基因数据等。该研究目前已建立了一套全新的中国人脑影像开放资源，并揭示了中西方脑结构与功能组织信息在大尺度水平的系统性差异。相关成果及其大数据资源于 2022 年 12 月在线发表于《自然·神经科学》(Nature Neuroscience)，并获得了国际同行的广泛关注。

CHCP 中国人脑连接组计划研究成果及其数据资源的公布不仅对于促进基于中国人磁共振影像的脑 - 行为和脑图谱方面的科学研究具有宝贵意义，更重要的是填补了当前国际上缺少来自非西方群体（比如中国人群）对照的空白，为探索人类不同文化与族裔背景中的脑 - 行为关联起到了推动作用。

I. Establishment of a new open resource of high-quality Chinese brain images

The human brain and behavior are shaped by genetics, environment, culture, and their interactions. In recent years, advances in neuroimaging methods call for integration of multimodal brain images and related large-scale datasets, which enable the exploration on the macroscopic structure and functional connectivity (i.e. the connectome) of the human brain and these important scientific questions.

Led by Professor Jia-Hong Gao, the "Chinese Human Connectome Project" (CHCP) was launched in recent years, aims to provide large sets of multimodal neuroimaging, behavioral and genetic data on the Chinese population. Importantly, the research protocol of CHCP is comparable with that of the US "Human Connectome Project" (HCP), including the procedure for 3T MRI scanning, the data acquisition parameters, and the task paradigms for functional brain imaging. CHCP also collected behavioral and genetic data that that were compatible with the HCP dataset. This project has established a new open resource of Chinese brain imaging and revealed systematic differences in the organization of brain structure and function between Chinese and Western populations at the large-scale level. The current study results and the large data resources were published online in Nature Neuroscience in December 2022 and receive extensive attention from international peers.

The publication of the research results and data resources of the CHCP not only contribute to promoting scientific research on brain-behavior relationship and brain mapping focused on Chinese population, but also fills the gap in the lack of brain images non-Western populations, promoting the direct comparison and exploration of human brain-behavior associations across different ethnicities and cultures.

二、基于微带靶的激光离子加速方案及三维同步质子照相技术

高品质离子束，尤其是质子束和重离子束，在癌症治疗、质子照相、激光核物理和实验室天体物理等诸多方面有非常重要的应用。相较于传统加速器，利用超短超强激光驱动的离子加速因其具有更高的加速梯度 (通常 3 个量级以上) 而受到广泛重视和研究，而不同的应用场景对激光驱动离子束的品质也有不同的要求。例如，在癌症治疗方面，为有效地杀死癌细胞而避免对正常细胞造成损伤，医疗临床要求的是能散在 1% 量级的准单能离子束；在质子照相应用方面，为实现对研究客体的时间分辨的单发次动态诊断，需要的是宽能谱且通量高的质子束。目前，主流的研究范式是结合数值模拟和实验验证来获得能够满足实际应用条件的激光驱动离子束。

目前驱动单能性好且能量高的离子束的主流加速机制是辐射压加速 (RPA)，但其加速过程中易发的不稳定性可能造成加速和聚束电场的破坏从而降低了单能性。为进一步提高激光加速离子束的单能性，乔宾教授与德国杜塞尔多夫大学理论物理研究所 Alexander Pukhov 教授课题组合作，提出通过拍瓦飞秒强激光辐照微胶带靶获得高品质离子束的新方案 (如图 1)。联合研究团队对微胶带靶进行精密设计，使其表面在激光辐照时激发出强表面等离子体波，进而加速电子共振，获得具有超大电荷量、超小发散角的高能电子束。当电子束注入真空时，由于电子电荷量远大于离子电荷量，自发形成稳定的箍缩电场，实现在高效加速质子的同时不断压缩质子的相空间，最终获得单能性极好的高品质离子束。三维粒子模拟结果显示，利用现有拍瓦飞秒强激光 (强度 7.8×10^{20} W/cm^2、能量为 50J)，可以获得峰值能量高于 100 MeV、能散为 1% 的高品质离子 (质子) 束。这项工作为激光离子加速机制提供了一条全新的途径，有望解决离子能散大这一长期存在的难题，为激光驱动的质子治疗肿瘤等应用奠定基础。相关研究工作发表于《物理评论 X》，（Phys. Rev. X, 11, 2021, 041002）。

在激光驱动离子束诊断源方面，目前利用激光驱动质子束开展质子照相诊断研究所采用的加速机制是靶背垂直鞘场加速 (TNSA)，由于受限于激光装置和实验技术，目前大都只能实现单束的二维质子照相。为突破现有的激光驱动质子照相技术的维度局限性，乔宾教授与中物院激光聚变研究中心合作，基于星光 - Ⅲ 激光装置具有纳秒、皮秒和飞秒脉冲的独特性能，提出同时利用皮秒和飞秒脉冲并基于 TNSA 加速机制驱动多束质子探针来实现对激光驱动自生电磁场的三维同步质子照相。联合团队通过特殊的靶材料和结构设计，在保证质子束数量和能量的同时避免皮秒和飞秒脉冲之间的相互干扰，获得了截止能量都超过 10MeV、相对时间抖动小于 10ps 的两束相互正交、互不干扰的质子探针，并且成功实现了对纳秒激光烧蚀固体靶自生磁场的三维同步质子照相，首次得到了高时空分辨的自生磁场三维结构实验数据。这项研究验证了利用激光同步驱动多束质子探针开展立体照相的可行性，该技术入选国家“十三五”科技成果创新成就展， 是“超强激光在高温高密度极端物质科学中的先进诊断技术”成果的主要内容之一，也是获得“国防科技工业突出贡献奖 (团队奖)”的主要内容之一。

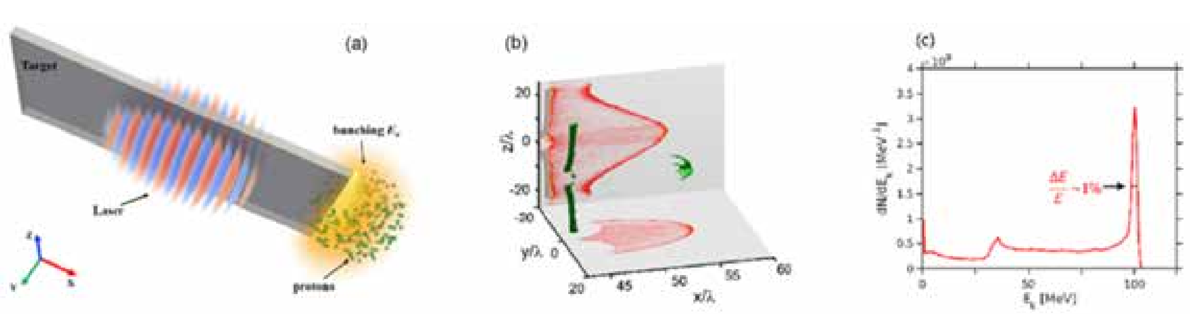


图 1. 强激光辐照微带靶离子加速新方案。

Fig 1. New scheme for ion acceleration by intense laser irradiating of microtape target.

系所中心研究亮点 | *Highlights*

II. Laser ion acceleration scheme based on microtape target and three-dimensional synchronous proton radiography technology

High-quality ion beams, especially proton beams and heavy ion beams, have very important applications in cancer treatment, proton radiography, laser nuclear physics and laboratory astrophysics. Compared to traditional accelerators, ion acceleration driven by ultra-short and ultra-intense laser has received widespread attention and research due to its higher acceleration gradient (usually more than three orders of magnitude), and different application scenarios have different requirements for the quality of laser driven ion beams. For example, in the field of cancer treatment, in order to effectively kill cancer cells and avoid damage to normal cells, medical clinical requirements require quasi-monoenergetic beams that energy spreading lower than 1%. In the application of proton radiography, in order to achieve time-resolved dynamic diagnosis of the research object in a single shot, a proton beam with wide energy spectrum and high flux is required. At present, the mainstream research paradigm is to combine numerical simulation and experimental verification to obtain laser-driven ion beams that can meet the practical application conditions.

At present, the most-investigated acceleration mechanism for achieving ion beams with high energy and narrow energy spread is the radiation pressure acceleration (RPA), but the instability that occur during its acceleration process may cause damage to the acceleration and bunching electric field, thereby increasing the energy spread of ion beam. In order to further reduce the energy spread, a new scheme is proposed by Professor Qiao and Professor Alexander Pukhov (Institute of Theoretical Physics at the University of Dusseldorf in Germany) for obtaining high-quality ion beams by irradiating microtape targets with femtosecond intense laser pulse (as shown in Fig 1). The joint research team has conducted precise design on the microtape target to excite strong surface plasma wave during laser irradiation along the tape surface, thereby accelerating abundant buckets of electron and obtaining high-energy electron beam with large charge amount and ultra-small divergence angle. When this electron beam is injected into vacuum later, because the amount of electron charge is far greater than the amount of ion charge, a stable pinch electric field is spontaneously formed, which can effectively accelerate the proton while continuously compressing the phase space of the proton, and finally obtain a high-quality ion beam with excellent monoenergetic. The 3D particle-in-cell simulation results show that using the existing femtosecond high-power laser (with intensity of 7.8×10^{20} W/cm^2 and energy of 50 J) can obtain high-quality proton beams with peak energy above 100 MeV and energy spread of 1%. This work provides a new scheme for the laser-driven ion acceleration, which is expected to solve the long-standing problem of wide ion energy spread and lay the foundation for applications such as laser-driven proton tumor treatment. This work has been published in Physical Review X (Phys. Rev. X, 11, 2021, 041002).

In terms of ion beam diagnostic sources driven by lasers, the acceleration mechanism currently used in proton radiography diagnostic research with laser driven proton beams is the Target Normal Sheath Acceleration (TNSA). Due to limitations in laser facility and experimental technology, currently only two-dimensional proton radiography with a single proton beam can be achieved. In order to break through the dimensional limitations of the existing laser driven proton radiography technology, professor Qiao cooperated with the Laser Fusion Research Center of the China Academy of Engineering Physics. Based on the unique performance of the Xingguang- Ⅲ laser facility with nanosecond, picosecond and femtosecond pulses, he proposed to simultaneously use picosecond and femtosecond pulses to drive multiple proton probes based on TNSA acceleration mechanism to achieve three-dimensional synchronous proton radiography of laser driven self-generated electromagnetic fields. Through special target materials and structural design, the joint team ensured the number and energy of proton beams while avoiding the mutual interference between picosecond and femtosecond pulses, obtained two mutually orthogonal and non-interference proton probes with cut-off energy exceeding 10MeV and relative time jitter less than 10ps, and successfully realized three-dimensional synchronous proton radiography of the magnetic field generated by nanosecond laser ablated solid targets, and obtained experimental data on the three-dimensional structure of self-generated magnetic field with high spatial-temporal resolution for the first time. This study verifies the feasibility of using laser synchronous driving multiple proton probes for 3D radiography. This technology has been selected for the National "13th Five Year Plan" Science and Technology Innovation Achievement Exhibition, which is one of the main contents of the "Advanced Diagnosis Technology of Ultra Strong Laser in High Temperature and High Density Extreme Matter Science" achievement, and also one of the main contents of winning the "Outstanding Contribution Award (Team Award) for National Defense Science and Technology Industry".

05 技术物理系 Department of Technical Physics

技术物理系现有教职员工 33 人，其中：教授 8 人（其中院士 1 人，杰青 3 人），教授级高级工程师 1 人，副教授 6 人，长聘副教授 4 人（其中优青 1 人，博雅青年学者 2 人），预聘助理教授 6 人（其中博雅青年学者 4 人），副研究员 1 人，高级工程师 2 人，和工程师 5 人。研究方向为：实验核反应与结构、理论核结构、高能实验物理、中高能核理论、应用核物理、辐射防护、探测器研发、核电子学。该系有一个亚原子粒子探测实验室；一个核技术应用实验室；一个核物理与核技术教学实验室；一个北大 - 兰州联合核物理中心。核技术应用实验室拥有包括电弧熔炼、2×1.7 MV 串列加速器、透射电子显微镜和 X 射线衍射仪等在内的新型核能材料的制备、辐照、表征和测试平台，主要用于应用核物理研究（核能材料与核技术应用）。

技术物理系是“核物理与核技术国家重点实验室”的重要组成部分，承担多项国家级科研项目；拥有全国唯一的核物理理科基地和核物理国防特色专业；建立了广泛的国内外合作，包括：中美“奇特核”理论物理研究所 (CUSTIPEN)；高能物理方面与欧洲 LHC 和北京 BEPC-BES 合作；核物理方面与日本 RIKEN-RIBF、兰州 HIRFL 和北京 CIAE 合作等；人才培养方面自 2008 年起与日本理化所合建了 Nishina School 等。

There are 33 faculty members in the department, including 8 full professors (including 1 academician of the CAS and 3 National Outstanding Young Scientists), 1 professorship engineer, 6 associate professors, 4 tenured Associate Professors (including 1 National Outstanding Junior Young Scientist and 2 Boya Young Scholars), 6 tenure-track Assistant Professors (including 4 Boya Young Scholars), 1 associate research fellow, 2 senior engineers, and 5 engineers. The research fields cover experimental nuclear reaction and structure, theoretical nuclear structure, experimental high-energy physics, theoretical intermediate and high-energy physics, applied nuclear physics, radiation protection, detector technique and nuclear electronics. The department has a subatomic particle detection laboratory, a nuclear technology application laboratory, an education laboratory for nuclear physics and technology, and a PKU-Lanzhou joint center for nuclear physics. The nuclear technology application laboratory is equipped with critical facilities such as arch melting system, 2×1.7 MV tandem accelerator, transmission electron microscope, X-ray diffractometer for the study of structural materials and ion beam materials.

The department is an important part of the State Key Laboratory of Nuclear Physics and Technology. The department undertakes some national research projects. It is the only department in the universities of China, which is supported by the national project for fostering talents of nuclear science and by the national defense characteristic discipline of nuclear physics. The department has established many international and national collaborations, including the China-U.S. Theory Institute for Physics with Exotic Nuclei (CUSTIPEN), high-energy physics collaboration with LHC in Europe and BEPC-BES in Beijing, nuclear physics collaboration with RIKEN-RIBF in Japan, HIRFL in Lanzhou and CIAE in Beijing. In terms of talent training, an undergraduate education program named the Nishina School has been established with RIKEN in Japan since 2008.

一、首次观测到四质子不稳定新核素 ^{18}Mg

北京大学实验核物理团队首次在实验中观测到四质子不稳定新核素 ^{18}Mg，其比自然界稳定存在的最轻的镁同位素少 6 个中子，通过奇特的四质子发射模式衰变到长寿命的 ^{14}O 末态（图 1）。实验同时发现 ^{18}Mg 中可能的第一个 2^+ 态，为质子滴线附近 $N = 8$ 幻数的消失提供了新的证据。相关研究成果发表于《物理评论快报》（Physical Review Letters 127, 2021, 262502），同时以编辑推荐（Editors' Suggestion）和 Physics 杂志点评（Featured in Physics）的形式被亮点报道。

北京大学实验团队使用美国国家超导回旋加速器实验室提供的 ^{20}Mg 放射性束流轰击 ^{9}Be 靶，通过双中子敲出反应成功产生了质子滴线外的新核素 ^{18}Mg，使用 S800 磁谱仪和 Si-CsI(Tl) 带电粒子望

远镜等装置对其瞬发衰变产生的五个末态粒子（^{14}O + 4*p*）进行了高效率、高分辨的符合探测，重建了母核 ^{18}Mg 的不变质量谱，在实验上首次确定了 ^{18}Mg 的基态质量和衰变宽度（图 2）。通过研究衰变末态的四个质子和剩余核 ^{14}O 的能量关联，发现 ^{18}Mg 基态经过级联的两步同时双质子发射过程进行衰变。作为中间态的 ^{16}Ne 基态寿命相对较长，因此前后两步双质子发射过程彼此相对独立。实验的另一个重要发现是同时观测到 ^{18}Mg 中可能的第一个 2^+ 态，其激发能比邻近的偶偶核同位素 ^{20}Mg（拥有 8 个中子的满壳层）更高，为 Mg 同位素中 $N = 8$ 中子壳能隙的减弱提供了新的证据。

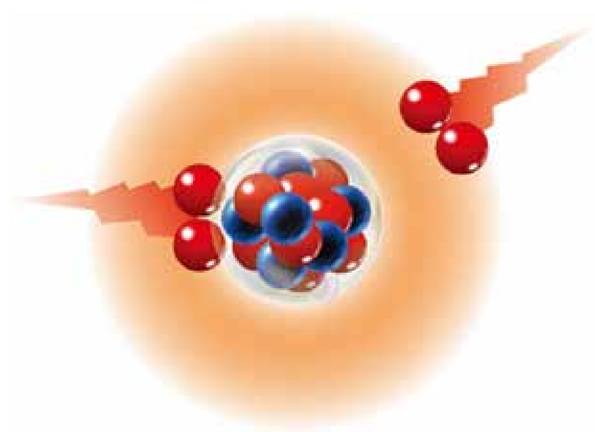


图 1. ^{18}Mg 四质子发射示意图

Fig 1. Diagram of four-proton emission in ^{18}Mg

I. First observation of the four-proton unbound nucleus ^{18}Mg

We observed four-proton unbound nucleus ^{18}Mg for the first time via its decay into ^{14}O + 4*p*. The first excited 2^+ state observed in 18Mg presents a challenge to magicity of $N = 8$ in magnesium. The results were published in Physics Review Letters (Physical Review Letters 127, 2021, 262502), selected as Editors' Suggestion and Featured in Physics.

The experiment was performed at the National Superconducting Cyclotron Laboratory at Michigan State University. ^{18}Mg was produced by two-neutron knockout reactions of radioactive beam 20Mg, and promptly decayed into ^{14}O and four protons, which were detected by the S800 spectrograph and ΔE - E telescope detectors, respectively. With the complete kinematics measurement of all final products, the decay energy spectrum of 18Mg was reconstructed using the invariant mass method (Fig 2) and two peaks can be clearly resolved above a smooth background. The observed correlations between the five decay products are consistent with two sequential steps of prompt 2*p* decay passing through the ground state of ^{16}Ne. Another interesting result in the experiment is the observation of state in ^{18}Mg. As shown in the inset in Fig 2, the E(2^+_1) values increase from ^{22}Mg (N = 10) to ^{18}Mg (N = 6), i.e., across N = 8, providing an argument for the possible demise of the N = 8 shell closure around the proton dripline.

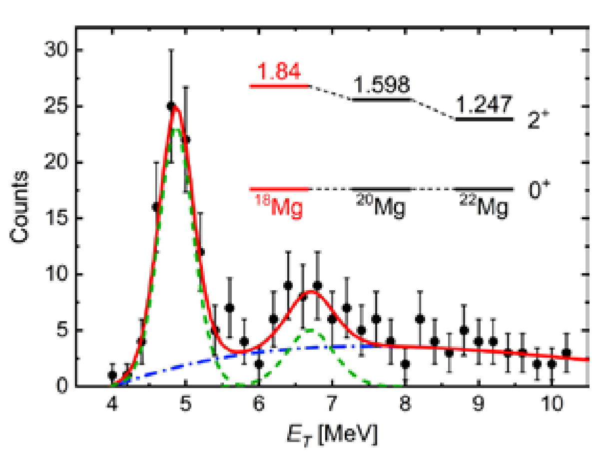


图 2. 实验中重建的 ^{18}Mg 不变质量谱及 Mg 同位素中 2^+ 态激发能的系统性演化。

Fig 2. Decay energy (ET) spectrum of ^{18}Mg. The inset shows the excitation energies of the first 2^+ states of the light magnesium isotopes.

二、三 W 玻色子共振态的首次探寻

北京大学物理学院技术物理系、核物理与核技术国家重点实验室高能物理CMS 团队冒亚军教授、李强研究员课题组，对三 W 玻色子共振态进行了世界首次探寻，相关研究成果于 2022 年 7 月 6 日以“在 13TeV 质子—质子对撞中寻找衰变到三个 W 玻色子的共振态”（Search for Resonances decaying to three W Bosons in Proton-Proton Collisions at sqrt(s)=13 TeV）和“在 13TeV 质子—质子对撞中通过强子末态寻找衰变到三个 W 玻色子的共振态”（Search for resonances decaying to three W bosons in the hadronic final state in proton-proton collisions at sqrt(s)=13 TeV）为题的两篇文章，同时发表于《物理评论快报》（Physical Review Letters）和《物理评论 D》（Physical Review D）。万维网 WWW，是欧洲核子研究中心（CERN）的高能物理学家们为了探索未知的粒子世界提出并且实现的。在高能物理中，WWW 也可表示三个 W 玻色子。在粒子物理的标准模型中，W 玻色子、Z 玻色子、光子和胶子等四种自旋为 1 的规范玻色子是传递相互作用的基本粒子。其中，重质量的 W 和 Z 玻色子传递短程的弱相互作用。寻找超出标准模型的新物理是粒子物理学的最重要的目标，也是 CERN 的大型强子对撞机（large hadron collider, LHC）的重大课题。长期以来，通过二体末态寻找新粒子包括双玻色子共振态，是高能对撞机上寻找新物理的重要途径。然而，新物理的事例特征可能具有更复杂的拓扑结构，例如，近期特殊的额外维度模型提出寻找三玻色子的必要性。从二体到三体的拓展，可以进一步挖掘 LHC 的物理潜力。北京大学物理学院技术物理系、核物理与核技术国家重点实验室高能物理团队冒亚军教授、李强研究员课题组，利用 CERN 的大型强子对撞机的紧凑缪子线圈（compact muon solenoid, CMS）探测器实验所收集的 13 TeV 质子—质子对撞数据，在世界上首次实现了三 W 玻色子共振态的寻找、开发了 3 夸克和 4 夸克特征喷注的鉴别及校准技术。此项研究开拓了新物理寻找的新航线。相关研究成果于 2022 年 7 月 6 日以两篇文章同时发表于《物理评论快报》及《物理评论 D》。冒亚军和李强课题组在 CMS 国际合作组提出并领导了这两项工作，北京大学物理学院博士后 A.Agapitos 及北京大学物理学院 2016 级博士研究生吕旭东担当分析负责人，A.Agapitos、吕旭东和北京大学物理学院 2016 级博士研究生陈城在 CMS 合作组内作了预审核及审核报告。上述研究工作得到国家自然科学基金、国家重点研发计划等大力支持。

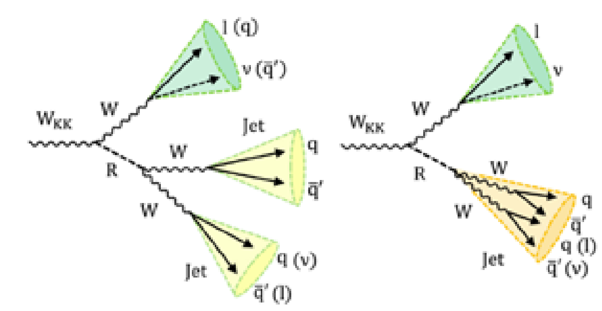


图 1. 三 W 玻色子共振态的典型衰变示意图。

Fig 1. Schematic representation of the three-body decay of a tri-W boson resonance.

II. First probe on tri-W boson resonance

A search for Kaluza-Klein excited vector boson resonances, WKK, decaying in cascade to three W bosons via a scalar radion R, WKK → WR → WWW, in a final state containing two or three massive jets is presented. The search is performed with sqrt(s)=13 TeV proton-proton collision data collected by the CMS experiment at the CERN LHC during 2016–2018, corresponding to an integrated luminosity of 138 fb − 1. Two final states are simultaneously probed, one where the two W bosons produced by the R decay are reconstructed as separate, large-radius, massive jets, and one where they are merged into a single large-radius jet. The observed data are in agreement with the standard model expectations. Limits are set on the product of the WKK resonance cross section and branching fraction to three W bosons in an extended warped extra-dimensional model and are the first of their kind at the LHC.

06 天文学系 Department of Astronomy

天文学系成立于 2000 年，前身为 1960 年在地球物理系成立的天体物理学专业。2001 年天文学系并入新成立的物理学院。在 2001 年底教育部组织的全国重点学科评审中，北京大学天体物理学科被评为全国重点学科。近年来，北京大学天文学专业连续入选国家级一流本科专业建设点和国家基础学科拔尖人才培养计划。 目前（2022 年底）天文学系有全职教师 10 名，包括国家杰出青年基金获得者 4 名，国务院“政府特殊津贴”获得者 1 名，万人计划科技领军人才 1 名，科技部创新人才 1 名，腾讯科学探索奖获得者 1 名，万人计划青年拔尖人才 1 名。该系还有在站博士后 4 名，博士研究生 87 名，本科生 112 名，办公行政人员 1 名。主要研究领域包括宇宙学与星系形成、高能天体物理、星际介质和恒星与行星系统、粒子天体物理等，涉及各种天文尺度及不同天体环境。

The Department of Astronomy of PKU was founded in 2000, based on the Astrophysics Division in the Department of Geophysics established in 1960. The Department of Astronomy became a member of the School of Physics when the latter was created in 2001. PKU Astronomy was given the status of National Key Discipline by Ministry of Education in 2001. Recently, astronomy major was selected as the construction point of national first-class undergraduate major and was selected into the national top talents training plan for basic disciplines. Currently (at the end of 2022) the Department of Astronomy has 10 full-time faculty members. Among them, there are 4 NSFC “Distinguished Youth Award” winners, 1 State Council Government special allowance awardee, 1 “Ten Thousand Talent Program” Leading Talent, 1 “Ten Thousand Talent Program” Youth Top-notch Talent, 1 MOST Innovation Talent and 1 Tencent Foundation XPLORER PRIZE awardee. The Department of Astronomy has 4 postdocs, 87 postgraduate students, 112 undergraduates, and 1 administrative staff. The main research fields include cosmology and galaxy formation, high-energy astrophysics, interstellar medium, stellar and planetary systems, and particle astrophysics, involving astronomical phenomena and astrophysical processes at all scales and various astrophysical environments.

一、椭圆吸积盘：一种产自北京大学的新型吸积盘模型

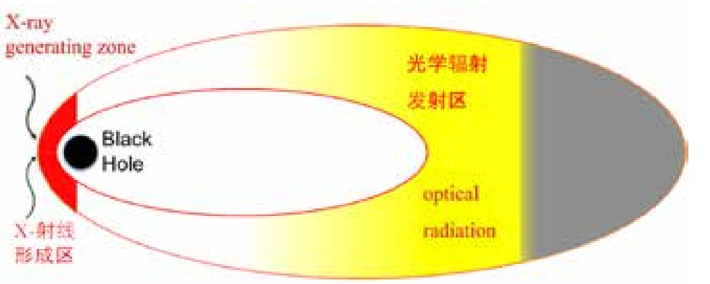
天文学家们相信，在几乎所有星系中心都潜伏着或单、或双的超大质量黑洞。这些超大质量黑洞平时不以任何踪迹示人，但它们的存在影响甚至决定着星系的形成和演化，它们的并合会产生宇宙中最猛烈的引力波暴。

当一颗恒星掠过这些超大质量黑洞时，会被其强大的潮汐力撕裂。恒星碎片在回落黑洞时，引发潮汐撕裂事件（TDE）。经典理论通常假设，广义相对论效应将导致回落物质轨道交叉，而回落物质在轨道交叉处相互碰撞会从而使回落物质形成的吸积盘有效圆化。然而，吸积盘有效圆化这一标准图像最近受到了来自对 TDE 的光学／紫外辐射谱和总辐射光度观测的严峻挑战。如果吸积盘如某些数值模拟所启示的那样圆化是低效率的，那么低角动量回落物质形成的吸积盘必然是椭圆形的。以色列著名科学家 Tsvi Piran 教授及其合作者最近提出了一个类似绳套的椭圆盘模型。在该模型中，回落物质绕黑洞形成椭形绳套，后续回落物质与已绕过黑洞后向外运动的前锋物质在远离黑洞的轨道交叉处相互碰撞，形成绳结。该绳套椭圆盘模型假设，辐射来自物质相互碰撞处，即绳结处的激波。该模型被国际同行称为潮汐撕裂事件的“激波模型”。

北京大学物理学院天文系和科维理天文与天体物理研究所刘富坤教授领导的研究团队提出了一个物理上完全不同的新型椭圆盘模型（见示意图）。在该吸积盘模型中，软 X- 射线光子在椭圆盘绕黑洞的近心点处产生，形成后被电子散射囚禁在吸积盘物质内，随物质一起绕黑洞旋转（类似光纤）。这些软 X- 射线光子在随物质一起绕黑洞作椭圆绕转的过程中光致电离吸积盘物质。被电离的物质在复合时，发射出低频连续谱和光学发射线。在最近发表在国际著名天体物理杂志 ApJ 的论文中，刘富坤带领团队研究了该理论模型的动力学和热辐射性质，并非常漂亮地回答了那些严峻挑战传统圆化吸积盘模型的难题。北京大学的博士研究生曹春洋、曹荣、周智勤，波兰尼古拉斯·哥白尼天文研究中心的 Marek Abramowicz 教授以及哈佛大学的 Maciek Wielgus 博士是论文的共同作者。

标准圆吸积盘通常被称为“波兰甜甜圈”（一个由著名科学家、英国皇家学会前主席 Martin Rees 爵士创造的名字。Martin Rees 爵士同时也是 TDE 经典理论之父之一）。为了突出椭圆吸积盘与标准圆吸积盘在几何形状上的不同，同时保留以糕点命名的传统，以色列著名科学家 Tsvi Piran 教授为椭圆吸积盘创造了“耶路撒冷百吉饼（Jerusalem bagel）”（见下图）这一名字。为了强调与以色列 Piran 教授等人的椭圆吸积盘模型在几何上的相似性和物理上的不同性，在最近发表的论文中所描述的椭圆吸积盘被称为“来自北京的耶路撒冷百吉饼（Jerusalem bagels from Beijing）”。值得注意的是，真实的波兰甜甜圈的形状更类似于具有球状几何的邦迪吸积（Bondi accretion）。

论文链接：https://iopscience.iop.org / article / 10.3847 / 1538-4357 / abd2b6



椭圆吸积盘

由北京大学刘富坤教授团队提出

Elliptical accretion disk

proposed by the group of Fukun Liu at Peking University

I. Elliptical accretion disk as a model for tidal disruption events: A Jerusalem bagel from Beijing

When a star passing closely enough by a supermassive black hole is disrupted by tidal forces, the stellar debris falls onto the black hole triggering a tidal disruption event (TDE). It is commonly assumed that the accretion disk that forms circularizes efficiently, because of the relativistic apsidal precession and interactions between the crossing streams of matter. This picture is challenged by observations of the optical/UV spectra and the total bolometric output of the TDEs. If the circularization is inefficient, which is suggested by some numerical simulations, such low angular momentum accretion flow should result in a formation of an elliptical accretion disk. Such a model, with radiation originating from the shocks at the self-intersection of streams and being called self-crossing shock model in the community, was proposed by Tsvi Piran and colleagues.

In the current paper, a physically different model of an elliptical TDE accretion disk (see figure), originating from the Beijing group of Fukun Liu at The Department of Astronomy and The Kavli Institute for Astronomy and Astrophysics of Peking University, is discussed. In this case the energy dissipation occurs mainly in the accretion disk near the pericenter of the flow. The elliptical accretion disk of Beijing group has the properties of dynamics and thermal emission that are distinctively different from those of both the classic circular accretion disk and the self-crossing shock model and well consistent with the observations of the optical/UV TDEs. Professor Fukun Liu is the leading author of the work. The PhD students Chunyang Cao, Rong Cao and Zhiqin Zhou from the research group of Fukun Liu, Professor Marek Abramowicz at the Nicolaus Copernicus Astronomical Center, and Doctor Maciek Wielgus at the Black Hole Initiative of Harvard University, contributed together to this research.

A standard circular accretion disk is commonly referred to as a "Polish doughnut" (a name coined by sir Martin Rees, who is also one of the fathers of the classic theory of TDEs). To highlight the geometric difference of the elliptical disk, while remaining in the pastry-inspired namespace, Piran coined a name "Jerusalem bagel" (see figure). To stress similarities and differences, the accretion disks described in this paper are referred to as "Jerusalem bagels from Beijing". It is worth noticing that the geometry of an actual Polish doughnut corresponds to a spherical geometry of Bondi accretion.

Paper Link: https://iopscience.iop.org/article/10.3847/1538-4357/abd2b6

二、北大天文团队发现近 200 个新的银道面背景类星体

2022 年 7 月 29 日，北京大学科维理天文与天体物理研究所傅煜铭博士和物理学院天文学系吴学兵教授所在团队在著名天文期刊 The Astrophysical Journal Supplement Series（ApJS）发表论文，在前期已选出 16 万多个银道面背景类星体候选体基础上，使用国内外 5 台光学望远镜的光谱观测高效证认了 204 个银道面背景类星体，其中 191 个为首次发现。研究结果验证了该团队提出的银道面背景类星体选源方法的有效性，为后续大样本的银道面背景类星体巡天打下了坚实基础。

类星体是明亮的活动星系核，其中心的超大质量黑洞通过吸积周围气体物质释放巨大能量。类星体是遥远宇宙的重要探针，对研究超大质量黑洞的形成和演化至关重要。过去数十年来，类星体巡天取得了很大进展，但在天区覆盖范围上仍然存在不足。大型类星体巡天主要关注北天的高银纬天区，而通常不覆盖银道面天区（银纬 |b|<=20° 区域）。截至 2021 年底，文献中已被证认的 I 型类星体和活动星系核接近 83 万个，其中仅有不到 6000 个位于 |b|<20° 内，仅有不到 300 个位于 |b|<10° 内。

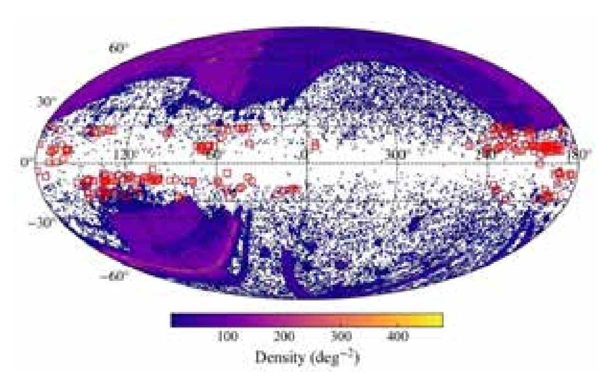


图 1. 通过光谱观测证认的 204 个银道面背景类星体（红色方框）在银道坐标系中的分布。背景图展示了所有已知类星体的全天密度分布。

Fig 1. The sky distribution of the 204 identified quasars behind the Galactic plane (red squares) in Galactic coordinates. The density map of known quasars is shown in the background.

尽管现有样本较少，银道面背景类星体（GPQ）具有其所处天区赋予的特别价值。高精度的天体测量数据对于研究银道面的盘恒星和核球恒星十分重要，但由于缺少该天区的背景类星体，以欧洲 Gaia 卫星为代表的天体测量研究难以对银道面的天体测量系统误差进行准确估计。一个较大的银道面背景类星体样本有助于建立更好的天体测量参考架，提高银道面天体测量的精度，帮助我们更好地了解银河系的结构和运动学性质。另一方面，利用银道面背景类星体的光谱特征还可以用于示踪银盘上的气体分布，以及测量银河系消光等。

由于银道面严重的尘埃消光、红化以及密集的星场，寻找银道面背景类星体十分困难。使用高银纬天区数据发展的类星体选源方法不能直接适用于银道面天区，因为高银纬天区和银道面天区的天体测光数据遵循不同的统计分布。为了应对这种类星体选源中的数据集偏移问题，北京大学傅煜铭博士和吴学兵教授所在团队构建了一种基于迁移学习的银道面背景类星体选源方法，通过模拟的方式减小训练数据与测试数据在天体特征分布上的差异，进而可以利用机器学习算法训练分类模型。为了进一

步排除恒星污染，该团队还发展了一种基于 Gaia 卫星自行数据的辅助选源方法，使用零自行概率密度判据选取类星体候选体。对 Pan-STARRS1 和 AllWISE 光学 - 红外测光星表中位于银道面方向的天体应用上述选源方法，最终构建了包含 16 万个源的银道面背景类星体候选体星表（文章 1）。

从 2018 年起，该团队通过与国内外研究团队合作，利用国家天文台兴隆站 2.16 米望远镜、云南天文台丽江站 2.4 米望远镜、美国帕洛玛天文台 5 米海尔望远镜、美国 MDM 天文台 1.3 米望远镜、澳大利亚国立大学 2.3 米望远镜对银道面背景类星体候选体开展了光谱观测证认。本次公布的数据一共包含 204 个银道面背景类星体，其中 191 个为首次发现，证认成功率高达 84%。该样本的类星体红移在 0.069 到 4.487 之间，因为只有更亮的类星体才能在银道面方向被观测到，所以通过光谱估算的银道面背景类星体黑洞质量高于美国斯隆数字巡天类星体表 DR7Q 的平均水平（图 3）。

该团队预期在未来两年中证认约 200 个位于银纬 5 度以内的背景类星体，并通过我国郭守敬望远镜（LAMOST）的光谱巡天证认上千个银纬 20 度以内的背景类星体。此外，银道面背景类星体候选体的天体测量应用研究也正在开展。北大天文团队主导的银道面背景类星体搜寻项目将类星体的系统搜寻拓展到了银道面的密集星场区域，展示了在复

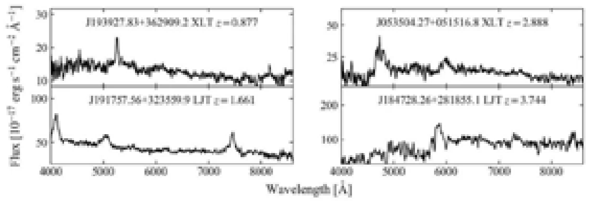


图 2. 使用国家天文台兴隆站 2.16 米望远镜（XLT）和云南天文台丽江站 2.4 米望远镜（LJT）拍摄的银道面背景类星体光谱示例。我国两台 2 米望远镜证认了 204 个类星体中的 137 个。

Fig 2. Examples of the spectra of the 204 identified quasars behind the Galactic plane obtained with the five optical telescopes (XLT, LJT, P200, ANU23, MDM13).

杂条件下使用天文领域知识提升数据挖掘效果的可行性，以及银道面背景类星体对天体测量和天体物理研究的重要意义。相关成果获得了包括欧洲 Gaia 卫星团队最近发表的多篇文章的引用。

该项目的最新论文（文章 2）已发表在国际著名天文期刊 ApJS (Fu, Wu, et al. 2022, 261, 32)，文章 1 已于 2021 年在 ApJS 发表 (Fu, Wu, et al. 2021, 254, 6)。论文的相关数据已通过中国国家天文科学数据中心发布。

本项目研究得到国家自然科学基金委和中国载人航天工程的资助，以及国家天文台兴隆站和云南天文台丽江站等单位的大力支持和帮助。

II. PKU astronomers discover nearly 200 new quasars behind the Galactic plane

We are located at the edge of the Galactic disk, and see our Galaxy as a hazy band of light made of countless stars in the night sky. Looking for extragalactic objects like quasars through this band of light is so hard that this region has long been called the "Zone of Avoidance" for extragalactic astronomy. But now, a new research program makes it hard for quasars to hide themselves behind the Galactic plane.

An international research team led by astronomers from Peking University has identified 204 quasars behind the Galactic plane, 191 of which are new discoveries, using five optical telescopes in China, USA, and Australia. The new research, recently published in the Astrophysical Journal Supplement Series (ApJS), marks the successful lift-off of the spectroscopic observation campaign, after releasing the candidate catalog of quasars behind the Galactic plane with more than 160,000 sources previously selected by this team.

Quasars are luminous active galaxies with supermassive black holes at their centers, which releases huge amounts of energy through accreting surrounding materials. Quasars are probes of the distant universe and are keys to understand the formation and evolution of the supermassive black holes. Over the past few decades, great progress has been made in quasar surveys, yet the sky coverages of them are mainly limited to high Galactic latitude. By the end of 2021, nearly 830,000 quasars are found in the literature, while fewer than 6,000 of them (< 1%) are located in |b| < 20° (the Galactic plane; 34% of the entire sky), and fewer than 300 of them are located in |b| < 10°.

Despite the deficit of quasars behind the Galactic plane (GPQs), such quasars are of special interest to

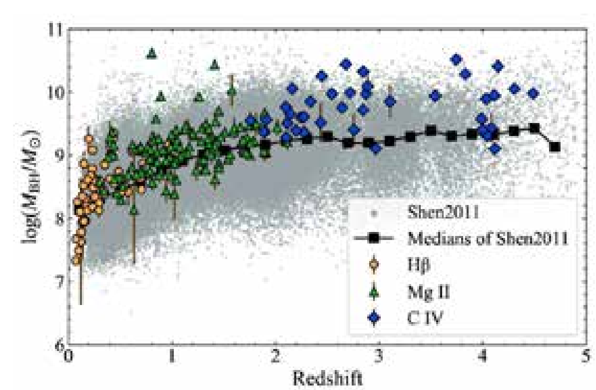


图 3. 证认的 204 个银道面背景类星体黑洞质量随红移分布图（黄色圆圈、绿色三角和蓝色菱形）。背景的灰色点为斯隆数字巡天（SDSS）类星体表 DR7Q 的黑洞质量分布，黑色方块为 SDSS DR7Q 的黑洞质量中值分布。

Fig 3. Distributions of the black hole masses with redshift of the 204 GPQs, with yellow circles, green triangles, and blue diamonds showing black hole masses estimated with different emission lines. The black hole masses of SDSS DR7Q are shown as gray dots, and the median black hole masses of DR7Q in 24 redshift bins are shown as black squares.

us due to their locations in the celestial sphere. "If we want to study the stars of the Milky Way disk, we need accurate measurements on their positions and motions from astrometric probes such as Gaia of the European Space Agency. To achieve that, astronomers use quasars to build the celestial reference frame, because quasars are so distant from us that they show almost no apparent motions on the sky," said Yuming Fu, the first author of the new research, and a postdoctoral researcher from the Kavli Institute for Astronomy and Astrophysics (KIAA) at Peking University.

"The Gaia mission has produced great data. However, we can barely determine the systematic errors of Gaia astrometry in the middle of the Galactic plane, just because we lack quasars there," said Xue-Bing Wu, corresponding author of the new research and Professor from Department of Astronomy and KIAA at Peking University. "A large sample of GPQs is crucial to a better astrometric reference frame and a better understanding of the structures and kinematics of the Milky Way. Also, GPQs can probe the gas in the Galactic disk and provide a unique way of measuring Galactic extinctions."

Finding GPQs is very difficult due to severe dust extinctions and reddening, as well as the crowded stellar fields in the Galactic plane. Existing selection methods for quasars developed using high Galactic latitude data cannot be applied to the Galactic plane directly, because the photometric data obtained from high Galactic latitude regions and the Galactic plane follow different probability distributions.

To alleviate such data set shift problem for quasar candidate selection, the research team led by Dr. Yuming Fu and Prof. Xue-Bing Wu has developed a transfer learning method for quasar selections, which reduces the difference of features(e.g. colors, magnitudes) between the training data and test data, and makes machine learning algorithm applicable to the classifications. To further remove stellar contaminants from the GPQ candidates, the team has also developed an additional method based on Gaia proper motions, which uses a cut on the "probability density of zero proper motion" to select quasar candidates. By applying these selection methods to the Galactic plane, they have obtained a reliable GPQ candidate catalog with 160,946 sources located at |b| ≤ 20° in Pan-STARRS-AllWISE footprint (Paper I).

The team has been identifying GPQ candidates since 2018 with the 2.16 m Telescope (XLT; Xinglong, NAOC), the 2.4 m Telescope (LJT; Lijiang, YNAO), the 200 inch Hale Telescope (P200; Palomar), the ANU 2.3 m Telescope (ANU23; Siding Spring), and the McGraw-Hill 1.3 m Telescope (MDM13; MDM Observatory). Among 243 candidates that have been observed, 204 sources (84%) are successfully identified as quasars (see Fig 2 for a few examples). This new GPQ sample covers a wide redshift range from 0.069 to 4.487. In comparison to a genuine quasar sample from the Sloan Digital Sky Survey (SDSS DR7Q), this GPQ sample has a higher average black hole mass, because intrinsically brighter quasars are more likely to be found in the Galactic plane (Fig 3).

The team expects to identify about 200 more new quasars at the very middle of the Galactic plane (|b| < 5°) in the next two years, and identify a few thousand GPQs at |b| ≤ 20° with the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) Spectral Survey. The team members are also investigating the astrometric properties of the GPQs to assess the systematic errors of Gaia data in the Galactic plane. The GPQ project led by PKU astronomers extends the systematic searches for quasars to the dense stellar fields of the Galactic plane and shows the feasibility of using astronomical knowledge to improve data mining under complex conditions.

The new research (Paper II) has been published (Fu, Wu, et al. 2022, ApJS, 261, 32), following the publication of Paper I, which described the selection methods and candidate catalog of GPQs (Fu, Wu, et al. 2021, ApJS, 254, 6). The data that accompany the papers are available at the National Astronomical Data Center (NADC) of China.

The research was funded by the National Science Foundation of China, and the science research grant from the China Manned Space Project. Candidate selections for the quasars were based on data from the Pan-STARRS survey, the AllWISE catalog, and Gaia Data Release 2. Spectroscopic observations were made possible with the Xinglong 2.16 m telescope, the Lijiang 2.4 m telescope, the Hale Telescope, the ANU 2.3 m telescope, and the MDM McGraw-Hill 1.3 m Telescope.

三、北大学者提出长时标伽马暴 GRB211211A 等起源于黑洞 - 中子星并合

人们相信，双中子星并合和黑洞 - 中子星并合事件会产生引力波暴，以及伽马射线暴（简称伽马暴）和千新星现象。2017 年 8 月 17 日，LIGO-Virgo 引力波探测器首次探测到一次双中子星并合事件的引力波信号，而空间伽马射线望远镜和地面巡天望远镜也分别探测到与之成协的短时标伽马暴（持续时间小于 2 秒）和千新星，因此证实了引力波暴、短伽马暴和千新星三者统一起源于双中子星并合的理论。关于黑洞 - 中子星并合，科学家也持续研究和搜寻其产生的引力波、伽马暴和千新星信号，但在观测上一直没有证实。直到 2020 年初，由黑洞 - 中子星并合产生的两例引力波信号（GW200105 和 GW200115）首次在 O3 时期（即引力波探测第三次运行）被 LIGO-Virgo 探测到，但是科学家并没有观测到预期的伽马暴和千新星。

理论上，黑洞 - 中子星并合只在黑洞拥有很大自旋时才会潮汐瓦解系统中的中子星，并由于吸积产生明亮的伽马暴，以及由并合抛射物产生千新星热辐射。与双中子星并合不同的是，黑洞较大的引力可能会使并合后抛出的一些物质重新回落，形成回落吸积辐射——导致伽马暴持续时间的延长。据理论估计，这些可以发生潮汐瓦解的系统在宇宙所有黑洞 - 中子星并合事件中的占比小于 20%。引力波观测结果证实 GW200105 和 GW200115 引力波事件中黑洞的自旋都非常小，这意味着它们没有呈现可观测的电磁辐射对应体是符合理论预期的。

另一方面，大质量恒星塌缩一般被认为是绝大部分长时标伽马暴（持续时间大于 2 秒）的起源，并且伴随产生明亮的超新星爆炸热辐射。然而，近年来科学家们陆续发现了 3 个长时标伽马暴（GRB 060614, 211211A 和 211227A），它们的起源存在争议，其特征展示更可能起源于致密星并合。它们爆发的时间均不在引力波探测器运行的时期内，无法通过引力波观测直接证实它们的真实起源。这 3 个伽马暴都没有呈现出明亮的超新星辐射，但是其中两个（GRB 060614 和 211211A）被探测到了疑似的千新星辐射。

北大天文一个高能天体物理研究小组系统地研究了这 3 个长时标伽马暴事件，从几方面提出证据证明它们可能的黑洞 - 中子星并合起源。他们发现这 3 个伽马暴早期的伽马射线辐射和 X 射线余辉中均包含了明确的回落吸积信号，与理论预言的黑洞 - 中子星并合事件导致的回落吸积辐射一致（见图 1）。其次，对这 2 例千新星辐射进行理论分析发现，它们产生的抛射物质可以达到 0.1 倍太阳质量（对 GRB 211211A 的千新星候选体光变曲线的拟合见图 2）。模拟计算表明，这么大质量的抛射物质几乎只能由极高自旋的黑洞与中子星并合才能产生。还有，基于这 3 例伽马暴事件的光度和探测率，研究小组还估计了它们在宇宙中的爆发率，与理论上预估的高自旋黑洞与中子星并合事件率一致。这些结果都揭示了长时标伽马暴和伴随的千新星辐射极有可能起源于黑洞 - 中子星并合。随着引力波探测能力的进一步加强，研究小组估计在 O4 和 O5 这两个运行时期黑洞 - 中子星并合事件引起的引力波和电磁信号的联合探测率分别为每年 0.1 例和 1 例。近日，这些结果以"源于快自旋黑洞 - 中子星并合的长时标伽马射线暴和成协的千新星辐射"（Long-duration Gamma-Ray Burst and Associated Kilonova Emission from Fast-spinning Black Hole–Neutron Star Mergers）为题发表于美国《天体物理杂志通讯》（Astrophysical Journal Letters）。此研究为解释这类特殊的伽马暴事件提出了新的理论，也在黑洞 - 中子星并合研究方面做出具有重大意义的观测预言。

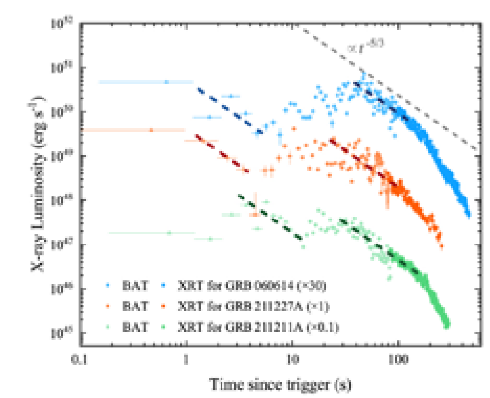


图 1. 三例致密星并合起源长伽马暴的 X 射线波段辐射，虚线代表回落吸积过程。

Fig 1. X-ray emissions of three merger-origin long-duration GRBs. Dashed lines represent the processes of fall-back accretion.

北京大学天文学系博士生朱锦平（现为澳大利亚莫纳什大学博士后）、云南大学中国西南天文研究所杨元培副教授（原北京大学科维理天文与天体物理研究所博士后）和北京大学物理学院天文学系黎卓研究员是发表文章的共同通讯作者，其他合作者包括南京大学空间与天文学院博士生王翔煜、中国科学院国家天文台孙惠助理研究员（原北京大学天文学系博士毕业生）、广西大学物理学院硕士生胡瑞 、安徽师范大学物理与电子信息学院秦颖研究员和德国爱因斯坦研究所博士生吴仕超。

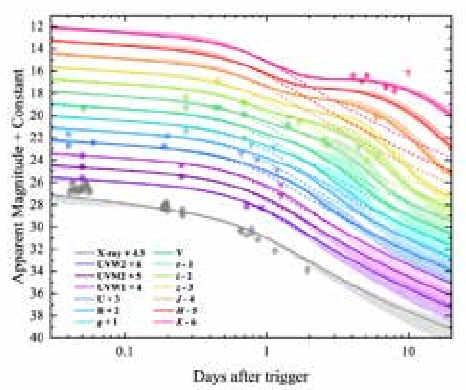


图 2. GRB211211A 光学波段余辉、千新星辐射及拟合结果。

Fig 2. The observations and fitting results of afterglow and kilonova emissions from GRB211211A.

III. Black hole-neutron star mergers as the origin of GRB 211211-like long-duration gamma-ray bursts

Neutron star mergers, including mergers of neutron star binaries and of a neutron star and black hole, are usually thought to be the progenitors of gravitational-wave bursts, gamma-ray bursts, and kilonova events. On 17 August, 2017, a gravitational wave signal from a binary neutron star merger, GW 170817, was first identified by the LIGO-Virgo Collaboration, while its associated short-duration gamma-ray burst (duration shorter than about 2 seconds), broad-band afterglow, and kilonova were revealed by subsequent data analyses. The joint observations of the gravitational wave signal and electromagnetic counterparts of this binary neutron star merger provided the smoking-gun evidence for the long-hypothesized origin of short-duration gamma-ray bursts and kilonovae.

However, the association between gravitational wave events, gamma-ray bursts, and kilonova from black hole-neutron star mergers has never been confirmed in observations. In early 2020, two gravitational wave events from binary neutron star-black hole mergers (GW 200105 and GW 200115) were detected during the third observing run of the LIGO-Virgo Collaboration. However, astronomers did not discover any gamma-ray bursts or kilonovae signatures that were expected to appear after black hole-neutron star mergers. In theory, the tidal disruption of black hole-neutron star mergers usually occurs only when the black hole component has a high spin, which allows the production of bright gamma-ray bursts and kilonova emissions. Different from binary neutron star mergers, the massive newborn black hole formed after neutron star-black hole mergers can drag back a fraction of debris resulting in powerful fallback accretion emissions. Based on previous simulations, these disrupted black hole-neutron star mergers should account for just <20% of the total black hole-neutron star population in the Universe. Gravitational wave observations confirmed that the black holes that formed from these two black hole-neutron star mergers had near-zero or negative spins, indicating that they were indeed unlikely to generate detectable electromagnetic counterparts.

系所中心研究亮点 | *Highlights*

Recently, Peking University PhD student Jinping Zhu, advised by Prof. Zhuo Li, showed that a peculiar class of long-lasting gamma-ray bursts, like GRB 211211, which lack bright supernova counterparts but are associated with candidate kilonova, can indeed originate from black hole-neutron star mergers. Most long-duration gamma-ray bursts (duration longer than about 2 seconds) are typically thought to be derived from core collapses of massive stars, which produce also bright supernovae. However, in recent years, three special long-duration gamma-ray bursts, GRBs 060614, 211211A, and 211227A, were argued to originate from neutron star mergers, but the physical origin is still under debate. These gamma ray bursts occurred outside the observing schedule of gravitational wave detectors, so their true origin cannot be directly confirmed. These three long-duration gamma-ray bursts did not show bright supernovae, but kilonova candidates were identified in the late-time optical afterglows from two of the three gamma-ray bursts, i.e., GRBs 060614 and 211211A.

By systematically studying the properties of these three gamma-ray bursts, Zhu and coauthors found evidence that they occurred because of the merger of a black hole-neutron star binary. First, the early gamma-ray and X-ray extended emissions of all these bursts contained clear fallback accretion signals, consistent with the fallback accretion emissions which are predicted to occur after black hole-neutron star mergers (see Fig 1), resulting in the extension of the burst activity duration. Secondly, the ejecta mass inferred from kilonova candidates of these long-duration gamma-ray bursts could be even as large as 0.1 solar mass (see Fig 2 for the fitting results of the GRB211211A-associated kilonova candidate). In numerical simulations, only extremely high-spinning black hole-neutron star mergers can finally eject materials with such a large mass. Moreover, based on the detection rate of the three events, the estimated event rate densities of long-duration gamma-ray bursts of this kind agree with the predicted rate densities of cosmological fast-spinning black hole-neutron star mergers. Thus, black hole-neutron star mergers can well explain the origins of GRB211211A-like long-duration gamma-ray bursts.

With the improvement in gravitational wave detection during the fourth and fifth observing run, more black hole-neutron star mergers will be discovered in the future. The authors further predict that the joint detection rates of gravitational wave, gamma-ray burst, and kilonova emissions from black hole-neutron star mergers are 0.1 and 1 per year, respectively, in the fourth and fifth observing runs of the LIGO-Virgo-KAGRA Collaboration. The future multi-messenger observations are encouraging.

These research results were published in the article, “Long-duration Gamma-Ray Burst and Associated Kilonova Emission from Fast-spinning Black Hole–Neutron Star Mergers” in The Astrophysical Journal Letters, vol. 936, L10, 2022 August 29. The anonymous referee placed the work in context, stating, “The work is very thorough and has the potential to make a significant contribution in both the interpretation of these special gamma-ray burst events, as well as the study of NS-BH mergers.” Authors in this work include PhD student Jinping Zhu from PKU, PhD student Xiangyu Ivy Xiang from Nanjing University, Dr. Hui Sun from National Astronomical Observatory of China (former graduate student from PKU), Prof. Yuanpei Yang from Yunnan University (former postdoc from PKU), Prof. Zhuo Li from PKU, M.S. student Ruichong Hu from Guangxi University, Dr. Ying Qin from Anhui Normal University, and PhD student Shichao Wu from Albert Einstein Institute, Germany.

系所中心研究亮点 | *Highlights*

07 大气与海洋科学系 Department of Atmospheric and Oceanic Sciences

北京大学大气与海洋科学系起源于 1929 年，具有悠久的历史和深厚的底蕴。90 多年来，大批杰出学者先后在此学习、执教，秉承自由、严谨、求实、创新的精神，为大气与海洋科学教育、科研和业务做出了卓越贡献。

本系是中国高校中唯一的大气科学一级重点学科，第四轮学科评估获 A+，拥有两个二级重点学科（气象学、大气物理学与大气环境），自设两个二级学科（气候学、物理海洋学），强调各学科方向的均衡发展。1993 年，本系被确定为第一批"国家理科基础科学研究和教学人才培养基地—大气科学基地"。2008 年，本系与北京大学其它地球科学学科共同成立了国家级"地球科学教学实验中心—大气科学综合实验室"。2010 年，为加强气候变化研究和开展海洋科学研究，增设了物理海洋专业，成立了"气候与海气实验室"。2019 年，入选一流本科专业。2020 年，入选教育部第二批基础学科拔尖学生培养计划 2.0 基地。2022 年，与广东省气象局联合共建"中国气象局龙卷风重点开放实验室"。

本系现有 28 名全职教师，包括杰青 4 人、优青 2 人、青年拔尖 2 人、海外高层次人才 9 人。四大重点方向包括极端天气与气候变化、大气物理与大气环境、海气相互作用与物理海洋、以及古气候与行星大气。聚焦基础与前沿科学问题，提倡在独立科研基础上的跨领域团队合作，致力于建设世界一流的大气与海洋科学学科。近年来，教师人均每年获得科研经费约 80 万元，人均每年发表 SCI 论文 5 篇。

The Department of Atmospheric and Oceanic Sciences (AOS) at Peking University originated from a meteorological program established in 1929, and has a long and prestigious history of academic excellence. Over the past 90 some years, many prominent scholars have taught or studied at AOS. Immersed in an environment of academic freedom, rigor and innovation, AOS scholars have made extraordinary contributions to education, research, and applications of atmospheric and oceanic sciences to the betterment of society.

AOS has the only first-tier focal discipline in atmospheric sciences in China. It has two second-tier focal disciplines (meteorology, atmospheric physics and atmospheric environment), and two other second-tier disciplines (climatology and physical oceanography). In 1993, AOS was selected in the first group of "National Natural Science Basic Scientific Research and Teaching Training Base — Atmospheric Science Base". In 2008, AOS established jointly with other Earth Science disciplines at PKU the national-level "Earth Science Teaching and Experiment Center — Atmospheric Science Laboratory". In 2010, AOS added the Physical Oceanography program, and established the "Laboratory for Climate and Ocean-Atmosphere Studies". In 2019, AOS was selected as a first-class undergraduate program. In 2020, AOS was selected as a Top-Notch Student Training Base of Atmospheric Science by the Ministry of Education's Top-Notch Program for Basic Sciences 2.0. In 2022, AOS established jointly with Guangdong Meteorological Service the "China Meteorological Administration Tornado Key Laboratory".

AOS has a total of 28 full-time faculty members. Research fields within AOS include severe weather and climate change, atmospheric physics and environment, sea-air interactions and physical oceanography, and paleoclimate and planetary atmospheres. AOS pursues fundamental and cutting-edge research, promotes multidisciplinary collaborations on the basis of independent research, and strives to become a world-leading institution in atmospheric and oceanic sciences. In each of recent years, each faculty member received about 800,000 RMB research funds and published 5 SCI papers on average.

一、全球化大气污染的气候效应

为应对气候变化，世界各国制定了《联合国气候变化框架公约》《京都议定书》《巴黎协定》等合作协议公约来划分各国的减排责任、推动气候目标的实现，而其背后的一个重要科学问题是各国排放的气候效应（即地区归因）。在经济全球化的背景下，国际贸易推动商品在国家之间流动的同时，也引起气溶胶等影响气候的污染物及其前体物的排放从消费地区转移到生产地区。传统的气候变化地区归因研究往往是基于产品生产地的排放，而没有考虑产品生产背后的推动因素——消费需求，因而忽略了隐藏在国际贸易背后的、由消费推动的排放和气候影响。

自 2014 年以来，物理学院大气与海洋科学系长聘副教授林金泰携国内外合作者，创建多学科研究框架，探索贸易活动及其与大气输送的协同作用所造成的"全球化大气污染"对地区之间污染转移、空气质量、公众健康和气候强迫的影响，成果多次发表于 PNAS、Nature 以及 Nature 子刊，并荣获 PNAS Cozzarelli Prize（年度论文奖）、国家自然科学基金资助项目优秀成果等重要学术荣誉。2022 年 2 月，林金泰与中国科学院大气物理研究所黄刚研究员合作得到的最新成果"发达国家和发展中国家消费活动所造成的硫酸盐气溶胶的气候效应相近"（Sulfur emissions from consumption by developed and developing countries produce comparable climate impacts）发表于《自然·地球科学》（Nature Geoscience）期刊上。该成果基于消费视角下的气候变化地区归因，首次定量揭示了在贸易 - 排放 - 化学 - 输送 - 气候过程的作用下，发达国家和发展中国家消费驱动下的硫酸盐气溶胶对全球温度和降水的影响，为促进可持续发展、推动国际合作以应对全球气候变化提供了新的思路。

硫酸盐气溶胶是人类活动所排放的二氧化硫在大气中被氧化而产生的二次无机气溶胶，可造成严重的局地空气质量和健康影响，并进一步通过大气输送和气候响应而造成全球气候效应。林金泰和黄刚合作团队以 2014 年各国消费和生产活动状态作为当今国际贸易背景，结合最新的污染物排放清单、国际贸易数据和地球系统模式，评估了发达国家和发展中国家消费活动所造成的硫酸盐气溶胶对全球温度和降水的影响。他们发现，作为净出口国，发展中国家的消费活动所造成的二氧化硫排放量远小于其生产活动所造成的排放量，而作为净进口国的发达国家的结果正好相反（图 1）。进一步，尽管发达国家消费活动所造成的二氧化硫排放量仅为发展中国家的 60%（图 1），但两者对全球近地表平均气温和降水量的影响却十分相似（温度下降约 0.2℃，降水减少 0.02mm/day）（图 2），其根本原因是，不同地区的消费所造成的二氧化硫排放及其对应的硫酸盐气溶胶具有明显不同的空间分布：发达国家排放的纬度更高并且纬向（东 - 西向）分布更为均匀，其单位二氧化硫排放所引起的有效辐射强迫和气候效应比发展中国家的更强。这些结果与在传统的生产视角下发达国家与发展中国家对气候影响

程度的地区归因研究结果截然不同。

林金泰、黄刚的博士生周春江以及林金泰的博士生陈璐璐为共同第一作者；林金泰、黄刚为共同通讯作者。该研究得到国家自然科学基金、国家重点研发计划等项目资助。

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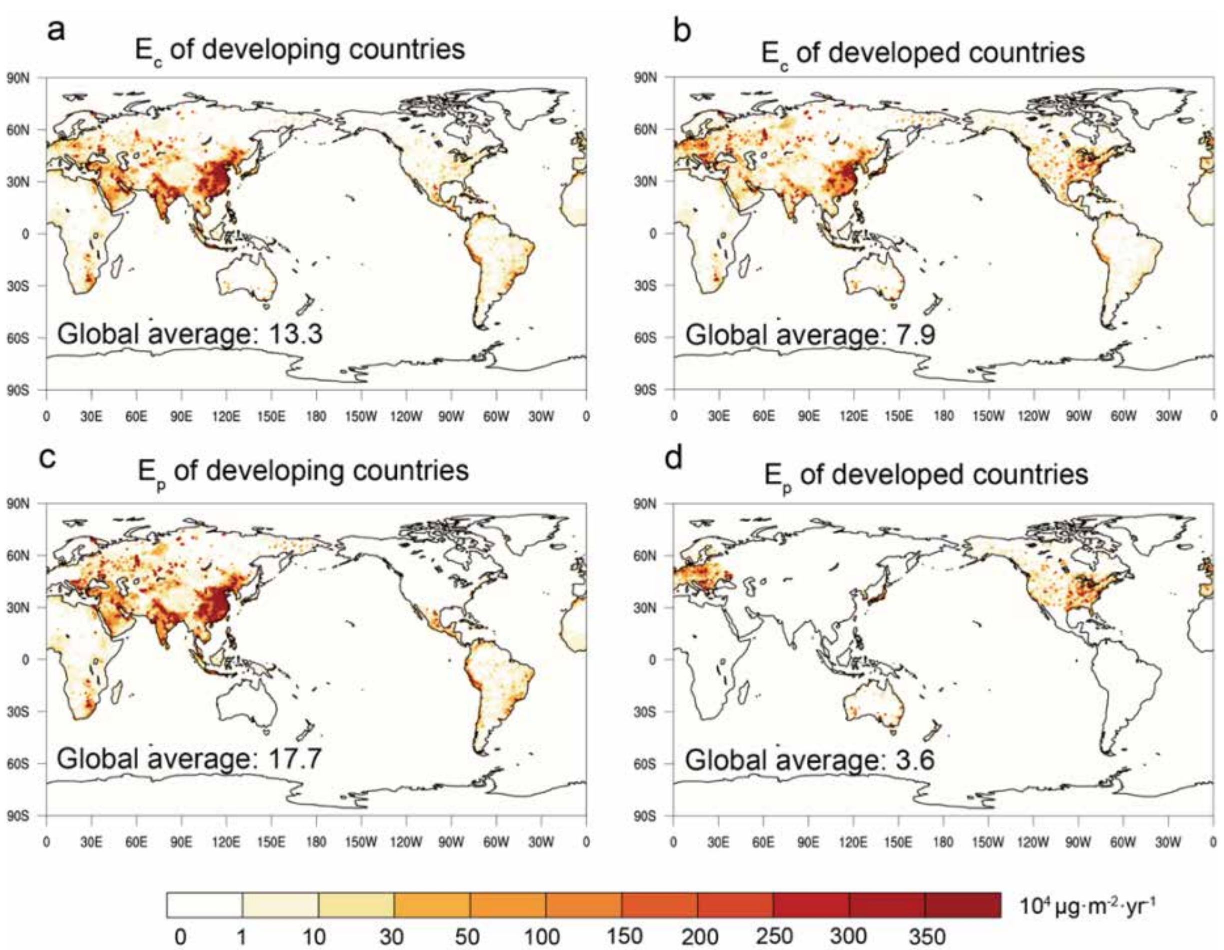

图 1. 发展中国家消费所引起的人为源 SO_2 排放（a）、发达国家消费所引起的人为源 SO_2 排放（b）、发展中国家生产所引起的人为源 SO_2 排放（c）、发达国家生产所引起的人为源 SO_2 排放（d）。

Fig 1. Anthropogenic SO_2 emissions associated with consumption activities of developing countries (a) and developed countries (b), along with production-based anthropogenic SO_2 emissions in developing (c) and developed countries (d).

I. Climate impact of globalizing air pollution

In order to combat climate change, countries all over the world have established multiple cooperative agreements such as the United Nations Framework Convention on Climate Change, the Kyoto Protocol, and the Paris Agreement to help achieve the climate goals. One important scientific question behind these agreements is the climate effects of emissions from different countries (i.e., regional attribution). Under economic globalization, international trade allows the flow of goods between countries, and at the same time causes emissions of climate-associated aerosols and their precursors to shift from consuming to producing countries. Research on regional attribution of climate change has traditionally focused on the role of emissions from the country of production, without considering the driving force of production, which is consumption demand. As a result, emissions and climate impacts driven by consumption and hidden behind international trade have been overlooked.

Since 2014, Professor Jintai Lin in the Department of Atmospheric and Oceanic Sciences, School of Physics, Peking University, has established a multidisciplinary research framework, together with domestic and international collaborators, to investigate the impacts of "globalizing atmospheric pollution", caused by the synergistic effects of trade activities and atmospheric transport, on pollution transfer between regions, air quality, public health and climate forcing. Their findings have been published in multiple high-impact journals such as PNAS, Nature and Nature Research Journals, and have won several prestigious academic honors such as the PNAS Cozzarelli Prize (Paper of the Year Award) and Outstanding Research Funded by the National Natural Science Foundation of China. In February 2022, Jintai Lin and Dr. Gang Huang from the Institute of Atmospheric Physics, Chinese Academy of Sciences, published their latest collaborative research findings, entitled "Sulfur emissions from consumption by developed and developing countries produce comparable climate impacts", in Nature Geoscience. Based on the climate change regional attribution from the perspective of consumption, this study reveals for the first time the impacts of sulfur aerosols driven by consumption in developed and developing countries on global temperature and precipitation through the trade-emissions-chemistry-transport-climate process. The study provides new insight to promote international cooperation to combat global climate change.

Sulfate are secondary inorganic aerosols chemically formed in the atmosphere from sulfur dioxide emitted from human activities. Sulfate aerosols can cause significant global climate impacts, in additional to their severe adverse impacts on human health. Jintai Lin and Gang Huang's collaborative team used the status of production and consumption activities in various countries in the year of 2014 as the starting point to assess the role of international trade on climate. Combining the latest emission inventory, international trade data, and Earth system model simulations, the research team evaluated the impacts of sulfate aerosols caused by consumption activities in developed and developing countries on global temperature and precipitation. They found that sulfur dioxide emissions caused by consumption activities in developing countries, as net exporting countries, are much smaller than the emissions caused by their production activities; while the opposite results are true for developed countries, which are net importing countries. Furthermore, although the sulfur dioxide emissions caused by consumption activities in developed countries are only 60% of those in developing countries (Fig 1), their impacts on global near-surface average temperature and precipitation are very similar (temperature decreases by about 0.2 ℃, and precipitation decreases by 0.02mm/day; Fig 2). The fundamental reason is that the sulfur dioxide emissions caused by consumption in different regions and their resulting sulfate aerosols have drastically different spatial distributions. Compared with the counterparts for developing countries, the latitude of emissions for developed countries is higher and their meridional (east-west) distribution is more uniform, resulting in a stronger effective radiative forcing and climate effect for each unit of sulfur dioxide emissions. These consumption-based results differ greatly from the climate impacts of developed and developing countries under the traditional production-based perspective.

Jintai Lin, Chunjiang Zhou (a PhD student of Dr. Huang), and Lulu Chen (a PhD student of Jintai Lin) are the co-first authors of the study. Jintai Lin and Gang Huang are the corresponding authors. This research was supported by the National Natural Science Foundation of China and the National Key Research and Development Program.

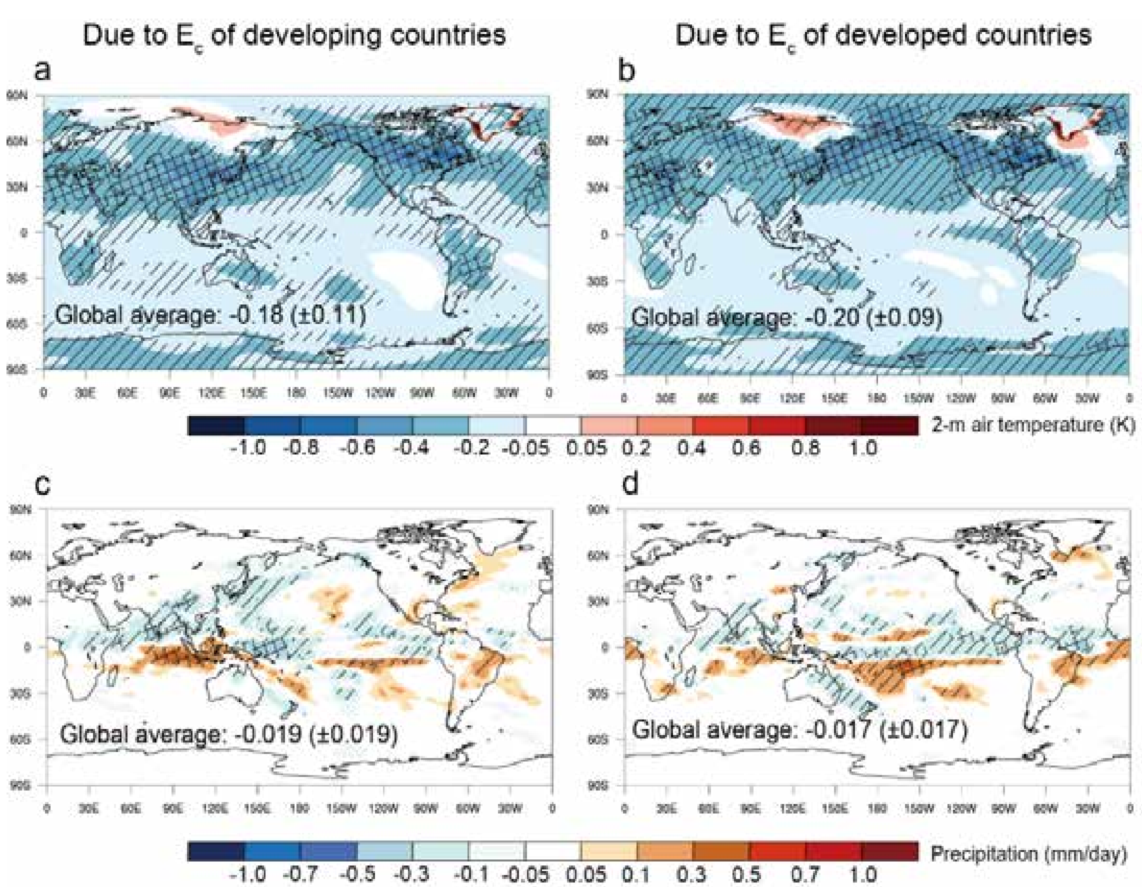

图 2. 发展中国家（a,c）和发达国家（b,d）消费相关的硫酸盐气溶胶所引起的全球温度响应（a,b）和降水响应（c,d）。

Fig 2. Changes in air temperature (a,b) and precipitation (c,d) due to consumption of developing (a,c) and developed countries (b,d).

系所中心研究亮点 | *Highlights*

二、全球变暖下的野火及野火 - 沙尘复合极端事件

野火是发生在自然植被类型上的生物质燃烧现象，是陆地生态系统的主要扰动源和气溶胶的主要自然排放源之一，影响全球碳循环、气候和经济社会。近年来频发的极端野火引起人们的关注：野火会导致哪些生态气候效应？在全球气候环境变化下，野火的未来趋势如何？这也是俞妍助理教授课题组近期探索的领域。

课题组利用本团队参与反演的沙尘和烟尘气溶胶卫星遥感产品，以及燃烧火点、植被、土壤湿度等多源遥感资料，对野火后沙尘排放这一全球现象进行探索，发现大面积、持续性的生物质燃烧破坏植被、降低土壤湿度，导致燃烧后沙尘排放。上述现象在全球干旱区以外的大范围地区造成了沙尘浓度显著升高；野火后沙尘排放强度主要受燃烧面积和持续时间调控，同时受到干旱程度调制（图 1）。本研究揭示了干旱—野火—沙尘这一联合气象—生态灾害，在全球变暖下这一联合灾害在部分地区将会加剧。相关研究成果发表于《自然地球科学》(Nat. Geosci. 2022, 15, 878)。

对于野火未来趋势的预测，需要借助地球系统模式，然而当前地球系统模式对野火的模拟仍然有较大不确定性，利用观测资料对模式进行误差矫正和约束是提高模式预测可信度的一种有效途径。课题组发展利用机器学习、多源观测和 CMIP6 地球系统模式预测未来野火分布的研究框架，预测在本世纪未来几十年内，全球野火的燃烧面积和碳排放都有增加趋势，但是其增加程度低于未经矫正的 CMIP6 模式估计（图 2）。本研究特别指出由于全球气候变化带来的干旱加剧和植被变化，非洲野火燃烧面积和碳排放在未来几十年将显著增加，对该地区国家快速发展的经济社会造成影响。相关研究成果发表于《自然通讯》(Nat. Commun. 2022, 13, 1250)。

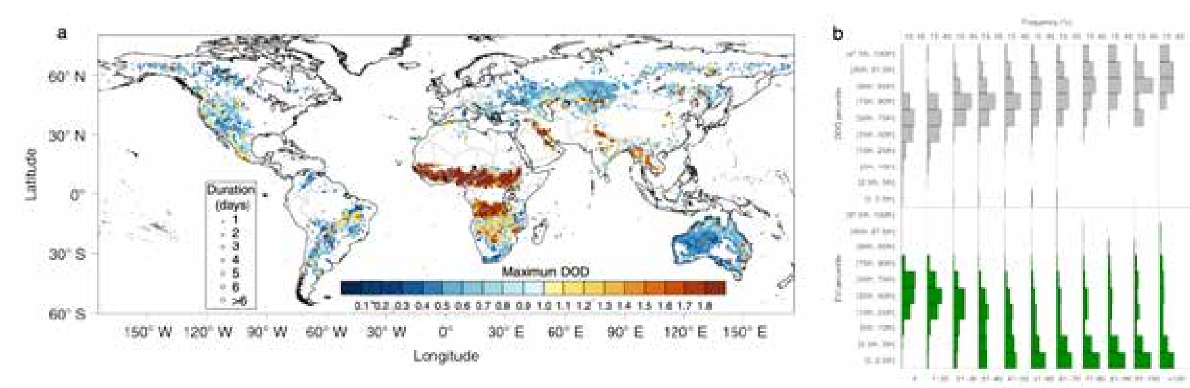

图 1. 燃烧后沙尘排放强度和驱动因子。a, 全球野火后沙尘排放导致的最大沙尘气溶胶光学厚度（DOD）和单次燃烧事件后沙尘排放最长持续天数的空间分布。b, DOD 和增强植被指数（EVI）随野火时空范围变化的概率分布。

Fig 1. Global distribution of post-fire dust events and drivers of their severeness. a, Maximum DOD (colour of dots), representing the columnar dust loading associated with the most intensive post-fire dust emission, and mean duration (days, size of dots) of post-fire dust events. b, Probability distribution of post-fire, 30-day average DOD (top) and EVI (bottom) as a function of number of precedent fires.

II. Wildfires and sequential wildfire-dust extremes under global warming

Wildfires represent a major ecosystem disturbance and aerosol emission source, affecting the global carbon budget, the climate and human life. A recent surge of disastrous fires motivated Assistant Professor Yan Yu and her team's research on the climatic responses and feedbacks of wildfires.

Using satellite measurements of active fires, aerosol abundance, vegetation cover and soil moisture from 2003 to 2020, Yan Yu and collaborator show that 54% of the examined ~150,000 global large wildfires are followed by enhanced dust emission, producing substantial dust loadings for days to weeks over normally dust-free regions. The occurrence and duration of post-fire dust emission are controlled primarily by the extent of precedent wildfires and resultant vegetation anomalies and modulated secondarily by pre-fire drought conditions (Fig 1). With the predicted intensification of regional wildfires and concurrent droughts in the upcoming decades, these results indicate a future enhancement of sequential fire and dust extremes and their societal and ecological impacts. The work is published in Nature Geoscience (Nat. Geosci. 2022, 15, 878).

The limited observational constraints for modeling outputs impairs the credibility of wildfire projections. Yan Yu and collaborators present a machine learning framework to constrain the future fire carbon emissions simulated by 13 Earth system models from the Coupled Model Inter-comparison Project phase 6 (CMIP6), using historical, observed joint states of fire-relevant variables. During the twenty-first century, the observation-constrained ensemble indicates a weaker increase in global fire carbon emissions but higher increase in global wildfire exposure in population, gross domestic production, and agricultural area, compared with the default ensemble (Fig 2). Such elevated socioeconomic risks are primarily caused by the compound regional enhancement of future wildfire activity and socioeconomic development in the western and central African countries, necessitating an emergent strategic preparedness to wildfires in these countries. The work is published in Nature Communications (Nat. Commun. 2022, 13, 1250).

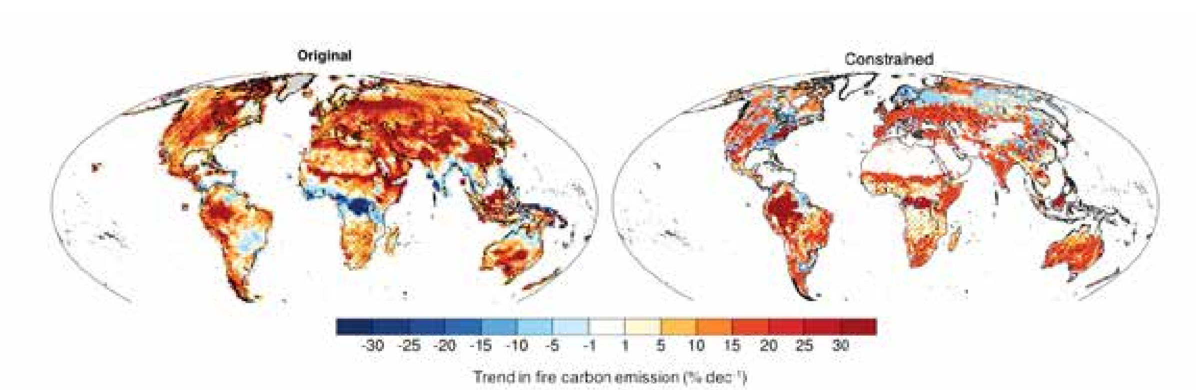

图 2. 基于 CMIP6 模式未经约束（左）和约束后（右）的 2011—2100 年野火碳排放趋势预测。

Fig 2. Global evolution of fire carbon emissions from the original and observation-constrained multimodel ensembles.

三、氮排放对全球 $PM_{2.5}$ 空气污染的形成贡献和减排成本

$PM_{2.5}$（空气动力学粒径小于 2.5 μm 的颗粒物）是一种主要的大气污染物，严重危害人体健康。世界卫生组织估算全球 $PM_{2.5}$ 污染每年造成数百万人过早死亡（指死亡年龄低于预期寿命），成为诸多国家亟需解决的重大环境问题。活性氮排放，包括氨氮（NH_3）和氮氧化物（NO_x），是造成大气 $PM_{2.5}$ 污染的重要排放来源。

张霖研究组联合浙江大学、英国生态水文中心等，提出 N-share（氮贡献率）指标，在全球尺度上表征氮排放对 $PM_{2.5}$ 空气污染及其健康效应的分摊贡献。N-share 与氮素在 $PM_{2.5}$ 中的质量占比不同，其含义是考虑对 $PM_{2.5}$ 二次无机盐形成的综合影响，通过在大气化学数值模型中关闭氨氮和氮氧化物排放但保留其他污染物（如 SO_2）排放来计算得到。研究团队量化了全球不同国家与地区氮排放对 $PM_{2.5}$ 空气污染的贡献率，评估了通过控制氮排放来减轻 $PM_{2.5}$ 污染的健康收益和减排成本，从而揭示了全球控制氨排放对减轻 $PM_{2.5}$ 污染的高社会收益。研究成果以控制氨比控制氮氧化物对减轻 $PM_{2.5}$ 空气污染更具有成本效益"为题发表于《Science》（Science, 2021, 374, 758-762）。

该研究发现，全球 $PM_{2.5}$ 污染的 N-share 从 1990 到 2013 年有整体增加，而区域差异很大(图 1)：亚洲、南美和南非地区显著增加，欧洲显著降低；全球多数国家与地区中氨氮排放对 $PM_{2.5}$ 污染的贡献率比氮氧化物排放贡献更大，表明 $PM_{2.5}$ 中二次无机盐形成受氨氮限制更强。1990—2013 年间，全球氨氮的 $PM_{2.5}$ 贡献率从 25% 增加到 32%，而氮氧化物贡献率从 17% 增加到 28%。总氮排放的 N-share 远小于氨氮和氮氧化物单独的 N-share 之和（图 1）体现出两者在二次 $PM_{2.5}$ 形成过程中的相互作用。

降低氮排放及其导致的 $PM_{2.5}$ 污染能带来巨大的健康效益。控制氨氮的成本收益率相较控制氮氧化物更高，其中北美地区在控制氨氮排放的成本收益率最大，其次是欧洲和亚洲（图 2）。氮氧化物排放主要来自交通、工业等行业中的化石燃料燃烧过程。全球许多国家和地区，尤其是美国、欧洲等发达地区，已经长期采取氮氧化物减排措施，使得进一步减排氮氧化物的边际成本加大。然而，氨排放主要来自农业活动，其排放尚未有效控制，减排成本也相对低廉。因此，在现有氮氧化物排放控制的基础上，加大对氨排放的控制，有助于全球 $PM_{2.5}$ 空气质量的持续改善。

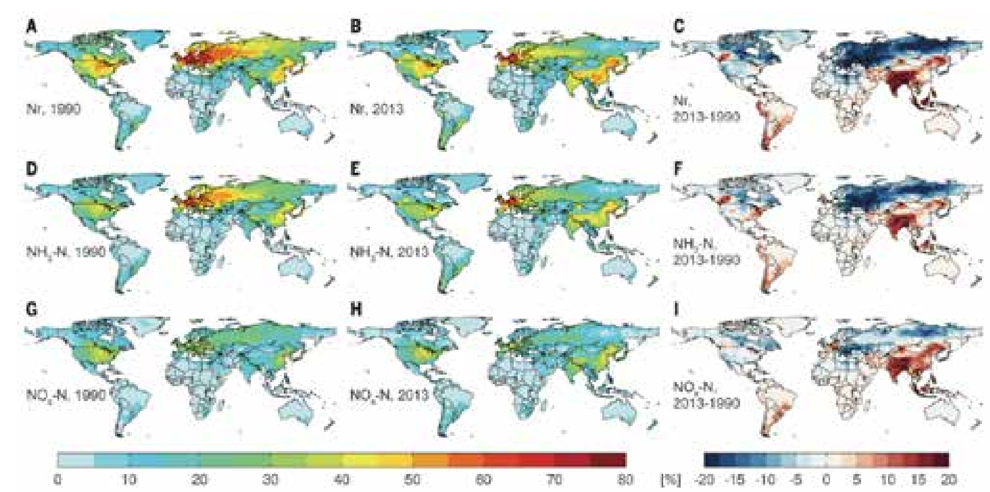

图 1. 1990—2013 年氮排放对全球 $PM_{2.5}$ 空气污染的贡献百分率：A ～ C. 活性氮（Nr）排放的 $PM_{2.5}$ N-share 及期间改变值；D ～ F. 氨氮（NH_3）排放的 $PM_{2.5}$ N-share 及期间改变值；G ～ I. 氮氧化物（NO_x）排放的 $PM_{2.5}$ N-share 及期间改变值。

Fig 1. N-shares of $PM_{2.5}$ pollution and their changes between 1990 and 2013.

III. Nitrogen emission contributions to global PM2.5 air pollution and their control cost

$PM_{2.5}$ is a major air pollutant that adversely affects human health. The World Health Organization estimates that global $PM_{2.5}$ pollution causes millions of premature deaths each year, becoming a major environmental issue that many countries urgently need to address. Emissions of reactive nitrogen, including ammonia nitrogen (NH_3) and nitrogen oxides (NO_x), are important sources of atmospheric $PM_{2.5}$ pollution.

Lin Zhang's group, in collaboration with Zhejiang University and the UK Centre for Ecology & Hydrology, proposed a metric called N-share to quantify the contribution of nitrogen emission to $PM_{2.5}$ air pollution and its health effects on a global scale. Unlike the mass fraction of nitrogen in $PM_{2.5}$, N-share considers the impact of nitrogen emission on the formation of secondary $PM_{2.5}$. It is calculated by shutting down ammonia and nitrogen oxide emissions in atmospheric chemistry models while retaining other pollutant emissions such as SO_2. The research team quantified the contribution of nitrogen emissions from different countries and regions to $PM_{2.5}$ air pollution, evaluated the health benefits and emission reduction costs of controlling nitrogen emissions, and thus revealed the high benefits of controlling ammonia emissions to reduce global $PM_{2.5}$ pollution. The findings were published in Science entitled "Abating ammonia is more cost-effective than nitrogen oxides for mitigating $PM_{2.5}$ air pollution" (Science, 2021, 374, 758-762).

The study found that the N-share of global $PM_{2.5}$ pollution overall increased from 1990 to 2013, with significant regional differences (Fig 1). Asia, South America, and South Africa showed significant increases, while Europe showed a significant decrease. Among the majority of countries and regions, the contribution of ammonia nitrogen emissions to $PM_{2.5}$ pollution was higher than that of nitrogen oxide emissions, indicating that the formation of secondary inorganic aerosol was more limited by ammonia. Between 1990 and 2013, the N-share of ammonia increased from 25% to 32%, while the N-share of nitrogen oxides increased from 17% to 28%. The N-share of total nitrogen emissions was much smaller than the sum of N-shares of ammonia and nitrogen oxides (Fig 1), indicating the nonlinear formation of secondary $PM_{2.5}$.

Reducing nitrogen emissions and resulting $PM_{2.5}$ pollution can bring significant health benefits. The benefit-to-cost ratio of controlling ammonia nitrogen is higher than that of controlling nitrogen oxides, with North America having the highest benefit-to-cost ratio for controlling ammonia nitrogen emissions, followed by Europe and Asia (Fig 2). Nitrogen oxide emissions mainly come from fossil fuel combustion. Many countries and regions, in particular, developed regions such as the United States and Europe, have implemented nitrogen oxide control measures, making further controlling nitrogen oxide emissions expensive. However, ammonia emissions mainly come from agricultural activities, and their emissions have not been effectively controlled, so the emission control cost is still relatively low. Therefore, increasing the control of ammonia emissions, along with existing nitrogen oxide emission controls, can help promote global $PM_{2.5}$ air quality improvements.

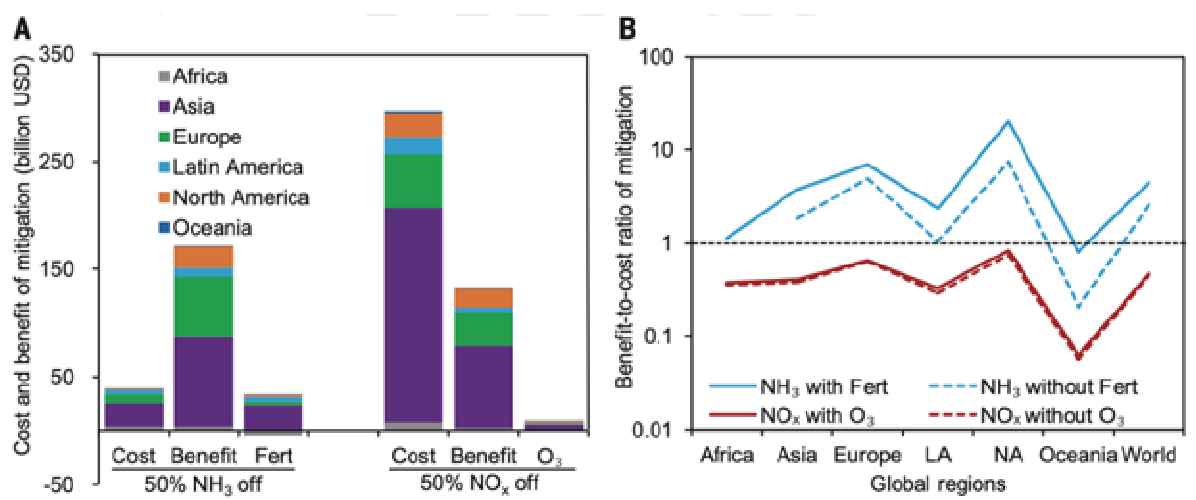

图 2. 全球各大区域氨氮和氮氧化物减排 50% 的成本和收益：A. 氨氮减排收益包含 $PM_{2.5}$ 污染减轻的健康效益以及减小氮肥施用量（Fert）的经济节约，氮氧化物减排收益包含 $PM_{2.5}$ 和臭氧（O_3）污染减轻带来的健康效益；B. 氮减排收益与成本的比值（高于"1"表示减排收益高于成本）。

Fig 2. Cost and benefit of reducing 50% of NH_3 and NO_x emissions in 2013 over different regions.

08 普通物理教学中心 Teaching Center for General Physics

北京大学物理学院普通物理教学中心是北京大学物理学院下属的一个三级机构，其前身为北京大学物理系普通物理教研室，负责普通物理各类课程的长期建设、教学研讨活动和对外教学交流活动的组织以及日常教学组织管理工作。中心下设一个演示实验室和 10 个主干基础课课程组，每个课程组设课程主持人和主讲人，中心的主要任务是承担全校普通物理 01-05 共五个系列平台课程的教学任务，授课对象为理科将近 2000 位学生，年授课工作量约 222000 人学时。普通物理教学中心努力传承北京大学普通物理教学的优良传统，初步形成了一支专任和兼任相结合，科研与教学相结合，老、中、青教师相结合的与北大地位相称的普物教学团队，团队的职称结构和年龄结构合理，专业分布广泛，团队规模适度，结构优化，学术水平高，教学质量好。

The Teaching Center for General Physics is a branch of the School of Physics at Peking University. Previously, it was called the Teaching and Research Section of the Physics Department. The main task of the Center is to supervise all the teaching programs of general physics courses, such as mechanics, electromagnetism, thermal physics, optics, atomic physics and modern physics for the science major undergraduate students of Peking University. It is also responsible for organizing seminars and arranging national and international exchange activities, which are closely related to teaching and learning. All the members of the Teaching Center have full teaching load each semester. They are heavily involved in making and managing the entire teaching schedule at School of Physics, too. The Teaching Center has one laboratory for demonstration and 10 teaching groups. Each of them is led by a moderator and is dedicated to teaching a specific subject. Their duties cover the whole Physics 01-05 series. Each year, more than 2,000 undergraduate students take these courses. It is equivalent to a working load of 222,000 teaching units (number of students times class hours) per year. Since its establishment, the Center has set very high standards for each course and made great effort to achieve teaching excellence, as the Teaching and Research Section of the Physics Department did traditionally in the passed time. As far as the teaching faculties are concerned, except several full-time members, many professors from other departments of the School of Physics participate also in teaching general physics. Since these lecturers are experienced researchers, they make their classes highly interesting and inspiring to the students. On the other hand, the Center invites also some retired teachers to be senior advisors. Therefore, each teaching group has an ideal structure with respect to the distributions of faculty ages, specialties, professional ranks and teaching experiences. These teams perform at very high professional levels which are compatible with the academic stature of School of Physics at Peking University. The Teaching Center for General Physics is dedicated to sustain such high teaching standards in future.

1. 出版教材《原子物理学》和《热学》

普通物理教学中心的两位教学名师出版了教材，《原子物理学》和《热学》。《原子物理学》是刘玉鑫教授根据多年教学经验和课程应该以科学品质（科学精神、科学素养和科学方法）为其魂作为基本理念而编著的，系统地介绍了量子物理和原子物理的基本现象、基本性质和基本规律以及分子和亚原子的现象和基本规律。本书对内容的选取系统而又全面，着重理论与应用的有机结合，理论分析力求循序渐进、准确严谨，着重物理图像和知识体系的建立，并适时联系前沿。整体以求窥得物理学 " 见物讲理、依理造物 " 的学科真谛，并通过对量子物理发展过程中的重大突破事例和前辈学者成长及工作的分析，既启迪智慧，又润物无声地实现课程思政、立德树人。《热学》采用了穆良柱教授的 ETA 物理认知模型写就，在讲述一般热学知识的同时，不断通过启发式的探讨帮助读者构建科学认知方法，这些方法不但适用于热学学习，将来从事各行各业的工作时都会很有帮助。

1. Atomic Physics and Thermal Physics published

Two famous teachers in Center for General Physics Teaching published textbooks, 《Atomic Physics》 and 《Thermal Physics》. 《Atomic Physics》 is compiled by Professor Yuxin Liu based on years of teaching experience. It systematically introduces the basic phenomena, basic properties and fundamental principles of quantum physics and atomic physics, as well as those of molecules and subatoms. The selection of content in the book is systematic and comprehensive, emphasizing the organic combination of theory and application. Theoretical analysis strives to be gradual, accurate, and rigorous, emphasizing the establishment of physics picture and knowledge systems, and timely contacting the forefront. With these efforts, a holistic understanding of the true essence of physics as a discipline of "seeing things with a reasoning mind, and creating things based on physics" can be gained, so that not only the intelligence and creativity can be inspired but also the excellent qualities of a natural human can be trained and promoted. The book 《Thermal Physics》 is written along the line of "ETA physical cognitive model" proposed by Professor Liangzhu Mu. While discussing general heat knowledge, it continuously helps readers construct scientific cognitive methods through heuristic exploration. These methods are not only suitable for thermal physics learning, but also very helpful for future work in various kind of works.

2. 提出 ETA 物理学习法

普通物理教学中心的穆良柱教授为了解决学生学习困难的现实问题，对 30 多名学生的学习困难现象做了深入研究，找到了学业困难背后的原因，并根据 ETA 物理认知模型提出了 ETA 物理学习法，主要解决了如何学和如何学好两个问题。

如何学的策略其实就是要突破中学应用认知教育带来的局限，学会全面系统的物理认知、物理方法、物理精神，其本质就是学会科学认知能力，即如何思考、如何做事、如何做人。

如何学好的策略其实就是学习习惯的养成，解决的是熟练程度和持久学习的问题。

将这套学习方法坚持下来，熟能生巧，学习效率就会提高，就可以节省出时间去探索更多有意义的问题。完整的认知能力培养，特别是探索能力的增强可以为个人发展寻求更多方向和空间，能有效解决内卷带来的学生心理问题。

2. Physics learning method ETA proposed

Prof. Liangzhu Mu conducted in-depth research on the learning difficulties of more than 30 students to solve the practical problem of student learning difficulties. He found the reasons behind various difficulties and proposed the ETA physics learning method based on the ETA physics cognitive model, mainly addressing the two issues of how to learn and how to learn well.

The strategy for how to learn is actually to break through the limitation brought by the application education in high school, learn comprehensive and systematic physics cognition, physics methods, and physics spirit, in other words, essentially learn scientific cognitive abilities, such as how to think, how to do things, and how to be a person.

The strategy for how to learn well is in fact to cultivate learning habits, solving the problems of proficiency and persistent learning.

By persistently adhering to this set of learning methods, one can become skillful, improve learning efficiency, and save time to explore more meaningful questions. The complete cultivation of cognitive abilities, especially the enhancement of exploratory abilities, can seek more directions and space for personal development, and effectively solve the psychological problems of students caused by "neijuan" (excessive competition among students).

系所中心研究亮点 | *Highlights*

09 基础物理实验教学中心 Teaching Center for Experimental Physics

北京大学基础物理实验教学中心是"国家级实验教学示范中心"，承担国家级精品课"普通物理实验"和"近代物理实验"的基础课教学，并从中开辟出"综合物理实验"和"前沿物理实验"的研究型实验课程。目前在岗专职教师 7 名（教授 2 名，副教授 5 名），实验技术人员 7 名（高级工程师 2 名，工程师 5 名）。

The Teaching Center for Experimental Physics at Peking University is "National Experimental Teaching Demonstration Center". We undertake the core course teaching of national outstanding courses "General Physics Experiment" and "Modern Physics Experiment", from which developed the research-oriented experimental courses "Comprehensive Physics Experiment" and "Frontier Physics Experiment". Currently, there are 7 full-time teachers (2 professors and 5 associate professors) and 7 experimental technicians (2 senior engineers and 5 engineers) on duty.

一、教师自制实验教学仪器设备获奖

仪器设备是实验教学活动开展的基本载体，实验教学仪器的研发是实验教学不断发展的重要推手。基础物理实验教学中心长期以来大力支持教师研发实验教学仪器，促进教师将本人的科研成果转化为实验教学仪器，建立基础物理实验教学与前沿科技的直接联系。

2021 年 5 月，由中国高等教育学会主办，中国高等教育学会实验室管理工作分会和《中国现代教育装备》杂志社承办的"全国高校教师教学创新大赛——第六届全国高等学校教师自制实验教学仪器设备创新大赛"于青岛举行，实验中心的参赛作品"多功能拉曼光学显微镜"（完成人：张朝晖、刘国超、荣新）获得大赛自由设计类组一等奖。大赛每两年举办一次，本届大赛经过线上初评，有 351 件作品入围决赛环节，最终评选出一等奖作品 12 件（其中理学组 3 件、其它学组 9 件）。

2022 年 8 月，由教育部高等学校物理学类专业教学指导委员会、教育部高等学校大学物理课程教学指导委员会和全国高等学校实验物理教学研究会主办，厦门大学、福建省物理学会和厦门市物理学会联合协办的第十一届全国高校物理实验教学研讨会于厦门召开。会议对自制教学实验仪器进行了评比。该评比每四年举办一次，是全国范围内最具同行影响力的物理教学实验仪器评比活动。本次会议对各高校 2016 年以来研制的教学实验仪器进行了评比，共 116 件（套）实验教学仪器进入复赛。最终，近代物理组共评出一等奖 9 项，实验中心研制的"双光子纠缠实验教学系统"（完成人：王伟、刘国超、张朝晖、傅兆　、王晨冰等）荣获一等奖。

I. Self-made experimental teaching instruments and equipment winning awards

Instruments and equipment are the basic carrier for conducting experimental teaching activities, and the research and development of experimental teaching instruments is an important driving force for the continuous development of experimental teaching. Our center has long strongly supported teachers in developing experimental teaching instruments, promoting them to convert their scientific research achievements into experimental teaching instruments, and establishing a direct connection between fundamental physics experimental teaching and frontier technology.

In May 2021, the "National Higher Education Teacher Teaching Innovation Competition - the 6th National Higher Education Teacher Self-made Experimental Teaching Instrument and Equipment Innovation Competition", organized by the Laboratory Management Branch of the China Higher Education Association and the China Modern Education Equipment magazine, was held in Qingdao. The participating work "Multi-functional Raman Optical Microscope" from our center (completed by Zhang Zhaohui, Liu Guochao, and Rongxin) won the first prize in the free design category of the competition. The competition is held every two years, and after online preliminary evaluation, 351 works were selected for the final stage. Finally, 12 first prize works were selected (including 3 in the science group and 9 in the other academic groups).

In August 2022, the 11th National Symposium on Experimental Physics Teaching in Higher Education Institutions, jointly organized by Xiamen University, Fujian Physics Society, and Xiamen Physics Society, was held in Xiamen, sponsored by the Teaching Guidance Committee for Physics Majors in Higher Education Institutions of the Ministry of Education, the Teaching Guidance Committee for University Physics Courses in Higher Education Institutions of the Ministry of Education, and the National Association for Experimental Physics Teaching in Higher Education Institutions of China. The meeting evaluated the self-made teaching experimental instruments. This evaluation is held every four years and is the most influential physics teaching experimental instrument evaluation event in the country. This meeting evaluated the teaching experimental instruments developed by various universities since 2016. 116 sets of experimental teaching instruments entered the semi-finals. In the end, the Modern Physics Group awarded a total of 9 first prizes, and the "Two-photon Entanglement Experimental Teaching System" developed by our center (completed by Wang Wei, Liu Guochao, Zhang Zhaohui, Fu Zhaorong, Wang Chenbing etc.) won the first prize.

二、本科生在实验竞赛中获得佳绩

全国大学生物理实验竞赛（含教学赛、创新赛）和中国大学生物理学术竞赛（CUPT）是高水平的全国性大学生物理实验竞赛赛事，基础物理实验教学中心负责北京大学参赛选手的组织和培训。

2021 年 7 月，第七届全国大学生物理实验竞赛（教学赛）于天津成功举办。由实验中心廖慧敏副教授担任领队，元培学院 19 级本科生高云浩，物理学院 19 级本科生陈贝乐、何沛一、李志昊组成的北京大学代表队获三项一等奖，其中，高云浩、陈贝乐分别获得基础性实验题（C）、基础性实验题（D）一等奖，何沛一、李志昊合作获得综合研究性实验题（C）一等奖。

2021 年 11 月，第七届全国大学生物理实验竞赛（创新）决赛在南昌落下帷幕。北京大学物理学院两支代表队凭作品"双光子量子干涉实验""利用彩虹全息术改进和拓展'全息照相'教学实验"分获自

选类一等奖和二等奖。“双光子量子干涉实验”获奖学生为物理学院本科生贡晓荀和张哲伦，该项目在实验中心张朝晖教授、王伟工程师指导下完成；“利用彩虹全息术改进和拓展‘全息照相’教学实验”获奖学生为物理学院本科生杨天骅、林织星、刘雨霖，该项目在实验中心刘国超工程师指导下完成。

2022 年 10 月，第 13 届中国大学生物理学术竞赛（CUPT）在线上举行。由北京大学物理学院刘芳兵老师、李慈航同学担任领队，物理学院 21 级本科生杨翰彬、齐思远、任勇钢、杨家宁、张宇翔 5 名同学组成的北京大学代表队参加了本次大赛。同学们秉承物院人团结协作、奋勇争先的优良传统，经过五轮比赛获得第 13 届 CUPT 一等奖。

II. Undergraduate students achieved excellent results in experimental competitions

China Undergraduate Physics Experiment Competition (including Teaching Competition and Innovation Competition) and the China Undergraduate Physics Tournament (CUPT) are high-level national college students' physics experiment competitions. Our center is responsible for organizing and training participants from Peking University.

In July 2021, the 7th China Undergraduate Physics Experiment Competition (Teaching Competition) was successfully held in Tianjin. Led by Associate Professor Liao Huimin of our center, the Peking University delegation consisting of 2019 undergraduate students Gao Yunhao from Yuanpei College and 2019 undergraduate students Chen Beile, He Peiyi, and Li Zhihao from School of Physics won 3 first prizes. Among them, Gao Yunhao and Chen Beile respectively won the first prizes for basic experimental questions (C) and basic experimental questions (D), and He Peiyi and Li Zhihao collaborated to win the first prize for comprehensive research experimental questions (C).

In November 2021, the final of the 7th China Undergraduate Physics Experiment Competition (Innovation) came to an end at Nanchang University. Two representative teams from School of Physics at Peking University won the first prize and second prize respectively for their works "Two-photon quantum interference experiment" and "Improving and expanding the teaching experiment of Holography using rainbow holography". The award-winning students of the "Two-photon quantum interference experiment" are Gong Xiaoxun and Zhang Zhelun, undergraduate students from School of Physics. The project was completed under the guidance of Professor Zhang Zhaohui and Engineer Wang Wei at our center. The award-winning students for "Improving and expanding the teaching experiment of Holography using rainbow holography" are Yang Tianhua, Lin Zhixing, and Liu Yulin, undergraduate students from School of Physics. The project was completed under the guidance of Liu Guochao, engineer at our center.

In October 2022, the 13th China Undergraduate Physics Tournament (CUPT) was held online. The Peking University delegation, led by Liu Fangbing and Li Cihang, including 5 undergraduate students from School of Physics, Yang Hanbin, Qi Siyuan, Ren Yonggang, Yang Jianing, and Zhang Yuxiang, participated in the competition. The students, adhering to the excellent tradition of unity and cooperation of School of Physics, won the first prize of the 13th CUPT after five rounds of competitions.

系所中心研究亮点 | *Highlights*

10 北京大学电子显微镜实验室 Electron Microscopy Laboratory of Peking University

电子显微镜实验室（电镜室）始建于 1964 年，创建之初就被定位为北京大学显微分析测试公共平台（第一个校级平台）。1990 年被批准为电子光学与电子显微镜国家重点学科专业实验室。电镜室在半个世纪的发展过程中，得到学校“世行贷款”、“211”、“985”项目的大力支持，现有大型电镜 12 台，包括透射电镜 6 台，扫描电镜 3 台，聚焦离子束 3 台，实验室单价 40 万元以上的大型设备有 22 台。2015 年电镜室采购了两台球差电镜用于材料科学，一台冷冻电镜用于生命科学，实验室仪器总价值接近 1.5 亿元，硬件配置和开放环境在国内已处于领先地位。电镜室现有工作人员 11 人，包括实验室主任俞大鹏院士、学术委员会主任叶恒强院士、高鹏研究员、工程技术系列人员 8 位，其中具有博士学位的 8 人，高级职称 9 人（含教授级高级工程师 2 人），平均年龄 45 岁。实验室人员专业背景涉及物理学、电子学、化学、材料科学和地质学，人员配备合理。

电镜室的两台球差矫正透射电镜的配置位于国际领先行列。其中一台是双球差矫正的 FEI-Themis，空间分辨率高达 60 pm，配置齐全，包括差分相位衬度探测器（DPC），球差矫正的 Lorentz 模式，多能谱探头，电子能量损失谱等。另一台是美国 Nion 公司工作电压为 30—200 kV 的配备单色仪的球差矫正电镜，主要特色是能量分辨率在 30 kV 高达 4 meV，空间分辨率在 200 kV 高达 60pm，而且是高真空系统无污染，高稳定性几乎无样品漂移。此外，电镜室还配置有多种原位样品台，可以在多台电镜中实现原位的力学、电学、降温、加热、液体池等实验。电镜上也配置有高速率、高灵敏度的相机（如 Oneview IS, K2 IS 等），能高速记录相变反应，而且能够对电子束敏感材料成像。电镜室还开展了一系列仪器研制开发工作，比如研制开发了电子束曝光系统和阴极荧光大面积均匀成像系统，已经在电镜室面向全校开放使用，并逐步向国内外进行推广。

Electron Microscope Laboratory (EML) of Peking University is a user facility center founded in 1964. EML is now equipped with 12 electron microscopes, including 6 transmission electron microscopes (TEMs), 3 scanning electron microscopes (SEMs), 2 Focused Ion Beam microscopes (FIBs) and 1 Helium Ion Microscope. There are two spherical aberration corrected TEMs for materials science, i.e., high energy resolution spherical aberration corrected electron microscope Nion U-HERMES with energy resolution better than 4 meV, and FEI Titan Cubed Themis transmission electron microscope (with spatial resolution up to 60 pm) that is equipped with monochromator, double spherical aberration corrector, K2 IS camera, Bruker Super-X EDX detectors and a few in situ TEM holders. Besides, the Zeiss ORION NanoFab He ion microscope, FEI Titan Krios cryo-electron microscope and ThermoFisher Helios G4 UX focused ion beam system are also the most advanced electron microscopes currently in the world. Totally, there are more than 40 large instruments more than 400,000 RMB for each. The total value of the instruments is about 150,000,000 RMB. At present, there are 11 staffs in EML, including 2 academicians of the CAS. In the staff team, there are 9 with senior professional titles and 8 with a doctor's degree. Typically, every year, EML provides characterization services for more than 200 research groups from different departments of Peking University, including School of Physics, College of

Chemistry and Molecular Engineering, School of Electronic Engineering and Computer science, College of Engineering, College of Environmental Sciences and Engineering, School of Earth and Space Science, School of Life Sciences, Academy for Advanced Interdisciplinary Studies, and Peking University Health Science Center. Every year around 300 people get trained in the EML, and after systematic training they can operate the electron microscopes independently. For the advanced users, all the instruments are available for 24 hours in 365 days. Generally, there are more than 200 Research Fund Projects and hundreds of publications supported by the EML every year. Besides the scientific research, EML has also been developing home-made instruments, including electron beam lithography system and cathode fluorescence systems, which have already been on active service in the EML.

一、电子显微镜实现纳米分辨率下界面声子色散测量

声子是决定凝聚态体系的热导率、电子迁移率、光散射行为等物性的重要因素。由于平移对称性的破缺，在晶体界面附近的几层原子内会存在不同于体态的界面声子，使得界面呈现诸多独特的物理性质。想要探测这些界面声子，测量手段须达到纳米甚至原子级别的空间分辨率，极高的探测灵敏度，很高的能量分辨率，以及足够的动量分辨率，而传统谱学手段均不能同时满足这些要求。高鹏课题组基于扫描透射电子显微镜发展了四维电子能量损失谱学技术 (4D-EELS；发明专利：ZL202011448013.7)。他们利用该方法，首次在实验上证实了晶体异质结界面处有界面声子的存在。通过不同实验参数的选择，他们实现了声子局域态密度的原子级测量，观测到局域在界面附近的增强和减弱的声子模式，并揭示了这些局域声子模式的色散关系。进一步的理论计算表明测得的界面声子模式不仅对界面热导有显著贡献，也通过电声相互作用直接影响界面二维电子气的迁移率。

此工作已于 2021 年 11 月 17 日在线发表在《自然》上（Nature 599, 2021, 399）。

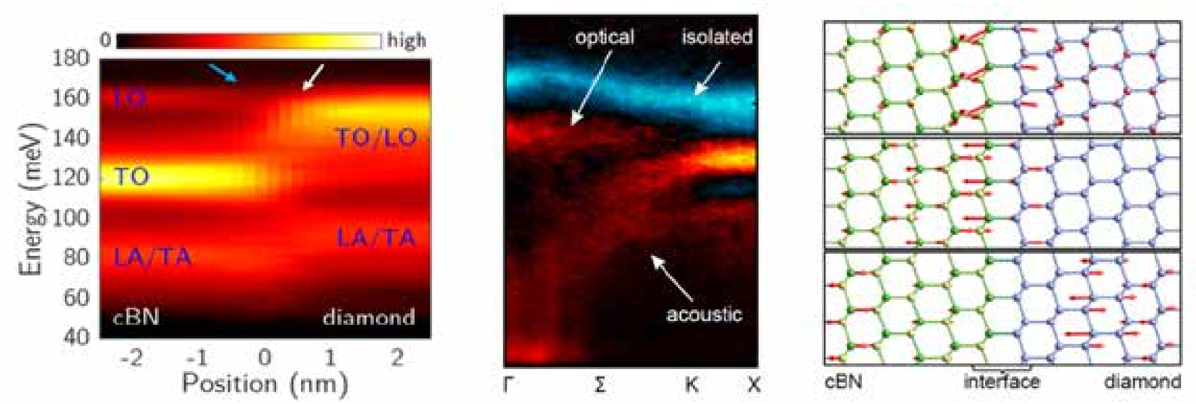

图 1.（a）实验测得的谱线随空间位置的变化，近似正比于声子局域态密度；原点标记界面位置；（b）界面模式的色散关系；（c）界面增强的声子模式（上、中）和界面减弱的模式（下）示意图。

Fig 1. (a) The measured EELS line profile across the interface, similar to phonon local density of states; (b) The dispersion of the interface phonon; (c) The schematics of enhanced phonon mode (upper, middle) and the weakened phonon mode (bottom) at interface.

系所中心研究亮点 | ***Highlights***

I. Nanoscale probing of interface phonon dispersion via electron microscope

Phonon plays an essential role in the condensed matter physics, determining the physical properties such as thermal conductivity, electron mobility, and light scattering behavior. Due to the breakdown of translational symmetry, the interface phonon localized within several atomic layers near the interface emerges, making system exhibit unique properties. To detect these interface phonons, the experiment technique must achieve nanometer or even atomic scale spatial resolution, ultrahigh sensitivity, high energy resolution, and enough momentum resolution. However, none of traditional spectroscopy techniques can satisfy these requirements. Dr.Peng Gao's group has developed the four-dimensional electron energy loss spectroscopy technique (4D-EELS; Chinese Patent: ZL202011448013.7) based on scanning transmission electron microscopy. By utilizing it, for the first time they experimentally confirmed the existence of interface phonon at the heterointerface. With different experimental geometry, they realized atomic-scale measurement of the phonon local density of states, observed the enhanced and weakened phonon modes localized at the interface, and revealed the dispersion of these local phonon modes. Further theoretical calculations show that the measured interface phonon modes not only make significant contribution to the interface thermal conductivity, but also show strong electron-phonon coupling and ultimately influence mobility of the two-dimensional electron gas at this interface. This work is published in Nature 599, 399 (2021).

二、电子束曝光机研制

北京大学物理学院电子显微镜实验室在精密仪器研发制造领域持续开展工作，参与国家实验室重大项目和广东省重点领域研发计划项目，承担电子束矢量扫描发生器、精密激光干涉样品台和样品室研发任务。近两年来，电子显微镜实验室作为核心单位合作搭建第二代 30 kV 电子束曝光系统原理样机和 50 kV 电子束曝光系统测试样机。

第二代 30 kV 电子束曝光系统原理样机采用稳定的电子光学系统，提高高压和束流稳定度；采用主动被动组合式减振机构，有效抑制低频振动；开发基于 FPGA 的图形扫描发生器固件程序；研发了激光干涉测量实时补偿技术，提高了曝光的拼接、套刻精度；优化系统控制程序，提高系统的易用性和曝光加工效率。目前，30 kV 电子束曝光原理样机的局部图形拼接和套刻精度优于 50 nm，图形发生器的输出扫描速度大于 20 MHz，激光干涉台位移范围达到 100 mm。原理样机已交付合作用户单位开展应用试用工作，能够满足其微纳加工领域重要科研需求。

II. Development of electron beam lithography system

Electron Microscopic Laboratory, School of Physics, Peking University persisted in development

系所中心研究亮点 | *Highlights*

and fabrication of precision instrument. With the support of the Major Project of National Lab and Key-Area Research and Development Program of Guangdong Province, the laboratory has carried out the development of electron beam pattern generator, laser stage and the main vacuum chamber of electron beam lithography system. In recent two years, the laboratory parted in the integration of 2nd generation 30 kV electron beam lithography system and 50 kV prototype system.

The 2nd generation 30 kV electron beam lithography system included stable electron optics components, active-passive hybrid vibration isolated base, pattern generator based on FPGA technology, laser stage with real-time feedback and easy-to-use UI software. The stitching and overlay error of the system was less than 50 nm; the scan speed reached 20 MHz; the laser stage was capable of 4 inches wafer. Recently, the system has been delivered to cooperative user and applied to fabricate micro-nano structures in scientific researches.

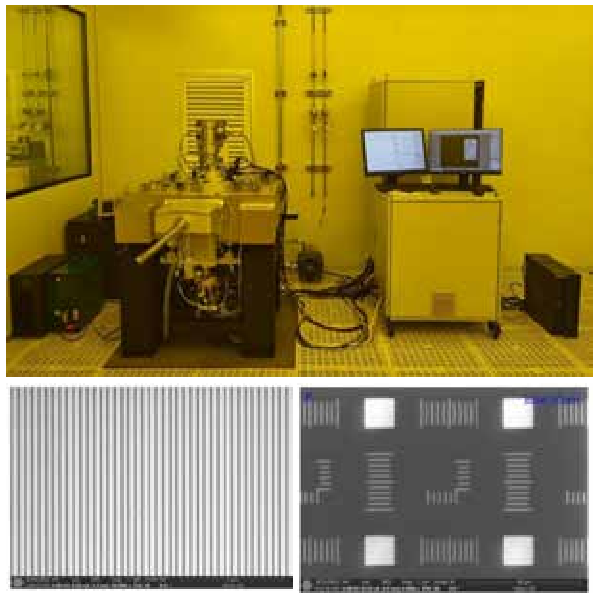

图 1. 已交付交付合作用户单位的第二代 30 kV 电子束曝光系统原理样机 (A)，利用电子束曝光系统原理样机得到的 200 nm 周期光栅结构 (B) 和写场拼接测试结果（C）。

Fig 1. The 2nd generation 30 kV electron beam lithography system located in the user's lab(A); 200 nm period grating structure (B) and stitching test results(C) fabricated by the electron beam lithography system.

11 量子材料与科学中心 International Center for Quantum Materials

北京大学量子材料科学中心（以下简称“中心”）成立于 2010 年，是一个直属于北京大学的新型教学与科研机构。量子材料科学中心致力于研究凝聚态物理和量子材料科学的前沿问题，营造国际化的学术创新环境，并力争成为国内领先、国际一流的物理学研究教学平台。

作为一个全新的科技创新平台，中心积极利用政策资源优势，不断改革与完善管理模式和工作方式，通过构建国际前沿的实验设施以及引进国际先进的研究技术，致力于打造一个适合物理学基础研究的开放型学术基地，培养一支具有国际影响力的研究团队，推进以量子科学为基础的高新技术的发展。中心一直着力于人才队伍建设，面向全球招聘教学科研人员，成功引进了一批拥有国际知名度的海内外专家以及众多活跃于国际前沿的年轻学者。截至 2022 年 12 月，已有教研系列人员 32 人 (全职到岗 30 人)，其中特聘讲席教授 1 人，讲席教授 4 人，教授 10 人，长聘副教授 9 人，预聘助理教授 8 人。中心所有教师均具有长期海外科研工作经验，并全部获得博士生导师资格。成员中 1 人获诺贝尔物理学奖，2 人当选中国科学院院士，3 人入选海外高层次人才计划项目，3 人当选中国教育部“长江学者特聘教授”，2 人入选“万人计划 - 科技创新领军人才”，1 人当选“长江青年学者”， 12 人获国家自然科学基金委杰出青年科学基金，4 人获国家自然科学基金委优秀青年基金，3 人获北京市杰出青年基金，20 人入选海外高层次人才计划青年项目，2 人获得国家自然科学基金委海外优秀青年基金，1 人入选中组部“青年拔尖人才支持计划”。

中心特别重视年轻学者的培养（包括博士后和研究生培养）。对于博士后人才，中心在世界范围内积极发掘具有潜力的理论和实验人员，目前共培养博士后研究人员 93 人（2022 年在站 40 人），多名博士后在相关领域内取得了重要进展。在研究生人才培养方面，中心现有研究生 192 名，他们均来自国内著名高校，专业成绩名列前茅，对科研有较高的热情。中心给他们提供了一个良好的学习、交流和科研平台。此外，通过夏令营、暑期学校、学术讲座等方式，也为青年学生提供了更多了解凝聚态物理前沿课题的机会。

中心以凝聚态物理和量子材料科学为主要研究领域，目前，中心根据研究方法分为低温及量子输运实验、谱学及高分辨探测实验、自旋及低维磁性实验、AMO 实验及精密测量、凝聚态物理理论、凝聚态物理计算六个研究部分。具体研究方向包括：量子霍尔效应、凝聚态物理中的拓扑效应、关联电子现象、低维电子气中的量子行为、自旋电子学、异质结构物性、介观超导现象、先进扫描探针显微学、中子和光子散射谱学、表面动力学、纳米材料及器件超快动力学实验、超冷原子气、超高压条件下的材料物理、水的特性研究、软物质材料研究等。目前中心共建有 18 个独立实验室、1 个综合物性测量公共实验室及 1 个纳米微加工公共实验平台。此外，依托中心还建有北京大学崔琦实验室和全校综合性氦气液化回收车间 (北京大学液氦中心)。

中心自成立以来，已承担多项国家重点科研项目，并涌现出一批高质量科研成果，获得了国际学术界的广泛关注与认可。截至 2022 年 12 月，中心共发表 SCI 论文 1600 余篇，其中多篇发表在 Science、Nature 及其它们子刊，Physical Review Letters 等国际顶级学术期刊上。中心教师牵头承担各类科研项目共计 50 余项，科研经费总计近 4 亿元人民币，其中包括科技部“973 计划”5 项、国家重点研发计划项目 6 项、国家自然科学基金基础科学中心项目 1 项、国家自然科学基金创新研究群体项目 1 项、国家自然科学基金重点项目 5 项。中心教授还获得了何梁何利奖、亚洲计算材料科学奖、中国科学十大进展、国家自然科学二等奖、国际先进材料终身成就奖、陈嘉庚科学奖、华人物理学会亚洲成就奖、求是杰出青年学者奖、马丁伍德爵士中国物理科学奖、国际纯粹与应用物理学联合会青年科学家奖、中国青年科技奖、高等学校科学研究优秀成果奖（青年科学奖）等国际国内多项奖励与荣誉。

随着对外合作交流日趋深化，量子材料科学中心已先后与德州大学奥斯丁分校、宾州州立大学、莱斯大学等多所国际著名大学签署了战略合作协议，积极推荐学生参与联合培养、双学位等项目。并通过积极举办具有国际影响力的学术活动和推动顶级学者经常性互访等方式，广泛探索科研合作和人才培养的创新机制，为年轻学者和学生营造一个开放性的、国际化的研究交流环境。

The International Center for Quantum Materials (ICQM) was established in 2010 as a major initiative of Peking University, aiming to create a new type of platform for research and education. ICQM has since been committed to perform cutting-edge research at the frontiers of condensed matter physics and quantum materials, to create an innovative academic environment, and to establish a world-class plateform for physics research and education.

As an innovative plateform for science and technology, ICQM has been devoting a great effort to recruit internationally-renowned scientists as well as excellent young researchers, and to provide first-class infrastructure and dynamical scientific environment for basic research. Located in Beijing and amid the fast socioeconomic transformation of China, ICQM endeavors to implement a new academic structure that is based on two major components: independent principle investigator system and tenure appraisal system. As of December 2022, the ICQM faculty members consist of 4 Chair Professors, 10 tenured Full Professors, 9 tenured Associated Professors, and 8 tenure-track Assistant Professors. Among the senior researchers there are 1 Nobel Laureate, 2 Member of Chinese Academy of Sciences, and 6 Fellows of American Physical Society.

ICQM provides solid training and great research opportunities for young scientists, including postdoctoral researchers and graduate students from both domestic and foreign institutions. In the past a few years, ICQM has hosted 93 postdocs with several of them making important achievements in their research fields. 192 students are currently enrolled in the ICQM graduate program. The ICQM graduate students are typically graduates from top Chinese universities with exceptional academic performances. The students at ICQM are provided with an active scientific environment to explore a wide-range of frontier research topics through a rich array of academic activities, such as seminars, lectures and summer schools.

The research at ICQM is organized into 6 divisions according to research interest and expertise, namely

Low temperature and quantum transport experiments;

Spintronics and low-dimensional magnetism experiments;

High-resolution Spectroscopy experiments;

AMO experiment and precision measurement;

Theoretical condensed matter physics;

Computational physics.

Topics of current research activities include quantum transport, strongly-correlated electron systems, low-dimensional quantum systems, topological effects in condensed matter physics, mesoscopic superconducting systems, spintronics, advanced scanning tunneling microscopy, ultra-fast spectroscopy, neutron spectroscopy, ultra-cold atoms, computational simulations for quantum materials, surface dynamics, water behaviors under confinement, and soft matters materials, etc. ICQM consists of 18 experimental laboratories, a public supporting laboratory for physical property measurement, a shared nanofab facility, and a helium center. The PKU Daniel Chee Tsui laboratory is affiliated to ICQM, which works on extremely low temperature physics.

By December 2022 since the establishment of the center in 2010, ICQM has published more than 1600 SCI papers, many of which were published in the most influential scientific journals in the world, such as Science、Nature and their series journals, Physical Review Letters, etc. The research funding received by ICQM faculty members from Chinese research funding agencies has almost reached 400 million RMB. ICQM members have garnered many national and international awards, such as the ACCMS Award, Ho Leung Ho Lee prize, OCPA AAA-Poe Prize, State Natural Science Award, Advanced Materials Laureate, etc.

In order to promote international academic exchanges and collaborations, collaboration agreements have been reached between ICQM and world-renowned institutions, such as the Rice University, University of Texas at Austin, and Pennsylvania State University. Incoming graduate students may take the advantage of such collaboration programs to work at different places and obtain Dual Degree Ph.D. in Physics. In addition, ICQM has been visited by more than 100 scientists annually through various capacities.

一、轴子绝缘体的半量子化输运和临界行为

凝聚态物理中的分数量子化通常与关联效应诱导的准粒子激发有关，例如分数量子霍尔效应。在无相互作用系统中，分数量子化现象也会出现，一个典型的例子就是宇称反常（parity anomaly）引发的半量子化的霍尔电导。但是，在 2+1 维狄拉克体系中实现宇称反常并观测到半量子化的输运信号是极具挑战性的。有趣的是，轴子绝缘体提供了一个理想平台来实现宇称反常。因为拓扑磁电效应，轴子绝缘体的表面是 2+1 维有质量的狄拉克体系，其上存在半量子化霍尔电导，自然地实现了宇称反常。当前实验上构建轴子绝缘体的方案中，材料的侧表面通常是金属化的。此时金属侧表面上是否存在我们期望的半量子化边缘激发，以及实验上如何利用这种半量子化的激发来帮助人们鉴别轴子绝缘体仍不清楚。

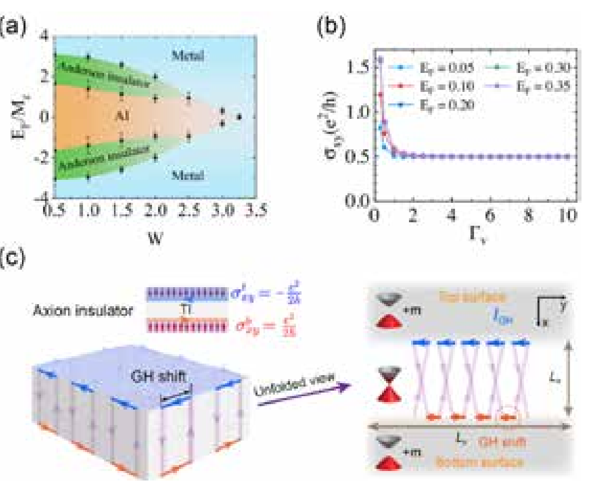

图 1. (a) 无序轴子绝缘体的相图；(b) 霍尔电导随退相干强度 Γv 变化曲线；(c) 轴子绝缘体侧表面半量子化棱电流的图像。

Fig 1. (a) Phase diagram of a disordered axion insulator. (b) Hall conductance as a function of Γv. (c) Physical picture of half-quantized hinge current in axion insulators.

量子材料科学中心谢心澄院士课题组对轴子绝缘体的半量子化输运和临界行为做了系统的研究。首先，课题组给出了利用普适安德森相变行为来探测轴子绝缘体的理论。他们给出三维轴子绝缘体中无序诱导的相图，发现了一种二维量子霍尔效应的相变普适类，并提出可以利用该相变在三维磁性拓扑绝缘体中探测轴子绝缘体态。该项工作发

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表于《物理评论快报》（Phys. Rev. Lett. 2021, 126, 156601）。其次，课题组揭示了轴子绝缘体半量子化输运微观机制。他们提出在轴子绝缘体金属化的侧表面上存在一对半量子化的螺旋棱电流激发，并指出这些棱电流起源于无能隙的侧表面电子在有能隙的上下表面的棱上反弹时积累的古斯 - 汉欣位移（Goos-Hänchen shift）。结合半经典波包运动分析，研究团队指出棱电流关于费米能级的微分为半量子化的，且受到拓扑保护。相关研究成果在线发表于《国家科学评论》（Nat. Sci. Rev. 2023, nwad025）。最后，课题组发展了一套 " 半轴子绝缘体"(一种半磁性拓扑绝缘体) 中半量子化霍尔电导的输运理论。从半磁性拓扑绝缘体异质结实验体系出发，他们系统地研究了半磁性拓扑绝缘体表面狄拉克锥的输运性质，揭示退相干强度对实现半量子化霍尔电导的重要性。他们发现有能隙的狄拉克表面边界存在一个一维半量子化的手性通道，并导致了半整数量子化的霍尔电导，而无能隙的狄拉克表面贡献了有限纵向电导。这些结果打破了量子化霍尔电导一般只存在于绝缘相的传统认知，因此超出了传统量子化输运的范式。他们给出的电导和电阻随温度变化规律与实验结果一致（Nat. Phys. 2022, 8 ,390）。相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2022, 129, 096601）。

I. Half-quantized Transport and Critical Behaviors of Axion Insulators

Fractional quantization in condensed matter materials is usually accompanied with the emergence of quasi-particles driven by strong correlations. A prominent example is the fractional quantum Hall effect (FQHE), which is the fairyland of fractionally charged quasi-particle excitations. Interestingly, fractional quantization can also emerge in non-correlated systems. Such a fractional quantization is triggered by parity anomaly, which generates a parity-violating current with the half-integer-quantized Hall conductance. However, realizing the parity anomaly in (2+1)-dimensions and observing the half-quantized transport signals in condensed matter systems are challenging problems for over 40 years. Encouragingly, the axion insulator (AI) provides an ideal platform to realize parity anomaly on its top and bottom surfaces. As a non-trivial topological phase, the AI manifests unique topological magnetoelectric (TME) effect and has stimulated extensive research interests. However, in the current experimental schemes for constructing axion insulators, the lateral surfaces of the materials are usually metallic. It is unclear whether the expected half-quantized edge excitations exist on the metallic side surfaces, and how to experimentally utilize such half-quantized excitations to help identify axion insulators.

The research group led by Prof. Xincheng Xie from the ICQM has conducted systematic research on the half-quantum transport and critical behaviors of axion insulators. Firstly, the group proposed a theory for detecting axion insulators using the universal Anderson phase transition behaviors. They presented a phase diagram induced by disorder in three-dimensional axion insulators, and identified a universal class of two-dimensional quantum Hall effect phase transitions. They suggested that this phase transition could be utilized to detect the axion insulator state in three-dimensional magnetic topological insulators. This work was published in Physical Review Letters (Phys. Rev. Lett. 2021, 126, 156601).

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Secondly, the group also revealed the microscopic mechanism of half-quantized transport in axion insulators. They proposed the existence of a pair of half-quantized helical edge current excitations on the metallic lateral surfaces of axion insulators, and pointed out that these edge currents originate from the Goos-Hänchen shift accumulated by the side surface electrons with zero energy gap when they bounce back and forth on the edges of the upper and lower surfaces with energy gap. Combining with semiclassical wave packet analysis, the group showed that the differential of the edge current with respect to the Fermi energy is half-quantized and topological protected by the π Berry phase. This work was published online in National Science Review (Natl. Sci. Rev. 2023, nwad025).

Lastly, the research group developed a theory for half-quantized Hall conductance using a semi-magnetic topological insulators model, which can be regarded as “halved axion insulators”. They systematically study the surface transport of the semi-magnetic topological insulator in the presence of the dephasing process. In particular, they reveal that the HQHC is directly related to the half-quantized chiral current along the edge of a strongly dephasing metal. The Hall conductance keeps a half-quantized value for large dephasing strengths, while the longitudinal conductance varies with Fermi energies and dephasing strengths. These results are in stark contrast to the common belief that quantized Hall conductance is generally observed in an insulating phase such as the quantum Hall effect, and thus goes beyond the conventional paradigm of quantized transport. Furthermore, they evaluate both the conductance and resistance as a function of the temperature, which is consistent with the experimental results (Nat. Phys. 2022, 8, 390). This work has been recently published online in Physical Review Letters (Phys. Rev. Lett. 2022, 129, 096601).

二、蜂窝晶格钴氧化物中的新型磁性现象

在晶体材料中，由于不同磁性相互作用之间的竞争，可以产生一种叫做“磁阻挫”的效应。该效应可能导致一些新奇的量子物态，如“量子自旋液体”，有望在拓扑量子计算等领域发挥重要作用。近年来，研究人员对一类具有六角蜂窝状晶格的钴氧化物材料产生了浓厚兴趣，因为它们有可能实现 Kitaev 量子磁性模型，这个模型具有量子自旋液体基态的严格解。然而，在实际的材料中，由于相互作用的性质往往会偏离 Kitaev 模型的理想状态，导致在低温下仍会出现磁有序。因此，通过实验手段研究这些磁有序的特征及其背后的微观相互作用模型对于探索新奇物态，如量子自旋液体，具有重要的科学价值。

量子材料科学中心的李源、林熙、彭莹莹与日本 J-PARC 中子源、加拿大光源、美国橡树岭国家实验室的多位谱仪科学家以及中国人民大学的于伟强和美国布鲁克海文国家实验室的 Igor Zaliznyak 等合作，运用以中子散射为主的综合实验研究方法，在蜂窝晶格钴氧化物 $Na_2Co_2TeO_6$ 和 $Na_3Co_2SbO_6$ 中分别发现了一种新型的“三波矢”磁有序态和巨大的面内磁各向异性，并且运用高质量的单晶样品，首次测定了 $Na_2Co_2TeO_6$ 的完整磁激发谱。这些实验结果表明，蜂窝晶格钴氧化物具有强烈的磁阻挫效应，导致复杂的磁有序态和丰富的磁性相变现象。在外磁场的作用下，这些材料有可能在相变边界附近诱导出量子自旋液体物态。实

验还发现，材料体系中存在“第三近邻”距离上的磁相互作用，这对于仅涉及最近邻相互作用的 Kitaev 模型来说是一个重要的补充。这些工作为进一步的理论研究和物态调控提供了重要依据。相关系列成果发表在《物理评论》期刊上（Phys. Rev. B 2021, 103, L180404; Phys. Rev. Lett. 2022, 129, 147202; Phys. Rev. X 2022, 12, 041024）。

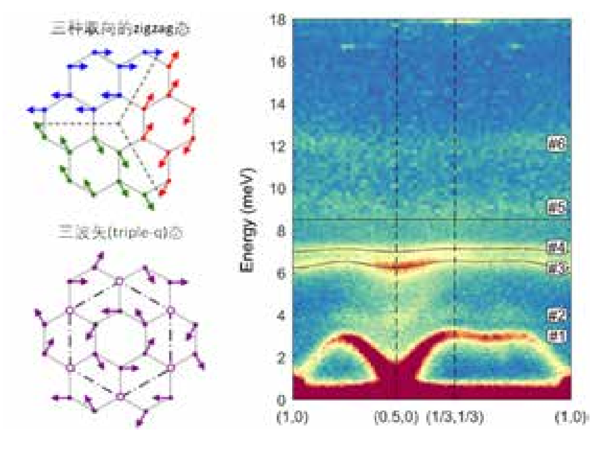

图 1. $Na_2Co_2TeO_6$ 中由三种取向的 zigzag 态叠加形成的三波矢态和完整磁激发谱。

Fig 1. Triple-q magnetic order in $Na_2Co_2TeO_6$ formed by superposition of zigzag states, and the full spectrum of magnetic excitations.

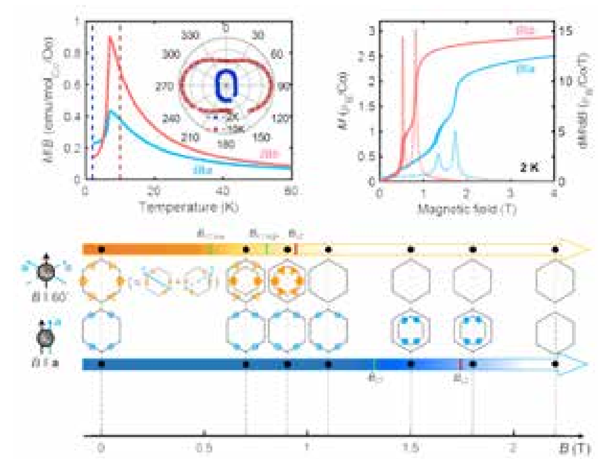

图 2. $Na_3Co_2SbO_6$ 在面内不同方向外磁场中展现出的巨大各向异性和丰富的磁相变。

Fig 2. Giant anisotropy and rich phase behaviors of $Na_3Co_2SbO_6$ in magnetic fields along different in-plane directions.

II. Novel magnetism in honeycomb cobalt oxides

In crystalline materials, an effect called "magnetic frustration" can occur due to the competition between magnetic interactions. This effect may lead to the emergence of novel quantum phases, such as quantum spin liquids, which are expected to play a crucial role in areas like topological quantum computation. In recent years, researchers have taken a keen interest in a class of cobalt oxide materials with a hexagonal honeycomb lattice, as they may potentially realize the Kitaev magnetic model, which has an exactly solvable quantum spin liquid ground state. However, in the actual materials, the nature of interactions often deviates from the ideal Kitaev model, leading to magnetic order formation at low temperatures. Therefore, investigating these magnetic order characteristics and their underlying microscopic interactions through experimental means is of significant scientific value for exploring novel states of matter, such as quantum spin liquids.

To push this scientific frontier, Profs. Yuan Li, Xi Lin and Yingying Peng at the ICQM teamed up with beamline scientists at the J-PARC neutron facility, Canadian Light Source and Oak Ridge National Lab, and with Prof. Weiqiang Yu at the Renmin University of China and Dr. Igor Zaliznyak at Brookhaven National Lab. Using a comprehensive set of experimental methods primarily based on neutron scattering, they discovered a novel "triple-q" magnetic order state and giant in-plane magnetic anisotropy in the cobalt oxides $Na_2Co_2TeO_6$ and $Na_3Co_2SbO_6$, respectively. Additionally, using high-quality single-crystal samples, the complete magnetic excitation spectrum of $Na_2Co_2TeO_6$ was measured for the first time. These experimental results demonstrate that the cobalt oxides indeed possess strong magnetic frustration effects, leading to complex magnetic order states and rich magnetic phase transition phenomena. Under the influence of external magnetic fields, these materials may potentially be induced into a quantum spin liquid state near phase transition boundaries. The experiments also revealed the existence of magnetic interactions at the "third-nearest-neighbor" distance in the material system, which is an important addition to the Kitaev model that only involves nearest-neighbor interactions. The series of works provide a crucial foundation for further theoretical research and experimental tuning of the quantum states of matter. They are published in Physical Review journals (Phys. Rev. B 2021, 103, L180404; Phys. Rev. Lett. 2022, 129, 147202; Phys. Rev. X 2022, 12, 041024).

三、核量子效应诱导的全新二维冰相

对称氢键是一种特别的氢键（X-H-X），其特点在于氢原子位于两个电负性较强的原子的几何中心位置，并与两个原子的相互作用强度相同，是一种理想的三中心四电子成键模型。对称氢键比正常氢键强得多，更加接近共价键，可催生凝聚态物质诸多奇异物性，例如：高温超导电性、绝缘体 - 金属相变、超快质子传输、超离子态等。因此，对称氢键在新物态的探索研究中受到了广泛的关注。然而，对称氢键的形成需要施加高压，以显著缩短原子间距和氢键的键长，严重制约了其实际应用。因此，如何降低形成对称氢键构型所需的压力是亟待解决的一个关键问题。

量子材料科学中心江颖教授、陈基研究员、王恩哥院士与北京师范大学化学学院郭静教授等合作，利用衬底对水的氢键网络进行预压缩和氢原子核的量子效应引起的量子涨落对氢键键长的压缩，在氢离子掺杂二维冰中，实现常压下的对称氢键构型，并使用 qPlus 原子力显微镜和路径积分分子动力学确认了对称氢键构型。这个研究小组取得了以下重大科学突破和发现：

1. 通过氢离子掺杂二维冰实现常压下的对称氢键构型。当氢离子浓度较小时，氢离子与水分子结合为 Eigen 构型水合氢离子（$H_3O^+(H_2O)_3$），并通过自组装形成短程有序的二维六角网络（图 1A），但其晶格常数较大，网络中只存在非对称氢键。当提升氢离子掺杂浓度时，Eigen 构型的氢离子会两两结合形成 Zundel 构型离子（$H_5O_2^+$）（图 1B），这种 Zundel 构型的二维冰较本征的二维冰产生了超过 10% 的晶格收缩，最小的氧 - 氧间距接近 250 皮米，部分氢键出现明显的对称化。

2. 为了能够从实空间确认对称氢键构型，研究人员在 2018 年探测到水合钠离子的基础上（Nature 2018, 557, 701），进一步开发了新一代 qPlus 型非侵扰式原子力显微镜技术（qPlus-AFM），并将其探测灵敏度和成像分辨率分别提升到 ~2 皮牛和 ~20 皮米（国际最好水平），成功区分了非对称氢键 Eigen 和对称氢键 Zundel 构型的水合氢离子，并通过针尖操纵实现了两种构型的相互转化（图 2A-C）。第一性原理路径积分分子动力学模拟（PIMD）的结果表明，氢离子的高密度掺杂大大增强了核量子效应，从而促进水分子间氢核的量

子离域，进而在常压下得到了对称氢键构型的二维冰。

3. 进一步研究发现，不同的金属表面对于对称氢键构型的形成有显著的影响（图 2D）。Au(111) 表面上 Zundel 构型的形成需要高浓度的氢离子掺杂，而在 Pt(111) 表面上低浓度掺杂就可以产生 Zundel 构型，这是由于 Pt(111) 衬底与氢的相互作用更强，同时具有更小的晶格常数，使得 Pt(111) 的预压缩能力更强，更容易得到对称氢键构型。

这项研究在常压下实现了二维冰中部分氢键的对称化，未来可通过界面 / 维度调控、掺杂、外场等手段进一步增强核量子效应，探索完全对称氢键构型的二维冰，及其可能的金属化和超导电性。该研究为设计和制备新型对称氢键体系提供了新的思路，有望为实现常压下与对称氢键有关的新奇物性及其实际应用奠定基础。

该工作以“Visualizing Eigen/Zundel cations and their interconversion in monolayer water on metal surfaces”为题于 2022 年 7 月 14 日发表于《科学》（Science）（Science 2022, 377,6603）。东京大学原子力显微镜领域著名专家 Yoshiaki Sugimoto 教授在同期《科学》“观点”（Perspective）栏目中以“冰定则如何被打破的直接观测”（Seeing how ice breaks the rule）为题对该工作进行了评述。此外，该工作还被《科学》杂志以网站首页图片形式进行重点报道。

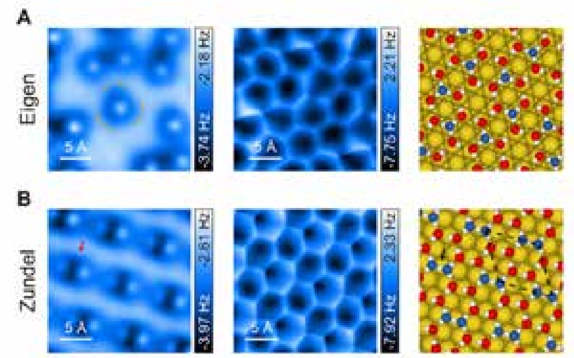

图 1. Au(111) 表面上 Eigen（A）以及 Zundel（B）构型二维冰的 AFM 实验图（第一列水合离子图；第二列氢键网络图）和原子结构模型图（第三列）。模型图中，蓝色代表 Eigen/Zundel 构型离子，红色代表水分子。

Fig 1. AFM experimental images of Eigen (A) and Zundel (B) configuration two-dimensional ice on Au(111) surface (the first column, hydrated ion diagram; the second column, hydrogen bond network diagram) and atomic structure model diagram (the third column). In the model diagram, blue represents Eigen/Zundel configuration ions, and red represents water molecules.

III. A Novel Two-dimensional Ice Phase Induced by Nuclear Quantum Effects

Symmetric hydrogen bond is a unique type of hydrogen bond (X-H-X), where the hydrogen atom is situated at the geometric center of two highly electronegative atoms and interacts equally with both, forming an ideal three-center four-electron bond model. The symmetric hydrogen bond is much stronger than normal hydrogen bond, closer to covalent bond, and can generate numerous peculiar properties in condensed matter, such as high-temperature superconductivity, insulator-metal phase transitions, ultrafast proton transport, and superionic state. Therefore, the symmetric hydrogen bond has received widespread attention in the exploration and research of new physical states. However, the formation of symmetric hydrogen bonds requires the application of high pressure to significantly shorten the atomic spacing and the bond length of the hydrogen bond, which severely restricts its practical application. Therefore, reducing the pressure required to form symmetric hydrogen-bonding configurations is a key problem to be solved.

Professors Ying Jiang, Ji Chen, Enge Wang from the International Center for Quantum Materials, in collaboration with Professor Guo Jing from the School of Chemistry, Beijing Normal University, used substrates to pre-compress the hydrogen-bonding network of two-dimensional ice and the quantum fluctuations of the hydrogen nuclei to compress the bond length of the hydrogen bond. They achieved symmetric hydrogen-bonding configurations at ambient pressure in proton-doped two-dimensional ice, and used qPlus atomic force microscopy and path integral molecular dynamics to confirm symmetric hydrogen-bonding configurations. The research group made the following major scientific breakthroughs and discoveries:

1.Symmetric hydrogen-bonding configurations were achieved at ambient pressure by doping two-dimensional ice with hydrogen ions. When the concentration of hydrogen ions is low, the hydrogen ions combine with water molecules to form Eigen configuration ($H_3O^+(H_2O)_3$), and form short-range ordered two-dimensional hexagonal networks through self-assembly (Fig 1A). However, its lattice constant is large, and only asymmetric hydrogen bonds exist in the network. When the hydrogen ion doping concentration is increased, the Eigen cations will bind in pairs to form Zundel configuration ions ($H_5O_2^+$) (Fig 1B). This kind of Zundel configuration two-dimensional ice has a lattice shrinkage of more than 10% compared to the intrinsic two-dimensional ice. The smallest oxygen-oxygen distance is close to 250 picometers, and some hydrogen bonds show obvious symmetrization.

2.In order to confirm the symmetric hydrogen-bonding configuration from real space, based on the detection of hydrated sodium ions in 2018 (Nature 2018, 557, 701), the researchers further developed a new generation of non-invasive qPlus atomic force microscopy technology (qPlus-AFM). Its detection sensitivity and imaging resolution have been improved to ~2 piconewtons and ~20 picometers (at an international leading level), respectively. They successfully distinguished the hydrated protons of the asymmetric hydrogen-bonding Eigen configuration and the symmetric hydrogen-bonding Zundel configuration, and realized the inerconversion between the two configurations through tip

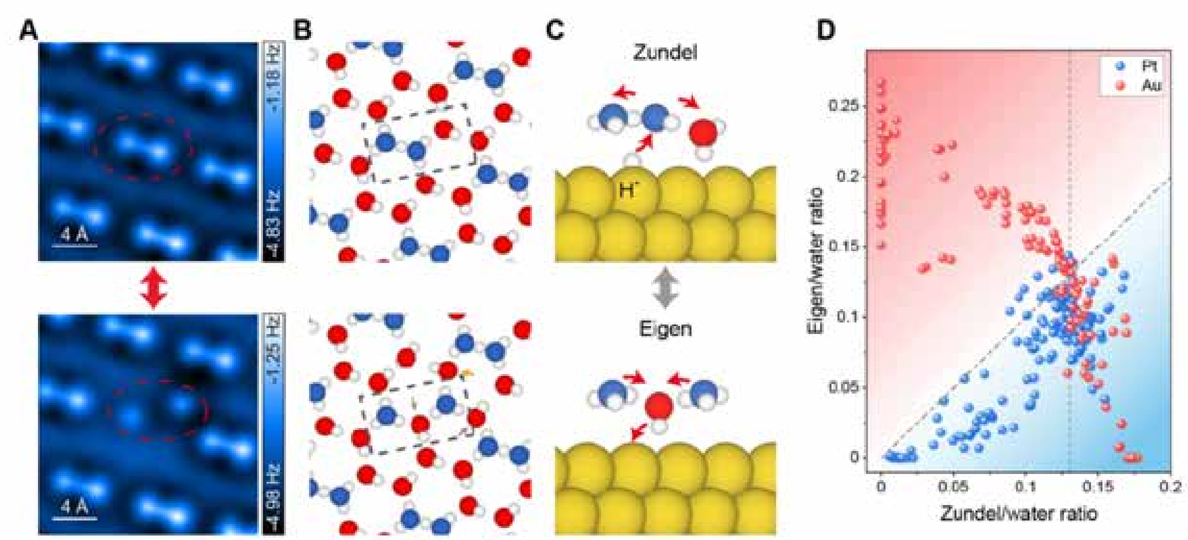

图 2.（A-C）针尖操纵 Eigen 和 Zundel 构型相互转变的实验图和模型示意图；（D）不同氢离子掺杂浓度下，Au(111) 与 Pt(111) 表面 Eigen 与 Zundel 离子浓度的关联。

Fig 2. (A-C) Experimental images and schematic diagram of the interconversion of Eigen and Zundel configurations manipulated by the tip; (D) Correlation between Eigen and Zundel ion concentration on the surface of Au(111) and Pt(111) under different hydrogen ion doping concentrations.

manipulation (Fig 2A-C). The results of the Path Integral Molecular Dynamics (PIMD) simulation based on first principles show that high-density doping of hydrogen ions significantly enhances nuclear quantum effects, thereby promoting the quantum delocalization of hydrogen nuclei between water molecules, and consequently leading to the formation of two-dimensional ice with symmetric hydrogen bonds under normal pressure.

3.Further, they have found that different metal surfaces have a significant impact on the formation of symmetric hydrogen-bonding configurations (Fig 2D). On the Au(111) surface, the formation of the Zundel configuration requires high concentrations of hydrogen ion doping, while on the Pt(111) surface, the Zundel configuration can be produced with low concentrations of doping. This is because the Pt(111) substrate has a stronger interaction with hydrogen and a smaller lattice constant, making the pre-compression ability of Pt(111) stronger and easier to realize symmetric hydrogen-bonding configurations.

This work has realized the symmetrization of some hydrogen bonds in two-dimensional ice under normal pressure. In the future, by controlling interface/dimension, doping, external fields, etc., nuclear quantum effects can be further enhanced to explore completely symmetric hydrogen-bonding configurations of two-dimensional ice and its possible metallization and superconductivity. This research provides new ideas for designing and preparing symmetric hydrogen bond and is expected to lay the foundation for realizing new physical properties related to symmetric hydrogen bonds and their practical applications under normal pressure.

This work, titled "Visualizing Eigen/Zundel cations and their interconversion in monolayer water on metal surfaces", was published in Science (Science 2022, 377,6603) on July 14, 2022. Yoshiaki Sugimoto, a renowned expert in the field of atomic force microscopy from the University of Tokyo, feartured this work in the same issue of Science in the "Perspectives" section, under the title "Seeing how ice breaks the rule". In addition, this work was also highlighted by the Science magazine with a cover image on its website.

12 科维理天文与天体物理研究所 The Kavli Institute for Astronomy and Astrophysics

科维理天文与天体物理研究所是北京大学和美国 Kavli 基金会合作于 2006 年 6 月成立的，并于 2007 年开始正式运行。研究所致力于建设一个国际一流的天文与天体物理研究中心，在活跃的学术氛围下，开展前沿天体物理领域的基础科学研究。工作语言为英语。研究所积极参加理论和观测天体物理研究项目，开发和利用观测设备，培养本科生、研究生和博士后。定期举办专题研讨会和学术会议，并开展一系列旨在推动与国内外天文界合作与交流的学术活动。研究所与其它 Kavli 研究所以及世界上很多大学和研究机构建立了各种交流与访问计划。 研究所的主要研究领域包括：1) 观测宇宙学，星系的形成与演化；2) 恒星形成，恒星与行星系统；3) 引力物理和高能现象；4) 计算天体物理。依托研究所建设的中国空间站工程巡天望远镜北京大学科学中心 2020 年 11 月正式揭牌成立。

研究所现任所长何子山，副所长吴学兵、Gregory J. Herczeg, 协调人陈建生。由国际科学顾问委员会 (SAC) 在学术活动、重大计划、研究方向和教师聘用等方面提供指导。 理事会直接向北京大学校长报告工作，以监督研究所的管理运行。目前（2022 年底）研究所有全职教师 11 名，包括 1 位海外高层次人才引进计划学者，10 位海外高层次人才青年计划学者，万人计划科技领军人才 1 名，科技部创新人才 1 名，腾讯科学探索奖获得者 1 名。研究所与天文学系合作密切，人员共聘，资源共享，联合开展科学研究和人才培养。另外还有 25 名博士后，多名访问学者和 5 名办公行政人员。

The Kavli Institute for Astronomy and Astrophysics (KIAA) is an international center of excellence in astronomy and astrophysics jointly supported by Peking University and the Kavli Foundation, USA. The KIAA has promoted basic astrophysical research at the frontiers of observational and theoretical fields since start of operations in 2007, with a mission that includes training of undergraduate and graduate students and postdoctoral fellows. The program of KIAA focuses on four major areas of astrophysics: 1) observational cosmology, galaxy formation and evolution; 2) star formation, stellar and planetary systems; 3) gravitational and high-energy astrophysics; and 4) computational astrophysics. In November of 2020, the KIAA-based Chinese Space Station Telescope PKU Science Center was formally inaugurated.

The Institute is under the leadership of its Director Luis C. Ho, Associate Directors Xue-Bing Wu and Gregory J. Herczeg, and coordinator Jiansheng Chen. An international Science Advisory Committee provides guidance concerning proposed academic activities, assistance on major projects to set research directions, and review of new faculty appointments. A Governing Board, which reports to the President of Peking University, oversees the management and operations of the Institute. KIAA faculty includes a thousand-talent program scholar and ten youth thousand-talent program awardees. KIAA works closely with the Department of Astronomy, via coordination of research activities, sharing of research facilities and resources, training and supervising of students, and joint participation in the routine operations of the Institute. Together with several joint appointments with the Department of Astronomy and other institutions, KIAA currently has 11 faculty, including 1 overseas high-level talent introduction program scholar, 10 overseas high-level talent youth program scholars, 1“Ten Thousand Talent Program”Leading Talent, 1 MOST Innovation Talent and 1Tencent Foundation XPLORER PRIZE awardee. There are also 25 postdoctoral fellows, many visiting scholars, and five administrative staff members.

一、宇宙再电离的能量来源

江林华团队首次证实类星体对宇宙再电离的贡献可以忽略不计，表明恒星形成星系提供了宇宙再电离的主要电离光子，从而基本解决了宇宙再电离能量来源这一重要天体物理问题。研究成果于 2022 年 6 月 16 日以研究长文的形式在线发表在《自然·天文》（Nature Astronomy）期刊上。

宇宙再电离发生于大约 130 亿年前（现在的宇宙年龄约为 138 亿年），也就是宇宙学红移 6.0 以上。之前的宇宙相对均匀且一片“黑暗”。在这“黑暗时代”末期，宇宙中最早的恒星、星系和类星体等天体开始形成。它们发出的紫外莱曼连续谱光子，即能量高至足以电离氢原子的光子，逐渐电离星系际

介质中的主要气体成分氢原子。此过程称为宇宙再电离，是宇宙演化历史中最重要的阶段之一。该过程庞大而复杂，其核心问题之一是电离能量来源问题，即何种天体提供了再电离宇宙的紫外光子。一般认为有两大主要能量来源，一是具有活跃超大质量黑洞的类星体（或活动星系核），二是拥有大质量恒星的产星星系（或称为恒星形成星系）。但长期以来，人们对类星体和星系的相对贡献并不清楚。

星系对宇宙再电离贡献的不确定性主要源于人们不清楚高红移（这儿主要指红移 6.0 以上或宇宙年龄小于 10 亿年）星系的电离光子逃逸率。观测表明，电离光子从中低红移星系逃逸到星系际介质的比例平均而言仅为百分之几。也就是说，尽管星系可能产生大量电离光子，但它们中的绝大部分会被星系本身或者星系周围的介质吸收（或散射）而无法逃逸到星系际空间。更糟糕的是，人们无法直接探测来自高红移星系的电离光子，这是因为视线方向上的星系际介质会将这些光子全部吸收。另一方面，高红移类星体对宇宙再电离的贡献也很不确定。尽管人们已经发现大量高光度类星体，但由于观测上的困难，对非常暗弱的类星体知之甚少，而这些暗弱类星体有数量上的优势，所以有可能提供更多的电离光子。

由于无法直接探测来自高红移星系的电离光子，江林华团队选择的策略是搜寻非常暗弱的类星体，并测量类星体所产生的电离光子总数，从而直接确定类星体的贡献。该策略的关键，也是难点，是需要探测到比目前已知最暗类星体还暗数十倍的类星体，这远超现有望远镜的光谱证认能力（如果利用常规的光谱证认方法）。为此，团队基于极深的哈勃空间望远镜和大型地面望远镜图像数据，开发了新的方法来搜寻和证认红移 6.0 至 6.6 之间的类星体。该方法主要包括两大步骤，首先，利用多波段图像数据将类星体候选体从低红移天体中分离（图 1a），然后利用哈勃高空间分辨率图像从这些候选体中证认点源状类星体（图 1b）。该方法避开了传统的光谱证认，从而使团队在探测暗弱类星体时达到了前所未有的深度。

江林华团队将上述方法应用于所有合适的哈勃望远镜深场图像，但并未在这些深场中发现红移在 6.0 与 6.6 之间的类星体，这为暗弱类星体的空间数密度设置了严格上限。利用该上限，并结合已知的较亮类星体样本，团队构建了覆盖 10 个星等范围（光度差一万倍）的类星体光度函数（即数密度随光度的变化，图 1c），然后计算了类星体产生的电离光子总数。通过比较上述红移范围内宇宙再电离所需的光子数，发现类星体的贡献小于 7%（95% 置信度，图 1d）。这是首次直接证据表明类星体对宇宙再电离的贡献几乎可以忽略不计。英国爱丁堡大学天文研究所前所长，著名天文学家 James Dunlop 教授高度评价了该工作，认为该工作通过仔细研究彻底解决了一个关于类星体对宇宙再电离贡献的长期问题。

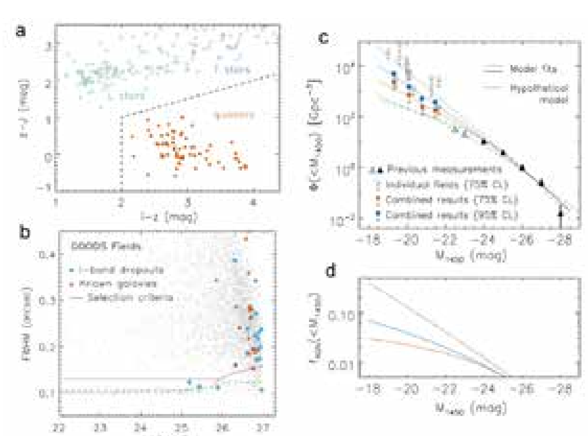

图 1. 高红移类星体的搜寻和证认及类星体对宇宙再电离的贡献。（a）利用多波段测光数据选择类星体候选体；（b) 利用哈勃高空间分辨率图像证认类星体；（c）覆盖近 10 个星等范围的高红移类星体光度函数；（d）类星体对宇宙再电离的贡献小于 7%（95% 置信度）。

Fig 1. Quasar selection and the quasar contribution to cosmic reionization. (a) Selection of high-redshift quasar candidates using multiband imaging data. (b) Quasars were further identified using high-resolution HST imaging data. (c) Quasar luminosity function that spans 10 magnitudes. (d) The quasar contribution to cosmic reionization is less than 7%.

以上成果进一步表明，高红移星系（尤其是小质量产星星系）是宇宙再电离所需电离光子的主要贡献者。这基本确定了宇宙再电离的能量来源，对理解宇宙再电离过程和物理机制有重要意义。该工作还为暗弱类星体的空间密度设置了严格上限，对理解宇宙早期超大质量黑洞形成和演化有重要促进作用。未来的中国空间站工程巡天望远镜等天文设备有望更深入地探索这些前沿问题。

江林华为论文的第一作者和通讯作者。该研究得到国家自然科学基金委和中国载人航天等单位的资助。

论文链接：

“Definitive upper bound on the negligible contribution of quasars to cosmic reionization”

（DOI:10.1038/s41550-022-01708-w）

I. What Reionized the Universe?

A team of astronomers, led by Professor Linhua Jiang at the Kavli Institute for Astronomy and Astrophysics and School of Physics at Peking University, has revealed that distant quasars or galactic nuclei with actively growing supermassive black holes made a negligible contribution of ionizing photons to cosmic reionization 13 billion years ago. This finding settles a long-standing issue about the quasar contribution to cosmic reionization, and suggests that galaxies are the major energy sources. The result was recently published as an article in Nature Astronomy on June 16, 2022.

Cosmic reionization occurred several hundred million years after the Big Bang (Fig 1; current age of the universe is about 13.8 billion years). Before the era of reionization, the universe was “dark” because there were no light sources other than the cosmic background radiation. By the end of this dark age, the earliest astrophysical objects — stars, galaxies, and quasars — started to form. They emitted copious ultraviolet Lyman continuum (LyC) photons that are energetic enough to gradually ionize most of the hydrogen atoms in the intergalactic medium. This epoch of “cosmic reionization” lasted a few hundred million years and represents the most recent major phase transition of the gas in the universe. One key question is what sources produced most of the LyC photons responsible for reionization. The most obvious candidates are quasars, which are powered by active supermassive black holes, and star-forming galaxies, which contain massive stars. However, the relative balance of these two sources has been a subject of long-standing debate.

The current understanding of the contribution of stars to reionization is hampered by our limited knowledge of the fraction of LyC photons that escape from galaxies at redshift around 6 or higher, when the universe was less than a billion years old. Observations indicate that the LyC escape fraction from low- and intermediate-redshift galaxies is only a few percent on average. This means that most of the ionizing photons produced by stars are absorbed (or scattered) by the galaxies themselves or their surrounding medium. Directly detecting the LyC from high-redshift galaxies is unrealistic because of intergalactic medium absorption along the light-of-sight. For high-redshift quasars, although bright quasar samples have been established, little is known about very faint quasars that surpass in number and thus may have played an important role in providing LyC photons for reionization.

Since a direct measurement of the contribution of galaxies to reionization is unfeasible, the strategy of Jiang's team was to directly constrain the number of LyC photons produced by quasars. The key challenge was to identify quasars that are a few tens of times fainter than the faintest quasars previously known, ones that are beyond the reach of the traditional method of spectroscopic identification even with the largest current telescopes. Jiang's team developed a new method, one that bypassed spectroscopy, to search for extremely faint quasars at redshift between 6.0 and 6.6 by combining deep Hubble Space Telescope (HST) and ground-based images. Using multiband imaging data to separate quasar candidates from lower-redshift objects (Fig 2a), in conjunction with the high spatial resolution of HST to identify point-like objects (Fig 2b), they succeeded in identifying point objects that are presumably quasars.

Jiang's team applied the above method to suitable archival HST images, but they failed to find any quasars at redshift between 6.0 and 6.6. The absence of observable quasars in this dataset puts a stringent upper limit on the abundance of faint quasars. Using this constraint and the abundance of bright quasars calculated by previous studies, they were able to construct the first high-redshift quasar luminosity function (abundance as a function of luminosity) that spans 10 magnitudes (factor of ten thousand; Fig 2c), and thus measure the total number of LyC photons emitted by the entire quasar population. By comparing the photon output required to ionize the universe at this redshift range, they found that quasars can only provide up to 7% (95% confidence level) of the photons required for reionization (Fig 2d). This conclusively demonstrates that quasars made a negligible contribution to cosmic reionization.

二、中国天眼揭示快速射电暴密近环境的动态演化

依托于中国科学院国家天文台运行的、我国自主研制的国家重大科技基础设施“中国天眼”500 米口径球面射电望远镜（FAST），一个由北京大学物理学院天文学系及科维理天文与天体物理研究所、中国科学院国家天文台李柯伽研究员、中国科学院国家天文台朱炜玮研究员、北京大学科维理天文与天体物理研究所东苏勃研究员、美国内华达大学拉斯维加斯分校张冰教授等人组成的 FAST 优先和重大科学研究团队对快速射电暴 FRB 20201124A 的深入观测取得重要成果，揭示了该快速射电暴密近环境的动态演化。2022 年 9 月 22 日，该研究成果以“一个位于棒旋星系的复杂、强磁场区域中的快速射电暴”（A fast radio burst source at a complex magnetised site in a barred galaxy）为题发表于国际著名期刊《自然》（Nature）杂志上。

快速射电暴（fast radio burst，FRB）是宇宙中偶发的无线电暴发事件。在几毫秒的时间内，所释放的无线电波段的能量相当于世界当前总发电量累计几百亿年的总和。快速射电暴是在 2007 年第一次被报道发现的，早先的探测主要是来自银河系外的快速射电暴，迄今已经发现了好几百个。但是，这类天文现象的物理起源仍然不清楚。2020 年人们探测到了来自银河系内磁星的快速射电暴，这表明有一些快速射电暴可以起源于磁星，即一类磁场极强的中子星。但是那些来自于宇宙学距离的快速射电暴，尤其是能够重复暴发的快速射电暴的起源仍不清楚。对于快速射电暴已有大量的无线电波段的观测资料，然而长期以来人们缺乏对其核心区物理参数直接观测的资料。

FAST 优先和重大科学研究团队使用 FAST 对 FRB 20201124A 进行长期监测，在 54 天的 82 小时观测中测到了来自于这个快速射电暴的 1863 个暴发脉冲信号，这样高的事件率使它成为最活跃的几个重复暴之一。研究团队通过对这个源的深度观测取得了多个国际首次的重要发现。天文学上，法拉第旋转量描述电磁波振荡方向随频率旋转的程度，可以用于直接探测介质中的磁场。研究团队“拍摄”到了快速射电暴法拉第旋转量动态演化的“电影”，首次发现了法拉第旋转量的奇异演化行为，即在前 36 天里法拉第旋转量出现了无规律的短时标演化，而在随后的 18 天里几乎不变；首次发现了快速射电暴的猝灭现象，即 FRB 20201124A 从保持高事件率态到在 72 小时内突然熄灭；首次在快速射电暴中探测到了与之前所有快速射电暴都显著不同的高圆偏振度脉冲，其最高值达到了 75%；还首次测到了偏振度随着电磁波波长振荡的现象。这些现象都说明了在这个快速射电暴周围 1 个天文单位（即太阳到地球的距离）的环境是非常复杂并且动态演化的。通过偏振观测显示出的振荡现象，该团队对这个快速射电暴周围 1 个天文单位内的环境的磁场给出直接限制，该磁场达到了高斯量级以上。通过国际合作，他们使用美国 10 米 Keck 光学望远镜对这个快速射电暴的宿主星系进行了深度观测，发现其宿主星系是约为银河系尺度大小、富金属的棒旋星系，并且发现这个快速射电暴所在区域恒星密度较低，处于旋臂之间，距离星系中心中等距离。该团队认为这个环境与由于大质量恒星极端爆炸导致的超亮超新星或伽马射线暴后形成的年轻磁星模型不相符。

FAST 对重复性快速射电暴 FRB 20201124A 的近 2000 个暴发的探测揭示了该暴非常复杂的、动态演化的、强磁场环境，这对于人们理解快速射电暴及其周围环境如何产生射电暴发并影响其传播提供了很大帮助。

北京大学与中国科学院国家天文台联合培养博士生胥恒、北京大学博士生陈平、中国科学院国家天文台博士生牛佳瑞等人深度参与了这项研究。

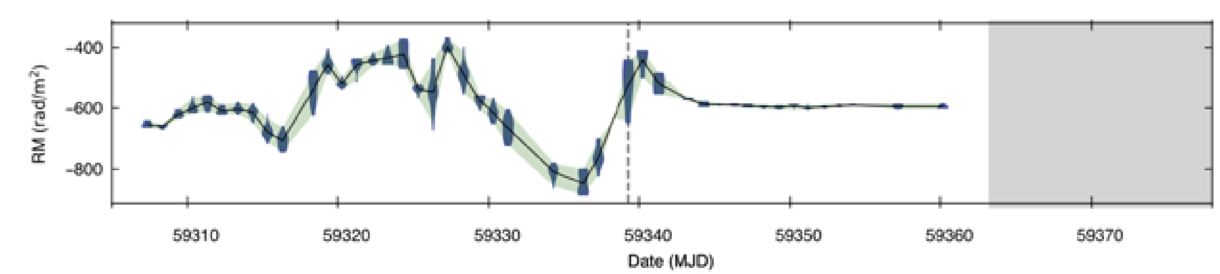

图 1. 法拉第旋转量的短时标演化。阴影区有 FAST 观测，但是没有探测到射电暴发，说明快速射电暴是突然熄灭的。

Fig 1. Faraday rotation measure as a function of time. The grey shaded region on the right side of the plot shows the epoch when no burst was detected, indicating that the radio activity is quenched in a short timescale.

II. FAST Reveals a Dynamically Evolving Environment Around a Repeating Fast Radio Burst Source

Fast radio bursts (FRBs) are highly dispersed millisecond-duration radio bursts. They are extremely powerful, to the amount of energy that would be produced by modern human civilization over tens of billions of years. Since the discovery of the first FRB in 2007, several hundred of them had been found,

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however, the physical origin of FRBs is still unsettled. Most of these FRBs come from outside of the Milky Way. Recent observations of a FRB originating from a Galactic magnetar (a type of neutron star beloved to have an extremely strong magnetic field) suggest that some FRBs come from magnetars, but the origin of the cosmological FRBs, especially those that actively repeat, remains unclear. To date, the constraints to the physical parameters of the environments close to FRBs are still weak.

Using the Five-hundred-meter Aperture Spherical radio Telescope (FAST), the FAST FRB Key Project Team, which includes Kejia Lee (Peking University, NAOC), Weiwei Zhu (NAOC), Subo Dong (Peking University), Bing Zhang (University of Nevada), Heng Xu (Peking Univsersity, NAOC), Ping Chen (Peking University), Jiarui Niu (NAOC), detected nearly 2000 radio bursts from FRB 20201124A. Their research strongly indicates that FRB 2021124A is embedded in a complicated, dynamically evolving magnetized environment. Their results help us understand how these radio bursts were generated, and how the radio burst signal propagated in the local magnetized environment.

In a Nature paper published on 21 September 2022, the FAST FRB team reported using FAST to monitor FRB 20201124A for about 2 months. They analyzed 1,863 bursts of FRB 20201124A detected by FAST in totally 84-hour observations obtained across 54 days, which is the largest sample of bursts recorded with polarization information so far. The high event rate makes FRB 20201124A among the most active known FRBs. They discovered several phenomena never detected before, the irregular short-time variation of the Faraday rotation measure, which probes the line-of-sight magnetic field strength, of individual bursts during the first 36 days, followed by a constant value;

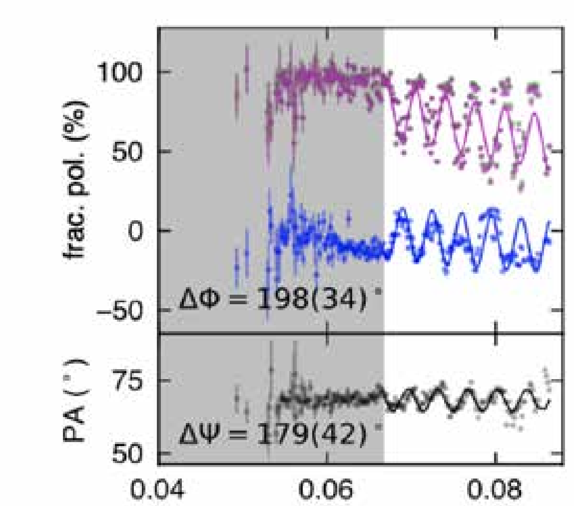


图 2. FRB 20201124A 中探测到的线 / 圆偏振度和偏振位置角的振荡现象。

Fig 2. Fractional polarizations, and linear polarization angle as a function of the square of wavelength, where green, magenta, blue and grey dots and error bars are respectively for total, linear, circular polarizations and linear polarization angle.

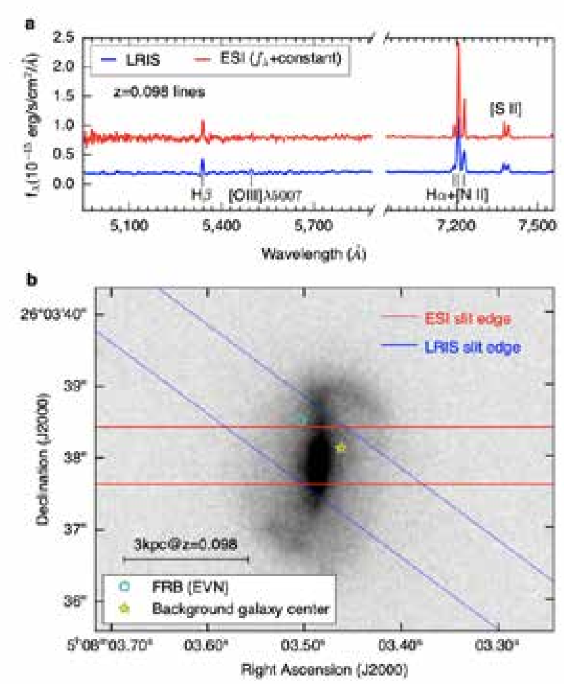


图 3. 通过 Keck 望远镜对 FRB 20201124A 的宿主星系进行的光谱和高分辨率成像观测。

Fig 3. Optical spectra and high spatial resolution adaptive-optics image of the host galaxy.

they witnessed the quenching of the burst activity on a timescale shorter than three days; they detected prominent circular polarization in these bursts (up to 75%); they detected ooscillations in fractional linear and circular polarizations as well as polarization angle as a function of wavelength.

All these features provide strong evidence for a complicated, dynamically evolving magnetized environment within about one astronomical unit of this FRB source. Based on the oscillation structures in polarizations, they set a constraint to the magnetic field to this magnetized local environment, which reaches gauss level.

Observations with the Keck 10m optical telescope reveal that FRB 20201124A resides in a low-density interim region of a Milky Way-like galaxy.This environment is inconsistent with a young magnetar engine formed during an extreme explosion of a massive star that resulted in a long gamma-ray burst or superluminous supernova.

"This is like taking a movie of the surroundings of an FRB source," said Bing Zhang, "and our film reveals a complex, dynamically evolving, magnetized environment that was never imagined before". Such an environment is not straightforwardly expected for an isolated magnetar. "Something else might be in the vicinity of the FRB engine, possibly a binary companion," added Zhang.

"This is the largest sample of FRB data with polarization information from one single source", said Weiwei Zhu.

"This location is inconsistent with a young magnetar central engine formed during an extreme explosion such as a long gamma-ray burst or a superluminous supernova, widely speculated progenitors of active FRB engines", said Subo Dong.

Published Paper: https://www.nature.com/articles/s41586-022-05071-8

三、东苏勃应邀在 ARA&A 发表系外行星统计研究的述评

国际天文界最具影响力的综述期刊 Annual Review of Astronomy and Astrophysics（《天文学和天体物理学年评》，简称 ARA&A）特别邀请北京大学科维理天文与天体物理研究所东苏勃研究员撰写述评文章，对太阳系外行星统计这一研究领域进行系统总结和展望。这篇题为《系外行星统计及其理论意义》（Exoplanet Statistics and Theoretical Implications）的文章于 2021 年 9 月 8 日正式发表。毕业于北京大学天文学系、现任清华大学天文系助理教授的祝伟为第一作者，东苏勃为通讯作者。

行星系统是如何形成和演化的？这是天文学中最古老、最基本的问题之一，对它的探索本质上也是在追溯我们自身的起源。长久以来，人类所知的行星系统只有太阳系这个"孤本"，这极大限制了对该问题的研究。自 1995 年发现绕类太阳恒星的第一颗系外行星（获 2019 年诺贝尔物理学奖）以来，已知系外行星的数量呈爆发式增长，促进了该领域的飞速发展，并使之成为目前天文学最活跃的前沿方向之一。系外行星研究一个非常出人意料的结果是，已发现的行星系统大多与太阳系行星的性质和轨道分布迥异，并呈现出惊人的多样性。这些发现极大地挑战了传统的行星形成理论，同时也给回答行星系统的起源问题带来了前所未有的机遇。近十年来，美国宇航局（NASA）的开普勒卫星用

凌星法（行星掩食恒星）搜寻到了数千颗系外行星，为相关领域的研究带来了一场革命。这些海量发现引领了系外行星前沿研究的一个重大趋势，即利用大样本观测数据系统地研究行星及其宿主恒星分布的统计性质，继而深入理解行星形成和演化的物理机制和环境。

《系外行星统计及其理论意义》这篇综述文章

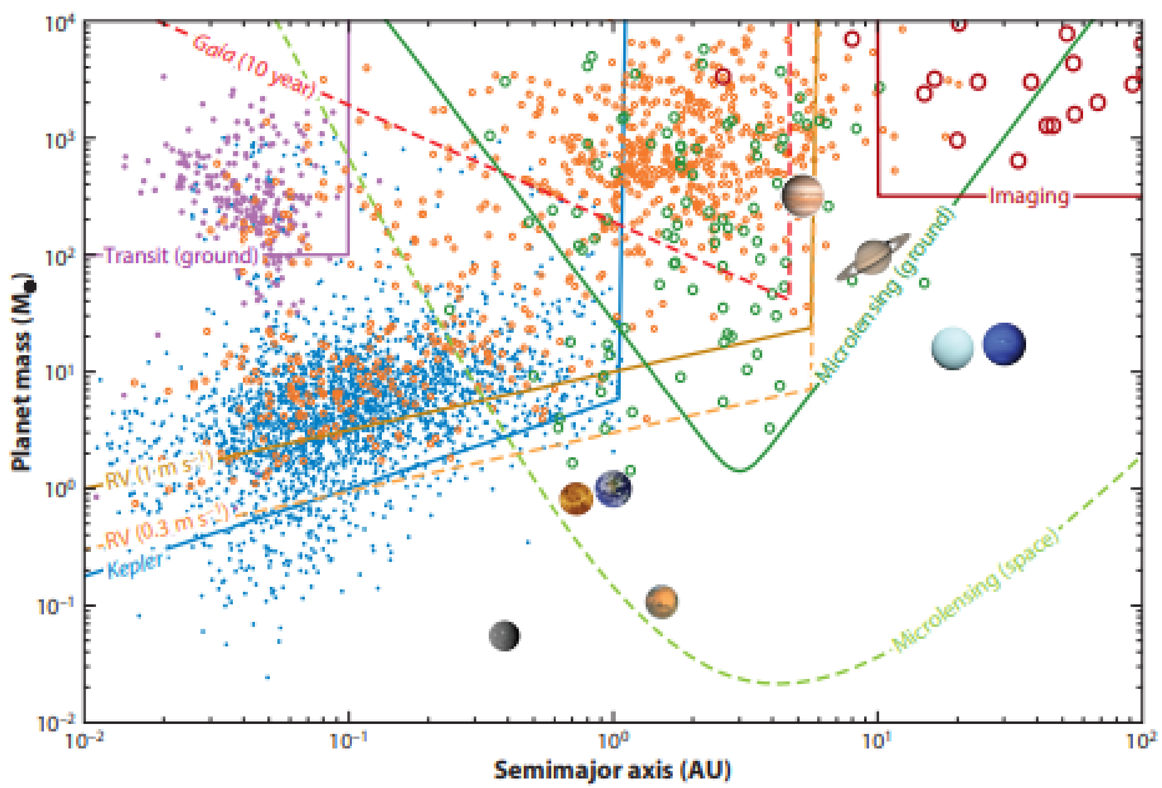


图 1. 已知系外行星的质量 - 轨道半径分布。不同颜色的点代表不同方法发现的行星：地基望远镜凌星 (紫色)，开普勒卫星凌星 (蓝色)，视向速度法 (橙色)，地基望远镜微引力透镜法 (绿色)，直接成像法 (褐色)。实线表示各方法探测的灵敏区间，绿色的虚线表示未来空间望远镜微引力透镜法的预计探测区间。小图标标识了太阳系八大行星 (来源于 ARA&A 述评图一）。

Fig 1. Mass versus semimajor axis of known planets, based on the "Confirmed Planets" list from the NASA Exoplanet Archive (Akeson et al. 2013; acquired in September of 2020) and the reliable "*Kepler*" planet candidates. Using different colors, we differentiate" planet detections as well as the approximate sensitivity curves from ground-based transit (purple), "*Kepler*" survey (blue), RV (*orange*" and "*brown*), microlensing (*green*), and direct imaging (*red*). The masses of the "*Kepler*" detections are estimated from the measured radii according to the Chen & Kipping (2017) mass–radius relation. The sensitivity curve of "*Kepler*" is also converted in a similar way from that measured on the period–radius plane. The sensitivity curve for the 10-year "*Gaia*" astrometry survey is also shown in red, for which we assume a Sun-like host at 20 pc and require a 3-σ" detection over the expected precision. For space-based microlensing, we adopt the sensitivity curve of the microlensing survey that will be performed by the "*Nancy Grace Roman Space Telescope*" (formerly known as WFIRST or "*Wide Field Infrared Survey Telescope*; Penny et al. 2019). The Solar System planet images are shown at their corresponding locations. Data for the dashed green line is taken from Penny et al. (2019). Abbreviation: RV, radial velocity.

评述了近年来行星统计研究方面的重要进展。重点讨论了轨道半径较短（短于日地距离）的行星的分布情况，这是开普勒卫星的主要探测区间（见上图）。虽然开普勒卫星发现的行星为研究统计分布提供了极佳的样本来源，但是其原始数据存在着重大的局限，即缺乏目标恒星的精确参数。近年来，人们进行了大量的工作来系统地刻画开普勒行星样本，从而充分实现其统计研究上的潜力。其中，国家重大科技基础设施郭守敬望远镜 (LAMOST) 的光谱巡天获得了开普勒目标恒星的最大光谱参数样本，为研究完备的开普勒行星样本作出了关键贡献。对开普勒行星完备样本的统计研究极大加深了人们对系外行星的理解，包括行星数目以及轨道分布。银河系中比地球大、轨道半径在日地距离之内的行星的总数与恒星相当，而每个行星系统中平均有约三颗这样的行星。这表明行星形成的效率比传统的基于太阳系发展而来的行星形成模型的预期要高得多。另外，行星轨道形状的分布显示与系统中行星数量的多少有关：行星数多的系统类似太阳系，即行星的轨道接近圆形且几乎处于同一个平面上，而行星数少的系统里行星则具有高椭率、高倾角的轨道。这表明行星间引力相互作用导致的动力学演化在塑造行星轨道构型上起了重要作用。综述文章还讨论并总结了视向速度法和微引力透镜法对轨道半径较长行星的研究结果，以及微引力透镜法发现的流浪行星族群的观测和理论意义。文章全面梳理了系外行星领域的统计结果，并探讨了其对行星系统形成和演化的理论意义。最后，文章展望了该领域未来有望取得突破的研究方向。

ARA&A 由 Annual Reviews 出版社出版，每年一卷，发表十余篇特邀述评文章。Annual Reviews 系列涵盖多学科，旨在为各领域最前沿的进展提供高度权威性的专业述评，并给科研提供方向性指导，被国际科学界公认为基本参考文献。ARA&A 长期以来是天文和天体物理领域中最具影响力的专业期刊，影响因子在 60 余种天文和天体物理类期刊中排名第一（2020 年影响因子为 30.065）。

III. Dong Subo was invited to publish a review of exoplanet statistical research in ARA&A

Annual Review of Astronomy and Astrophysics (ARA&A), the most influential review journal in the international astronomy community, invited researcher Dong Subo from the Kavli Institute of Astronomy and Astrophysics of Peking University to write a review article to systematically summarize extrasolar planet statistics and evaluate prospects for the future. This article entitled "Exoplanet Statistics and Theoretical Implications" (Exoplanet Statistics and Theoretical Implications) was officially published on September 8, 2021. Zhu Wei, who graduated from the Department of Astronomy of Peking University and is currently an assistant professor of the Department of Astronomy of Tsinghua University, is the first author, and Dong Subo is the corresponding author.

How do planetary systems form and evolve? This is one of the oldest and most fundamental questions in astronomy, and the exploration of it is essentially tracing our own origins. For a long time, the only planetary system known to mankind is the solar system, which greatly limited the research on this issue. Since the discovery of the first exoplanet around a sun-like star in 1995, which won the 2019 Nobel Prize in Physics, the number of known exoplanets has exploded, motivating rapid development in the field and enabling exoplanets to become one of the most active frontier directions in astronomy. An unexpected result of exoplanet research is that most of the discovered planetary systems are very different from those of the solar system in terms of properties and orbital distributions, with an astonishing diversity of architectures. These discoveries have greatly challenged the traditional theory of planetary formation, and at the same time brought unprecedented opportunities to answer the question of the origin of planetary systems.

In the past ten years, NASA's Kepler satellite has searched for thousands of exoplanets using the transit method (planets eclipsing stars), bringing a revolution to research in related fields. These massive discoveries have allowed astronomers to systematically study the statistical properties of the distribution of planets and their host stars, and then gain a deep understanding of the physical mechanisms and environments of planet formation and evolution.

The review article "Exoplanet Statistics and Its Theoretical Implications" reviews the important progress in the study of planet statistics in recent years. The discussion focuses on the distribution of planets with shorter orbital radii (shorter than the distance between the Sun and the Earth), which is the main detection interval of the Kepler satellite (see Fig above). Although the planets discovered by the Kepler satellite provide an excellent sample source for the study of statistical distribution, there are major limitations in its raw data, that is, the lack of precise parameters of the target star. In recent years, a great deal of work has been done to systematically characterize the Kepler sample of planets in order to realize its full statistical research potential. Among them, the spectral survey of Guo Shoujing Telescope (LAMOST), a major national science and technology infrastructure, obtained the largest sample of spectral parameters of Kepler's target stars, making a key contribution to the study of complete Kepler planet samples. The statistical study of Kepler's complete sample of planets has greatly deepened people's understanding of exoplanets, including the number of planets and their orbital distribution. The total number of planets in the Milky Way galaxy that are larger than Earth and within orbital radii within the distance of the Sun is comparable to the number of stars, with an average of about three such planets per planetary system. This suggests that planet formation is much more efficient than expected from conventional models of planet formation based on the development of the solar system. In addition, the distribution of the shape of planetary orbits shows that it is related to the number of planets in the system: a system with a large number of planets is similar to the solar system. The orbits of planets in multi-planet systems are close to circular and almost on the same plane, while planets in a system with a small number of planets have high ellipticity and are on highly inclined orbit. This suggests that dynamical evolution resulting from interplanetary gravitational interactions plays an important role in shaping planetary orbital configurations.

The review article also discusses and summarizes the research results of radial velocity method and microlensing method on planets with long orbital radii, as well as the observational and theoretical significance of the rogue planet population discovered by microlensing method. This article comprehensively sorts out the statistical results in the field of exoplanets and discusses their theoretical significance for the formation and evolution of planetary systems. Finally, the article looks forward to the research directions that are expected to make breakthroughs in this field in the future.

ARA&A is published by Annual Reviews Publishing House, one volume per year, with approximately ten invited review articles published each year. The Annual Reviews series covers multiple disciplines and aims to provide highly authoritative professional reviews of the most cutting-edge progress in various fields and provide directional guidance for scientific research. It is recognized as a basic reference by the international scientific community. ARA&A has long been the most influential professional journal in the field of astronomy and astrophysics, and its impact factor ranks first among more than 60 astronomy and astrophysics journals (the impact factor in 2020 is 30.065).

13 人工微结构和介观物理国家重点实验室（北京大学）
State Key Laboratory of Artificial Microstructure and Mesoscopic Physics, Peking University

人工微结构和介观物理国家重点实验室 1990 年经国家计划委员会拨款开始建设，1992 年通过国家教育委员会组织验收通过并正式对外开放。实验室发展的主导思想是：研究时空尺度变化时介观物理新现象及新规律，加强小空间、短时间尺度物理过程理论方法创新和测量手段的发展。注重学科交叉，推动人工微结构和介观物理的研究手段和观念在生命科学、能源以及各种应用学科延伸。面向国家重大战略需求，力争做到既对国家的经济建设和国防建设作出贡献，又要在基础科学的发展上作出贡献。

实验室以《国家中长期科学和技术发展规划纲要》为指导，建设有明显介观物理研究特色、光学与凝聚态紧密结合的研究基地，深入开展介观物理中的重大基础科学问题、应用前沿问题的研究。结合介观物理研究前沿科学问题和所承担的国家重大计划和任务，形成了三个重大研究方向，分别为“介观光学与飞秒光物理”、“介观体系凝聚态物理与器件”和“介观物理交叉与重大应用”。

实验室现在拥有雄厚的创新人才队伍，包括：中科院院士 5 人，发展中国家科学院院士 1 人，长江特聘教授 9 人，国家杰出青年科学基金获得者 20 人，万人计划人才 8 人，教育部新世纪/跨世纪人才 14 人，青年长江学者 4 人，国家优秀青年科学基金获得者 13 人。

实验室有国家基金委创新研究群体 3 个，教育部创新研究团队 2 个，在站博士后 50 余人，研究生 300 余人。2021-2022 年实验室主持承担了 200 多项国家级科研项目，包括牵头主持 1 项科技创新 2030 重大项目（龚旗煌），7 项（王新强、杨金波、刘运全、施可彬、于彤军、唐宁、刘开辉）国家重点研发计划、2 项（吕国伟、许秀来）基金委重大研究计划，2 项（欧阳颀、肖云峰）基金委重大项目以及 1 项（王新强）国家重大科研仪器设备研制专项等。

实验室获得 5 项国家自然科学奖二等奖，1 项国家技术发明奖二等奖，以及何梁何利科学与进步奖、教育部一等奖、青年科学奖、中国青年科技奖、中国高等学校十大科技进展、中国光学十大进展、中国半导体十大研究进展、2018 全球 30 项光学重大进展，国际光学工程学会、美国光学学会、英国物理学会、中国光学学会会士等国际国内多项奖励和荣誉。

2021-2022 年，实验室承担科研经费超过 3.2 亿元，发表 SCI 论文 400 余篇，其中，1 篇刊登于 Science、3 篇刊登于 Nature；多篇发表在 Nature 子刊、Physical Review Letters 等国际顶级学术期刊上，获国家授权发明专利 92 项。

State key Laboratory of Artificial Microstructure and Mesoscopic Physics was founded in 1990, and was supported by the State Planning Commission. In 1992, the laboratory passed the evaluation of the State Education Commission and started to operate. The guideline for the laboratory is to investigate the new phenomena and new laws of mesoscopic physics when the matters changes spatially and temporally, and the laboratory aims to strengthen the development of theoretical methods and the measurement of physical processes in ultrasmall space and ultrafast time scale. Paying attention to the intersection of disciplines, the laboratory develops the research methods and builds the concepts to promote the artificial microstructure and mesoscopic physics in life sciences, energy, and various applied disciplines. The laboratory aims to meet the country's major strategic needs, and strive to contribute to the country's economic construction and national defense construction, but also makes the significant contribution to the development of basic science.

Guided by the Outline of the National Medium-and Long-Term Science and Technology Development Plan, the laboratory builds a research basement with the Mesoscopic physical research features and the close integration of atomic, molecular, optical physics and condensed matter physics, and in-depth development of major basic scientific issues and application frontiers in mesoscopic physics. Combined with the frontier scientific issues of mesoscopic physics research and the major national plans and tasks undertaken, three major research directions have been formed in the laboratory, namely, “Mesoscopic optics and Femtophysics”, “Mesoscopic System Condensed Matter Physics and Devices”, and “Mesoscopic physical intersection and major applications”.

The laboratory has a strong team of innovative talents, including 5 academicians of the Chinese Academy of Sciences, 1 academician of the Academy of Sciences of the Developing Countries ,9 special professors of the Yangtze River, 20 winners from the China National Funds for Distinguished Young Scientists, 8 winners from the National special support program for high-level personnel recruitment, 14 winners from the New Century Excellent Talents in University, 4 Young Yangtze Scholar and 13 winners from the National Natural Science Foundation of China Youth Fund.

The laboratory has 3 innovative research groups of the National Fund supported by NSFC, 2 innovative research team in university of Ministry of Education of China and has undertaken more than 200 national-level scientific research projects in the past two years, including science and technology innovation 2030- major project and the national key research and development plans and major scientific research plans and special national research equipment development projects.

The laboratory won the second prize of 5 National Natural Science Awards, the second prize of the National Technology Invention Award in 2018, as well as more than 10 other awards, such as the He Liang He Li Science and Progress Award, the first prize of the Ministry of Education, the Youth Science Award，the China Youth Science and Technology Award，the two awards on the top-ten-scientific and technological advances in Chinese university of science and technology，the one award on the 30 major advances in optics worldwide, three awards on the top-ten scientific and technological advances of Chinese Optics, two awards on the top-ten scientific and technological advances of semiconductor in China, 1 Fellow of Institute of Physics（IOP）,1 Fellow of Society of Photo-Optical Instrumentation Engineers（SPIE）, 4 Fellows of Chinese Optical Society（COS）, 2 Fellows of the Optical Society of America（OSA）, 1 Fellows of American Physical Society (APS) and 1 Fellows of Royal Society of Chemistry (RSC) .

In 2021 and 2022, the laboratory has obtained grants more than 320 million yuan, published more than 400 SCI papers, many of which were published in the most influential scientific journals in the world, such as Science ,Nature /Nature series journals, Physical Review Letters, etc., including 1 Science paper and 3 Nature papers; 92 patents were granted.

一、超快分子动力学的成像和调控

超快分子动力学成像需要极高的时间、空间分辨率，该研究的最终目的是直接观测化学反应过程中原子及电子的运动，从而为研究并控制化学反应、分子相变等提供实验上的依据。在分子动力学成像技术发展的早期，由于时空分辨率、信号强度、样品制备等的限制，研究者只能把这种直接观测过程作为“理想实验”。随着超快激光、X 射线自由电子激光、电子加速器等技术的迅速发展，基于超快激光强场效应的隧道电离、激光诱导光电子再散射以及高次谐波产生过程、超快 X 射线衍射、超快电子衍射（显微镜）等成像手段已可实现超高时空分辨能力，并逐渐应用于各类分子超快成像中。通过测量分子在化学反应、相变等过程中不同时刻的衍射信号，从而得到化学键长、粒子动量分布等信息随时间的变化，由此“逐帧”还原超快分子动力学过程，这些技术被广泛应用于制作“分子电影”。

刘运全教授和李铮助理教授的课题组与华中科技大学黎敏教授和陆培祥教授合作，通过库仑爆炸成像则通过探测碎片离子的动量获取分子结构信息的方法，对分子的 Jahn-Teller 对称性自发破缺进行了时间分辨的成像。Jahn-Teller 效应是分子和固态系统中自发对称性破缺的基本机制，对许多领域都具有深远的影响。实验采用亚 10 飞秒分辨率的超快离子相干库仑爆炸成像技术，明确地成像了对称空间中 CH_4^+ 阳离子 Jahn-Teller 畸变的超快动力学。研究发现，该系统从 C_{3v} 到 C_{2v} 几何结构的 Jahn-Teller 畸变需要 20+/-7 飞秒的特征时间。经典和量子分子动力学模拟与实验结果相符，并揭示了 C_{2v} 结构的构建动力学，其中涉及到 CH_4^+ 阳离子的多个振动通路的复杂相干拍频。研究工作发表于《自然 通讯》（Nature Commun. 2021, 12, 4233）。基于一系列在超快分子动力学成像领域的研究，课题组应邀在《物理化学快报》发表相关评述（J. Phys. Chem. Lett. 2022, 13, 1668）。

同时，课题组提出了基于超快衍射进行分子量子态层析的新方法。针对关键的维度问题，通过比较量子层析问题和晶体中相位恢复问题在本质上的共同点，提出通过体系与光场相互作用部分哈密顿量的形式和密度矩阵本身的性质出发在迭代过程中引入限制条件来补充丢失的维度信息，对于分子体系的转动自由度问题提出了量子层析的迭代投影算法。这一方法不同于传统的量子层析方法，能够突破维度问题的限制，对于任意维度的分子体系通过超快衍射重建密度矩阵。研究工作发表于《自然 通讯》(Nature Commun. 2021, 12, 5441)，并得到编辑推荐。基于对分子动力学中的量子态的

认识，课题组提出了将量子芝诺效应应用于分子动力学过程中，实现通过动态外场对分子反应通道的选择性调控。论文发表于《物理评论快报》（Phys. Rev. Lett. 2022， 129, 013402）。

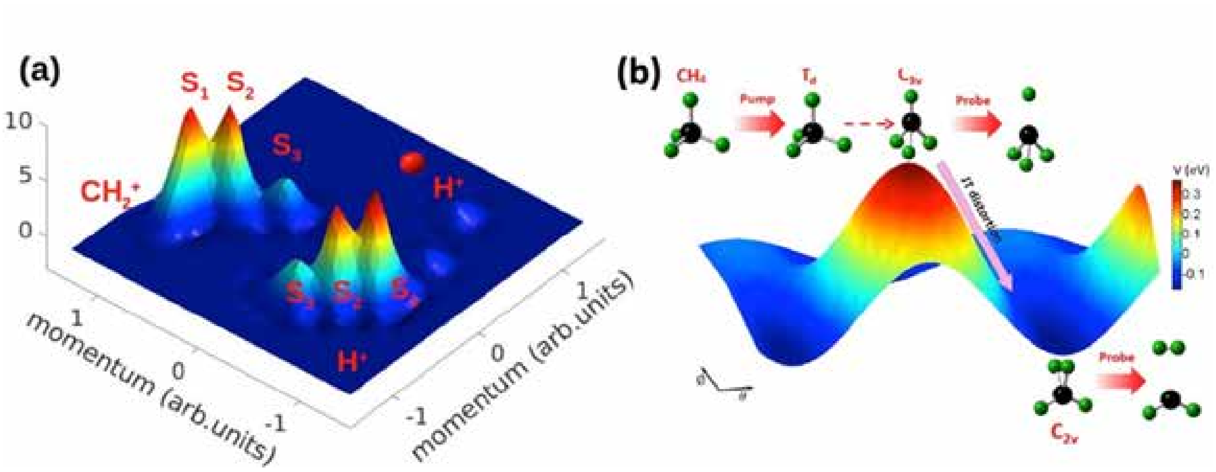


图 1. (a) 为在 8 飞秒时的库仑爆炸的牛顿图；(b) 为 CH_4^+ 阳离子中的 Jahn-Teller 效应的示意图。

Fig 1. (a) Newton plot of Coulomb explosion at 8 fs; (b) Sketch of Jahn-Teller effect in CH_4^+ cation.

I. Imaging and control of ultrafast molecular dynamics

Ultrafast molecular dynamics imaging requires high temporal and spatial resolution. The ultimate goal of the research is to directly observe the motion of atoms and electrons during chemical reactions, providing experimental evidence for the study and control of chemical reactions, phase transitions, and other phenomena. In the early stages of the development of molecular dynamics imaging technology, researchers could only consider this direct observation process as an "ideal experiment" due to limitations in temporal and spatial resolution, signal intensity, and sample preparation. With the rapid development of technologies such as ultrafast lasers, X-ray free-electron lasers, and electron accelerators, imaging techniques based on the strong field effect of ultrafast lasers, such as tunnel ionization, laser-induced photoelectron scattering, high harmonic generation, ultrafast X-ray diffraction, and ultrafast electron diffraction, current techniques can achieve ultra-high temporal and spatial resolution capabilities and have been applied in various types of molecular ultrafast imaging. By measuring the diffraction signals of molecules at different times during chemical reactions and phase transitions, information on chemical bond length, particle momentum distribution, and other changes over time can be obtained, thus "frame by frame" reconstructing the ultrafast molecular dynamics process. These techniques are widely used in making "molecular movies".

Professor Yunquan Liu and Assistant Professor Zheng Li's research groups, in collaboration with Professor Min Li and Professor Peixiang Lu from Huazhong University of Science and Technology, used Coulomb explosion imaging to obtain molecular structure information by detecting the momentum of fragment ions, and conducted time-resolved imaging of the spontaneous breakdown of Jahn-Teller symmetry in molecules.

The Jahn-Teller effect is a fundamental mechanism of spontaneous symmetry breaking in molecular and solid state systems, and has far-reaching consequences in many fields of physics. Up to now, to directly image the onset of Jahn-Teller symmetry breaking remains unreached. The researchers employ ultrafast ion-coincidence Coulomb explosion imaging with sub-10 fs resolution and unambiguously image the ultrafast dynamics of Jahn-Teller deformations of CH_4^+ cation in symmetry space. It is unraveled that the Jahn-Teller deformation from C_{3v} to C_{2v} geometries takes a characteristic time of 20+/-7 fs for this system. Classical and quantum molecular dynamics simulations agree well with the measurement, and reveal dynamics for the build-up of the C_{2v} structure involving complex revival beating of multiple vibrational pathways of the CH_4^+ cation. The paper was published in "Nature Communications" (Nature Commun. 2021, 12, 4233). Based on the series of studies in the ultrafast imaging of molecular dynamics, the researchers are invited to publish the review in the "Journal of Physical Chemistry Letters" (J. Phys. Chem. Lett. 2022, 13, 1668).

In addition, the research group proposed a new method for molecular quantum state tomography based on ultrafast diffraction. To address the key issue of dimensionality, the researchers compared the quantum tomography problem with the phase retrieval problem in crystallography and proposed an iterative projection algorithm for quantum tomography by introducing constraints in the iterative process based on the form of the system and the interaction of the system with the optical field, as well as the properties of the density matrix itself. This method is different from traditional quantum tomography methods and can overcome the limitation of dimensionality, and enable the reconstruction of the density matrix for molecular systems of any dimensionality through ultrafast diffraction. The research was published in Nature Communications (Nature Commun. 2021, 12, 5441) and received editorial highlight. Based on the understanding of quantum states evolution in molecular dynamics, the research group proposed applying the quantum Zeno effect to selectively control the reaction channels of molecules through dynamic external fields in molecular dynamics processes. The paper was published in Physical Review Letters (Phys. Rev. Lett. 2022, 129, 013402).

二、纳米尺度下的光子自旋角动量操控

方哲宇团队利用阴极荧光显微技术，实现了基于金属纳米天线的光自旋霍尔效应的动态操控，并且在 40 纳米的尺度实现了该效应的开关。此外，还成功将该技术应用于操控二维材料能谷激子的定向辐射上，实现了能谷激子辐射在远场的定向分离和方向调控。这些成果为手性纳米光子学与自由电子量子光学的研究提供了新的手段，为能谷光电器件的纳米集成提供了新的思路。相关工作发表于《科学进展》（Sci. Adv. 2021,7:eabf8011）和《先进材料》（Adv. Mater. 2023, 2204908）。

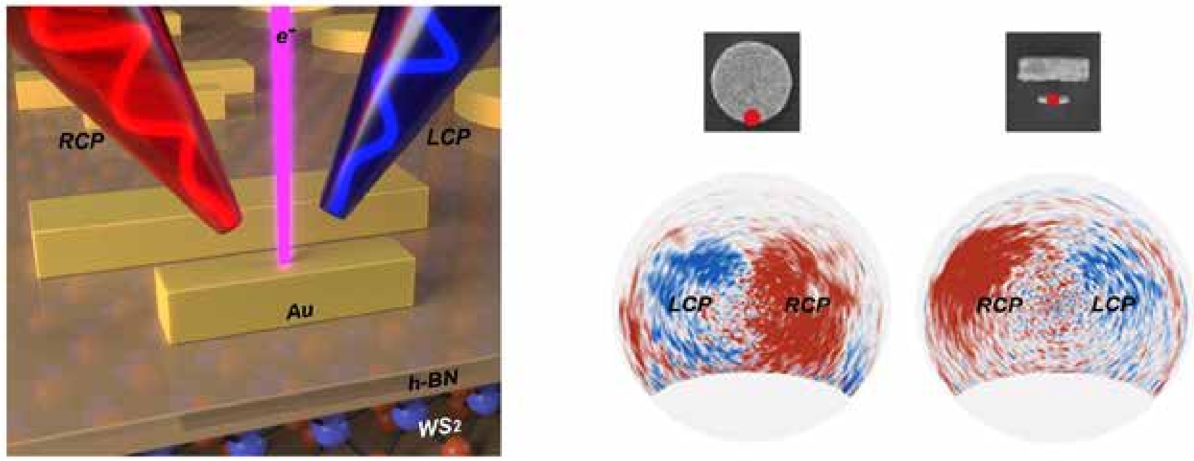


图 1. 自由电子束调控能谷激子辐射定向分离的示意图与利用角分辨阴极荧光显微测量得到的远场圆偏振分量辐射强度。

Fig 1. Schematic of electron-induced chirality-selective routing of valley photons via metallic nanostructure and far-field radiation intensity of circularly polarized components measured by angle-resolved CL.

II. Nanoscale photon spin angular momentum manipulation

The team led by Zheyu Fang has used cathodoluminescence microscopy to achieve dynamic manipulation of the optical spin Hall effect based on metallic nanoantennas, and has achieved the switching of this effect at the scale of 40 nanometers. In addition, they have also successfully applied the technique to manipulate the directional radiation of energy valley excitons in two-dimensional materials, achieving directional separation and directional regulation of energy valley exciton radiation in the far field. These results provide new tools for the study of chiral nanophotonics and free-electron quantum optics, and new ideas for the nano-integration of valleytronics and optoelectronic devices. The related work was published in Science Advances (Sci. Adv. 2021, 7:eabf8011) and Advanced Materials (Adv. Mater. 2023, 2204908).

14 核物理与核技术国家重点实验室（北京大学）
State Key Laboratory of Nuclear Physics and Technology, Peking University

北京大学核物理与核技术国家重点实验室于 2007 年经过严格评审由国家科技部批准筹建，2009 年通过验收正式挂牌运行，是我国第一个核科学领域的国家重点实验室。实验室依托粒子物理与原子核物理、核技术及应用、理论物理和高能量密度物理四个学科，其骨干力量主要来自北京大学物理学院技术物理系、重离子物理研究所和理论物理所。依据核科学的国际发展趋势及国家重大战略需求，实验室确定了放射性核束物理、强子物理、先进粒子加速器技术和核技术应用四个研究方向。

实验室现有骨干研究人员 90 人，其中中科院院士 3 人，长江特聘教授 4 人，国家杰出青年基金获得者 16 人。在站博士后约 50 人，研究生约 300 人。2021-2022 年实验室承担科研项目约 120 项，包括牵头承担国家重点研发计划项目和国家重大科研仪器设备研制专项等。年均外部竞争性科研经费约 8 千万元，研究成果发表高水平论文约 120 篇。

实验室拥有 4 台大型加速器设备：2×6 MV 串列静电加速器、4.5 MV 静电加速器、2×1.7 MV 串列加速器，以及 ^{14}C 测量加速器质谱计（AMS），提供粒子束流支撑多学科用户的研究和应用。

实验室开展广泛的国际国内合作，典型的如与日本理化所合办的仁科学校 Nishina School（2008- ）；由美国能源部和中国自然科学基金委支持的中美奇特核理论研究所（CUSTIPEN）；在欧洲 LHC、日本 RIKEN、美国 ANL 和 FRIB 等实施实验研究计划等。

The State Key Laboratory of Nuclear Physics and Technology at Peking University (SKLNPT) is the first state key lab in the nuclear science field in China. The Lab was initially approved in 2007 and formally established in 2009. It mainly consists of the Department of Technical Physics, the Institute of Heavy Ion Physics, the Institute of Theoretical Physics, with disciplines of Particle Physics & Nuclear Physics, Nuclear Technology & Applications, Theoretical Physics, Plasma Physics and High Energy Density Physics. The main research fields of the laboratory include the Hadron physics, Radioactive nuclear beam physics, Accelerator physics and techniques and Nuclear technique applications.

The lab is composed of 90 key researchers, including 3 academicians of the Chinese Academy of Sciences, 4 special professors of Yangtze River, 16 National Outstanding Young Scientists. In 2021 and 2022, the lab has about 50 postdocs and 300 PhD candidate students. About 120 research projects including the National Key Research and Development Plans and Special Fund for Research on National Major Research Instruments are undertaken by this lab. The lab has an annual budget of about 80 million yuan from the competitive funding resources and published more than 120 high level papers per year.

In addition to carry on basic research experiments at large scale facilities world-wide, the lab provides low energy ion beams for the multidisciplinary research, based on the user facilities, such as the 2 x 6 MV tandem accelerator, the 4.5 MV Van De Graaff accelerator, the 2 x 1.7 MV tandem accelerator and the compact accelerator for ^{14}C AMS.

The lab is operating with broad international and domestic collaborations, of which the representative examples include the Nishina School organized by RIKEN-PKU (since 2008), the CUSTIPEN supported by DOE of US and NSFC of China (since 2013), many experimental programs at user facilities in worldwide such as LHC in Europe, RIKEN in Japan, ANL and FRIB in USA and so on.

一、高精度激光核谱技术及不稳定核奇特结构研究进展

不稳定原子核基本性质和奇特结构研究，是当今各科技强国均重点部署的核物理基础前沿，被列入国际国内新一代核物理大科学装置的主要科学目标。基于多学科交叉的精密激光核谱学方法，在认识不稳定核性质和结构、核子 - 核子相互作用、不稳定核数据、以及物质世界基本对称性等方面发挥着重要作用，已成为一个快速发展的新兴研究方向，在国际各大型放射性束装置上广泛部署。

北京大学激光核谱与核性质课题组近年来在国内牵头发展用于不稳定核基本性质测量的共线激光谱装置，并依托国内外大学科装置开展不稳定核性质和奇特结构研究。在技术发展方面，课题组完成了全套基于荧光探测的共线激光谱装置（含离线激光溅射离子源）的建设、整体性能测试、及针对 ^{40,42,44,48}Ca 稳定同位素的物理测试。结果发表在《核技术杂志》（Nucl. Sci. Tech. 33, 2022, 9），并被选为该杂志 2022 年第一期封面文章并推荐做后期“research story”动画宣传。该论文入选 2022 年度第七届中国科协优秀科技论文。基于以上离线技术发展和全面测试，课题组与中国原子能科学研究院核物理所密切合作，于 2021 年下半年在我国 ISOL 型放射性核束装置 BRIF 上，完成了首个在线激光核谱物理实验。实验成功测量了 BRIF 提供的不稳定核 ^{38}K 和稳定核 ^{39}K 的原子超精细结构谱，提取的核磁矩和电荷半径等基本性质参数与文献一致，验证了整套共线激光装置的性能。这为我国不稳定核性质和结构研究带来了新的机遇。该成果发表在《物理研究中的核仪器与方法》（Nucl. Inst. Meth. in Phys. Res. A 2022, 1032, 166622）。

在不稳定核奇特结构研究方面，课题组在中等质量钙核区丰中子核素新幻数和单粒子结构研究中取得进展。针对 $N = 32$ 是否为新幻数的国际热点问题，课题组提出并首次采用了 β 衰变标记的共线共振电离谱实验方法，开展了极端丰中子核 52K 的激光谱实验。实验结果表明钾同位素的电荷半径在 $N = 28$ 之后连续快速增大，不支持此前提出的 $N = 32$ 中子幻数，且目前国际上多种理论模型无法合理解释电荷半径的实验结果，成为丰中子核区出现的又一奇特现象。该成果发表于 Nature Physics17, 2021, 439，被 Nat. Phys. 的“News & Views”专栏亮点点评。采用同类技术，课题组开展了临近的丰中子 Sc 同位素的基本性质的实验

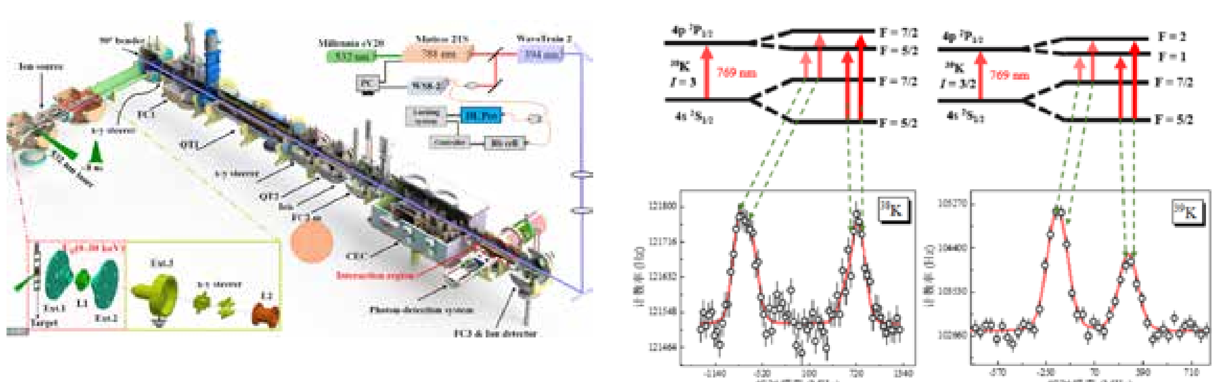


图 1.（左）在北京大学亚原子粒子探测器实验室完成共线激光谱设备 ;（右）在国内 BRIF 放射性核束装置上利用新发展的共线激光谱测量的 ^{38}K 和 ^{39}K 核素的超精细激光谱。

Fig 1. (left)Layout of the newly developed collinear laser spectroscopy device; (right) The hyperfine structure spectra of ^{38}K and ^{39}K isotopes observed at BRIF facility using the newly developed collinear laser spectroscopy.

研究。实验结果表明 ^{41}Sc 和 ^{49}Sc 核素的基态具有典型的单粒子结构，与壳模型图像一致。特别是实验测量的 ^{49}Sc 核素的电四极矩，为独立粒子模型的图像提供了教科书级别的实验实例。此工作为理论模型的进一步发展提供了实验基础。成果发表于《物理快报 B》（Physics Letters B 2022, 829, 137064）。

I. Progress on the development of the high-resolution laser spectroscopy setup and the study of exotic structure of unstable nuclei

The research group for laser spectroscopy and nuclear properties at Peking University has recently taken the responsibility to develop the collinear laser spectroscopy (CLS) technique aiming at studying the basic properties of unstable nuclei at domestic RIB facilities. The group has accomplished the apparatus implementation, the complete tests of the device performances and the off-line experiments for stable nuclei ^{40,42,44,48}Ca. The results were published at Nucl. Sci. Tech. in January 2022 which was selected as the Journal's cover story. This article has later been awarded the excellent science article in 2022 by the China Association for Science and Technology. Based on the above technique preparation and the close cooperation with the nuclear physics institute at China Institute of Atomic Energy, the group has carried out the first on-line CLS experiment at the national ISOL-type radioactive ion beam facility (BRIF). The experiment succeeded to measure the hyperfine structure spectra for unstable ^{38}K and stable ^{39}K, provided by BRIF. From the observed spectrum, the magnetic moment and the charge radius of these nuclei were extracted which are in good agreement with the literature values, demonstrating the good performance of the entire CLS system. The work allows to open the new opportunities in China for studying the properties and structure of unstable nuclei. The results were published in Nucl. Inst. Meth. in Phys. Res. A 2022, 1032, 166622.

The research group has made substantial progress in the investigation of exotic structure of unstable nuclei, especially in the study of new magic number and single-particle characteristic around calcium region. To answer the question “whether $N = 32$ is a new magic number or not”, our group proposed and used the beta-decay tagged collinear resonance laser spectroscopy technique for the first time, for the measurement of extremely neutron-rich 52K isotope. Charge radii of potassium isotopes are extracted, showing a rapid growth along the isotopic chain after $N = 28$, which does not support the magic nature of $N = 32$. Advanced theoretical models still faced challenges to interpret these experimental nuclear charge radii. These results were published in Nature Physics17, 2021, 439 and highlighted by “News & Views” of Nature Physics. Recently, our group carried out another on-line experiment to investigate the basic properties of nearby neutron-rich scandium isotopes. The results revealed the single-particle structures of ^{41}Sc and ^{49}Sc isotopes, which is consistent with shell-model prediction. Particularly, the extracted quadrupole moment of ^{49}Sc provided a textbook example for the independent-particle shell-model picture, providing an important test of the nuclear theory. This work was published in Physics Letters B 2022, 829, 137064.

二、激光驱动的超重离子加速研究

长期以来，通过激光加速产生的超重离子（质量数～200）的最高能量仅为 MeV/u 量级，远低于同期质子加速近百 MeV/u 的最高能量。这是因为，一方面，靶表面沾污层或靶内的质子和低 Z 离子会对重离子加速产生屏蔽效应；另一方面，超重离子极难被电离至高价态，低的荷质比使其难以有效被加速。作为激光离子加速最后的难题，超重离子加速理论与实验研究亟待突破。

联合研究团队攻克众多关键技术，研制出基于碳纳米管与超重金属纳米薄膜的复合靶材，利用拍瓦级超短脉冲激光产生的 10^{22} W/cm^2 的超强光场，通过激光加热靶后表面降低质子、碳和氧对超重离子加速的抑制作用，成功获得最高电荷态为 61+、最高能量达 1.2 GeV/u 的金离子束，将原飞秒激光金离子加速能量纪录提高了 6 倍。

他们首次使用自校准探测方法，在实验中同时获得了准确的绝对能谱和金离子的电荷态分布。实验与数值模拟结果表明，不同横向位置的金离子所经历的电离动力学过程（起始电离时间、电离速率、最高电荷态等）存在较大差异，导致其在能量增益有明显不同。他们所揭示的超重离子加速中的电离动力学过程，对于进一步提高离子束能量、提升束流品质有重要的意义。

相关研究成果以“超短超强激光驱动的超重离子加速”（Super-heavy ions acceleration driven by ultrashort laser pulses at ultrahigh intensity）为题，发表于《物理评论 X》（Physical Review X, 2021, 11, 021049）。物理学院 2016 级博士研究生王鹏杰为第一作者（导师马文君），马文君、颜学庆、Chang Hee Nam、Il Woo Choi 为共同通讯作者。值得一提的是，该工作是 Physical Review X 上所发表的第一项激光离子加速领域的研究工作。

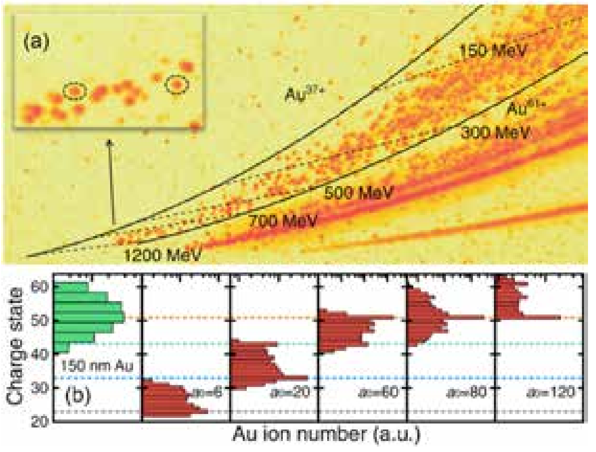


图 1. 最高能量为 1.2 GeV 的 TPS 实验结果；(b) 超重离子（Au）的电荷态分布：绿色为实验结果，红色为 PIC 模拟结果。

Fiq 1. The experimental results indicating Au ions with the highest energy of 1.2 GeV (b) The charge state distribution of Au ions: green bars are the experimental results and the red bars are the particle-in-cell simulation results.

II. Laser-driven acceleration of very-heavy ions

By conquering a number of key technical problems, the joint research team has developed composite targets based on carbon nanotubes and very-heavy metal nanofilms. By utilizing the ultra-strong light field of 10^{22} W/cm^2 generated by the watt-level ultra-short laser pulse and a separate laser to heat the targets, the inhibitory effect of carbon and oxygen ions on the acceleration of very-heavy ions was successfully suppressed. Au ions with the highest charge state of 61 + and the highest energy of 1.2 GeV/u were obtained, which enhances the previous energy record with femtosecond lasers by six times.

For the first time, they invent a self-calibration detection method to obtain absolute energy spectra and accurate charge state distributions of gold ions simultaneously. Experimental and numerical simulation results show significant differences in the ionization kinetics (initial ionization time, ionization rate, highest charge state, etc.) experienced by gold ions at different lateral positions in the focal spot, resulting in differences in their energy gain in the acceleration process. The ionization dynamics in the acceleration of very-heavy ions revealed by them are of great significance for further improving the energy of ions.

The above research was published online in Physical Review X (Physical Review X, 2021, 11, 021049) titled "Super-heavy ion acceleration driven by ultrashort laser pulses at ultrahigh intensity." The first author Wang Pengjie is a 2016 doctoral student at the School of Physics, and Ma Wenjun, Yan Xueqing, Chang Hee Nam, and Il Woo Choi are the co-corresponding authors. It is worth mentioning that this work is the first research work in the field of laser ion acceleration published in Physical Review X.

15 北京大学高能物理研究中心 Peking University Center for High Energy Physics

北京大学高能物理中心由李政道先生担任主任。目前有 8 位海外资深学者，33 位国内特聘兼职研究员，10 位青年学者，15 位博士后研究人员。研究的领域包括：宇宙学、量子场论、粒子物理唯象学、强子物理等。

With Prof. T. D. Lee as the director, the Center for High Energy Physics at Peking University now has 8 senior fe llows from abroad, 10 research associates, 33 junior fellows and 15 postdocs. The research interests include: cos mology, quantum field theory, particle physics phenomenology and hadronic physics.

一、格点量子色动力学研究取得系列进展

北京大学高能物理研究中心冯旭、刘川教授带领格点量子色动力学研究团队，在理论计算缪氢原子兰姆位移方面取得突破，成功获得双光子交换对兰姆位移的修正。质子内部的电荷分布半径对质子大小的衡量具有重要意义，而双光子交换图影响了从缪氢兰姆位移中提出电荷半径的精度。北大格点团队的研究不仅解决了双光子图的红外发散问题，还发展了新的长程减除方案，利用中国超算天津中心的超级计算机对双光子图进行了国际上首个格点计算。团队发现，格点 QCD 研究还可用于研究超精细光谱和其他重要的光谱学物理量，为夸克和胶子尺度的高能物理研究与极高精度的原子光谱学研究构建了跨学科的桥梁。同样地，格点 QCD 在强子谱学和强子结构领域也具有重要应用。北大格点团队与合作者解决了引入电磁相互作用时的有限体积效应问题，并在此基础上计算了带电 π 介子和中性 π 介子的质量差，计算精度较前提高了 5～10 倍；此外，团队利用格点 QCD 模拟对横向动量依赖软

函数进行研究，发展了新的计算方案和重整化方案，有效降低了高扭度效应的影响，为 Drell-Yan 过程和半单举深度非弹性散射实验提供理论输入。这些研究为理解强相互作用基本规律和物质深层次结构提供了重要的理论支持。

上述几项工作均在线发表于《物理评论快报》。北京大学物理学院博士研究生傅杨、李媛、夏世城为相关论文的第一作者。

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.128.172002

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.128.052003

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.128.062002

I. A Series of Progress Achieved in Lattice QCD Research

Profs. Xu Feng and Chuan Liu, together with their research team at Center for High Energy Physics have made significant progress in theoretical calculations of the muonic hydrogen Lamb shift using lattice quantum chromodynamics (QCD). They successfully obtained corrections to the Lamb shift due to the exchange of two photons. The determination of the charge distribution radius within the proton is of great significance, and the two-photon exchange diagrams affect the precision of extracting the charge radius from the muonic hydrogen Lamb shift. The lattice QCD research conducted by the team not only resolves the infrared divergence issue in the two-photon diagrams but also develops a novel long-range subtraction scheme. The team performed the first lattice calculation of two-photon exchange using the supercomputers at the Tianjin Supercomputing Center in China. The research team at Peking University found that lattice QCD studies can also be applied to investigate hyperfine splitting and other important spectroscopic quantities, thus bridging the interdisciplinary gap between high-energy physics with quarks and gluons as the basics degree of freedom and precise atomic spectroscopy. Similarly, lattice QCD also finds important applications in the study of hadron spectroscopy and hadron structure. The team at Peking University, together with their collaborators, addressed the finite volume effects when incorporating electromagnetic interactions and calculated the mass difference between charged and neutral pions with an accuracy improved by 5 to 10 times compared to previous results. Additionally, the team used lattice QCD simulations to study transverse momentum-dependent soft functions, developed new calculation and renormalization schemes, effectively reducing the impact of high-twist effects, and providing theoretical input for Drell-Yan processes and semi-inclusive deep inelastic scattering experiments. These studies provide important theoretical support for understanding the fundamental laws of strong interactions and the deep structure of matter.

The aforementioned works have been published online in Physical Review Letters. Yang Fu, Yuan Li, and Shicheng Xia, doctoral students from the School of Physics at Peking University, are the first authors of these papers.

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.128.172002

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.128.052003

https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.128.062002

16 北京大学纳光电子前沿科学中心
Frontiers Science Center for Nano-Optoelectronics, Peking University

纳光电子前沿科学中心是教育部成立的首批七个前沿科学中心之一。中心融合集成纳光子与微电子的优势，围绕纳光电子物理与器件、纳光电子融合与测试、纳光电子芯片与应用等三大方向开展研究，汇聚了包括光学、凝聚态物理、微电子与固体电子学等多方向的研究力量。

The Frontier Science Center for Nano-Optoelectronics is one of the first seven frontier science centers established by the Ministry of Education. The center integrates the advantages of nano-photonics and microelectronics, and carries out research in three main directions: nano-optoelectronics physics and devices, nano-optoelectronics integration and testing, and nano-optoelectronics chips and applications. It brings together research forces from multiple disciplines including optics, condensed matter physics, microelectronics, and solid-state electronics.

一、大规模集成光量子信息处理芯片的研究进展

量子芯片是实现大规模量子计算机的关键，有望应用于医疗、制药、人工智能、能源和信息安全等领域。以光子为量子信息载体的光量子芯片，是实现量子计算机的重要平台之一，受到国内外学术界、科学界和产业界的高度重视。中心龚旗煌院士领导的研究团队发展出了大规模集成硅基光量子芯片加工和量子调控技术，并用于高维量子相干性、高维量子计算和拓扑量子纠缠光源等基础物理问题与关键量子器件研究。相关工作发表在《自然光子学》（Nature Photonics 2022, 16, 248–257）和《自然通讯》（Nature Communications, 2021, 12, 2712，Nature Communications 2022, 13, 1166）。

研究团队实现了一款基于大规模硅基集成光量子芯片的可编程高维量子处理器。该处理器单片集成了约 450 个光学元器件和 116 个可编程器件，在单个芯片上实现了高维单量子位和双量子位的初始化、操作和测量。全功能集成和强可编程性提供了一种至上而下、从算法到量子门操作、从顶层需求到底层物理实现的高维量子计算架构。不同的计算任务可在软件层面编译成不同的量子线路，然后在硬件层面通过编程重构光量子芯片的物理配置来执行该量子线路，从而在同一处理器上可执行多种量子计算任务。团队编程重构该处理器超过百万次以上，实现了一系列高保真量子逻辑门操作，执行了多种重要的高维量子傅立叶变换类算法，包括高维 Deutsch-Jozsa 和 Bernstein-Vazirani 算法、高维量子相位估算和高维 Shor 大数分解（求阶）算法；并通过高维量子算法的有效运行，实现了高维量子计算的原理验证演示，可提升量子计算容量、计算精度和计算速度等。

团队实验了一款可惠勒延迟选择测量装置的多路径马赫 - 曾德尔干涉仪。该芯片单片集成 350 多个光子元器件和近 100 个可调相移器。利用该芯片，团队开发了量子纠缠片上产生、量子受控型 d 模式普适化分束器、d 模式普适化马赫 - 曾德尔干涉仪以及量子态重构等功能器件和模块。团队验证了多路径干涉体系中的玻恩准则，测得 -0.0031±0.0047 的 Sorki 参数，与已发表文献中最精确测量的结果齐平，排除了高阶干涉的存在。通过相干纠缠量子态和量子过程，实现了一种量子受控的 d 模式分束器，其状态决定了 d 模式观测仪器的状态，从而可在惠勒延迟选择条件下观测粒子的多路径波粒二象

性。通过测量多模式粒子性 D 和多路径量子相干性 C，首次在多路径量子体系中验证了普适化玻尔不等式 C2+D2≤1。团队还展示了对高维量子相干性的直接探测和高维随机数的产生。

研究团队通过控制 280 个微环量子光源的相互耦合，形成一个整体的新量子光源，从而使其获得全新的物理性质，在拓扑保护的光学拓扑绝缘体边界产生赝自旋关联的纠缠光子态。实现了拓扑保护的集成量子纠缠光源，在基于硅基二维耦合谐振环构型的反常弗洛凯（Floquet）拓扑绝缘体器件的拓扑边界上，制备出了具有拓扑鲁棒性的 Einstein-Podolsky-Rosen（EPR）纠缠态和多光子纠缠态。联合研究团队通过实验观测量子干涉和量子态层析技术，并对比完美无结构缺陷的拓扑量子纠缠光源、带结构缺陷的拓扑量子纠缠光源、以及平凡的量子光源等多种构型，首次在实验上证明了量子纠缠源在存在某些类结构缺陷和加工误差的情况下，依然具有和完美器件近乎一致的高量子态保真度和纯度。

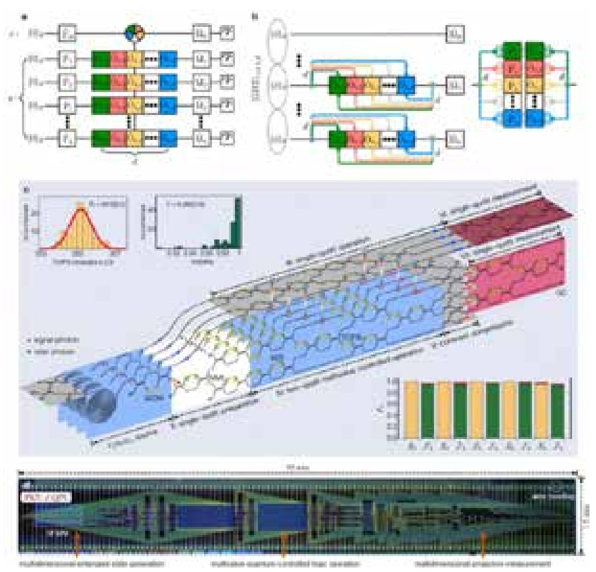


图 1. 高维量子计算芯片的线路图、方案图、结构图和显微镜实物图。

Fig 1. A qudit-based photonic quantum computing chip: diagram, scheme and optical microscope image of the device.

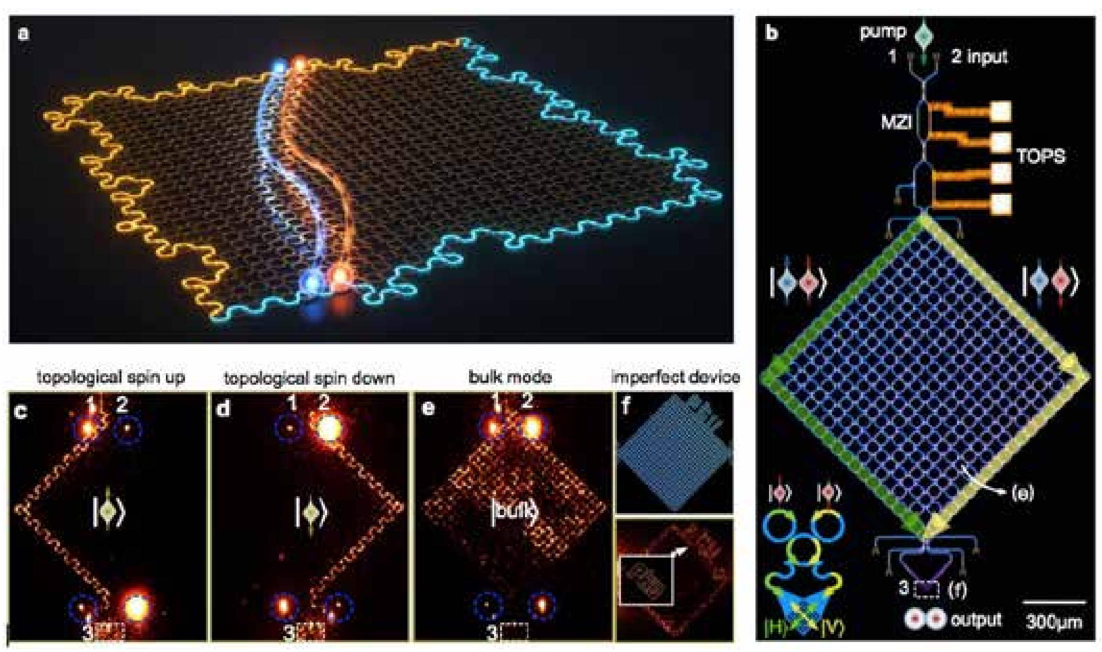


图 2. 带缺陷的拓扑保护纠缠光源示意图、显微镜实物图、上下赝自旋的拓扑边界态成像图。

Fig 2. Topologically protected quantum entanglement sources: diagram, optical microscope image, and imaged topological edge states.

I. Development of large-scale integrated quantum photonics

Photonics is an appealing platform for the implementation of quantum computing, Boson sampling, quantum simulation, and quantum communication. Processing these quantum tasks requires a high level of sophistication in the integration of a large number of quantum photonic components. Silicon integrated quantum photonics is capable of on-chip encoding, operating, processing and detecting quantum states of light, together with its wafer-scale CMOS fabrication abilities, and such that it provides a compelling platform for implementing modern quantum technologies. The Peking University team led by Prof. Qihuang Gong and Dr. Jianwei Wang has made significant contributions to silicon quantum photonics and in particular the team has developed several state-of-the-art large-scale quantum photonic devices and circuits for quantum information processing.

Controlling and programming quantum devices to process quantum information by the unit of quantum dit, i.e., qudit, provides the possibilities for noise-resilient quantum communications, delicate quantum molecular simulations, and efficient quantum computations, showing great potential to enhance the capabilities of qubit-based quantum technologies. The PKU team has reported a programmable qudit-based quantum processor in silicon-photonic integrated circuits and demonstrated its enhancement of quantum computational parallelism. The processor monolithically integrates all the key functionalities and capabilities of initialisation, manipulation, and measurement of the two quantum quart (ququart) states and multi-value quantum-controlled logic gates with high-level fidelities. By reprogramming the configuration of the processor, the team implemented the most basic quantum Fourier transform algorithms, all in quaternary, to benchmark the enhancement of quantum parallelism using qudits, which include generalised Deutsch-Jozsa and Bernstein-Vazirani algorithms, quaternary phase estimation and fast factorization algorithms. The monolithic integration and high programmability have allowed the implementations of more than one million high-fidelity preparations, operations and projections of qudit states in the processor. This work shows an integrated photonic quantum technology for qudit-based quantum computing with enhanced capacity, accuracy, and efficiency, which could lead to the acceleration of building a large-scale quantum computer.

Bohr's complementarity is one central tenet of quantum physics. The paradoxical wave-particle duality of quantum matters and photons has been tested in Young's double-slit (double-path) interferometers. The object exclusively exhibits wave and particle nature, depending measurement apparatus that can be delayed chosen to rule out too-naive interpretations of quantum complementarity. All experiments to date have been implemented in the double-path framework, while it is of fundamental interest to study complementarity in multipath interferometric systems. The PKU team has demonstrated generalized multipath wave-particle duality in a quantum delayed-choice experiment, implemented by large-scale silicon-integrated multipath interferometers. Single-photon displays sophisticated transitions between wave and particle characters, determined by the choice of quantum-controlled generalized Hadamard operations. The team has characterised particle-nature by multimode which-path information and wave-nature by multipath coherence of interference, and demonstrate the generalisation of Bohr's multipath duality relation. This work provides deep insights into multidimensional quantum physics and benchmarks controllability of integrated photonic quantum technology.

Entanglement and topology portray nature at the fundamental level but differently. Entangled states of particles are intrinsically sensitive to the environment, whereas the topological phases of matter are naturally robust against environmental perturbations. Harnessing topology to protect entanglement has great potential for reliable quantum applications. Generating topologically protected entanglement, however, remains a significant challenge, requiring the operation of complex quantum devices in extreme conditions. The PKU team has reported topologically protected entanglement emitters that emit a topological Einstein–Podolsky–Rosen state and a multiphoton entangled state from a monolithically integrated plug-and-play silicon photonic chip in ambient conditions. The device emulating a photonic anomalous Floquet insulator allows the generation of four-photon topological entangled states at non-trivial edge modes, verified by the observation of a reduced de Broglie wavelength. Remarkably, the team has shown that the Einstein–Podolsky–Rosen entanglement can be topologically protected against artificial structure defects by comparing the state fidelities of 0.968±0.004 and 0.951±0.010 for perfect and defected emitters, respectively. This topologically protected devices may find applications in quantum computation and in the study of quantum topological physics.

二、基于光发射电子显微镜的超高时空分辨研究进展

超高时空分辨光子学研究是纳米光子学研究的前沿之一，能够从微观层面揭示光与物质的相互作用的超快动力学规律，因而在集成光子器件和集成光子芯片等领域都具有重要的应用前景。龚旗煌院士领导的研究团队依托自主研制的飞秒—纳米超高时空分辨光发射电子显微镜测量系统，在超快时域拓扑光子学和二维电子气缺陷畴研究中取得重要研究进展，相关工作发表在《纳米快报》（Nano Lett. 2021, 21, 9270）和先进电子材料（Advanced Electronic Materials, 2021, 7(3), 200968）上。

在超快时域拓扑光子学的研究中，研究团队利用电子束曝光刻蚀技术制备出 Su–Schrieffer–Heeger（SSH）模型金纳米链，利用超高时空分辨光发射电子显微镜测量系统从空间尺度和时间尺度综合研究了等离激元拓扑边界态的时域动力学过程，研究发现局域等离激元拓扑边界态的退相干时间随着体晶格数的增加而增加，并最终达到饱和，该现象从时域动力学角度展现了拓扑边界态的本质演化过程，即体晶格与边界晶格之间存在耦合而并非各自独立，这种耦合影响了拓扑边界态退相干时间，即体晶格参与并促成了拓扑边界态的时域演化。研究团队进一步揭示了局域等离激元拓扑边界态的时域动力学过程：光激发后体晶格和边界晶格同时被激发，电场能量会在体晶格和边界晶格之间的振荡，然后逐渐集中于边界晶格，最终能量由边界晶格继续弛豫后趋于消散。进一步发现形成具有稳定退相干时间的拓扑边界态对体晶格数有阈值要求，在一维等离激元拓扑纳米链中体晶格数应至少为 6 个周期。工作不仅为时域拓扑光子学的基础理论研究铺平了道路，也有助于推动新型高性能拓扑光子器件的实现。

在二维电子气缺陷畴研究中，研究团队发现在钛酸锶表面二维电子气中局域极性缺陷会极化邻近区域并导致空间分布上出现缺陷畴，缺陷畴的尺度达百纳米甚至微米量级，影响二维电子气的电学和磁学效应。在钛酸锶表面二维电子气中，缺陷畴中游离态电子被极性缺陷捕获束缚，导致二维电子气密度降低，铁磁效应被抑制。研究发现在铝酸镧 / 钛酸锶介面二维电子气中氧缺陷产生的势垒被解除，导致载流子密度的局域增强。这些成果不仅弥补了二维电子气微观尺度表征的空白，而且提出了一种基于缺陷精确调控低维系统电子动力学行为的新方案。

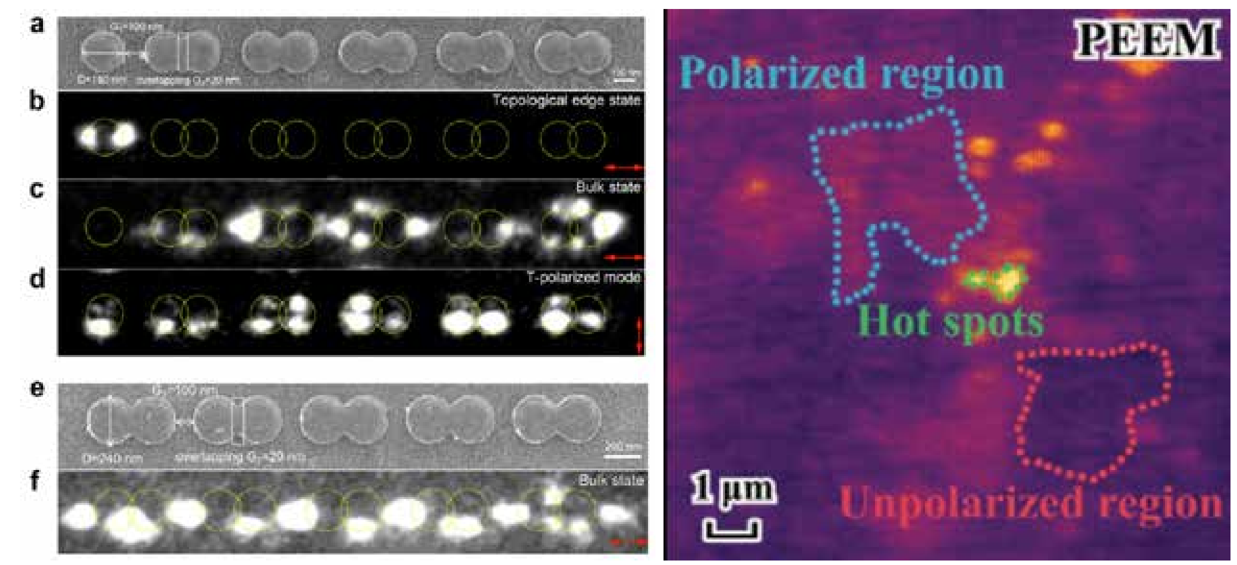


图 1. (a) 金拓扑纳米链 SEM 图、拓扑边界态和体态的近场分布；(b) 钛酸锶二维电子气中的缺陷畴。

Fig 1. (a) SEM image of gold topological nanochain. (b) Defect domains in two-dimensional electron gas of strontium titanate.

II. Research progress of ultrahigh temporospatial resolution study based on photoemission electron microscopy

Ultrahigh temporospatial resolution photonics is one of the frontiers of nanophotonics, which could reveal the ultrafast dynamics laws of interactions between light and matters. Ultrahigh temporospatial resolution photonics has great potential applications in integrated photonic devices and integrated photonic chips. The research group led by academician Qihuang Gong has made great research progress in the ultrafast time-domain topological photonics and two-dimensional electron gas defect domains based on self-developed femtosecond nanometer ultra-high spatiotemporal resolution photoemission electron microscopy experimental system. Research works were published in Nano Letters (Nano Lett. 2021, 21, 9270) and Advanced Electronic Materials (Advanced Electronic Materials, 2021, 7(3), 200968).

In the research work of ultrafast time-domain topological photonics, the research group fabricated gold nano-chain with a configuration of Su–Schrieffer–Heeger (SSH) model by using electron-beam lithography technology. They utilize ultrahigh

系所中心研究亮点 | *Highlights*

temporospatial resolution photoemission electron microscopy (PEEM) measurement system to study the time-domain dynamic process of surface plasmon topological states in the aspects of spatial scale and temporal scale. It was found that the decoherence time of surface plasmon topological states increases with the increment of bulk lattices, and then reached saturation finally. This phenomenon exhibits the essential evolution process of topological boundary states from the perspective of time-domain dynamics, i.e. there is a coupling between the bulk lattices and the boundary lattice rather than being independent of each other. This coupling affects the decoherence time of topological boundary states, which means that the bulk lattices participate in and contribute to the temporal evolution of topological boundary states. The research team further revealed the time domain dynamics of the topological boundary states of localized surface plasmons. After excitation both bulk lattices and the boundary lattice are excited at the same time. The electric-field energy oscillates between bulk lattices and the boundary lattice, and then gradually concentrates on the boundary lattice. Finally, the energy tends to dissipate in the boundary lattice. It is further found that the formation of topological boundary states with stable decoherence time has a threshold requirement for the number of bulk lattices. the number of bulk lattices should be larger than 6 in the one-dimensional surface plasmon topological nanochain. This work not only paves the way for the fundamental theoretical research of time-domain topological photonics, but also helps to promote the implementation of new high-performance topological photonic devices.

In the research work of two-dimensional electron gas defect domains, the research group found that localized polar defects in a two-dimensional electron gas on the surface of strontium titanate can polarize adjacent regions and lead to defect domains in spatial distribution. The scale of defect domains can reach hundreds of nanometers or even micrometers, affecting the electrical and magnetic responses of two-dimensional electron gases. In the two-dimensional electron gas on the surface of strontium titanate, the free electrons in the defect domain are trapped and bound by polar defects, resulting in a decrease in the two-dimensional electron gas density and suppression of ferromagnetic effects. It is found that the potential barrier generated by oxygen defects in the two-dimensional electron gas at the lanthanum aluminate/strontium titanate interface is removed, resulting in a localized enhancement of carrier density. This result not only fills the gap in the microscale characterization of two-dimensional electron gases, but also provides a new strategy of precisely modulating the electronic dynamics behavior of low-dimensional systems.

学生活动
Students

2021 年 4 月 25 日，物理学院举办“两弹一星”功勋郭永怀事迹报告会暨物理学院与山东荣成郭永怀事迹陈列馆党建共建签约仪式。

On April 25, 2021, the School of Physics held a symposium on “Two Bombs and One Satellite” awardee Guo Yonghuai's heroic deeds and a signing ceremony of the school’s joint construction of the Exhibition Hall of Guo Yonghuai’s stories in Rongcheng, Shandong.

物理学院在 2021 年和 2022 年的春秋季运动会中取得佳绩，运动积分名列全校前茅。学院两年均获得体育育人杰出单位奖。

The School of Physics scored big wins in the Spring and Autumn Sports Games of 2021 and 2022, with its ranking points in the topflight. The school won the award of Outstanding Physical Education Group in both years.

2021 年 4 月 30 日，物理学院组织 200 余名师生参加第三届五四青春长跑。

On April 30, 2021, more than 200 teachers and students from the School of Physics participated in the third May Forth Long-Distance Running, which covers 5.4 km in commemoration of the May Forth Movement.

2021 年 5 月 4 日，学院为 2020 年因疫情无法返校参加毕业典礼的同学补办专场典礼。

On May 4, 2021, the School of Physics held a special commencement ceremony for students who missed the previous year’s event due to Covid-19.

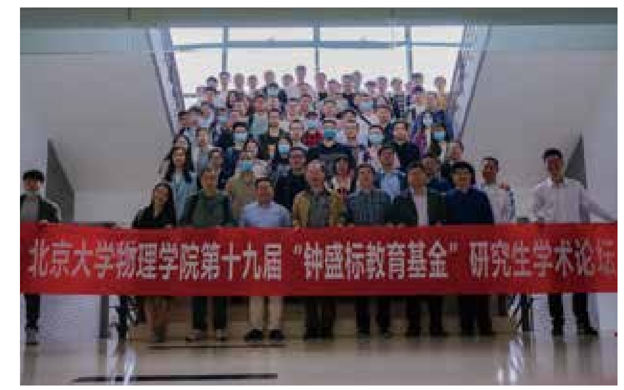
2021 年 5 月 14 日，物理学院举办物理文化节开幕式活动，邀请赵凯华先生作《物理学照亮世界》的主题报告。

On May 14, 2021, the School of Physics held the opening ceremony of the Physics Cultural Festival and invited Mr. Zhao Kaihua to give a keynote speech titled “Physics Enlightens the World”.

学生活动 | *Students*

2021 年 5 月和 2022 年 5 月，分别举办了第十九届和第二十届钟盛标教育基金研究生论坛。基金捐赠人钟赐贤先生和夏晓峦女生线上出席第二十届开幕式并致辞。

In May 2021 and May 2022 respectively, the 19th and 20th Zhong Shengbiao Education Fund Graduate Forum were held. Fund Doners Mr. Zhong Cixian and Ms. Xia Xiaoluan attended the ceremony via video link and delivered speeches.



2021 年 6 月 3 日，高原宁院长做《肩负时代重任，永攀科技高峰》主题党课报告。

On June 3, 2021, Professor Gao Yuanning, dean of the School of Physics, gave a party lecture titled “Shouldering the Responsibility of the Times and Striving towards the Peak of Science and Technology”.

2021 年 7 月 1 日，学院 47 名师生参与建党百年庆祝大会服务保障工作。

On July 1, 2021, 47 teachers and students from the School of Physics played their part in delivering a successful gathering celebrating the centenary of the Communist Party of China.

2021 年和 2022 年暑假，学院共组织 400 余名本科生在全国各地开展社会实践，共建立 6 个思想政治教育实践课程基地。

During the summer holidays of 2021 and 2022, 400 undergraduates from the School of Physics conducted social research projects all over the country. Five moral and political education bases featuring hands-on courses were established.

2021 年 11 月 20 日，学院物理科普志愿者参加北京大学学术科创文化节，物理学院获得十佳展示摊位奖。

On November 20, 2021, volunteers from the School of Physics contributed to PKU’s Academic Science and Technology Festival by sharing their physics knowledge with the public. The school’s stand was listed as one of the “Top Ten Stands”.

2021 年 11 月 26 日，学院举行 2021 级本科生新生 - 院长午餐交流会，高原宁院长为同学答疑解惑。

On November 26, 2021, the School of Physics held a lunch meeting where Dean Gao Yuanning

2021 年 12 月 4 日，学院获得北京大学一二·九师生合唱甲组一等奖。

On December 4, 2021, the College won the first prize of PKU’s Singing Contest (Group A) in commemoration of the December 9th Movement.

2021 年 12 月 12 日，学院举办冰雪文化节，组织师生体验滑雪。

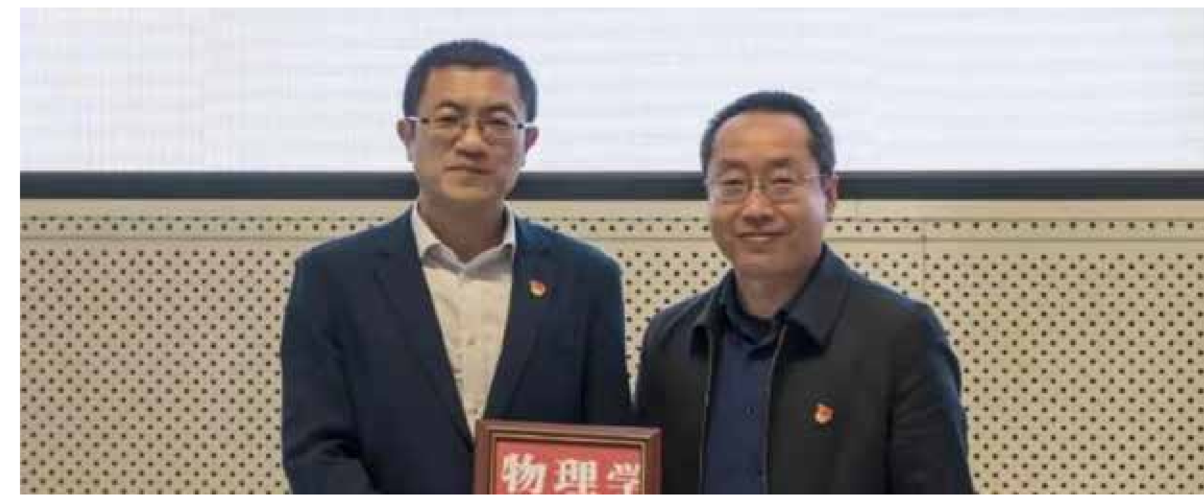
On December 12, 2021, teachers and students from the School of Physics enjoyed themselves during the Ice and Snow Cultural Festival.

2022 年 1 月 30 日，学院党委书记刘雨龙等领导老师慰问春节留校同学。

On January 30, 2022, Liu Yulong, secretary of the Party Committee of the School of the Physics, visited the students staying at school during the Spring Festival with others.

2022 年 3 月 27 日，学院邀请中国五四青年奖章获得者，物理学院 2005 届本科校友，中国航天科技集团有限公司第五研究院总体设计部型号副总设计师黄震做报告。

On March 27, 2022, the School of Physics invited Huang Zhen to give a lecture. Huang is an alumnus from the Class of 2005, a recipient of the China Youth May Forth Medal, and the deputy chief designer at the overall design department of the fifth institute of China Academy of Space Technology.



2022 年 3 月 -4 月，物理学院共有 26 名师生参加北京冬奥会冬残奥会服务保障工作，图为师生参加北京大学总结表彰大会。

From March to April 2022, 26 teachers and students from the School of Physics provided services for the Olympic Winter Games Beijing 2022 and Beijing 2022 Paralympic Games. The photo shows the teachers and students attending an event honoring their contributions held by Peking University.

2022 年 5 月，学院组织学生参与学校疫情防控志愿服务。

In May 2022, students from the School of Physics volunteered in the fight against Covid-19.

2022 年 5 月，物理学院 2019 级本科班荣获北京大学五四班集体荣誉称号，大气与海洋科学系 2019 级博士生获得北京大学十佳党支书荣誉称号。

In May 2022, Undergraduate Class One, from the Class of 2023 of the School of Physics, was given the honor “Outstanding May Forth Class” by Peking University. A doctoral student from the Department of Atmospheric and Oceanic Sciences won the title of “Top Ten Secretaries of Party Branch of Peking University”.

2022 年 5 月 21 日，学院举办北京大学 2022 年物理文化节，邀请时任北京大学常务副校长龚旗煌院士作报告。

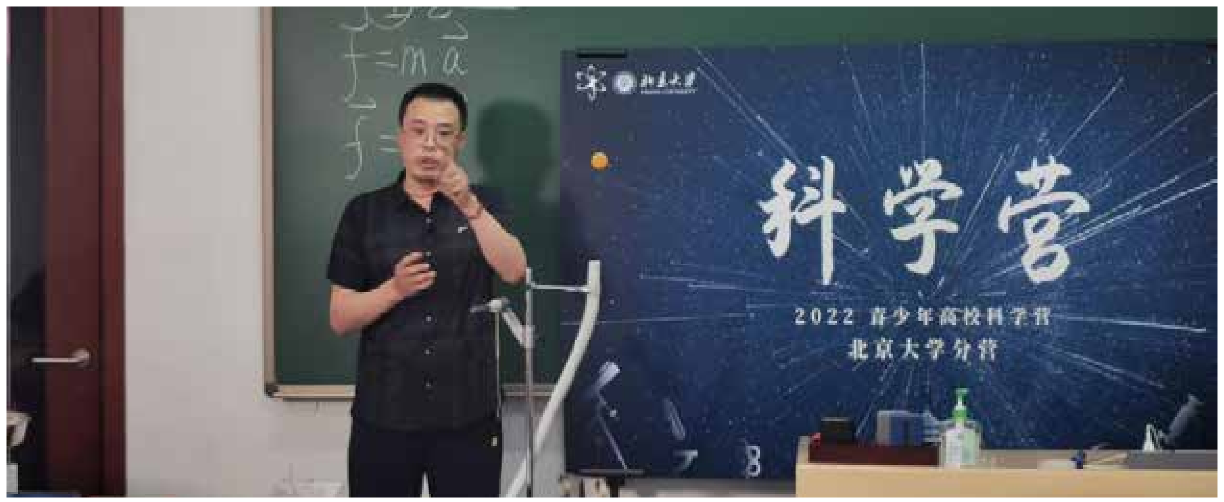
On May 21, 2022, the School of Physics held the 2022 Physics Cultural Festival of Peking University and invited Academician Gong Qihuang, then Executive Vice President of Peking University, to give a speech.

2022 年 6 月 25 日，学院举办 2022 年毕业歌会，图为江颖老师为毕业生唱歌祝福。

On June 25, 2022, the School of Physics held a graduation songfest. The photo shows Professor Jiang Ying sending his best wishes to graduates in songs.

2022 年 7 月，学院与北大团委、中国科学技术协会联合开展“未名格物”全国中学生科普活动。

In July 2022, together with the PKU Youth League Committee and China Association for Science and Technology, the School of Physics launched a national science popularization campaign named “Weiming Gewu” for middle school students.



2022 年 9 月 3 日，学院组织 560 余名 2022 级新生参加学校开学典礼。

On September 3, 2022, upwards of 560 freshmen from the School of Physics attended PKU’s opening ceremony for the new academic year.

2022 年 9 月 18 日，学院邀请燕园派出所曹爱利警官为新生开展防诈骗教育。

On September 18, 2022, the School of Physics invited Officer Cao Aili from Yanyuan Police Station to deliver an anti-fraud lecture for new students.

2022 年 9 月 24 日，学院为 2022 级本科新生举办迎新晚会。

On the night of September 24, the School of Physics held performances to give its freshmen a warm welcome.

2022 年 10 月 1 日，学院组织师生前往天安门广场观看升旗仪式。

On October 1, 2022, teachers and students from the School of Physics watched the flag-raising

2022 年 10 月 2 日，学院组织师生前往北京展览馆参观学习“奋进新时代”主题成就展。

On October 2, 2022, teachers and students from the School of Physics attended the “Forging ahead in the New Era” exhibition at Beijing Exhibition Center.

2022 年 10 月 16 日，学院组织师生共同观看二十大开幕式直播。

On October 16, 2022, teachers and students from the School of Physics watched the live broadcast of the opening ceremony of the 20th National Congress of the Communist Party of China.

2022 年 11 月 13 日，学院邀请革命烈士彭湃的孙女、时代楷模彭士禄的女儿彭洁做报告。

On November 13, 2022, the School of Physics invited Peng Jie, the granddaughter of revolutionary martyr Peng Pai and the daughter of “Role Model of the Times” Peng Shilu, to give a speech.

2022 年 10 月，学院学生党支部与中核战略规划总院系统工程研究所党支部共同开展“红色 1+1”项目。该项目获评北京大学优秀项目。

In October 2022, the student party branch of the School of Physics and the party branch of the Institute of Systems Engineering of the Strategic Planning Research Institute of China National Nuclear Corporation jointly launched the “Red 1+1” project. The project was awarded as an outstanding project of Peking University.

2022 年 11 月 4 日，学院组织老教授茶座活动，邀请胡晓东教授做北大摄影分享交流。

On November 4, 2022, the School of Physics held a tea salon, inviting Professor Hu Xiaodong to share his photographs of Peking University.

校友与基金
Alumni and Funds

2021 年 6 月 18 日，物理学院“传承百年薪火，诠释教师使命”专题讲座在物理西楼思源多功能厅举办。被授予北京市优秀共产党员荣誉称号的北京邮电大学电子工程学院、信息光子学与光通信国家重点实验室教授张晓光校友应邀以“高校教师的教学与科研并重之路”为题主讲。

On June 18, 2021, a special lecture on "Inheriting a Century of Fire, Interpreting the Mission of Teachers" was held in the Siyuan Multi-functional Hall of the West Building of Physics. Professor Xiaoguang Zhang from the School of Electronic Engineering and State Key Laboratory of Information Photonics and Optical Communication of Beijing University of Posts and Telecommunications (BUPT), who was awarded the honorary title of Excellent Communist Party Member in Beijing, was invited to give a lecture on the topic of "The Road of Teaching and Scientific Research for College Teachers".

2022 年 5 月 1 日，北京大学物理学院校友会第十三次理事会在物理学院思源多功能厅举行。各年级共 33 位校友理事通过线上或线下方式“齐聚一堂”，共同为物理学院的建设和校友工作的开展建言献策。

On May 1, 2022, the 13th Board Meeting of the Alumni Association of the School of Physics of Peking University was held in the Siyuan Multi-functional Hall of the School of Physics. 33 alumni board members from all grades "gathered" online or offline to give advice and suggestions for the construction of the School of Physics and the development of alumni work.

2022 年 5 月 1 日，正值北京大学 124 周年校庆来临之际，北京大学物理学院校友会在物理学院中楼 212 教室举行校友亲子科普活动。本次活动通过内涵深刻的科普讲座、丰富奇妙的物理实验演示，让校友和小朋友们感受物理的神奇之处。

On May 1, 2022, just in time for the 124th anniversary of Peking University, the Alumni Association of the School of Physics of Peking University held a popular science activity for alumni and children in Room 212 of the Middle Building of the School of Physics. The event allowed alumni and children to experience the magic of physics through profound science lectures and rich and wonderful physics experiments demonstrations.

2022 年 9 月 10 日，时值第 38 个教师节，叶企孙师表奖设立仪式暨首届颁奖典礼在物理学院思源报告厅举行。首届叶企孙师表奖获奖者为吴学兵教授、刘运全教授。

On September 10, 2022, the 38th Teachers' Day, the ceremony for the establishment of the Ye Qisun Teacher's Award and the first award ceremony were held in the Siyuan Lecture Hall of the School of Physics. The winners of the first Ye Qisun Teacher's Award were Prof. Xuebing Wu and Prof. Yunquan Liu.

校友与基金 | *Alumni and Funds*

校友基金项目：
Alumni Funds:

设立时间 Time of Establishment	项目名称 Project Title	捐赠人 Donators
1987	叶企孙实验物理基金 Ye Qisun Experimental Physics Fund	叶企孙先生的友人和学生 Mr. Ye Qisun'friends and students
1996	谢义炳基金 Xie Yibing Fund	谢义炳先生和他的学生毛节泰等 Mr.Yibing Xie and his students（Mr. Mao Jietai et al.)
2002	1977 物理班级基金 1977 Physics Class Fund	北大物理 1977 级校友 The 1977 physics alumni
2002	钟盛标物理教育基金 Paul Shin-Piaw Choong Educational Fund for Physics	钟赐贤先生与夫人夏晓峦女士 Mr. Philip Tsi Shien Choong and Ms. Hsia Shaw-lwan Choong
2005	1980 物理兰怡女子助学金 1980 Ellen Lan Yi Woman Physicist Scholarship	北大物理 1980 级校友、兰怡女士的家人和朋友 The 1980 alumni, Ms. Lan Yi's family, and friends
2005	1986 物理班级基金 1986 Physics Class Fund	北大物理 1986 级校友 The 1986 physics alumni
2006	1988 物理班级基金 1988 Physics Class Fund	北大物理 1988 级校友 The 1988 physics alumni
2008	陈互雄物理教育基金 Chen Huxiong Educational Fund for Physics	陈敬熊院士与夫人常菊芳女士 Mr. Chen Jingxiong and Ms. Chang Jufang
2008	胡宁奖学金 Hu Ning Scholarship	胡宁家属，秦旦华、苏肇冰夫妇，赵光达等 Mr. Hu Ning's family, Ms. Qin Danhua, Zhaobing Su couple and Mr. Zhao Guangda et al.
2010	赵凯华物理教育基金 Zhao Kaihua Educational Fund for Physics	北大校友、师生及相关单位 PKU alumni, teachers, students, and concerned departments
2011	求索奖学金 Truth-seeking Scholarship	北大物理 1980 级校友汤漪先生与夫人杨洪女士 The 1980 alumni Mr. Tang Yi and his wife Ms. Yang Hong
2011	张文新教育基金 Zhang Wenxin Educational Fund	北大物理 1949 级校友张文新先生 The 1949 alumni Mr. Zhang Wenxin
2011	海鸥奖学金 Hai Ou Scholarship	北大物理 1978 级校友张兴云先生、樊培女士 The 1978 alumni Mr. Zhang Xingyun and Ms. Fan Pei
2011	1991 物理班级基金 1991 Physics Class Fund	北大物理 1991 级校友 The 1991 physics alumni
2011	物理学院学生发展基金 Students Development Fund	北大物理 2000 级校友李川、夏英姿，天美公司等 The 2000 alumni Mr. Li Chuan, Xia Yingzi, the Tianmei company and et al.
2011	沈克琦物理教育基金 Shen Keqi Educational Fund for Physics	北大物理 1988 级校友王多祥先生 The 1980 alumni Mr. Wang Duoxiang
2012	近代物理研究所奖学金 Institute of Modern Physics Fund	中国科学院近代物理研究所 The Institute of Modern Physics，Chinese Academy of Sciences
2012	1985 念恩奖学金 1985 Physics Class Fund	北大物理 1985 级校友（方晶、雷弈安等）The 1985 physics alumni (Ms. Fang Jing, Mr. Lei Yi'an et al.)
2013	物理学院紧急救助基金 School Emergency Aid Fund	北大物理校友、社会各界 PKU Physics alumni and community
2013	物理新楼报告厅座椅认捐基金 Physics Building Lecture Hall Chair Donation Fund	北大物理校友、社会各界 PKU physics alumni and community
2013	1979 级校友捐赠园林基金 1979 Physics Class Fund for Garden Donation	北大物理 1979 级校友 The 1979 physics alumni
2013	物理新楼视频会议室基金 Physics Building Video Meeting Room Fund	北大物理 1977 级校友夏廷康 The 1977 alumni Mr. Tingkang Xia
2013	物理新楼楼前花园捐赠基金 Physics Building Front-garden Fund	北大物理 1978 级校友胡铭 The 1978 physics alumni Mr. Ming Hu
2013	物理新楼 7802 会议室基金 Physics Building 7802 Meeting Room Fund	北大物理 1978 级校友 The 1978 physics alumni

设立时间 Time of Establishment	项目名称 Project Title	捐赠人 Donators
2013	兴诚本科生科研基金 Xingcheng Fund for Undergraduate Research	北大技物系 1979 级校友 The 1979 Technical Physics alumni
2014	1980 校友捐赠基金 1980 Physics Class Fund	北大物理 1980 级校友 The 1980 physics alumni
2014	物理新楼图书馆新馆阅览室基金 Physics Building New Library Reading Room Fund	北大物理校友、社会各界 PKU physics alumni and community
2015	物理新楼中 212 会议室座椅认捐基金 Physics Building 212 Middle Room Chair Donation Fund	北大物理校友、社会各界 PKU physics alumni and community
2015	津徽学生发展基金 Jinhui Students Development Fund	北大物理 1997 级校友王晨扬先生与夫人程雅女士 The 1997 alumni Mr. Wang Chenyang and his wife Ms. Cheng Ya
2017	物理学院发展基金 School Development Fund	北大物理校友、社会各界 PKU physics alumni and community
2018	锐天明日之星助学金 Ruitian Rising Star Scholarship	北大物理 2005 级校友 徐晓波 / 上海锐天投资管理有限公司 The 1997 alumni Mr. Xu Xiaobo, Shanghai Ruitian Investment Management Co., Ltd.
2019	衍复奖学金 Yan Fu Scholarship	北大物理 2004 级校友高亢先生 The 2004 alumni Mr. Gao kang
2020	王晨扬 - 程雅物理教育基金 Wang Chenyang-Cheng Ya Educational Fund for Physics	北大物理 1997 级校友王晨扬先生与夫人程雅女士 The 1997 alumni Mr. Wang Chenyang and his wife Ms. Cheng Ya
2020	宛扬奖教金 Wanyang Teaching Scholarship	北大物理 2007 级技术物理系校友徐震翔先生 The 2007 alumni Mr. Xu Zhenxiang
2022	传承奖学金 Heritage Scholarship	北大物理 2013 级校友（侯尧先生等） The 2013 physics alumni(Mr. Hou Yao, etc.)
2022	张岑优秀科研奖学金 Zhang Cen Excellent Research Scholarship	张岑父母：张鸣先生和岑献青女士，张岑亲友 Zhang Cen's parents: Mr. Zhang Ming and Ms. Cen Xianqing, friends and relatives of Zhang Cen

合作与交流
Exchange & Cooperation

一、学术讲座 Lectures

I 北京大学物理学院学术论坛
The Distinguished Colloquium

2021~2022 年，北京大学物理学院学术论坛举办第 5~17 讲，邀请国内外高校和研究机构高层次科技创新领军学者就物理学及相关领域的基础前沿探索、关键技术突破和热点问题等做学术演讲，旨在推进高质量学术交流，促进学科交叉融合和开拓新兴特色方向研究，培养具有科学精神、全球视野、创新能力、批判性思维的优秀青年人才。

Lecture 5-17 of the Distinguished Colloquium of the School of Physics, Peking University, were held between 2021 and 2022. Renowned scholars at home and abroad were invited to give public lectures on cutting-edge research, key technological breakthroughs and hot topics in areas like physics, astronomy and atmospheric and oceanic sciences. With a focus on high-quality academic exchanges, interdisciplinary integration and new research areas, the colloquium aims to equip young talents with scientific spirit and global vision and empowers them to think critically and creatively.

	时间	报告人	主题
第五讲	2021.03.26	陈大可院士	物理海洋学漫谈
第七讲	2021.06.01	祝世宁院士	当微纳光学研究遇上量子信息
第八讲	2021.06.11	段路明教授	量子计算机——现状与未来
第九讲	2021.09.24	尤力教授	量子增强的精密测量——见证玻色凝聚原子演示的“华尔兹”
第十讲	2021.10.15	Hugues Chaté 教授	Long-range orientational order in 2D active matter
诺奖解读专场	2021.10.15	胡永云教授	从全球变暖到复杂物理系统——2021 年度诺贝尔物理学奖解读
第十一讲	2021.11.26	Ali Alavi 教授	Towards an understanding of strongly correlated electronic systems using Quantum Chemistry methods
第十二讲	2021.12.23	贾金锋院士	Manipulation of topological materials

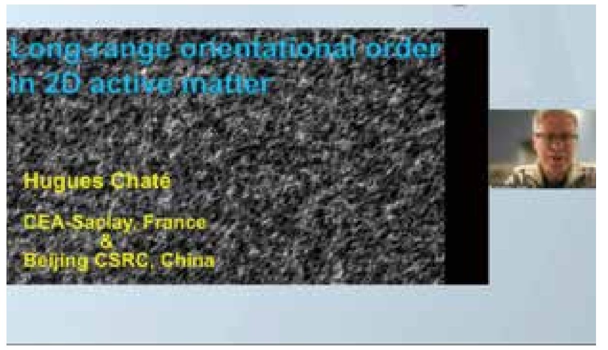
	时间	报告人	主题
第十三讲	2022.03.18	TOBIAS J. KIPPENBERG 教授	Photonic Chip based Frequency Combs
第十四讲	2022.04.01	邹冰松院士	强相互作用诺贝尔物理学奖漫谈
第十五讲	2022.05.13	Jörg Wrachtrup 教授	Quantum Physics with Spins in 2D and 3D Materials
第十六讲	2022.06.10	陈仙辉院士	笼目结构超导体 CsV3Sb5 中的竞争电子序和拓扑
第十七讲	2022.10.14	Vincenzo Vagnoni 博士	味物理：寻求超越标准模型的新秩序 Flavour physics: seeking new order beyond the Standard Model
诺奖解读专场	2022.11.11	孙昌璞院士	贝尔不等式的量子违背及其实验检验——解读 2022 年诺贝尔物理学奖

陈大可

祝世宁


段路明


尤力



Hugues Chaté

胡永云


Ali Alavi


贾金锋


TOBIAS J. KIPPENBERG


邹冰松

Jörg Wrachtrup

陈仙辉

Vincenzo Vagnoni


孙昌璞

II 北京大学格致论坛
Peking University Gezhi Forum

北京大学格致论坛是北京大学物理学院发起的面向青年教学科研人员学术交流活动。自 2010 年 4 月启动以来，论坛围绕学科领域前沿，面向国家重大需求，针对基础科学问题，开展了十余场学术研讨，分享最新研究成果，促进学科交叉融合，培育新兴方向增长点，展现了北大物理人学术无畏、攀登无限的新风貌。2021 年 5 月，于物理学院成立二十周年之际重启，并增设在线参与通道。2021~2022 年，共成功举办 1~13 讲。

Peking University Gezhi Forum is a platform for academic exchanges among young teachers and researchers established by the School of Physics, Peking University. Since its launch in April 2010, in line with the country's major needs, Gezhi Forum has hosted more than ten academic discussions on basic issues occupying scientific frontiers. By setting a stage for sharing latest achievements, promoting interdisciplinary integration and supporting research on new fields, the forum gives concrete expression to the grit and perseverance of Peking University's physicists. In May 2021, the 20th anniversary of the founding of the School of Physics, the forum was restarted with an online access. Between 2021 and 2022, 13 lectures (Lecture 1- Lecture 13) were successfully held.

	时间	报告人	主题
第一讲	2021.05.14	刘开辉	米级二维单晶的通用制造及应用
第二讲	2021.05.28	杨军	太阳系外行星及其宜居性
第四讲	2021.09.17	高宇南	半导体胶体纳米晶体与发光
第五讲	2021.11.05	裴俊琛	核裂变的新认识与新应用
第六讲	2021.11.19	王一男	现代几何与理论物理
第七讲	2021.12.10	张焱	追迹电子态的演化——角分辨光电子能谱和原位样品精密调控
第八讲	2022.03.25	郭志彬	受控聚变中的新物理
第九讲	2022.04.29	稻吉恒平	The Age of Discovery with the James Webb: Excavating the First Massive Black Holes
第十讲	2022.05.20	贾爽	如何发现新的量子材料
第十一讲	2022.07.08	聂绩	全球变暖下的极端降水
第十二讲	2022.09.30	黄华卿	非周期体系中的拓扑物态
第十三讲	2022.11.04	杨晓菲	放射性原子 / 分子超精细谱带来的新机遇

刘开辉

杨军

高宇南

裴俊琛

王一男

张焱


郭志彬

稻吉恒平


贾爽


聂绩


黄华卿


杨晓菲

2021 年 6 月 4—6 日，北京大学“格致论坛 • 青年”暨格致论坛（第三期）在北京大学昌平校区举行。论坛分为座谈会和学术报告会两个部分，旨在加强青年教师之间的合作交流、推动相关学科方向的交叉融合与协同创新。来自物理学院科研实体单位、基础物理实验教学中心和科维理天文与天体物理研究所的四十余名教学科研人员参会。

From June 4 to 6, 2021, “Gezhi Forum·Youth” & Gezhi Forum (Lecture 3) was held at Changping Campus, Peking University. The forum, consisting of a symposium and an academic lecture, served to boost cooperation and exchanges among young teachers, and promote the integration and collaborative innovation of related

disciplines. More than forty teachers and researchers from the Kavli Institute for Astronomy and Astrophysics, Teaching Center for Experimental Physics and other institutions of the School of Physics took part.

2022 年 7 月 8 日，格致论坛“科普对话”（第一期）特别邀请了北京大学物理学院教授、世界气象组织 WWRP 项目高影响天气国际协调办公室主任张庆红，北京大学物理学院大气与海洋科学系聂绩助理教授和中国气象科学研究院陈阳副研究员，就“极端降水：现在与未来”主题讨论极端降水的过程、预报和风险等话题，张庆红、聂绩和陈阳三位专家用通俗易懂的语言、简洁直观的演示实验等，生动形象地向大众普及了极端降水的相关知识，包括极端降水的基本定义、我国极端降水的分布特征、气象学家们如何做天气预报与极端降水预报等；并且分析了在全球变暖背景下，极端降水的可能变化及这些变化对人们社会生产、生活与经济等产生的影响，以及分享了应对挑战可能的方法和思路。

On July 8, 2022, themed “Extreme Precipitation: Present and Future”, Gezhi Forum “Science Popularization Dialog" (1st Dialog) invited Zhang Qinghong, professor from Peking University’s School of Physics and director of the International Coordination Office for High-Impact Weather of the World Meteorological Organization’s World Weather Research Program (WWRP), Nie Ji, assistant professor from the Department of Atmospheric and Oceanic Sciences of Peking University’s School of Physics, and Yang Chen, associate research professor from the Chinese Academy of Meteorological Sciences, to discuss the process, forecast and risks of extreme precipitation. The three experts gave a readily accessible introduction to the mysteries of extreme precipitation in a public-friendly way through simple demonstration experiments, including the definition of extreme precipitation, its geographical distribution across China and the workings of weather forecast and extreme precipitation forecast. Besides, they also shared their understanding of the potential changes in extreme precipitation patterns against the backdrop of global warming and offered some possible responses to the impacts they may have on how the economy functions and how people live and work.

III 其他讲座活动

Another Lectures

2021 年 4 月凝聚态物理·北京大学论坛第 500 期暨创办二十周年纪念活动在北京大学物理学院中楼 212 教室举行。4 月 15 日，物理学院量子材料科学中心王恩哥院士应邀作了题为“亚分子级研究揭示水的全量子本质”（Full quantum nature of water: a study at sub-molecular level）的第 500 期首场学术报告。4 月 22 日，北京理工大学王学云副教授应邀作了题为“六角锰氧化物铁电体中的拓扑铁电畴”（Topological ferroelectric domain in hexagonal manganites）的第二场学术报告。

In April 2021, the 20th anniversary of the Peking University Forum on Condensed Matter Physics, its 500th forum was held in Room 212, School of Physics Middle Building, Peking University. On April 15, Academician Wang Enge from the Center for Quantum Materials Science of the School of Physics was invited to give a speech entitled "Full Quantum Nature of Water: A Study at Sub-Molecular Level”, ushering in the 500th Forum. On April 22, Associate Professor Wang Xueyun from Beijing Institute of Technology was invited to give the second academic lecture of the forum entitled "Topological Ferroelectric Domain in Hexagonal Manganites".

二、国际会议 International Conference

2021 年 12 月 16—18 日，第四届原子核形变相对论连续谱质量表研讨会成功举办。本届研讨会线上、线下同步进行；中方线下主会场设在北京大学物理学院，韩方线下主会场设在湖西大学。本届研讨会以“研讨形变相对论连续谱理论构建原子核质量表的最新进展”为主要议题，会议主席为北京大学物理学院孟杰教授。本届研讨会上，来自韩国基础科学研究所、香港大学、中国科学院理论物理研究所等十六家 DRHBc 质量表合作组（DRHBc Mass Table Collaboration）成员单位的学者逐一介绍了所在研究团队的最新进展。其中，北京大学物理学院 2017 级博士研究生张开元和 2018 级博士研究生潘琮分别作了题为“DRHBc 质量表概览：偶偶核”（Overview of DRHBc Mass Table: even-even nuclei）和“奇 -A 和奇奇核的 DRHBc 计算”（DRHBc Calculations for Odd-A and Odd-odd Nuclei）的主旨报告，概述了 DRHBc 理论对偶偶原子核质量的研究成果，介绍了奇 -A 和奇奇原子核的 DRHBc 理论计算中所面临的困难以及提出的解决方案。

From December 16 to 18, 2021, the forth workshop on nuclear mass table in deformed relativistic Hartree-Bogoliubov theory in continuum (DRHBc) was successfully held. The workshop was held in a hybrid format. The onside venues for the Chinese side and Korean side were located respectively at Peking University and Hoseo University. The main topic of this workshop was "the latest progress in constructing the nuclear mass table with DRHBc theory". Professor Meng Jie from School of Physics, Peking University, chaired the discussion. At the workshop, scholars from sixteen members of the DRHBc Mass Table Collaboration, including the Institute of Basic Science in Korea, the University of Hong Kong and the Institute of Theoretical Physics of Chinese Academy of Sciences, shared their teams’ newly obtained results. Among them, two doctoral students from Peking University’s School of Physics, Zhang Kaiyuan and Pan Cong, gave detailed talks at the event, entitled “Overview of DRHBc Mass Table: Even-Even Nuclei” and “DRHBc Calculations for Odd-A and Odd-Odd Nuclei” respectively. Their speeches summarized the development of the research on even-even nuclear mass with DRHBc theory and in particular, shared the obstacles they met in the DRHBc calculations for Odd-A and Odd-Odd Nuclei and their coping strategies.

2022 年 7 月 25 日至 27 日，由北京大学物理学院和北京大学核物理与核技术国家重点实验室主办的“希格斯物理研讨会（Higgs Potential 2022）”通过多平台直播的形式在线上成功举办。会议组织委员会由北京大学物理学院冒亚军教授、曹庆宏教授、李强长聘副教授、孙小虎研究员和周辰研究员组成，其中孙小虎研究员担任会议主席。来自国内外数十所高校的百余名专家及学者应邀或报名参与了本次会议，蔻享学术平台直播点击率达到近 15000 人次。会上近 50 个精彩的报告，从希格斯物理理论和实验两方面充分交流了国际上最前沿的成果，讨论了希格斯物理的未来发展方向。学者们重点展示了一批由中国主导完成的最新研究结果，获得了国内外同行的一致认可。会议最后一天，邀请到美国匹兹堡大学杰出教授及粒子物理天体物理宇宙学中心主任、美国物理学会会士、美国物理学会粒子物理与场论分部主席韩涛教授，为大家分享了题为“希格斯玻色子：过去、现在和未来”的公开讲座。

The "Higgs Potential 2022" workshop was held online by the School of Physics of Peking University and the State Key Laboratory of Nuclear Physics and Nuclear Technology of Peking University from July 25 to 27 in 2022, via multiple platforms of live broadcast. The conference organization committee was composed of Professor Mao Yajun, Professor Cao Qinghong, Associate Professor with Tenure Li Qiang, Research Professor Sun Xiaohu and Research Professor Zhou Chen from the School of Physics, Peking University, among whom Sun Xiaohu served as the chairman of the conference. More than one hundred experts and scholars from dozens of universities at home and abroad were invited and registered to participate, with the event’s live broadcast on Koushare academic platform getting nearly 15000 views. The seminar featured nearly 50 insightful reports on the world’s latest development in both Higgs physics theories and experiments. The attendees also exchanged views on the future development directions related to Higgs physics. One of the seminar’s highlights was the latest achievements made by Chinese researchers that won recognition from their peers internationally. On the last day of the meeting, Professor Tao Han was invited to give a lecture entitled “The Higgs Boson: The Past, Present and Future”. Mr. Han was a distinguished professor from the University of Pittsburgh, the founding director of the Pittsburgh Particle Physics, Astrophysics and Cosmology Center (PITTPACC), a member of the American Physical Society and the chair of the society’s Particle Physics and Field Theory Division.

三、重大活动 Academic Conferences

2021 年 10 月 17 日，是我国物理教育家，北京大学物理学院已故教授、原副校长沈克琦先生诞辰一百周年纪念日。北京大学物理学院撰写专稿，激励广大师生了解沈克琦先生的成长历程，学习他对科教兴国育英才的执着追求，弘扬他甘当育人铺路石的中国科学家精神，为建设具有世界影响力的北大物理学科，培养具有科学精神、创新能力、批判性思维的未来领军人才做出更大贡献。

October 17, 2021 marked the centenary of the birth of Professor Shen Keqi of School of Physics, Peking University. Mr. Shen was a physics educator and the vice president of Peking University. In a special article in memory of the late professor, the School of Physics detailed Mr. Shen’s dedication to education and science as two drivers of the country’s development, and his commitment, typical of Chinese scientists, to nurturing the next generation. By encouraging teachers and students to learn more about Mr. Shen’s inspiring life and thus carry forward his legacy, the School of Physics called for greater contributions to the building of a world-class physics discipline of Peking University, and more efforts to the cultivation of future leading scientists who are equipped with scientific spirit and can think critically and creatively.

百年诞辰纪念专版

纪念与党同龄的物理教育家沈克琦先生

克允格物 一生有恒
琦行致理 百年不渝

百年诞辰纪念专版

沈克琦先生在我们身边的日子

2021 年 11 月 6 日，由北京论坛、北京大学物理学院主办，北京现代物理研究中心、北京物理学会承办的北京论坛（2021）“科学照亮世界”分论坛在北京大学物理西楼思源多功能厅成功举办。北京大学前沿交叉学科研究院院长、中国科协 - 北京大学科学文化研究院院长、中国科学技术协会名誉主席韩启德院士出席并致辞。随后，中国科学院高能物理研究所所长、中国科学院大学核科学与技术学院院长王贻芳院士，欧洲核子研究中心（CERN）研究与计算主管副主任 Pippa Wells 博士，北京生命科学研究所学术副所长邵峰院士，深圳量子科学与工程研究院院长俞大鹏院士，复旦大学芯片与系统前沿技术研究院院长、中国科学院微电子研究所学术委员会主任刘明院士相继发表了主旨演讲。

On November 6, 2021, the “Science Lights up the World" sub-forum of the Beijing Forum 2021, co-organized by Beijing Forum and Peking University’s School of Physics and co-sponsored by Beijing Institute of Modern Physics and Beijing Physical Society, was successfully held in Siyuan Hall, W301 Physics Building, Peking University. Academician Han Qide, dean of Peking University’s Academy for Advanced Interdisciplinary Studies, honorary chairman of China Association for Science and Technology and head of CAST-PKU Culture of Science Institute, attended the forum and delivered opening remarks. Subsequently, Academician Wang Yifang, director of Institute of High Energy Physics of Chinese Academy of Sciences and dean of the School of Nuclear Science and Technology, University of Chinese Academy of Sciences, Dr. Pippa Wells, deputy director for Research and Computing of the European Organization for Nuclear Research (CERN), Academician Shao Feng, deputy director for academic of the National Institute of Biological Sciences, Beijing, Academician Yu Dapeng, dean of Shenzhen Institute for Quantum Science and Engineering, and Academician Liu Ming, head of Frontier Institute of Chip and System, Fudan University and director of the academic committee of the Institute of Microelectronics of the Chinese Academy of Sciences, gave keynote speeches.

合作与交流 | *Cooperation*

2021 年 11 月 23 日，由北京大学物理学院、北京现代物理研究中心主办的“燕园有李”庆祝北京现代物理研究中心成立三十五周年暨庆贺李政道先生九十五岁华诞研讨会在北京现代物理研究中心 101 报告厅举行。

On November 23, 2021, “Yanyuan Campus and Tsung-Dao Lee” seminar took place in Lecture Hall 101 of Beijing Institute of Modern Physics. Co-organized by Peking University’s School of Physics and Beijing Institute of Modern Physics, the event was held in commemoration of the 35th anniversary of the establishment of Beijing Institute of Modern Physics and Mr. Tsung-Dao Lee’s 95th birthday.

奖励与荣誉
Awards & Honors

2021 年度
In 2021

- 俞启威、高志强完成的论文入选 2021 年北京市普通高等学校优秀本科生毕业设计（论文）, 欧阳颀、王垡获优秀毕业设计 (论文) 指导教师。
  The theses completed by Yu Qiwei, Gao Zhiqiang, respectively, were selected as the Outstanding Undergraduate Graduation Designs (theses) of colleges and universities in Beijing in 2021; and Ouyang Qi, Wang Fa won the award of Outstanding Graduation Design (thesis) Supervisor.

- "未名学者天文学拔尖学生培养基地"入选 2021 年度教育部基础学科拔尖学生培养计划 2.0 基地。
  " Weiming-scholar Top-Notch Undergraduate Training base of astronomy" was selected as one of the bases for the Top-Notch Undergraduate Talents Program of Basic Subjects 2.0 of Ministry of Education in 2021.

- 刘玉鑫获教育部拔尖计划 2.0 优秀教师奖。吴桃李获教育部拔尖计划 2.0 优秀管理人员奖。杨天骅获教育部拔尖计划 2.0 优秀学生奖。
  Liu Yuxin was awarded the Excellent Teacher Award; Wu Taoli was awarded the Excellent Manager Award ;Yang Tianhua was awarded the Excellent Student Award under the 2.0 Top-Notch Talents Program by the Ministry of Education in 2021.

- 王次天获教育部拔尖计划首届"提问与猜想"活动特等奖。
  Wang Citian, under the guidance of Huang Huaqing, was awarded the Special Prize in the first "Questioning and Guessing" event of the Top-Notch Talents Program by the Ministry of Education in 2021.

- 陈贝乐、高云浩、何沛一、李志昊在第七届全国大学生物理实验竞赛（教学赛）中获三项一等奖。
  Chen Beile, Gao Yunhao, He Peiyi, Li Zhihao won three first prizes in the 7th China Undergraduate Physics Experiment Competition (Teaching Competition).

- 张哲伦和贡晓荀获第七届全国大学生物理实验竞赛（创新）一等奖。
  Zhang Zhelun and Gong Xiaoxun won the first prize in the 7th China Undergraduate Physics Experiment Competition (Innovation).

- 林织星、杨天骅、王雨晨、张哲伦获 2021 年世界大学生理论物理竞赛第 2 名。
  Lin Zhixing, Yang Tianhua, Wang Yuchen, Zhang Zhelun won the 2nd place in the International Theoretical Physics Olympiad for Undergraduate Students in 2021.

- 程谋阳、石霆章、代君豪、邹子航、殷知骏、穆济生获第十三届中国大学生物理学术竞赛二等奖。
  Chen Mouyang, Shi Tingzhang, Dai Junhao, Zou Zihang, Yin Zhijun, and Mu Jisheng won the second prize in the 13th China Undergraduate Physics Tournament.

- 李聪乔获 CMS 2020 年度奖。
  Li Congqiao won the CMS Award for 2020.

- 刘泓君获第十四届东亚中尺度对流系统及高影响天气会议最佳学生海报展示奖。
  Liu Hongjun won the Best Student Poster Presentation of the 14th International Conference on Mesoscale Convective Systems and High-Impact Weather in East Asia.

- 段晓苇获第七届中澳天体物理研讨会中方最佳海报奖。
  Duan Xiaowei won the Best Chinese Poster Award of the 7th Australia-China Workshop on Astrophysics.

- 张双乐获北京大学第二十九届"挑战杯"——五四青年科学奖一等奖。
  Zhang Shuangle won the first prize of the 29th "Challenge Cup" - May Fourth Youth Science Award of Peking University.

- 武媚获第十届亚洲和澳大利亚真空与表面科学会议 IUVSTA-Elsevier 学生奖。
  Wu Mei won the IUVSTA-Elsevier Student Award at the 10th Vacuum and Surface Science Conference of Asia and Australia.

- 极端光学创新研究团队荣获"第六届全国专业技术人才先进集体"称号。
  The Extreme Optics Innovation Research Team was honored with the title of "Sixth National Advanced Collective of Professional and Technical Talents".

- 汤超受聘国家自然科学基金委员会交叉科学部首任主任（兼职）。
  Tang Chao was appointed as the first director (part-time) of the Cross-Science Department of the National Natural Science Foundation of China.

奖励与荣誉 | *Awards & Honors*

- 龚旗煌、谢心澄、欧阳颀、沈波任“十四五”国家重点研发计划重点专项指南编制专家。
  Gong Qihuang, Xie Xincheng, Ouyang Qi, and Shen Bo were appointed as experts in preparing the guiding principles for the key special projects of the 14th Five-Year Plan.

- 龚旗煌连任国际光学委员会副主任。
  Gong Qihuang was re-elected as the Vice Chairman of the International Commission for Optics.

- 汤超、欧阳颀、叶沿林当选国际纯粹与应用物理联合会（IUPAP）新一届专业委员会委员。
  Tang Chao, Ouyang Qi, and Ye Yanlin were elected as members of the new professional committee of the International Union of Pure and Applied Physics (IUPAP).

- 秦庆、俞大鹏当选美国物理学会会士。
  Qin Qing and Yu Dapeng were elected as Fellows of the American Physical Society.

- 肖云峰当选 2021 年度中国光学学会会士。
  Xiao Yunfeng was elected as a Fellow of the Chinese Optical Society in 2021.

- 杨金波获颁国际稀土永磁与先进磁性材料及其应用大会杰出成就奖。
  Yang Jinbo received the Outstanding Achievement Award at the International Conference on Rare Earth Permanent Magnets and Advanced Magnetic Materials and their Applications.

- 马仁敏、刘开辉获 2021 年腾讯科学探索奖。
  Ma Renmin and Liu Kaihui won the 2021 Tencent Science Exploration Award.

- 朱瑞获第 17 届王大珩中青年科技人员光学奖。
  Zhu Rui won the 17^{th} Wang Daheng Young Scientist Award in Optics.

- 陈基入选《麻省理工科技评论》“35 岁以下科技创新 35 人” 2021 年亚太地区榜单。
  Chen Ji was selected as one of the "35 Innovators Under 35" in the Asia-Pacific region by MIT Technology Review.

- 杨起帆入选《麻省理工科技评论》“35 岁以下科技创新 35 人”2021 年中国区榜单。
  Yang Qifan was selected as one of the "35 Innovators Under 35" in China by MIT Technology Review.

- 李源、江颖获第五届马丁 • 伍德爵士中国物理科学奖。
  Li Yuan and Jiang Ying won the 5th Sir Martin Wood Prize for Chinese Physics.

- 彭良友获选美国物理学会 2021 年度杰出审稿人。
  Peng Liangyou was chosen as an Outstanding Referee of the American Physical Society in 2021.

- 肖云峰、高原宁获选 2021 年度《中国科学》和《科学通报》优秀编委。
  Xiao Yunfeng and Gao Yuanning were selected as excellent editors of Chinese Science and Science Bulletin in 2021.

- 徐仁新、吴学兵获中国天文学会 2012—2021 年突出贡献奖。
  Xu Renxin and Wu Xuebing received the Outstanding Contribution Award of the Chinese Astronomical Society from 2012 to 2021.

- 肖云峰获 2021 年度北京市杰出青年中关村奖。
  Xiao Yunfeng won the Beijing Zhongguancun Outstanding Youth Award in 2021.

- 叶堉合作研究成果“二维半导体单晶晶圆的可控制备”和高鹏合作研究成果“探测半导体界面晶格动力学的新谱学方法”入选 2021 年度中国半导体十大研究进展。
  Ye Yu's collaborative research on "Controllable Preparation of Two-Dimensional Semiconductor Single Crystal Wafers" and Gao Peng's collaborative research on "A New Spectroscopic Method for Detecting Semiconductor Interface Lattice Dynamics" were chosen as two of the top ten semiconductor research advances in China in 2021.

- 吕劲等完成的项目“二维晶体管理论”获 2021 年度北京市自然科学奖二等奖。
  Lv Jin and colleagues completed the project "Two-dimensional Crystal Management Theory," which received the second prize in the 2021 Beijing Natural Science Award.

奖励与荣誉 | *Awards & Honors*

2022 年度
In 2022

- "核物理"入选 2021 年度国家级一流本科专业建设点。‘’
  "Nuclear Physics" made the list for first-class national undergraduate majors of 2021.

- 刘东禹、权衡完成的论文入选 2022 年北京市普通高等学校优秀本科生毕业设计（论文）， 李铮、KOLL DANIEL DRAGOMIR BENEDIKT、肖云峰获优秀毕业设计 (论文) 指导教师。
  The theses completed by Liu Dongyu, Quan Heng, respectively, were selected as the Outstanding Undergraduate Graduation Designs (theses) of colleges and universities in Beijing in 2022; and Li Zheng, KOLL DANIEL DRAGOMIR BENEDIKT, Xiao Yunfeng won the award of Outstanding Graduation Design (thesis) Supervisor.

- 刘川获 2022 年北京市优秀教师称号。
  Liu Chuan was awarded the title of Excellent Teacher of Beijing in 2022.

- 《理论力学》入选 2022 年北京高校"优质本科教材课件"。
  "Theoretical Mechanics" was selected as a high-quality undergraduate textbook and courseware for Beijing universities in 2022.

- 吴桃李完成的论文获北京高校第十二届青年教师教学基本功比赛论文比赛一等奖。
  The thesis completed by Wu Taoli won the first prize in the 12th Basic Teaching Skills Competition (Thesis Competition) for Young Teachers in Beijing's colleges and universities.

- 基础物理实验教学中心研制的仪器"双光子纠缠实验教学系统"在第十一届全国高校物理实验教学研讨会自制教学实验仪器评比中荣获一等奖。
  The instrument "Dual-Photon Entanglement Experimental Teaching System" developed by the Basic Physics Experiment Teaching Center won the first prize in the self-made teaching experimental instrument evaluation at the 11th National Conference on Physics Experiment Teaching in Higher Education.

- 2 项教育部拔尖计划 2.0 课题立项。
  Two projects of the Ministry of Education's Top-Notch Talents Program 2.0 was approved.

- 元培物理方向高乐耘在李强老师指导下获教育部拔尖计划第二届"提问与猜想"活动一等奖。
  Gao Leyun, majoring in physics of Yuanpei College, won the first prize in the second "Questioning and Guessing" event of the Ministry of Education's Top-Notch Talents Program under the guidance of Li Qiang in 2022.

- 杨翰彬、李慈航、齐思远、任勇钢、杨家宁、张宇翔获第十四届中国大学生物理学术竞赛一等奖。
  Yang Hanbin, Li Cihang, Qi Siyuan, Ren Yonggang, Yang Jianing and Zhang Yuxiang won the first prize in the 14th China Undergraduate Physics Tournament in 2022.

- 康亚城获第五届全国大学生天文创新作品竞赛一等奖。
  Kang Yacheng won the first prize in the 5th Chinese undergraduate Astronomical Innovation Contest in 2022.

- 龚旗煌院士团队荣获 2022 年北京市优秀研究生指导教师团队称号。
  A team led by Academician Gong Qihuang won the title of 2022 Beijing Excellent Graduate Supervisor Team.

- 李耀龙（指导教师：龚旗煌）、任燕（指导教师：张宏 ）的博士学位论文获评为 2022 年北京市优秀博士学位论文。
  The doctoral dissertations of Li Yaolong (supervisor: Gong Qihuang) and Ren Yan (supervisor: Zhang Hongsheng) were awarded the 2022 Beijing Excellent Doctoral Dissertation.

- 傅杨获中国物理学会高能物理分会第十二届"晨光杯"青年优秀论文一等奖。
  Fuyang won the first prize of the 12th "Chenguang Cup" Youth Excellent Paper by the Committee on High Energy Physics of the Chinese Physical Society.

- 李洪波获第八届中澳天体物理研讨会中方最佳海报奖。
  Li Hongbo won the Best Chinese Poster Award of the 8th Australia-China Workshop on Astrophysics.

- 段晓苇获北京大学第二十八届"挑战杯"——五四青年科学奖竞赛特等奖。
  Duan Xiaowei won the grand prize of the 28th "Challenge Cup" - May Fourth Youth Science Award of Peking University.

- 姚泽钦获北京大学第三十届"挑战杯"——五四青年科学奖竞赛一等奖。
  Yao Zeqin won the first prize of the 30th "Challenge Cup" - May Fourth Youth Science Award of Peking University.

- 王一男入选第八届中国科学技术协会青年人才托举工程。
  Wang Yinan was selected for the 8th Youth Talent Support Program of the China Association for Science and Technology.

- 赵丽宸入选北京市科技新星计划。
  Zhao Lichen was selected for the Beijing Science and Technology Rising Star Program.

- 何子山当选美国天文学会会士。
  He Zishan was elected as a Fellow of the American Astronomical Society.

- 胡永云当选美国气象学会会士。
  Hu Yongyun was elected as a Fellow of the American Meteorological Society.

- 肖云峰当选国际光学工程学会会士。
  Xiao Yunfeng was elected as a Fellow of the International Society for Optics and Photonics.

- 冯旭获中国青年科技奖。
  Feng Xu won the China Youth Science and Technology Award.

- 江颖获第十八届霍英东教育基金会高等院校青年科学奖。
  Jiang Ying received the 18th Henry Fok Foundation Young Scientist Award for Higher Education Institutions.

- 刘玉鑫、许秀来分获中国物理学会 2021—2022 年度吴有训物理奖和饶毓泰物理奖。
  Liu Yuxin and Xu Xiulai won the Wu Youxun Physics Prize and Rao Yutai Physics Prize of the Chinese Physical Society for 2021-2022.

- 赵凯华、陈佳洱、甘子钊、赵光达教授及周光召、王乃彦、杨国桢、杜祥琬校友获中国物理学会终身贡献奖。
  Professors Zhao Kaihua, Chen Jia'er, Gan Zizhao, Zhao Guangda, and alumni Zhou Guangzhao, Wang Naiyan, Yang Guozhen, and Du Xiangwan received the Lifetime Contribution Award of the Chinese Physical Society.

- 何琼毅、马仁敏获中国光学学会王大珩光学奖中青年科技人员奖。
  He Qiongyi and Ma Renmin won the Wang Daheng Optical Award for Young Scientists of the Chinese Optical Society.

- 王剑威获亚太物理学会联合会 - 亚太理论物理中心杨振宁奖。
  Wang Jianwei won the Yang Zhenning Award of the Asia-Pacific Physics Association-Asia-Pacific Center for Theoretical Physics.

奖励与荣誉 | *Awards & Honors*

- 李婧获美国气象学会 Henry G. Houghton 奖。
  Li Jing won the Henry G. Houghton Award of the American Meteorological Society.

- 王晨旭获美国陶瓷学会青年科学家奖。
  Wang Chenxu won the Young Scientist Award of the American Ceramic Society.

- 孟杰获德国亚历山大·洪堡基金会洪堡研究奖。
  Meng Jie won the Alexander von Humboldt Foundation Research Award in Germany.

- 江颖、李柯伽获腾讯基金会科学探索奖。
  Jiang Ying and Li Kejia won the Tencent Foundation Science Exploration Award.

- 邵立晶获阿里巴巴达摩院青橙奖。
  Shao Lijing won the Alibaba DAMO Academy Youth Orange Award.

- 罗昭初入选《麻省理工科技评论》“35 岁以下科技创新 35 人”2022 年中国区榜单。
  Luo Zhaochu was named one of the 2022 MIT Technology Review "35 Innovators Under 35" in China.

- 王健获 2022 年度全球华人物理与天文学会亚洲成就奖。
  Wang Jian won the Asia Achievement Award of the 2022 Global Chinese Physics and Astronomy Association.

- 肖云峰、曹启韬等完成的项目“对称破缺微腔光物理与应用”获中国光学学会光学科技一等奖；刘文静等获中国光学学会第十一届饶毓泰基础光学奖。
  The project "Symmetry Breaking Microcavity Photonics and Applications," completed by Xiao Yunfeng, Cao Qitao, and colleagues , won the Optical Science and Technology First Prize of the Chinese Optical Society. Liu Wenjing and colleagues won the 11th Rao Yutai Basic Optics Prize of the Chinese Optical Society.

- 杨晓菲获评第七届中国科协优秀科技论文。
  Yang Xiaofei was awarded the Outstanding Scientific and Technological Paper of the 7th China Association for Science and Technology.

- 王新强等完成的项目获日内瓦国际发明展览会金奖。
  The project completed by Wang Xinqiang and colleagues won the gold medal at the Geneva International Invention Exhibition.

- 刘运全、彭良友、吴成印、龚旗煌等合作完成项目“超快强激光场下量子隧穿理论和实验研究”获 2022 年度中国光学学会科技奖基础研究类一等奖；王新强、张国义、沈波、于彤军、刘放等合作完成项目“第三代半导体发光器件衬底技术”获 2022 年度中国光学学会科技奖应用成果类一等奖。
  Liu Yunquan, Peng Liangyou, Wu Chengyin, Gong Qihuang, and colleagues completed the project "Theoretical and Experimental Study of Quantum Tunneling in Ultrashort Strong Laser Fields" and won the First Prize of the Basic Research Category of the 2022 China Optical Society Science and Technology Awards. Wang Xinqiang, Zhang Guoyi, Shen Bo, Yu Tongjun, Liu Fang, and colleagues completed the project "Third-Generation Semiconductor Lighting Substrate Technology" and won the First Prize of the Application Achievement Category of the 2022 China Optical Society Science and Technology Awards.