2019—2020 年报 Bi-annual Report

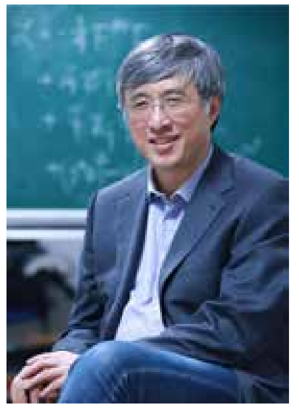
北京大学 物理学院

School of Physics, Peking University

年报 2019—2020

BI-ANNUAL REPORT

院长寄语
Message from the Dean



从 1913 年北京大学物理门的设立，历经上世纪五十年代北京大学物理学系的调整，又经历本世纪初北京大学物理学院的整合，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，跨越了百零六年的风雨兼程。

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书写青春华章、用科学道德涵养精神气质，为我国科学技术与高等教育事业铸就了世纪荣光。

这里是唯实、求真的北大物理。让我们永葆对科学的好奇心，大胆怀疑和挑战，敢于试错和纠偏；永葆对科学的敬畏心，诚信为人，严谨治学，在物理学领域做真学问，练真本领，讲真话，寻真理。

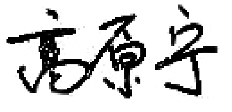
这里是向善、臻美的北大物理。让我们在保持逻辑思维能力的同时，珍惜直觉、想象与审美；在理解物理学原理直接、原始的逻辑性的同时，期待实验观察的奇妙现象和理论推导的完美架构，从而享受内心的惊喜、感动与震撼。

这里是有理想、有抱负的北大物理。让我们弘扬“两弹一星”精神，铭记“干惊天动地事，做隐姓埋名人”的无名英雄；瞄准世界学术前沿、国家战略需求、国民经济主战场，勇于提出新理论、开辟新领域、探寻新路径。

这里是大视野、大情怀的北大物理。让我们坚持全球视野和科学视角，秉承以基础研究驱动科技创新、以开放共融谋求合作共赢的理念，积极参与国际大科学研究，与国际同行凝聚共识，为物理学推进人类文明进步贡献北大智慧和中国力量。

2021 年，将迎来北京大学物理学院成立二十周年；2023 年，亦将迎来北大物理学科建立百十周年。我们理当承继老一辈北大物理人重教乐育的优良传统和对知识、真理的执著追求，不惧任重与时艰，把学生培养、学科建设和学院发展融入尊重知识与人才、科学与人文交织的浓厚氛围，凝心聚力，守正日新，以坚实行动诠释新一代北大物理人学术无畏、人格无瑕的风貌，无愧于学生、家长、院友、学校、国家和世界对“北大物理”的瞩目与期盼。

北京大学物理学院院长



Welcome to the School of Physics at Peking University!

Physics is concerned with the study of the universe from the smallest to the largest scale. Discoveries in physics have formed the foundation of countless technological advances and the contributions to solving global problems.

It is my honor and privilege to receive an opportunity to guide the School where I was extraordinarily fortunate to pursue my education in the 1970-80s.

The School has an outstanding historical record of impressive achievements. Our tradition of excellence has been established by many eminent professors, lecturers and a large amount of baccalaureate and doctoral degrees we have produced for decades, and as a result, the School is consistently top-ranked in the nation.

The School is diverse in its teaching programs and research interests that span discipline from theoretical to the experimental. With more than 210 affiliated faculty members, 1150+ graduate and 780+ undergraduate physics majors and 100+ postdoctoral fellows, it promotes a lively intellectual environment that everybody can thrive in, and emphasis is placed on inspiring and encouraging our students to be at the forefront of the next generation of leading physicists or in the science-driven high-tech industrial world. Aside from continuous degree programs, our students' horizons are broaden by co-curricular initiatives and activities.

The School has attracted a number of distinguished scientists with international stature in recognition of their scientific backgrounds. The cutting-edge research are carried out by vibrant community at state-of-the-art facilities and laboratories that bring transformative and inter-disciplinary perspectives to address fundamental questions, to satisfy human curiosity, to promote the public understanding, and to help improve the quality of our lives.

Motivated by a strong commitment to ensure the School will be as creative and inclusive as ever, I very much look forward to working with everyone enthusiastic and most able in the years that followed as we collectively enhance and realize the full potential of the School that is poised to reach greater height, and amplify the major impacts that the School can make to science and on ever-changing society.

Dean of the School of Physics,
Peking University

目录 *Contents*

发展进程
Developments

2019 年 1 月，组织胡济民先生诞辰一百周年纪念会。
In January 2019, organized the commemoration of the 100th Birth Anniversary of Professor Hu Jimin;

2019 年 5 月，隆重举行北京大学大气科学学科建立 90 周年庆祝大会。
In May 2019, the 90th Anniversary Celebration for the Establishment of the Department of Atmospheric Sciences at Peking University was held;

2019 年 6 月，物理学院第五届行政班子任职。
In June 2019, inaugurated the fifth administrative leadership team of the School of Physics;

2019 年 8 月，组织纪念黄昆先生百年诞辰暨“五校联合半导体物理专门化”学术研讨会。
In August 2019, organized the commemoration of the birth centenary of Professor Huang Kun and the seminar on "Specialization of Semiconductor Physics Jointly Hosted by Five Universities";

2019 年 9 月，8 位离休老同志和 11 位科研工作者突出老师获“庆祝中华人民共和国成立 70 周年”纪念章。
In September 2019, 8 retirees and 11 faculty members were honored with the medals for "Celebrating the 70th Anniversary of founding of the People's Republic of China";

2019 年 9—10 月，在庆祝中华人民共和国成立 70 周年系列重大活动中，物理学院 145 名师生参加并圆满完成了群众游行、广场联欢和志愿服务等任务，受到党中央嘉奖。
In September and October 2019, a total of 145 students and teachers of School of Physics attended and successfully accomplished the mass pageantry, square celebration and volunteer service to mark the 70th anniversary of the founding of the People's Republic of China;

2019 年 11 月，承办“中微子与宇宙”未来科学大奖与北京大学联合学术报告会。
In November 2019, hosted the "Neutrinos and the Universe" Joint Academic Conference of Future Science Prize and Peking University.

2019 年，怀柔科学城北京激光加速创新中心正式启动，北京大学长三角光电科学研究院成立。
In 2019, the Beijing Laser Acceleration Innovation Center in Huairou Science City was officially launched and Peking University Yangtze Delta Institute of Optoelectronics was founded;

2019 年，物理学院获批国家重点研发计划项目 3 项，课题 8 项，启动项目 2 项。新增国家自然科学基金项目 53 项，其中创新研究群体项目 2 项，国家重大科研仪器研制项目 2 项，重大研究计划重点支持项目 2 项、重点项目 5 项，组织间国际（地区）合作研究与交流项目 2 项。
In 2019, 3 program and 8 projects of national key research and development plan were approved, 2 programs have been initiated. 53 National Natural Science Foundation programs were approved, including 2 programs of Creative Research Groups, 2 programs of National Major Research Instrument, 2 key support programs and 5 key programs in Major Research Plan, and 2 International (Regional) Cooperation and Exchange Program.

2019 年，物理学院师生作为第一作者和通讯作者发表 SCI 论文 800 余篇，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 2019, more than 800 SCI papers were published by faculty and students of the School of Physics as the first author and corresponding author; more than 60 papers were published in international leading journals such as Science series, Nature series, PRL, PNAS, etc.;

2020 年 5 月，举办赵凯华先生九十寿辰暨从教七十周年庆祝会。
In May 2020, held the celebration of Professor Zhao Kaihua's 90th Birthday and 70th Anniversary of Teaching;

2020 年 7—8 月，开展“心有所信，方能行远”暑期思政实践。
In July to August 2020, launched the summer ideological and political practice of "Going beyond with faith in heart";

2020 年 9 月，与广东省广州市白云区政府共建的广东省激光等离子体技术研究院正式签约。
In September 2020, the Guangdong Institute of Laser Plasma Accelerator Technology, jointly constructed with the government of Baiyun District, Guangzhou, Guangdong Province, was officially contracted;

2020 年 9 月，物理学院学术论坛第一期开讲。
In September 2020, the Distinguished Colloquium of School of Physics was launched;

- 2020 年 11 月，中国空间站工程巡天望远镜北京大学科学中心成立。
  In November 2020, the Peking University Science Center of the Chinese Space Station Telescope (CSST) was founded;

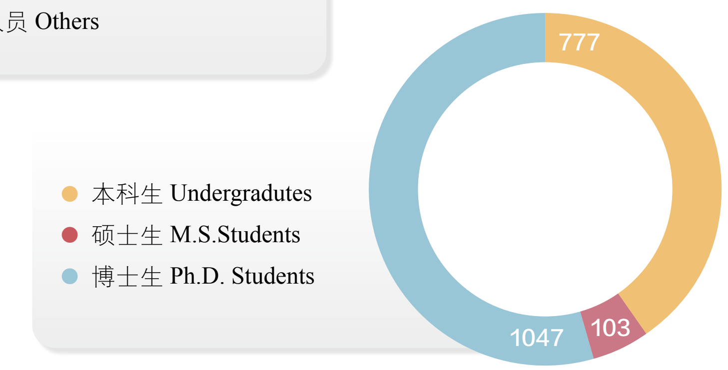
- 2020 年 12 月，中共北京大学物理学院第五届委员会委员经选举产生。
  In December 2020, The Fifth Committee of the Chinese Communist Party of the School of Physics of Peking University was elected;

- 2020 年 12 月，物理学院被评为北京大学抗击新冠肺炎疫情先进集体，9 位行政人员被评为北京大学抗击新冠肺炎疫情先进个人。
  In December 2020, the School of Physics was awarded as an Advanced Group in the Anti-COVID-19 Campaign of Peking University, while 9 administrators were honored as Advanced Individuals in the Anti-COVID-19 Campaign of Peking University;

- 2020 年，物理学院师生作为第一作者和通讯作者发表 SCI 论文约 750 篇，其中在 Science 及其子刊、Nature 及其子刊、PRL、PNAS 等顶级杂志发表文章 90 余篇。
  In 2020, about 750 SCI papers were published by faculty and students of the School of Physics as the first author and corresponding author; more than 90 papers were published in international leading journals such as Science series, Nature series, PRL, PNAS, etc.;

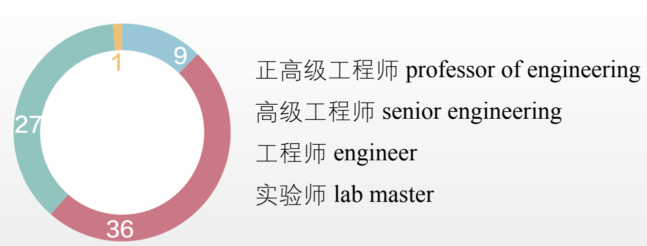
- 2020 年，新增国家重点研发计划重点专项项目 3 项、课题 4 项，启动项目 2 项；新增国家自然科学基金项目 43 项，其中国家杰出青年科学基金项目 1 项，重大项目 1 项，国家重大科研仪器研制项目 2 项，重大研究计划重点支持项目 1 项、战略研究项目 1 项、重点项目 4 项，组织间国际（地区）合作研究与交流项目 4 项；“新冠肺炎疫情等公共卫生事件的应对、治理及影响”专项项目 1 项。
  In 2020, 3 programs and 4 projects of national key research and development plan were approved, 2 programs have been initiated. 43 National Natural Science Foundation programs were approved, including one National Science Fund for Distinguished Young Scholars, 1 major program, 2 National Major Research Instrument programs; 1 key support program, 1 Strategic Research Program and 4 key programs in Major Research Plan; 4 International (Regional) Cooperation and Exchange Programs and 1 special program that Anti-COVID-19 related.

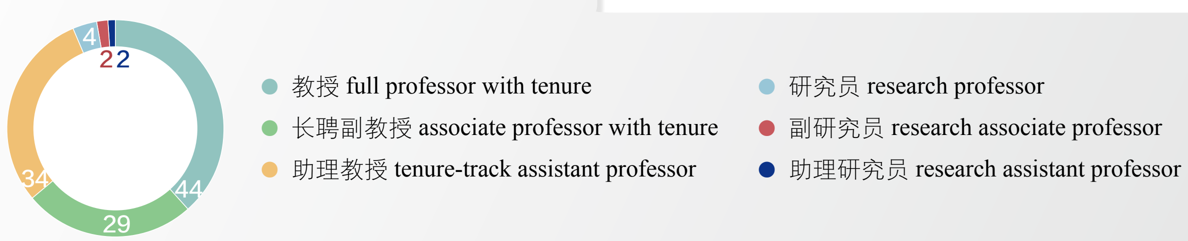
人员概况
General View of Personnel



教学研究人员 Faculty

教辅人员 Research Staff





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*

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、通过第一原理计算揭示强子内部结构

研究强子（比如质子、中子）的内部结构，对理解强相互作用规律以及我们现实世界的物质构成至关重要。然而，对强子结构的理论研究极其困难，在提出强相互作用基本理论量子色动力学（quantum chromodynamics, QCD）约 40 年后的今天，人们依然未能利用 QCD 完全计算出夸克和胶子在质子内部的动量分布函数（parton distribution function, PDF）。近些年，在 PDF 的第一原理计算方法上有了巨大的突破，特别是提出了准 PDF 及其推广“格点散射截面”方法。

在量子场论框架下，为了使该方法能够严格计算 PDF，格点计算量必须具有紫外发散的可重整性质。马滟青研究员与合作者严格证明了这一性质，为该方法的应用奠定了坚实的理论基础。该成果于 2019 年发表在《物理评论快报》（Phys. Rev. Lett. 2019, 122, 062002）。

此外，为了能够从格点计算中抽取出 PDF，需要知道格点计算量与 PDF 之间的关联系数。马滟青研究员与合作者首次把这一关联系数在微扰论中计算至两圈水平，使得从格点中抽取 PDF 的精度能达到从实验数据中抽取 PDF 的精度。该成果于 2021 年发表在《物理评论快报》（Phys. Rev. Lett. 2021, 126, 072001）。

I. Exploring internal structure of hadrons based on ab initio calculation

Study of the internal structure of hadrons, like the proton or neutron, is crucial to understand both the nature of strong interaction and the constitutive substance of the real world. However, this problem is so hard that, 40 years after the establishment of the fundamental theory of strong interaction, quantum chromodynamics (QCD), one is still unable to fully calculate parton distribution function (PDF) of quarks or gluons inside of the proton based on QCD. Significant breakthroughs of ab initio calculations of PDF based on lattice QCD are achieved in recent years, especially because of the new method quasi-PDF and its generalization “lattice cross sections”. In quantum field theory, it is needed to prove that the quantities calculated by lattice can be multiplicatively renormalized. Yan-Qing Ma and his collaborators proved this property rigorously, which is an important theoretical foundation for the new method. The result was published in Physical Review Letters (Phys. Rev. Lett. 2019, 122, 062002).

Besides, to extract PDF from lattice calculation, matching coefficients between PDF and the quantities calculated by lattice are needed. Yan-Qing Ma and his collaborators calculated the matching coefficients to two-loop order in perturbation theory, which improves the precision of PDF extracted from lattice to be comparable with that from experimental data. This result was published in Physical Review Letters (Phys. Rev. Lett. 2021, 126, 072001).

二、 用超级计算机探索高精度粒子物理与核物理前沿

量子色动力学 (quantum chromodynamics, QCD) 是研究夸克和胶子之间强相互作用的基本理论。由于强相互作用在低能区的强耦合、非微扰特性，微扰解析的计算方法不再适用。格点量子色动力学（格点 QCD）凭借超级计算机为低能 QCD 提供了一种非微扰的解决方案——通过对 QCD 系统进行蒙特卡洛模拟，人们能从第一性原理出发得到精确的理论预言并与实验进行对比。这在研究核子内部结构、精确检验标准模型等多个方面，都起到至关重要的作用。

冯旭课题组针对光子 -W 玻色子高阶圈图的计算构建了一套完整的新方法，解决了复杂 4 点关联函数计算和分析过程中的一系列技术难题，并通过我国超级计算天津中心的“天河三号”原型机和美国阿贡国家实验室的“Mira”超级计算机，在国际上首次完成了对光子 -W 玻色子圈图的格点计算。从该计算出发，冯旭课题组将 pion 介子半轻衰变宽度的理论预言精度提高了 3 倍，这为高精度 CKM 物理提供了重要的理论信息。该项工作发表于《物理评论快报》(Phys. Rev. Lett. 2020, 124, 192002)。

冯旭课题组对双 pion 系统的衰变振幅的计算，迈出了从夸克尺度向核尺度过渡的重要一步。该项工作发表于《物理评论快报》（Phys. Rev. Lett. 2019, 122, 022001）。

II. Exploration in the high-intensity frontier of the particle and nuclear physics using supercomputers

Quantum chromodynamics (QCD) is the fundamental theory describing the strong interactions between quarks and gluons. Because of the non-perturbative nature of strong interaction in the low energy region, the perturbation theory is not applicable in this case. Using the supercomputers, lattice QCD provide a non-perturbative approach to solving QCD in low energy. Through the Monte Carlo simulation of the QCD system, one can obtain the precise theoretical predictions from first principles and compare them with experimental measurements. Nowadays, lattice QCD is playing important role in many aspects in nuclear and particle physics, such as the study of hadron internal structure and the high-precision test of the Standard Model.

The group of Xu Feng developed a complete set of methodology to calculate the photon-W box diagrams using lattice QCD. They solved the key technological difficulties in the computation and analysis of the four-point correlation functions and performed the first lattice QCD calculation of photon-W box diagrams using the supercomputers, namely Tianhe-3 (prototype) at Chinese National Supercomputer Center in Tianjin and Mira at the Argonne Leadership Class Facility. From this calculation, the precision of theoretical prediction for the pion semileptonic decay rate is improved by a factor of 3, which provides important information for the high-precision determination of the CKM matrix elements. This work was published in Physical Review Letters (Phys. Rev. Lett. 2020, 124, 192002).

Besides, the group of Xu Feng studied the neutrinoless double beta decays from the two-pion system. Neutrinoless double-beta decay is the most sensitive laboratory probe to confirm whether neutrino is a Majorana fermion. The observation of this decay will demonstrate that neutrinos are Majorana fermions, shed light on the neutrino absolute masses and mass-generation mechanism, and give insight into leptogenesis scenarios key to understand the matter-antimatter asymmetry in the universe. Theoretically, the interpretation of the experiments of neutrinoless double beta decays relies on a seamless connection between the theory at quark and nuclear level and reliable calculations of the nuclear matrix elements, with robust uncertainty estimation. The lattice QCD calculation of the neutrinoless double beta decay amplitude performed by Feng’s group can be viewed as an important step moving from the quark level towards the nuclear level. The results was published in Physical Review Letters (Phys. Rev. Lett. 2019, 122, 022001).

三、液态惰性气体探测器中太阳轴子的逆普里马科夫效应

轴子（axion）是 1977 年 Peccei-Quinn 理论为解决量子色动力学中的强 CP 问题而假设的一种赝标量基本玻色子。根据天文学研究，暗物质占据了宇宙物质的 85%，如果轴子存在，且质量低于电子伏，则可以是冷暗物质的有力候选者。由于它能够同时解决强 CP 问题和暗物质问题，因而引起众多粒子物理学家的广泛关注。

轴子可与包括胶子、光子和各种费米子在内的标准模型粒子产生非常微弱的相互作用。根据相互作用的不同，可以通过各种实验探索轴子的性质。来自太阳的轴子可通过直接探测 XENON1T 和 PANDAX 等暗物质的实验进行探索。轴子在太阳中的产生集中于太阳核心，该区域温度大约为一千五百万开尔文，对应能量在 keV 量级。XENON1T 实验组曾在 2020 年 6 月发表的预印本论文（arXiv: 2006.09721）中指出，探测到在 1—7 keV 的电子反冲事例多于预期，且集中于 2—3 keV。该工作于 2020 年 10 月正式发表于《物理评论 D》（Phys. Rev. D 2020, 102, 072004）。太阳轴子由于其理论上的重要性，并且能量与 XENON1T 实验事例接近，因而受到广泛关注。2020 年 8 月一篇文章指出，太阳轴子理论对实验的解释在天文观测上面临着严重的限制，该文章发表于《物理评论快报》（Phys. Rev. Lett. 2020, 125, 131804）。

刘佳研究员及合作者发现，XENON1T 及以往液体惰性气体类直接探测实验在太阳轴子模型实验分析中所使用的理论框架忽视了一个重要的探测过程，即逆普里马科夫过程。如果轴子和光子具有相互作用，可以通过氙原子核的电场转化成为光子。由于在该类实验中，keV 光子和具有 keV 动能的电子在液氙的能损非常迅速且极为相似，二者无法通过实验分辨，因此轴子的逆普里马科夫效应对实验分析有重大影响，并且该效应还可以缩小与天文观测结果的差异。该工作发表于《物理评论快报》（Phys. Rev. Lett. 2020, 125, 131806），得到 XENON1T 实验组在《物理评论 D》论文中的认可，同时即将收录于 Particle Data Group 撰写的 2021 年粒子物理综述。

III. The inverse Primakoff effect of solar axion in the liquid noble gas detector

Axion is a hypothetical pseudoscalar particle, proposed by Peccei and Quinn in 1977 to solve the strong CP problem in the Quantum Chromodynamics. On the other hand, according to astrophysical observations the dark matter has occupied 85% of the matter content. If Axion exists and its mass is lower than eV, it can be a natural candidate of cold dark matter. Since it can simultaneously solve the strong CP problem and dark matter problem, it has received lots of attention from the particle physics community.

Axion can have feebly interaction with gluon, photon and various fermions in the Standard Model. According to different interactions, many different experiments have been proposed to search for axion. For the solar axion, it can be detected by dark matter direct detection experiment like XENON1T and PANDAX. Axion can be produced inside the core of the Sun, where the temperature is about 15 million Kelvin which corresponds to energy at keV. XENON1T group has published an arXiv paper (arXiv: 2006.09721) at June 2020, and pointed out, there are more electronic recoil events than expected in energy range 1-7 keV and is mostly accumulated between 2-3 keV. Later, this paper formally published in Physical Review D (Phys. Rev. D 2020, 102, 072004) in October 2020. Since solar axion is very important theoretically and its energy is so close to the XENON1T events, it has been widely concerned by the community. Moreover, a paper appeared in Physical Review Letters (Phys. Rev. Lett. 2020, 125, 131804) in August 2020 and pointed out that the solar axion interpretation faces severe astrophysical constraints.

Jia Liu and the collaborators found that including XENON1T, the past liquid noble gas direct detection experiments have missed an important detection channel, the inverse Primakoff process, in the experimental analysis of the solar axion model. If axion can interact with the photon, it can convert into photons through the electric field of the xenon atom. Since such experiment cannot distinguish photon and electron energy deposit due to the fast and similar energy loss patterns, the inverse Primakoff effect is important and should be included. Moreover, this effect can alleviate the constraints from the astrophysical bounds. The work has been published in Physical Review Letters (Phys. Rev. Lett. 2020, 125, 131806), recognized in the formal Physical Review D paper of XENON1T, and will be included in the Review of Particle Physics 2021 written by the Particle Data Group (PDG).

系所中心研究亮点 | *Highlights*

02 凝聚态物理与材料物理研究所简介
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 62 人，其中，教授 22 人，副教授 20 人，预聘制助理教授 3 人，研究技术人员 2 人，工程技术人员 15 人。研究队伍中包括院士 6 人，长江特聘教授 5 人，国家杰出青年 9 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 62 faculty members in the Institute of Condensed Matter and Material Physics, consisting of 22 professors, 20 associate professors, 3 tenure-track assistant professors, 2 research technicians and 15 engineering technicians. Among the senior researchers are 6 academicians of the CAS, 5 Chang Jiang scholar professors, and 9 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、大尺寸多指数晶面单晶铜箔库制备

铜在现代信息社会中发挥着极为重要的作用，被广泛应用于电气、电子、通信、国防等关键领域。然而，目前市场上的商业用铜基本上为多晶铜，其中存在的各种缺陷致使电子、声子输运效率大幅降低。理论上，具备完美晶体结构的单晶铜可将铜的本征电学和热学性能发挥到极致，预期会在低损耗、高散热的电力、电子器件应用方向产生重要影响。此外，近年来随着二维材料研究的兴起，铜被广泛应用于二维单晶材料的外延制备。具备各种指数晶面的单晶铜箔衬底是实现不同结构二维单晶材料外延生长的基础。因此，制备大尺寸、多种指数晶面的单晶铜箔是产业界、科研界亟待解决的科学和技术问题。

在材料科学中，单晶铜箔按晶面指数可以划分为两类：低指数晶面和高指数晶面。其中低指数晶面仅有 Cu(001)，Cu(011)，Cu(111) 三种，而高指数晶面理论上有无限种。2016 年以来，刘开辉研究员与合作者在低指数晶面铜单晶研究上取得了系列进展：在单晶 Cu(111) 上实现米级石墨烯单晶的超快外延制备（Nat. Chem. 2019, 11, 730；Sci. Bull. 2017, 62, 1074；Nat. Nanotechnol. 2016, 11, 930）；在近邻 Cu(110) 单晶上实现分米级二维六方氮化硼单晶外延制备（Nature 2019, 570, 91）。与低指数晶面相比，高指数晶面铜箔能提供更丰富的表面结构，可极大地拓宽外延制备二维材料体系的种类。然而，传统退火方法通常只能得到表面能最低的 Cu(111) 单晶，高指数晶面结构在热力学及动力学上均不占优势，其可控制备极具挑战性。

针对这一难题，北京大学物理学院刘开辉研究员、王恩哥院士、俞大鹏院士与合作者将攻关目标锁定在铜箔再结晶过程的热力学和动力学调控上，在国际上首次报道利用热力学“成核”控制和动力学“核长大”控制技术实现 A4 尺寸单晶铜箔库的制备，得到了超过 30 余种晶面指数的单晶铜箔。相关成果以“Seeded growth of large single-crystal copper foils with high-index facets”为题发表于《自然》(Nature 2020, 581, 406）。他们通过特殊的热力学预处理过程，将 Cu(111) 晶面的绝对优势打破，“变异”得到了非正常的高指数晶面核；同时利用动力学消除晶界的趋势，使得该高指数晶面核扩散并长大，进而制备出了多达 30 余种晶面的单晶铜箔。随后，类比生物学中的“遗传”思想，团队将制备出的单晶作为“种子”放到商业多晶铜箔上，进行退火处理，实现了特定晶面大尺寸单晶铜箔的定向复制制造。同时，该方法具有普适性，可推广至其它金属材料的原子制造，将对我国通信等领域的核心材料储备以及后续装备研发产生重要、深远的影响。

I. Seeded growth of large single-crystal copper foils with high-index facets

Copper plays an important role in the modern society and is widely used in electronics, communications, national defence and other fields. However, most of the commercial copper foils on the market are polycrystalline, and the defects in it greatly reduced the transport efficiency of electron and phonon. Theoretically, single-crystal copper with a perfect crystal structure can maximize its intrinsic electrical and thermal properties and is expected to have an important impact on the application of low-loss and high heat-dissipation electronic devices. Besides, with the rise of two-dimensional materials, single-crystal copper foils with various facets are the basis for realizing the epitaxial growth of two-dimensional single-crystal materials with different symmetries. Therefore, the production of large-size single-crystal copper foil is a long-term pursuit for the scientists.

Based on their Miller indices （hkl）, metal facets are classified into low-index (no index greater than one) and high-index (at least one index larger than one) ones. For a certain metal, there are only three sets of low-index facets (（100）,（110）and （111）). As a comparison, high-index facets are in principle infinite and, therefore, could afford richer surface structures and properties. Since 2016, Professor Kaihui Liu and his collaborators have made a series of progress in the study of low-index copper foils: the ultra-fast epitaxial growth of meter-scale graphene on single-crystal Cu(111) (Nat. Chem. 2019, 11, 730；Sci. Bull. 2017, 62, 1074；Nat. Nanotechnol. 2016, 11, 930), and the epitaxial growth of single-crystal hexagonal boron nitride on single-crystal Cu(110) (Nature 2019, 570, 91). Compared with low-index ones, high-index copper foils can provide a richer surface structure, which can greatly broaden the types of two-dimensional materials grown on it. However, the synthesis of a single-crystal metal foil with high-index facet is all the more challenging since the formation of such facets is neither thermodynamically nor kinetically favourable.

To address this problem, A team of Peking University researchers leaded by Academician Enge Wang, Academician Dapeng Yu, Professor Kaihui Liu and their collaborators have focused on the thermodynamics and kinetics control of the recrystallization process. They realized the fabrication a library of A4 paper-size (30×21 cm2) single-crystal copper (Cu) foils with more than 30 kinds of facets by a designed seeded abnormal grain growth from originally polycrystalline Cu foils. Their work was published on Nature entitled by “Seeded growth of large single-crystal copper foils with high-index facets” (Nature 2020, 581, 406). By applying the special pre-treatment process, the Cu(111) facet is no longer the only thermodynamically favourable facet, and the abnormal high-index grain is obtained. Kinetically, the large abnormal grain consumes the surrounding small normal grains and eliminates the grain boundaries in the Cu foil which leading to the formation of the large single-crystal copper foil. By repeating the procedure, more than 30 kinds of single-crystal Cu foils with various facets have been prepared. What’s more, in analogy with the "inheritance" in biology, researchers further proposed a facet ‘transfer’ method to copy the facet of the obtained high-index single crystals. First, a small piece of a high-index single-crystal Cu cut from a large single-crystal Cu foil was placed on a large polycrystalline Cu foil to serve as a new seed. When annealed at a high temperature, the polycrystalline Cu foil transferred into a single crystal with the same facet as the seed. Besides Cu, they have demonstrated that the technique is potentially applicable to produce libraries of other single-crystal foils. The fundamental exploration and technical applications of these large high-index single-crystal metal foils are therefore of highly expectation.

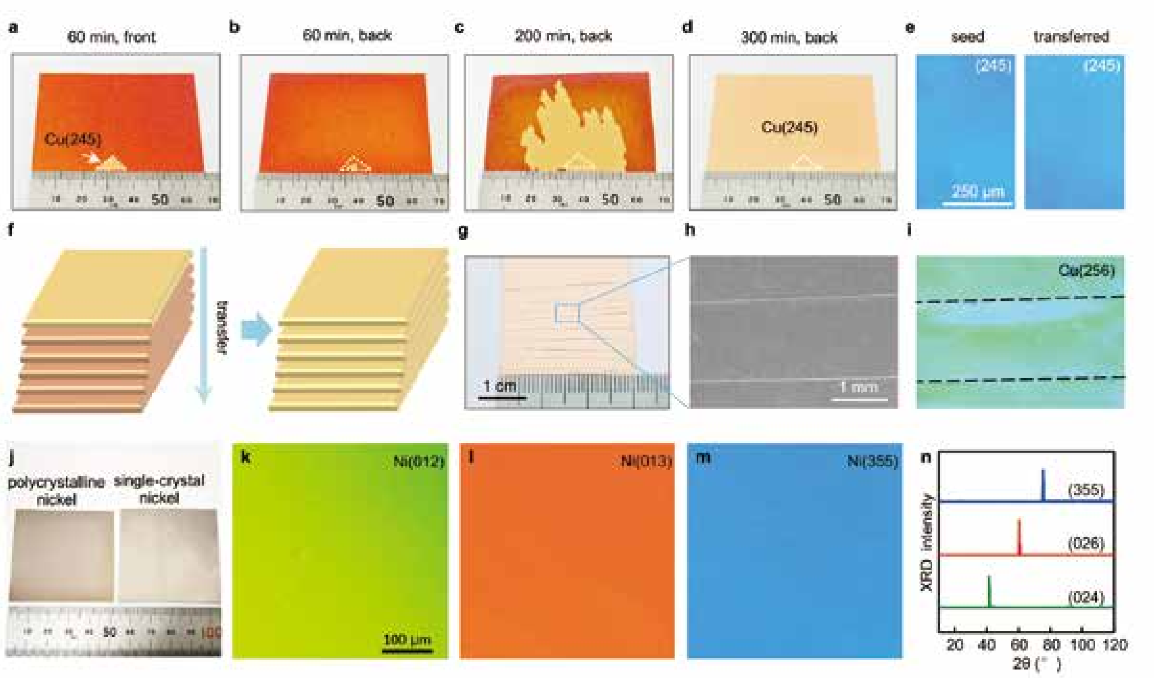


图 1. 大尺寸多指数晶面单晶铜箔库制备

Figure1. Single-crystal Cu foils of A4 paper size with various facet indices

二、微纳光场调控与激光物理

光反射是构建光学反馈的基础，光的反射机制包括金属反射、全内反射、光子晶体禁带反射。马仁敏课题组发现了一种光反射新机制：能带反转光反射。这一反射新机制可解决微型激光中难以实现高的方向性出射的问题。目前具有垂直出射方向性的微型激光器是垂直腔面发射激光器（VCSEL），但是垂直腔面发射激光器需要上下两个分布反馈式（DBR）介质反射镜，这使得其制备工艺复杂，同时材料体系受限。马仁敏课题组发现了能带反转光反射机制并实现了新型拓扑体态激光器。从能带结构中的动量维度来看，能带反转光反射只发生在面内动量近于零处，因此不需要 DBR 便可实现高的垂直出射方向性。此外，这种新型激光器直径只有数微米、窄线宽、单横模、单纵模，能够在室温下以千瓦每平方厘米阈值稳定工作，单模输出边模抑制比超过 36 dB。这些性能与商业化激光二极管相当，根据 IEEE 以及相关工业标准，指标满足多数应用领域需求。该研究工作发表于《自然·纳米科技》（Nat. Nanotechnol. 2020, 15, 67-72）。另外，在拓扑光子体系中，马仁敏课题组还利用自旋-动量锁定拓扑边界态的非厄密面外辐射新特性，实现了高性能拓扑涡旋激光器，并发现了近场的拓扑模式信息与远场的激光光场信息存在一一对应关系。相关研究工作发表在《物理评论快报》（Phys. Rev. Lett. 2020, 125, 013903），并被选为编辑推荐论文和封面论文。

在物理学中，辐射场（光场、声场等）并非完全是由辐射源本身的固有属性决定的，其所处的环境也起到了同样重要的作用。马仁敏课题组在宇称—时间对称光学系统的奇异点引入偶极辐射源，首次发现了基于约当矢量的新辐射机理，观察到辐射源可以完全不激发体系唯一存在的本征态，而是激发出了体系中不存在的约当矢量，打破了辐射源和辐射环境共同决定辐射场这一传统观点（图 1）。相关研究工作发表于《自然·物理》（Nat. Phys. 2020, 16, 571-578），并获得了第 49 届 Winter Colloquium on the Physics of Quantum Electronics 最佳摘要奖。

碱金属被理论预言具有更低金属损耗，但其器件在实验上一直未能实现。马仁敏课题组与南京大学研究团队合作首次实现了通讯波段极低阈值的钠基纳米激光器，创造了同类纳米激光器阈值新低，仅为 140 KW/cm^2。值得一提的是，得益于有效的封装保护，该激光器件在正常环境下 6 个月后仍然保持着良好的工作性能。相关研究工作发表于《自然》（Nature 2020, 581, 401-405），并入选 2020 年度中国半导体十大研究进展。

II. Microscale field manupulation and laser physics

Topological insulators are materials that behave as insulators in the bulk and as conductors at the edge or surface due to the particular configuration of their bulk band dispersion. However, up to date possible practical applications of this band topology on materials’ bulk properties have remained abstract. Ren-Min Ma’s group proposes and experimentally demonstrates a topological bulk laser (Nat. Nanotechnol. 2020, 15, 67-72). They pattern semiconductor nanodisk arrays to form a photonic crystal cavity showing topological band inversion between its interior and cladding area. In-plane light waves are reflected at topological edges forming an effective cavity feedback for lasing. The band-inversion-induced confinement occurs in a small range of wave vectors around the Γ point that provides a novel lasing mode selection mechanism and renders emission directionality. They also report an emerging out-of-plane radiation feature of spin-momentum locking in a non-Hermitian topological photonic system and demonstrate a high performance topological vortex laser based on it. This work is published in Physical Review Letters (Phys. Rev. Lett. 2020, 125, 013903), and is selected as Editor's Suggestion and Cover Article of Physical Review Letters.

The radiation of electromagnetic and mechanical waves depends not only on the intrinsic properties of the emitter but also on the surrounding environment. In the conventional wisdom, the environment is defined exclusively by its eigenstates, and an emitter radiates into and interacts with these eigenstates. Ren-Min Ma et al. show experimentally that this scenario breaks down at a non-Hermitian degeneracy known as an exceptional point. They find a chirality-reversal phenomenon in a ring cavity where the radiation field reveals the missing dimension of the Hilbert space, known as the Jordan vector. The work is published in Nature physics (Nat. Phys. 2020, 16, 571-578), and win the Best Abstract Award in 49th Winter Colloquium on the Physics of Quantum Electronics

Plasmonic materials with a lower loss than noble metals have long been sought. Ren-Min Ma et al. present stable sodium-based plasmonic nanolasers with state-of-the-art performance at near-infrared wavelengths. The sodium-based plasmonic nanolaser is with a record low threshold of 140 kW/cm^2 among plasmonic nanolasers at near-infrared wavelengths. The results indicate that the performance of plasmonic nanolasers can be significantly improved beyond that of noble metal limits, which provides tremendous opportunities for plasmonics, nanophotonics and metamaterials. This work is collaborated with Prof. Jia Zhu, Prof. Lin Zhou and Prof. Shi-Ning Zhu of Nanjing University. The work is published in Nature (Nature 2020, 581, 401-405) and is selected as "China's Top 10 Breakthroughs in Semiconductor 2020".

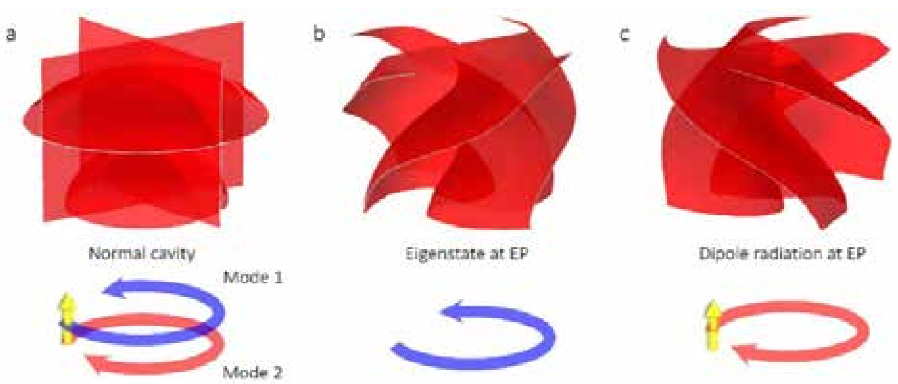


图 1. 约当矢量光辐射新机理；（a）偶极子辐射源在普通电磁环形谐振腔中激发出的辐射场；（b）引入宇称 - 时间对称折射率调制之后处于奇异点的环形谐振腔的辐射场；（c）偶极子辐射源激发的处于奇异点的环形谐振腔的辐射场

Figure 1. Chirality-reversal radiation at an exceptional point. (a) Radiation field from a single emitter inside a normal ring cavity. (b) Schematic of a ring cavity operating at an exceptional point, where the two eigenstates coalesce. (c) A single emitter can become fully decoupled from the coalesced eigenstate and radiate to the missing dimension with the opposite handedness.

三、狄拉克半金属中的拓扑量子态输运研究进展

除了石墨烯和拓扑绝缘体之外，狄拉克半金属最近被广泛的关注。狄拉克半金属在动量空间的三个方向都具有线性的能带色散关系，可以看作是石墨烯的三维类似。由时间反演对称性或空间反转对称性的破缺，狄拉克半金属能转变为具有奇异手征反常效应的外尔半金属，并具有受拓扑保护的费米弧状表面态，呈现出许多新奇的物理性质。

廖志敏课题组近年来在狄拉克半金属拓扑表面态量子输运特性方面取得系列进展。他们在狄拉克半金属 Cd_3As_2 纳米片的量子霍尔效应的观测中发现量子霍尔电导平台出现在奇数值位置，这反映了 Berry 相位的存在，给出了狄拉克半金属表面态拓扑性质的实验证据，相关成果发表于《物理评论快报》（Phys. Rev. Lett. 2019, 122, 036602）。进一步，他们通过探测自旋输运，发现了这个体系中拓扑表面态的自旋—动量锁定特性，并通过调控栅极电压，实现了自旋极化电流的开关效应，给出了狄拉克半金属中自旋极化费米弧表面态的实验证据，相关成果发表于《物理评论快报》（Phys. Rev. Lett. 2020, 124, 116802）。在这些工作的基础上，他们构筑了狄拉克半金属—超导近邻体系，发现了 4π 周期的超导电流，揭示了该体系中存在马约拉纳零能模；进一步调控栅压，发现超导临界电流在狄拉克点附近出现了一个最大值，这与费米弧表面态在狄拉克点具有最大的态密度是一致的。实验还发现超导临界电流在平行磁场呈现周期性振荡，揭示了拓扑表面态超导电流的轨道干涉效应，并发表于《自然·通讯》（Nat. Commun. 2020, 11, 1150）。有趣的是，在这个约瑟夫森结体系中，他们利用超导量子干涉效应，通过增加狄拉克半金属的沟道长度，发现了超导电流从三维体态到二维表面态，再到一维拓扑棱态的输运维度的降低过程，提供了高阶拓扑半金属量子态的实验证据，相关成果发表于《物理评论快报》（Phys. Rev. Lett. 2020, 124, 156601）。

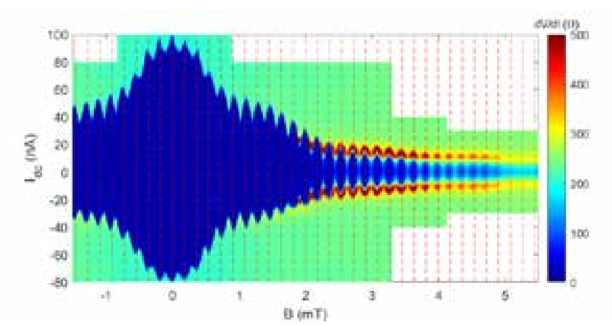


图 1. 狄拉克半金属 Cd_3As_2 纳米片约瑟夫森结中的量子干涉图样表明沿一维边缘态传输的超导电流。

Figure1. The SQUID-like pattern in a Nb-Dirac semimetal Cd_3As_2 nanoplate-Nb Josephson junction suggests that the supercurrent is strongly confined to the 1D edges of the junction.

III. Quantum transport properties of topological electronic states in Dirac semimetals

Dirac electronic materials beyond graphene and topological insulators have recently attracted considerable attention. Cd_3As_2 is a newly booming Dirac semimetal with linear dispersion along all three momentum directions and can be viewed as 3D analog of graphene. As breaking of either time reversal symmetry or spatial inversion symmetry, the Dirac semimetal is believed to transform into Weyl semimetal with exotic chiral anomaly effect. Topological surface states with Fermi arcs are predicted on the surface and have been observed by angle-resolved photoemission spectroscopy experiments.

The team led by Zhi-Min Liao of Peking University has achieved the first experimental evidence for the topologically non-trivial nature of surface states in a topological Dirac semimetal (Phys. Rev. Lett. 2019, 122, 036602). It is a significant advance upon recent related QHE measurements in Cd_3As_2. They have also provided direct evidence of the spin-polarized Fermi arc states in Dirac semimetals by transport measurements. The nonlocal spin signals can be completely switched off, owing to a gate-induced topological phase transition of the surface states, providing a deep understanding of the topological surface states of Dirac semimetals (Phys. Rev. Lett. 2020, 124, 116802). They further construct the Nb-Dirac semimetal Cd_3As_2-Nb Josephson junctions. Contrary to the minimum normal-state conductance, the Fermi-arc carried supercurrent shows a maximum critical value near the Dirac point, which is consistent with the fact that the Fermi arcs have maximum density of state at the Dirac point. Moreover, the critical current exhibits periodic oscillations with a parallel magnetic field, which is well understood by considering the in-plane orbital effect from the surface states (Nat. Commun. 2020, 11, 1150). Using superconducting quantum interference, they have demonstrated the transport dimensional reduction from a 3D bulk to a 2D surface, and then to 1D hinge states by increasing the geometry size in a proximity-induced superconducting Cd_3As_2 nanoplate, providing evidence of 1D hinge states and thus the higher-order topological semimetal of Cd_3As_2 (Phys. Rev. Lett. 2020, 124, 156601).

四、 Si 衬底上 GaN 基功率电子材料和器件

GaN 基宽禁带半导体具有带隙大、击穿电场高、饱和电子漂移速度大等优点，在新一代通用电源、5G 移动通讯等领域具有重要应用前景，对国家的高技术发展和国防建设具有重要意义。由于缺乏天然的 GaN 单晶衬底，GaN 基半导体材料和器件主要在异质衬底上外延生长。Si 衬底上外延 GaN 因具有大尺寸、低成本及易于集成等优点，成为近年来学术界和产业界高度关注的热点领域。

目前用于 GaN 外延生长的 Si 衬底主要是 Si(111) 衬底，其表面原子结构为三重排列，可为六方结构的 GaN 外延提供六重对称表面。Si(100) 衬底是 Si 集成电路技术的主流衬底，获得 Si(100) 衬底上 GaN 外延薄膜对于实现 GaN 器件和 Si 器件的集成至关重要。然而，Si(100) 表面原子为四重对称，外延生长时无法有效匹配；此外，Si(100) 表面存在二聚重构体，导致 GaN 面内同时存在两种不同取向的晶畴。迄今国际上还未能实现标准 Si(100) 衬底上单晶 GaN 薄膜的外延生长。宽禁带半导体研究中心沈波、杨学林课题组与刘开辉课题组、李新征课题组合作创造性地使用单晶石墨烯作为缓冲层，在标准 Si(100) 衬底上实现了单晶 GaN 薄膜的外延生长，并系统研究了石墨烯上 GaN 外延的成核机理和外延机制。该突破不仅为 GaN 器件与 Si 器件的集成奠定了科学基础，而且对当前国际上关注的非晶衬底上氮化物半导体外延生长和 GaN 基柔性器件研制具有重要的指导价值。相关工作发表于《先进功能材料》（Adv. Funct. Mater. 2019, 29, 1905056）。

在另一项工作中，他们针对 Si(111) 衬底上难以生长 GaN 厚膜的难题，提出了空位工程，在生长中故意引入高浓度 Ga 空位，使位错发生弯曲湮灭的同时很好地保持压应力，由此在 Si(111) 衬底上得到的 GaN 外延膜连续厚度高达 10.2 μm。在此基础上实现了准垂直结构 GaN 肖特基二极管，开关比为 10^{10}，为国际同类器件最高值。相关工作发表于《物理评论材料》（Phys. Rev. Mater. 2020, 4, 073402）。

IV. GaN Based Power Devices and Materials on Si Substrates

GaN based materials and power devices have attracted much attentions due to their promising applications in next generation power supply, and mobile communications, thanks to the properties of wide band gap, high breakdown field, and high electron velocity. Because native bulk GaN substrates are not available at low cost yet, GaN based materials are usually grown on foreign substrates. Due to the advantages of large-wafer size, low cost, and the great potential of the compatibility with existing processing technologies developed for Si integrated circuits, GaN based materials and power devices grown on Si substrates have attracted much more attentions.

The main Si substrates for GaN epitaxy is based on Si(111), which exhibits a surface with three-fold symmetry and can provide the six-fold symmetry orientation for wurtzite GaN epitaxy. However, the monolithic integration of GaN with current CMOS devices requires the growth of single-crystalline GaN on Si(100), the most foundational materials for ICs. Si(100) possesses a 4-fold symmetry and generates asymmetric surface domains due to surface reconstruction. GaN based materials directly grown on Si(100) exhibits 12-fold symmetry with rough surface due to the two-domain structure duplicated from Si(100) surface. Up to now, there has been no report yet to achieve epitaxial single-domain GaN directly on standard Si(100) substrates.

Bo Shen and Xuelin Yang’group at Research Center for Widegap Semiconductor in School of Physics, collaborated with Kaihui Liu’group and Xizhen Li’group in School of Physics, in School of Physics have demonstrated the epitaxy of single-crystalline GaN film on Si(100) substrate by utilizing single-crystalline graphene as a buffer layer. The nucleation mechanisms and domain evolutions are further clarified by surface science exploration and first-principle calculations. The work lays the foundation for the integration of GaN-based devices into Si-based integrated circuits, and also broadens the choice for the epitaxy of nitrides on unconventional amorphous or flexible substrates. The work was published in Advanced Functional Materials (Adv. Funct. Mater. 2019, 29, 1905056).

In addition, in order to address the challenging in growing thick GaN layer on Si (111) substrates, they have proposed a vacancy engineering, by intentionally introduced Ga vacancies during growth, which leads to dislocation inclination and annihilation in GaN. In addition, this dislocation inclination can proceed without relaxing the compressive lattice stress. Thus, a thick and crack-free GaN layer with a thickness of 10.2 μm has been achieved on Si(111) substrates. With these advances, a quasi-vertical GaN Schottky barrier diode with the highest on/off ratio of 10^{10} has been demonstrated. The work was published in Physical Review Materials (Phys. Rev. Mater. 2020, 4, 073402).

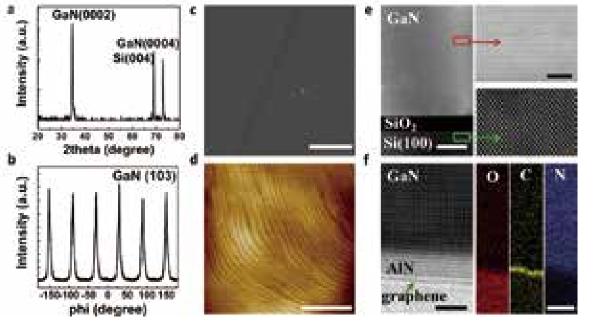


图 1. Si(100) 衬底上单晶 GaN 薄膜的外延生长

Figure 1. Epitaxial growth of single-crystalline GaN film on Si(100)

五、纳米尺度微纳光子结构超高分辨物性表征及应用

随着纳米光子学的发展，具有独特性质的人工微结构吸引了众多研究者的目光。得益于等离激元共振的光局域和场增强效应，金属纳米结构能够在纳米尺度调控光与物质的相互作用，比如促进光吸收、增强光发射。金属等离激元具有丰富的电磁模式，可以显著地改善周围的光场环境，提高光学态密度，提高量子跃迁的自发辐射速率。阴极荧光显微技术能够突破光学衍射极限，近年来被广泛地应用于微纳结构光学模式的探测，以及自发辐射的光学态密度分布的确定。利用亚纳米尺度的聚焦电子束，激发微纳结构的共振并产生荧光，可以实现深亚纳米尺度上的光学及量子现象探测。

辐射局域态密度直接影响量子发射器的自发辐射过程，深入了解手性光子环境对研究光与物质的相互作用具有重要的意义。方哲宇课题组利用高分辨阴极荧光显微系统，在纳米尺度上表征金属纳米结构的手性辐射局域态密度，在金纳米天线中实现了超过 93% 的手性局域态密度，另外还构建了金与 WSe_2 的复合结构。WSe_2 的辐射性质受到了调控，产生手性光致发光信号，如图 1 所示。该实验结果为研究手性量子纳米光子学，如单光子源和光发射器件的应用提供了有效的参考。相关研究成果发表于《纳米快报》（Nano Lett. 2019, 19, 775）。

针对日益增长的研究和设计需求，方哲宇课题组结合贝叶斯优化和卷积神经网络构建了一种自洽的框架——BoNet，实现了纳米结构对于超强光学手性的自学习。基于此框架，将纳米结构设计表示为图形，并输入卷积神经网络进行电场分布和反射光谱的学习，同时利用贝叶斯优化以实现对纳米结构远场光学手性的优化。利用 BoNet，针对远场反射光谱的圆二色性进行优化并逼近了其理论极限 (CD = 1)，在实验上也进行了光谱测量和模式表征，并对获得的强光学手性进行了分析与解释。相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2019, 123, 213902）。

根据手性调控原理，方哲宇课题组研究了一种利用超高分辨电子束操控金属等离激元调控低维量子材料谷极化的新方法。如图 2 所示，他们首先设计了结构对称的金纳米天线与 h-BN/ WSe_2/h-BN 的金属 / 介质复合纳米结构，利用入射电子束精准激发了金纳米天线的圆偏振偶极电磁模式，通过近场相互作用在纳米尺度实现了对低维材料谷极化的操控，能够在电子束移动步长 50nm 内实现谷极化的“开”和“关”，以及 100nm 内的谷极化态反转。该工作提供了一种谷极化的近场激发方式，为深亚波长谷电子学研究、光电路集成和未来的量子信息科技提供了新的研究方向。相关研究成果发表于《自然通讯》(Nat. Commun. 2021, 12, 291）。

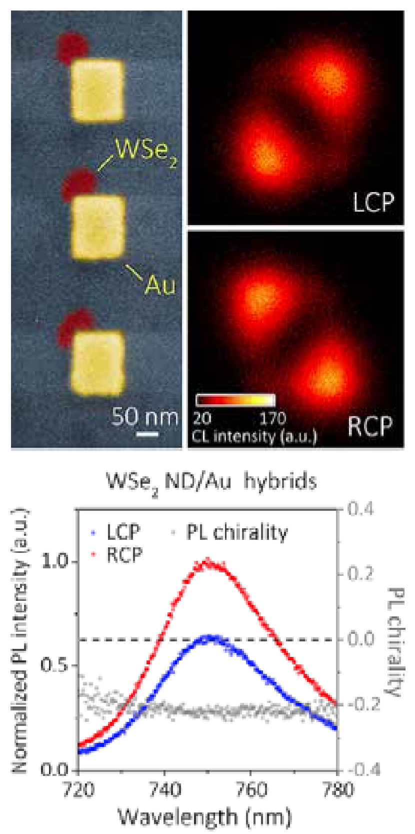


图 1. 手性光子局域态密度的表征及光学激发金和 WSe_2 复合结构的光谱

Figure 1. The cathodoluminescence characterization of chiral photonic local density of states and photoluminescence spectra of Au/WSe_2 hybrid structure

V. Nanoscale Resolved Characterization and Applications of Nanophotonic Structures

With the development of nanophotonics, artificial nanostructures with characteristic properties inspire wide interest for researches and applications. With the exploitation of plasmonic light localization and field enhancement effects, metallic nanostructures exhibit unprecedented talents for the manipulation of light-matter interactions at the nanoscale, such as enhancing light absorption and emission. Intriguingly, abundant electromagnetic modes of metallic nanostructures also provide a versatile platform for tailoring the photonic environment and increasing the local density of states (LDOS), thus allowing the flexible control of spontaneous decay rate. As a nanoscale characterization technique, cathodoluminescence (CL) microscopy which breaks through the optical diffraction limit, has been successfully used for plasmonic electromagnetic field investigation and the detection of radiative LDOS. Under the electron-beam stimulation, surface plasmon modes of metallic nanostructures can be effectively excited, contributing to CL signals, which can realize the detection of optical and quantum phenomena at deep sub-nanoscale.

The chiral radiative properties of quantum emitters strongly depend on the photonic environment, which can be drastically altered by plasmonic nanostructures with a high LDOS. Hence, precise knowledge of the chiral photonic environment is essential for manipulating the chirality of light-matter interactions. The research team led by Professor Zheyu Fang has imaged chiral radiative LDOS distributions of single plasmonic nanostructures at the nanoscale by using CL nanoscopy. Radiative LDOS hot-spots with the chirality larger than 93% are obtained by properly designing chiral plasmonic modes of Au nanoantennas. After forming monolayered WSe_2 nanodisks/Au hybrid structures, the chiral radiative properties of WSe_2 are significantly modified, leading to chiral photoluminescence, shown as Figure 1. Our experimental concept and method facilitate future applications in chiral quantum nanophotonics such as single-photon sources and light emission devices. This work has been published in Nano Letters (Nano Lett. 2019, 19, 775).

To satisfy increasing demands for structure designs, Fang's Group presented a self-consistent framework of BoNet [Bayesian optimization (BO) and convolutional neural network (CNN)] for self-learning perfect optical chirality. With parameterizing structure designs into features, BoNet directly learns electric field distributions and reflection spectra properties. Meanwhile, BO is performed to optimize circular dichroism in the far-field. Utilizing this self-consistent framework, optical chirality in the reflection spectra is optimized and approaches its theoretical maximum (CD=1). After measuring their spectra and analyzing the corresponding electric-field distributions, a detailed physics explanation for the origin of obtained strong CD is given. The related work has been published in Physical Review Letters (Phys. Rev. Lett. 2019, 123, 213902).

Recently, Fang's Group reported a new method to manipulate valley polarization of low-dimensional quantum material via metallic surface plasmon excited by an electron beam with a high spatial resolution. As shown in Figure 2, researchers firstly designed achiral nanoantenna and h-BN/WSe_2/h-BN hybrid nanostructure and precisely excited the circularly polarized dipole modes in Au nanoantenna by the incident electron beam. The control of valley polarization of low-dimensional material at the nanoscale by near-field interaction can be realized, leading to the switch of ‘on’ and ‘off’ state of valley polarization within a 50 nm move of electron beam excitation position, as well as the reverse of valley polarization state within about 100 nm. This report provides a near-field excitation methodology of valley polarization, which offers exciting opportunities for deep subwavelength valleytronics investigation, optoelectronic circuits integration and future quantum information technologies. This work has been published in Nature Communications (Nat. Commun. 2021, 12, 291).

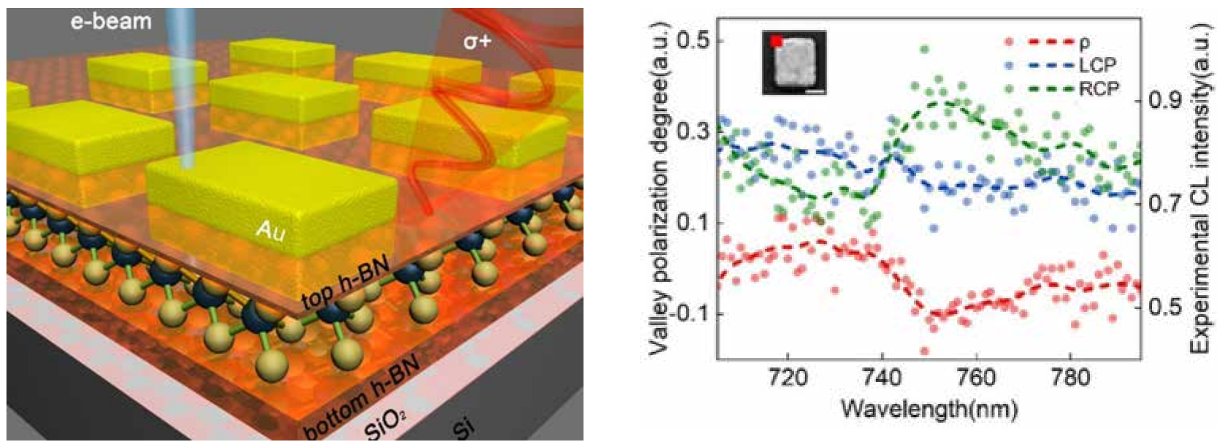


图 2. 电子束激发 h-BN/WSe_2/h-BN 异质结和金纳米天线杂化结构的示意图及实验测量的谷偏振度

Figure 2. Schematic illustration of h-BN/WSe_2/h-BN and Au rectangle nanoantenna hybrid structure and experimental measured valley polarization degree

03 现代光学研究所 Institute of Modern Optics

现代光学研究所于 1933 年由饶毓泰先生开创，有着悠久的历史和良好的研究基础。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，现任所长为龚旗煌院士。 北京大学光学学科是“211 工程”、“985 工程”和“双一流”重点建设内容，是国家重点学科和“人工微结构和介观物理国家重点实验室”的主要支撑学科。以现代光学研究所为基地，北京大学还与中国科学院联合成立了“中科院—北京大学超快光科学和激光物理联合中心”，2020 年，为了服务“实施创新驱

动战略、建设创新型国家”的战略定位，响应国家“长三角一体化”的战略部署，北京大学与南通市人民政府合作共建北京大学长三角光电科学研究院。 现代光学研究所包含光学、原子与分子物理两个二级学科。研究所始终坚持高质量科研队伍建设， 拥有国家自然科学基金委数理学部光学学科创新群体和科技部重点领域创新团队。通过培养和引进一批优秀青年学者，十多年来研究队伍发展迅速，科研水平逐步提升。截至 2020 年底，现代光学研究所有固定人员 26 人，其中教授 12 人（含博雅讲席教授 1 人、博雅特聘教授 6 人），博雅青年学者 6 人，副教授 2 人，教授级高级工程师 1 人，高级工程师 1 人，工程师 2 人。固定人员中包括中科院院士 1 人，长江特聘教授 3 人，国家 973 项目和国家重大研究计划项目首席科学家 2 人，万人计划领军人才 3 人，杰出青年基金获得者 7 人，优秀青年基金获得者 7 人。光学研究所成员在各自领域均已取得非常显著的成绩并得到国内外同行的肯定。多位研究所成员当选美国光学学会（OSA），国际光学工程学会（SPIE）和英国物理学会（IoP） Fellow，担任 Advanced Optical Materials、Optics Letters、Chemical Physics Letters 等国内外重要杂志编委和 Photonics Asia, Nonlinear Optical Phenomena and Applications（SPIE）, Asian Conference on Ultrafast Phenomena 等学术会议主席等职。

2019—2020 年度，现代光学研究所累计发表 SCI 论文 130 余篇，其中，2019 年朱瑞研究员、龚旗煌教授小组发表 Nature Reviews Materials 学术论文一篇；2020 年肖云峰教授、龚旗煌教授团队发表 Nature Communications 学术论文一篇。人才培养方面，2019 年刘运全教授当选中国光学学会会士，2019 年王剑威研究员获得饶毓泰基础光学奖二等奖， 2020 年李焱教授当选中国光学学会会士，2020 年肖云峰教授获得陈嘉庚青年科学奖。学生培养方面，2019 年曹启涛同学获得王大珩学生光学奖， 2019 年韩猛同学获得国际阿秒科学技术大会（ATTO2019）学生海报奖。 现代光学研究所以提高创新能力和服务国家重大需求为责任，以建设一流学科为目标，在多年的科研基础上，凝练形成了具有特色和优势的介观光学与纳米光子学、飞秒科学与非线性光学、量子光学与量子信息、强场原子与分子物理、光电功能分子与材料和器件等多个研究方向。在国内外的影响力日益增加，建成了具有国际竞争力的光学和原子与分子物理科研和教学的重要基地。光学学科为学校“双一流” 建设做出了重要贡献。

The modern optics research at Peking University (PKU) was initiated by Mr. Yutai Rao in 1933. It has a long history and a good research foundation. The Institute of Modern Optics (IMO) was established in May 2001, based on the previous Optics discipline of Department of Physics at PKU. The present director is Professor Qihuang Gong, who is an academician of the Chinese Academy of Sciences (CAS). The optics discipline at IMO is a National Key Discipline, and is a key construction content of “211 Project”, “985 Project”, and “The Double First Class”. IMO constitutes one of the two research branches in the State Key Laboratory for Artificial Microstructure and Mesoscopic Physics. IMO has established several joint research centers, such as the CAS-PKU Ultrafast Optics & Laser Physics Center. In 2020, Peking University Yangtze Delta Institute of Optoelectronics was jointly established by PKU and Nantong Municipal People's Government in order to serve the strategic orientation of “implementing innovation driven strategy and building an innovative country”, and respond to the national strategic deployment of “Yangtze River Delta integration”. IMO has two secondary disciplines of optics and atomic/molecular physics. IMO always adheres to constructing a high-quality scientific research team, and possesses the Optics Discipline Innovation Group of the National Natural Science Foundation of China (NSFC) and the Key Fields Innovation Team of the Ministry of Science and Technology of China. The research team has developed rapidly in the past ten years through training and introducing a lot of outstanding young scholars. By the end of 2020, IMO has 26 faculty members (including 22 academic faculty members and 4 engineers). There are 12 professors (including 1 Boya Chair Professor, 6 Boya Distinguished Professors), 6 Boya Young Scholars, 2 Associate Professors, 1 senior engineer with the rank of professor, 1 senior engineer and 2 engineers. There are 1 academician of the CAS, 5 Changjiang Scholars, 2 Chief Scientists of 973 projects, 3 Leading Talents in Scientific and Technological Innovation of Ten Thousand People project. Seven faculties won the Distinguished Young Scholars of NSFC. Seven faculties won the Excellent Young Scholars of NSFC. Many faculties have received great achievements and obtained great recognitions in their research fields. Several faculties were elected as the American Optical Society (OSA) Fellow, International Society for Optical Engineering (SPIE) Fellow, and the Institute of Physics (IoP) Fellow. Many faculty members were elected as editorial committee or vice editor-in-chief of the journals including Advanced Optical Materials, Optics Letters, and Chemical Physics Letters. Many faculty members were elected as president of the international academic conferences including Photonics Asia, Nonlinear Optical Phenomena and Applications (SPIE), Asian Conference on Ultrafast Phenomena.

During 2019-2020, IMO faculties have published more than 130 papers. In 2019, Professors Rui Zhu and Qihuang Gong published a paper in Nature Reviews Materials. In 2020, Professors Yunfeng Xiao and Qihuang Gong published a paper in Nature Communications. In the aspect of talent development, Professor Yunquan Liu was elected as the Chinese Optical Society Fellow in 2019. Professor Jianwei Wang won the second prize of Rao Yutai basic optics Award in 2019. Professor Yan Li was elected as the Chinese Optical Society Fellow in 2020. Professor Yunfeng Xiao won the Chen Jiageng Award for Youth Science. In the aspect of student development, Meng Han won the Student Poster Award at the International Congress of attosecond science and technology (ATTO2019) in 2019.

IMO takes improving the innovation ability and serving the major needs of the country as the responsibility, and takes building a first-class discipline as the goal. Based on many years of scientific research, IMO has condensed and formed many research directions with remarkable characteristics and advantages, including mesoscopic optics and nanophotonics, femtosecond science and nonlinear optics, quantum optics and quantum information, strong field atom and molecular physics, optoelectronic functional materials and devices. With its increasing international impact, IMO has become globally competitive basis for research and education in optical science, and atom and molecule physics. The Optics discipline has made important contributions to the “double first class” construction of PKU.

一、飞秒—纳米超高时空分辨光子学研究进展

飞秒纳米超高时空分辨光子学是介观光学与微纳光子学领域的研究前沿和国际竞争的焦点之一，对于推动新物理探索和光子学器件研究都具有非常重要的意义。龚旗煌院士团队在国家重大科研仪器研制项目的支持下，研制成功飞秒—纳米超高时空分辨光学实验系统。该实验系统能够同时实现几个飞秒的超高时间分辨率和四纳米的超高空间分辨率，成为介观光学与微纳光子学前沿研究的强大实验测量手段。研究团队利用超高时空分辨光发射电子显微镜（PEEM），首次从近场微观角度揭示了局域表面等离激元近场增强与退相干时间的内在关联，相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2020, 124, 163901）。研究团队还首次从时间和能量布居演化两个维度全面揭示了单层 WS_2 超快电子冷却和弛豫动力学过程，相关成果发表于《纳米快报》（Nano Lett. 2020, 20, 3747）。

研究团队在表面等离激元光子学实验中，利用 PEEM 高空间分辨率的优势直接观测到金纳米结构二聚体阵列体系中局域表面等离激元模式的近场分布，通过激发光波长依赖的光发射强度测量和基于超短脉冲的光发射自相关测量，分别获得同一结构的表面等离激元的近场增强和退相干时间，发现两者之间的关联依赖于金纳米结构二聚体间隙和激发光的偏振方向，首次揭示出这种关联性由近场—远场耦合和纳米结构局域作用共同决定。研究成果对于推动表面等离激元光子学研究具有重要意义。研究团队在二维材料超快动力学实验中，发现单层 WS_2 存在 0.3ps 和 3ps 两个时间尺度的超快弛豫动力学过程（图 1），通过能量分辨的 PEEM 测量，发现第一个过程与电子在导带的冷却相对应，第二个过程反映了电子在导带底的弛豫。通过对比悬空的单层 WS_2 样品的 PEEM 测量，并结合荧光光谱和拉曼光谱表征，发现该弛豫过程主要与缺陷态有关。此项研究借助于 PEEM 在空间、时间与能量等多维度的分辨能力，揭示了典型 TMDs 材料单层 WS_2 超快的电子冷却和缺陷捕获的动力学过程。研究还发现缺陷态的产生与真空下光照有关，这对于二维材料及其应用研究具有重要意义。

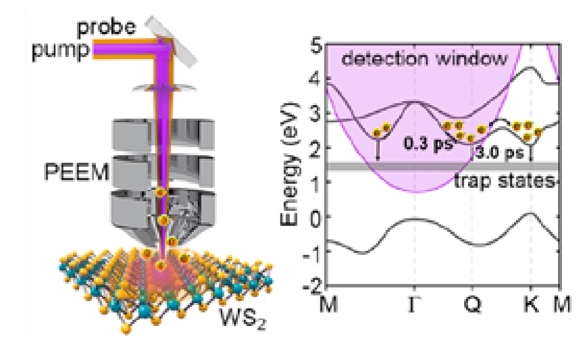


图 1. 飞秒纳米时空分辨测量单层 WS_2 超快电子冷却和弛豫动力学过程

Figure1. Femtosecond-nanometer temporospatial resolution measurement of ultrafast electron cooling and relaxation dynamics of single layer WS_2

I. Research progress of femtosecond-nanometer ultrahigh temporospatial resolution photonics

Femtosecond-nanometer ultrahigh temporospatial resolution photonics is one of the research frontiers and international competition focus, having great significance to promote the exploration of new physics and photonic device research. CAS Academician Qihuang Gong’s group has successfully developed femtosecond-nanometer ultrahigh temporospatial resolution experimental system under the support of national major scientific instrument development project. This experimental system has a ultrahigh time resolution of several femtoseconds and ultrahigh spatial resolution of four nanometers, becoming a powerful experimental measurement method for the research of mesoscopic optics and micro/nano photonics. For the first time, the research group revealed the inherent correlation between near-field enhancement and decoherence time of localized surface plasmon polarization from the near-field microscopic point of view by using ultrahigh temporospatial resolution photoemission electron microscopy (PEEM). These results were published in Physical Review Letters (Nano Lett. 2020, 20, 3747). Moreover, for the first time, the research group revealed the cooling and relaxation dynamics of ultrafast electrons in monolayer WS_2 from two dimensions of time and energy population evolution. These results were published in Physical Review Letters（Nano Lett. 2020, 20, 3747）.

In the experiment of surface plasmonics, the near-field distribution of localized surface plasmon modes in gold nanostructure dimer arrays was observed directly by using the advantage of high spatial resolution of PEEM. Through the measurement of optical emission intensity depended on the wavelength of excitation light and the autocorrelation measurement of optical emission based on ultrashort laser pulse, the near-field enhancement and decoherent time of identical gold nanostructure was obtained separately. It was found that the correlation depended on the interval of gold nanostructure dimer and polarization direction of excitation light. For the first time, it was revealed that the correlation was jointly determined by the coupling between near-field and far-field, and the nanostructure localization. This research work was very important for the study of surface plasmonics. During the research of ultrafast electron cooling and relaxation dynamics of single layer WS_2, it was found that there existed two time-scale ultrafast dynamics processes with a relaxation time of 0.3 ps and 3 ps respectively (as shown in Figure 1). It was also found that the first process corresponded to the cooling of electrons in conduction band, and the second process corresponded to the relaxation of electrons in the bottom of conduction band based on the energy resolution PEEM measurement. It was revealed that the relaxation process was mainly related to the defect states through comparing the PEEM measurement results of suspended single-layer WS_2 and combining fluorescence and Raman spectroscopy characterization. This research work revealed the dynamic process of ultrafast electron cooling and defect trapping in single-layer WS_2 based on the multiple dimensional resolution energy in space, time and energy of PEEM. It was also found that the generation of defect states was related to the light illumination in vacuum, which was very important for the study of two-dimensional materials and their applications.

二、提出一种改进型阿秒钟实现对量子遂穿时间的统一性描述

关于量子隧穿有一个充满争议的基本问题——隧穿的过程是否需要时间？如果需要时间，又该如何测量呢？随着超短激光脉冲的问世，人们一直希望在强场隧道电离的范畴来解决这个重要争议问题，由此学术界提出可以通过阿秒钟方案测量隧道电离的发生时间（即时间延迟），阿秒钟可以巧妙地将隧穿时间延迟转化为光电子发射角的偏移，但大家一直未对实验结果取得一致的看法。经过十

多年的研究，学术界基本上形成了两种对立的观点——瞬时隧穿（隧穿几乎不需要时间）与延时隧穿（隧穿需要百阿秒量级的时间），这两种观点都有相应的理论与实验支持。传统的阿秒钟是采用单个椭圆偏振或近圆偏振的激光脉冲，因此传统阿秒钟的校准依赖于少周期激光的载波包络相位和椭偏率的确定，它们的噪声抖动会给阿秒钟的测量带来很大的误差。

刘运全教授的课题组提出并实现了一种全新改进型阿秒钟，在一束圆偏振飞秒激光场中加入了另一束线偏振的倍频光来校准阿秒钟，使得光电子发射角偏移量的定标更加精准。这种增强型阿秒钟使得隧穿时间的测量更加准确可靠。理论上还证明了上述两种看似对立的隧穿图像可以被统一在同一个理论框架下进行描述。在强场近似理论框架下，他们分别建立了瞬时隧穿图像以及基于 Wigner 表象的延时隧穿图像，对于增强型阿秒钟的实验结果，这两种隧穿图像的理论结果都与实验结果相符合。因此，这是第一次使用同一个理论框架和同一个实验完美地统一了长期的学术争议，为隧穿时间研究提供一种思路。研究工作发表于《物理评论快报》（Phys. Rev. Lett. 2019, 123, 073201）。

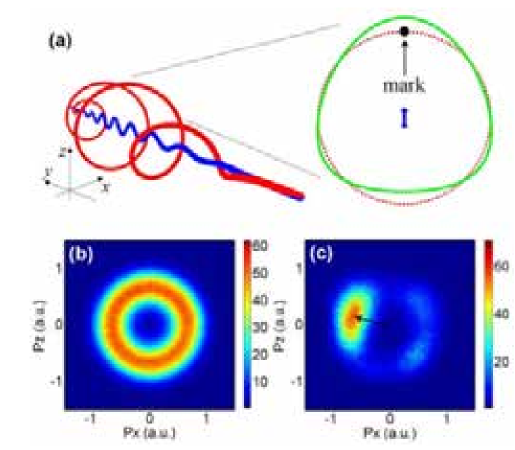


图 1.（a）线偏振的二次谐波打破了圆偏振的基频光的对称性，标记了最大值激光电场的方向与时刻；（b）不加二次谐波时测量的光电子动量谱；（c）加入标记光场后测量的光电子动量谱

Figure 1. (a) The laser fields in the improved attoclock. A perturbative linearly-polarized 400-nm light field (blue curve or arrow) is used to mark the ionization instant (black dot) in the attoclock constructed by an intense circularly-polarized 800-nm light field (red curve or dots). The green curve represents the synthesized light field. (b, c) The measured photoelectron momentum distributions in the polarization plane without and with the 400 nm field, respectively

II. Unifying Tunneling Pictures of Strong-Field Ionization with an Improved Attoclock

The issue of tunneling time, i.e., how long a particle passes through a potential barrier, is replete with controversy and paradoxes since the birth of quantum mechanics. The controversy stems from the fact that time is not a quantum operator. Advances in laser technology have led to the generation of ultrashort intense laser pulses. The light electric field is comparable and is even much stronger than the Coulomb potential in atoms, rekindling the passion of solving the puzzle by means of the laser-induced tunneling in strong-field regime. It has been shown that hundreds of attoseconds of time delay with non-vanishing exit momenta exist in tunneling ionization according to the Wigner formalism. The finite tunneling time delay is further validated by the numerical virtual detector method and the experiments, including the experiment performed with a gas mixture of argon and krypton atoms. However, why does the same issue have the two wildly different conclusions? Both seem to be convincing.

Recently, the group lead by Prof. Yunquan Liu have demonstrated a novel attoclock. In this geometry,

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they added a perturbative linearly polarized light field at 400 nm to calibrate the attoclock constructed by an intense circularly polarized field at 800 nm. This approach can be directly implemented to analyze the recent hot and controversial topics involving strong-field tunneling ionization. The generally accepted picture is that tunneling ionization is instantaneous and that the tunneling probability synchronizes with the laser electric field. Alternatively, recently it was described in the Wigner picture that tunneling ionization would occur with a certain of time delay. They unified the two seemingly opposite viewpoints within one theoretical framework, i.e., the strong-field approximation (SFA). They illustrated that both the instantaneous tunneling picture and the Wigner time delay picture that are derived from the SFA can interpret the measurement well. The results show that the finite tunneling delay will accompany nonzero exit longitudinal momenta. This is not the case for the instantaneous tunneling picture, where the most probable exit longitudinal momentum would be zero. This work has been published onPhysical Review Letters (Phys. Rev. Lett. 2019, 123, 073201).

三、强场物理理论研究进展

超短激光与原子分子的相互作用将导致很多新奇的、高度非线性的物理现象。利用特定的激光脉冲或精心设计的泵浦探测实验，人们一方面通过观测现象来了解原子分子内部的结构和动力学过程；另一方面，通过测量特定的物理量也可以反推激光脉冲本身的各种参数。彭良友教授和龚旗煌教授领导的团队近年来在相关理论研究方面取得了系列进展。

利用超短强激光脉冲，人们可以实现原子分子尺度下电子位置的超快及超高精度的位置控制。然而，现有的实验探测技术却无法实现对电子如此微小位移的精确测量。团队利用强场电离中的时间双缝干涉，理论上提出了对电子在超短激光脉冲下的微小位移进行测量的新方案，使分辨率可达 0.01 纳米。为了测量电子在超短脉冲作用下的位移，他们把导致电子位移的任意波形的超短脉冲置于两束较长反向旋转的圆偏振光之间。两束反旋向的圆偏振光先后电离电子，构成时间上的电子波包双缝干涉，在电子动量谱中产生涡旋结构。在没有中间的超短脉冲时，该涡旋结构角向是均匀分布的。若中间加入一束任意的被测超短脉冲，它将作用于前一圆偏光电离的电子波包使之产生微小位移。这个微小位移使得电子波包获得一个额外相位，从而导致先后两个电子波包的干涉结构在角方向产生了非均匀性。他们提出，通过测量这个非均匀的角向分布可以准确地提取出电子在超短脉冲作用下产生的亚纳米量级的微小位移。该理论方案对激光的焦斑效应以及两束圆偏振光的相位抖动具有很好的抗干扰能力。相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2019, 122, 053201）。

研究团队还与吉林大学丁大军教授领导的实验组紧密合作，理论上提出并在实验上实现了对椭圆偏振强激光椭偏率的原位测量新方案。他们利用两束其它参数相同而旋向相反的椭偏光来电离惰性气体氙（Xe）原子，强场电离得到的电子阈上电离谱和单电离离子总产率谱敏感地依赖于两束光脉冲之间的延时。这些能谱和产率随延时的周期性调制，能够准确反映一个光学周期之中椭圆偏振光的电场强度的最小和最大值间的比值，因此可以用来准确提取每一束椭偏光的椭偏率。研究表明，这一椭偏率测量方案在很大的激光参数范围内普遍适用。这一工作在准确表征超快强激光场的性质方面迈出了重要一步，将对强场物理研究中精细操控原子分子内的超快过程起到重要推动作用。相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2019, 122, 013203）。

氦原子是最简单的多电子体系，是研究强场物理中电子—电子关联效应的最佳载体。2020 年，团队与德国法兰克福大学 Dörner 研究组、深圳大学的姜维超助理教授、维也纳工业大学 Burgdörfer 教授合作在氦原子双电离研究方面取得了重要进展。当前，世界上多个实验室和重大科学设施致力于产生各种新型光源，包括自由电子激光和台式超短强激光脉冲。利用这些光源与物质的相互作用，很多崭新的物理机制不断被人们发现和认识。随着光源和探测技术的发展，大光子能量下的光电离过程成为新的研究对象。当光子波长和电子运动尺度可比拟时，非偶极效应将不可忽略，为理论计算和实验测量带来了新的挑战。另外，在强 XUV 脉冲作用下，为理论计算的稳定性和复杂度方面提出了更苛刻的要求。团队长期致力于发展系列数值方法精确求解少电子原子分子体系的含时薛定谔方程，开发了数套大规模并行计算程序，部分程序的运行效率和计算精度达到了业界领先水平。在原有工作的基础上，此次他们将氦原子双电离的程序分别拓展到能精确处理任意偏振光下电离时的非偶极效应以及高强度 XUV 脉冲下的双电离过程。

当考虑了光的非偶极作用以后，光压和光子线动量对电离过程的影响便能得到有效研究，氦原子单光子双电离时光子线动量在离子、两个电子三者间如何转移和分配是一个重要问题。团队利用新开发的包含非偶极效应的全维含时薛定谔方程计算程序，精确计算了氦原子单光子双电离过程中的离子、电子在激光偏振方向所获得的动量及能量的一阶微分谱，其结果与德国合作组近期的实验测量数据高度吻合。进一步的理论分析表明，双电离的电子动量—能量线性关系与氢原子的既有相似之处，也有电子关联带来的重要影响，并且进一步观察到了离子的动量与光子的动量反向这一反常现象。这一工作开启了多电子体系中的光子线动量转移和分配的研究，近期发表于《物理评论快报》（Phys. Rev. Lett. 2020, 124, 043201）。

研究团队与来自深圳和维也纳的合作者一起，利用推广优化后的氦原子双电离程序，在理论上预言了单个超强 XUV 激光脉冲与 He 原子相互作用时在双光子双电离谱中将会出现一种新奇的双电子波包干涉现象。研究团队在他们前期双电离的虚序列图像的基础上（Phys. Rev. Lett. 2015, 115, 153002），进一步加上强场近似，建立了相应的半解析模型，明确解释了导致双电子能谱中干涉结构的物理机制。他们系统的理论研究表明，这种双电子能谱上新型的网格状干涉结构，与超短强 XUV 激光脉冲下的动态干涉效应、双电离的多个电离通道，以及两电子的交换对称性等密切相关。研究指出，与单电离过程中的动态干涉相比，双电离中动态干涉出现的条件更为宽松，为动态干涉在实验上的验证提供了新的可能。相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2020, 124, 043203）。

III. Theoretical progresses in strong field physics

The interaction of short laser pulses with atoms and molecules will induce many novel nonlinear phenomena. On one hand, by using specifically designed laser pulses or pump-probe experiments, one can examine the structure and dynamics inside atoms and molecules. On the other hand, one can characterize many important parameters of laser pulses themselves by measuring appropriate physical observables. The

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research team led by Prof. Liang-You Peng and Prof. Qihuang Gong have made several progresses in the years of 2019-2020.

By utilizing the ultrashort laser pulses, people can control of the electron position inside atomic and molecular targets. However, the precise measurement of such a tiny displacement of electron is beyond the current technologies. Using the double-slit interference of time domain in strong field ionization, the team theoretically proposed a method to achieve such a goal with a spatial resolution of 0.01 nm. In this scheme, a target short pulse of arbitrary waveform is placed between two time-delayed counter-rotating circularly polarized pulses, which will launch two ionizing electronic wave packets with a certain time interval. One can observe vortex structures in the ionized electron momentum spectrum. Should there be no target pulse, the angular distribution of the vortex is evenly distributed. On the contrary, an extra phase will be added to the first electronic wave packets due to the existence of the target pulse, which will change the angular structures into uneven distributions. The team found that it is possible to accurately extract the tiny electron displacement caused by the target pulse from the uneven angular distributions. In addition, they showed that their method is robust against the laser focusing effects and the jitter of the carrier envelope phase of the circular laser pulses. This work has been published in Physical Review Letters (Phys. Rev. Lett. 2019, 122, 053201).

The ellipticity of a strong laser pulse is an important parameter in strong field physics. However, its acquisition is usually based on optical methods, which are especially not accurate at a high ellipticity. The team closely collaborated with a team lead by Prof. Dajun Ding in Jilin University, proposing and demonstrating an in-situ measurement method. In this method, two counter-rotating but otherwise identical elliptically polarized pulses are used to ionize Xe in the gas phase. By finely tuning the time delay of the two pulses within a laser cycle, the ionized electron spectrum and the yield of the singly charged Xe ion will be delicately modulated, which will truthfully reflect the maximum and the minimum of the strength of electric field synthesized by the two pulses. They identified that it is possible to accurately extract the ellipticity of each pulse. They found this method is applicable in a wide range and is robust against the fluctuations of laser parameters. This work was published in Physical Review Letters (Phys. Rev. Lett. 2019, 122, 013203).

Helium is the simplest multiple-electron system and a realm to study the electron-electron correlation in strong field physics. In 2020, the team collaborated with colleagues from Frankfurt, Vienna, and Shenzhen made some progress in double ionization of He. Nowadays, many labs and large facilities aim to build many versatile and novel light sources, with the expectations of identifying new physical phenomena in different regime of light parameters. In recent years, intense lasers in short wavelengths have attracted much attention. In such a regime, the nondipole effects cannot be neglected, which pose significant challenges in theoretical simulations and experimental measurements. The team have extended their numerical methods for the two-electron system to include such effects and to be able to deal with the cases of intense xuv pulses, respectively. With the consideration of nondipole terms in the Hamiltonian, it is possible to investigate the transfer and partition of the photon linear momentum among the ion and the two electrons. For the simplest one-photon double ionization, the team accurately calculated the differential and integral spectra relevant to the many-body breakup, which excellently agree with recent experimental measurements by the group led by Prof. Dörner in Frankfurt. Subsequent analysis showed that the law of the photon linear momentum transfer in He has some similarities with that of H, but with significant effects induced by the electron-electron correlation. In addition, they found that the momentum gained by the ion is opposite to the direction of the light propagation. This work opened the study of photon momentum transfer in many-electron system and was published in Physical Review Letters (Phys. Rev. Lett. 2020, 124, 043201).

In addition, a joint theoretical effort has been made by this team with colleagues from Shenzhen and Vienna, to investigate the two-photon double ionization of helium by extremely intense xuv pulses. In this study, they found a novel interference pattern of two-electron interference. Based on a sequential picture proposed earlier by the team (Phys. Rev. Lett. 2015, 115, 153002), they established a semi-analytical model to successfully explain the features in the interference and the underlying physical mechanisms. Their studies showed that the grid-like interferences originate from the interplays of the multiple ionization pathways, the dynamical interference effects, and the exchange symmetry of the two electrons. They pointed out it is easier to observe the dynamical interferences in the two-electron than in the single-electron system. This work has been published in Physical Review Letters (Phys. Rev. Lett. 2020, 124, 043203).

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

为了发展新中国的核事业，1955 年周恩来总理亲批成立北京大学物理研究室，几十年来为国家培养了五千多名核科学高级人才，其中包括两弹一星元勋朱光亚、西北核基地司令钱绍钧等 22 位两院院士，被誉为“核科学家摇篮”。新时期面向能源和生命健康等人类生存与发展等重大问题，北京大学重离子物理研究所探索加速器前沿科技，聚焦能源和肿瘤放疗中的挑战性问题，建设国际顶尖的核科学研究和人才培养基地。

作为新中国第一个高校核科学人才培养基地，在陈佳洱院士的带领下北京大学一直引领着中国加速器科学的发展。研究所近年来在激光加速、超导加速、核物理及核磁共振技术等领域进一步获得重要突破，得到了习总书记的持续关注。近五年承担 48 项国家科研项目，包括 10 个国家重点研发计划和重大科学仪器设备开发项目，到账经费接近 6 亿元。在 Nature、PRL 等期刊发表论文近 400 篇，获得国际国内奖励 20 余项。

研究所拥有一支年龄结构合理的高水平师资队伍，包括院士 3 位（含双聘 1 位）、海外高层次人才 2 位、国家杰青 4 位、国家级青年人才 6 位和一个国家自然科学基金创新群体团队。研究生主要来源于国内重点大学的优秀毕业生，学科为他们建设了一套完善的课程和独具特色的核科学教学实验室。毕业生大部分进入国内外高校、知名机构以及大型企业。有上百人进入中物院、中核集团、西北核技术研究院等国

家重要单位，部分已经成为单位学术骨干和带头人；优秀毕业生进入国家经济或人民健康领域，取得了良好的社会效益。

研究所多位教师在国内外学术组织担任副理事长、副主席、主任，获得了重要奖励。陈佳洱院士曾担任中国物理学会理事长、IUPAP 副主席。颜学庆获得 2019 年全球加速器 Hogil Kim 奖（大陆首位）和 2020 何梁何利科技进步奖；高家红担任国际人类脑图谱学会主席，为该学会成立 25 年以来首位担任主席的亚洲人；秦庆就任欧洲同步辐射装置 ASD 主任，为获得同类职位的首位亚洲人；王宇钢担任核径迹与辐射测量国际委员会执行副主席；刘克新就任中国粒子加速器学会副理事长。青年科学家不断涌现，如乔宾获亚太等离子体物理杰出青年奖，郭志彬获 Pellat Festival 奖，弓正等 3 名博士生获亚太等离子体物理 U30 奖等。北大核科学论坛是国内知名的系列学术讲座，每年举办或协办“国际高能量密度物理会议”和“高能量密度物理青年论坛”系列会议。

Peking University has long been leading the development of accelerator science in China. As the first nuclear science facility based in a Chinese university, the Institute of Heavy Ion Physics led by Prof. Chen Jiaer has long been standing at the forefront of both research and training. Over the past few decades, more than 5000 senior nuclear science talents have graduated, including Zhu Guangya and Qian Shaojun and 20 other academicians of the Chinese Academy of Sciences. In the current era, facing the major issues in energy and health, the Institute of Heavy Ion Physics continues to develop cutting-edge accelerator technologies and apply them to challenging issues such as nuclear energy and cancer radiotherapy, and to build an international base for top nuclear science research and training.

In recent years, important breakthroughs have been made in laser acceleration, superconducting acceleration, nuclear physics and nuclear magnetic resonance technology, which have received the continuous attention of General Secretary Xi Jinping. In the past five years, the institute has undertaken 48 national scientific research projects, including 10 National Key R&D Plans and Major Scientific Instrument and Equipment Development Projects, bringing in funds totaling 600 million RMB. More than 400 papers have been published in Nature, Physical Review Letters and other high-impact journals, and the institute has won more than 20 international and domestic awards. The discipline boasts a highly qualified teaching staff with a healthy age structure, including 3 academicians (1 double employed), 2 overseas high-level talents, 4 national outstanding young talents, 6 national young talents and an NSFC innovation group team. Graduate students mainly come from excellent graduates of key universities in China. A series of balanced courses and quality instruments are available for the students majoring in nuclear science. Most graduates enter universities, well-known institutions and large enterprises around the world. More than 100 of these are working in important national units, and some have gained great success in these units. Many other graduates are working in the national economy or the health services, bringing benefits to society.

Many teachers have served in important roles in academic organizations as vice presidents or directors, and many academic awards have been gained in recent years. Prof. Chen Jiaer was the president of the Chinese Physical Society and vice chairman of the International Union of Pure and Applied Physics (IUPAP). Prof. Yan Xueqing won the international accelerator community’s 2019 Hogil Kim Award and the 2020 Ho Leung Ho Lee

Foundation Award for scientific and technological progress. Prof. Gao Jiahong is the chairman of the international Organization for Human Brain Mapping (OHBM) – the first Asian to serve as chairman since the establishment of the organization 25 years ago. Prof. Qin Qing is the director of the European Synchrotron Radiation Facility (ESRF) Accelerator and Source Division (ASD). Prof. Wang Yugang is the executive vice chairman of the International Committee on Nuclear Tracks and Radiometry. Excellent young scientists are constantly emerging, such as Qiao Bin, Guo Zhibin and Gong Zheng, who won the Asia Pacific Young Researcher Award for plasma physics, the René Pellat Memorial Festival Prize, and the Asia Pacific U30 Scientist and Student Award for plasma physics, respectively. The Peking University Nuclear Science Forum has become a well-known series of academic lectures in China, and in recent years our discipline has hosted conferences such as the International High Energy Density Physics Conference and the High Energy Density Physics Youth Forum.

一、基于纳米靶的激光离子加速与辐射产生

光强达到相对论强度（I>10^{18} W/cm^2）的超强激光与特定的靶相互作用时，可驱动大量电子集体运动，产生极强的纵向电场及横向电磁场加速和扭摆带电粒子。其加速梯度可达传统加速器的 10^3-10^6 倍，是有着巨大潜力的新型粒子加速方法。激光加速过程发生在激光到靶后微米—飞秒量级的时空尺度内。核心问题是如何通过激光与靶的非线性相互作用，形成超强且稳定的电磁场来加速或扭摆带电粒子。传统的靶主要包括惰性气体及由常见固态材料制成的膜片，组分单一、结构简单，无法实现精巧复杂的加速过程。

马文君研究员基于对激光加速物理的深刻理解，利用先进纳米技术，在纳米—微米尺度构建加速结构来高效加速或强烈扭摆带电粒子，在基于纳米靶的激光离子加速与辐射产生领域取得了重大突破。

在前期工作基础上不断开拓，开发出了基于碳纳米管的次临界密度纳米靶。这种靶由大量单壁 / 双壁碳纳米管束无序搭接构成，在纳米尺度具有大量中空结构，占空比仅为约 1%，但在微米尺度又是高度均匀的。马文君研究员与颜学庆教授合作，利用碳纳米管与纳米薄膜构成的双层复合靶，实验产生了最高能量为 580 MeV(48MeV/u) 的碳离子，将飞秒激光加速碳离子能量纪录提高至原纪录的 2.6 倍，相关成果发表于《物理评论快报》（Phys. Rev. Lett. 2019, 122, 014803）。数值模拟表明，超强激光在次临界密度碳纳米管靶中传播时会驱动大量电子集体运动形成 10^5T 的超强环向磁场，部分电子在自生磁场的约束下可通过共振直接加速过程加速，最高可达 100 MeV 并聚集在激光尾端。当激光传播通过碳纳米管层到达固体纳米薄膜靶时，大量碳离子会在光压作用下脱离固体靶，进而在随后到来的来自碳纳米管靶的高能电子所形成的长寿命加速电场中被加速至数百 MeV。这种级联加速过程通过将高能电子产生与重离子注入这两个过程时空分离，一举解决重离子加速离子注入困难和加速时间短的两个关键问题，为激光驱动的重离子及超重离子的加速开拓出了一条可行的道路，也为开展基于激光加速离子束的激光核物理、高能量密度物理研究奠定了重要基础 (如图 1)。该工作发表后，被评为北京大学 2019 年度科研亮点工作，马文君研究员受邀在欧洲先进概念加速器研讨会 (EAAC)、亚太等离子体大会 (AAPPS) 等多个重要国际会议作报告。

除了用于离子加速，碳纳米管靶还可用于高亮度辐射的产生。高能电子与相向传播的超强激光相

互作用时，可发生非线性康普顿散射，产生高能伽马光子。实验上利用尾波场加速的电子与第二束激光或经等离子镜反射回来的驱动激光相互作用，已成功实现了数十 MeV 伽马光子的产生，但产额较低。与已有方案不同，马文君研究员提出可利用次临界密度碳纳米管靶与纳米薄膜组成的双层靶结构，来产生高通量的 x/γ 辐射，相关研究发表于《等离子体物理》（Phys. Plasmas 2019, 26, 033109）。电子首先在碳纳米管靶中通过共振直接加速机制被加速到百 MeV 量级，由于激光群速度大于电子前向速度，激光经过一定时间传播后会领先这些高能电子，当其在第二层靶被反射时，就会与前向电子发生非线性康普顿散射。这种方案相比基于尾波场加速电子的方案，总光子数目与能量转化效率更高，可用于大照野 x/γ 光子成像与光核嬗变研究。依据该方案的实验于近期圆满完成，测量到的光子平均能量高达 200 keV，光子产额显著高于已有结果。

I. Laser ion acceleration and radiation generation based on nano-targets

Ultra-intense lasers of relativistic intensity ($I>10^{18}$ W/cm^2) can collectively drive a large number of electrons by interacting with specific targets, resulting extremely strong longitudinal electric and transverse electromagnetic fields to accelerate and wiggle charged particles. As a new acceleration method with great potential, its acceleration gradient can be 10^3-10^6 times higher than that of conventional accelerators. The laser acceleration process takes place in the micrometer-femtosecond space-time scale when the laser interacts with the target. The key problem is how to accelerate and wiggle the charged particles by virtual of the nonlinear interaction between the laser and the targets. Conventional targets include inert gases and foils made of common solid materials, which cannot realize delicate and complex acceleration processes due to their simple structures.

Based on his deep understanding of laser acceleration physics, Prof. Wenjun Ma has made a major breakthrough in the field of laser ion acceleration and radiation generation by using advanced nanotechnology to build acceleration structures at the nano-micron scale.

Based on his previous work, he recently developed a sub-critical-density nanotarget made of carbon nanotubes. Such target consists of a large number of single/double-walled carbon nanotube bundles, resulting a large number of hollow structures at nanoscale, yet highly homogeneous at the micron scale. In collaboration with Prof. Xueqing Yan, he experimentally generated carbon ions with a maximum energy of 580 MeV (48 MeV/u) using a double-layer composite target composed of carbon nanotubes and nanofilms, enhancing the previous record carbon ion energy by 2.6 time utilizing femtosecond lasers (Phys. Rev. Lett. 2019, 122, 014803). Numerical simulations show that the ultra-intense laser propagating in a sub-critical-density carbon nanotube target drives a large number of electrons to move collectively to form an ultra-intense magnetic field of 10^5 T. Some of the electrons can be accelerated to up to 100 MeV by the resonant direct acceleration process under the confinement of the self-generated magnetic field and gather at the tail of the laser. When the laser propagates through the carbon nanotube layer and reaches the solid film, a large number of carbon ions will be pushed out of the solid target by the radiation pressure, and then accelerated to hundreds of MeV in the long-lived accelerating electric field formed by the subsequent high-energy electrons from the carbon nanotube target. This cascade acceleration process, by separating the two processes of high-energy electron generation and heavy ion injection, solves the difficult in heavy ion injection and prolongs the acceleration time, and opens up a feasible path for laser-driven acceleration of heavy and super-heavy ions, and lays an important foundation for laser nuclear physics and high-energy density physics research based on laser-accelerated ion beams (see figure). After the publication of this work, it was awarded as the 2019 Research Highlight Work of Peking University, and Wenjun Ma was invited to give presentations at several important international conferences, including the European Advanced Concept Accelerator Symposium (EAAC) and the Asia-Pacific Plasma Conference (AAPPS).

In addition to being used for ion acceleration, carbon nanotube targets can also be used for the generation of high-brightness radiation. High-energy electrons can undergo nonlinear Compton scattering by interacting with a counter-propagating super-intense laser pulse, producing high-energy gamma photons. Experimentally, the generation of tens of MeV gamma photons has been successfully demonstrated by colliding laser-wakefield accelerated electrons with counter-propagating laser pulses, but the yield is low. In contrast to existing schemes, Prof. Wenjun Ma proposed that a double-layer target composed of sub-critical-density carbon nanotube target and a nanofilm could be used to generate high flux x/γ radiation (Phys. Plasmas 2019, 26, 033109). Electrons are firstly accelerated to the order of a hundred MeV in the carbon nanotube target through resonant direct acceleration mechanism. Since the laser' s group velocity is higher than the electrons' forward velocity, the laser propagates ahead of these high-energy electrons after a certain time. When it is reflected at the second solid layer, nonlinear Compton scattering from the forward electrons will produces high-brightness x/γ radiation. This scheme has higher photon yield and energy conversion efficiency as compared to existing scheme, and can be used for large-field x/γ photon imaging and photonuclear transmutation studies. Experiments based on this scheme have been successfully completed recently. The measured average photon energy is as high as 200 keV, and the photon yield is significantly higher than the reported results.

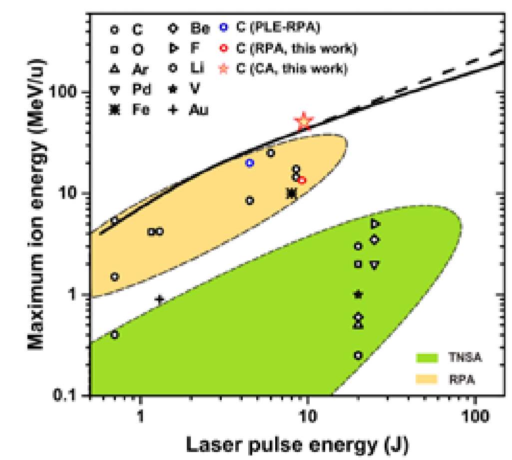

图 1. 激光驱动重离子加速结果总结，☆结果为本成果。

Figure 1. Summary of laser-driven heavy ion acceleration results, ☆ results for this result.

二、磁约束等离子体高约束模式研究进展

高约束运行模式（简称 H 模）是未来聚变堆稳态运行的一个基本模式。通常，H 模面临的挑战之一是高约束条件下边缘局域模（Edge Localized Mode, ELM）引起的等离子体边缘区温度、密度台基的周期性突发式崩塌。这些崩塌过程释放的强脉冲热流会导致偏滤器热负荷过载，靶板材料溅射损伤甚至融化——不仅引起偏滤器靶板的损坏，而且可能导致大量高原子序数杂质进入芯部等离子体引起大破裂（Major Disruption）。例如，数值估算国际热核聚变实验堆（International Thermonuclear Experimental Reactor, ITER）的 ELM 爆发所释放的热流强度甚至可达 100 MW/m^2, 而目前已知的偏滤器材料能承受的最大热负荷仅为 10 MW/m^2，二者相差一个数量级。这无疑对实现磁约束聚变能源是极大的挑战。近年来，国内外主要托卡马克装置实验中发现了在某些条件下 H 模运行可以进入一种几乎无崩塌状态，即 QH 模（Quiescent H-mode）。如何理解 QH 模的形成机制成为当前磁约束等离子体物理研究的一个关键科学问题。QH 模理论研究面临的最大困难是要同时处理多种自由能（电流、压强、涡度梯度等）在等离子体边缘区的耦合。

郭志彬研究员在深入分析边缘区等离子体湍流性质的基础上，提出了一种研究等离子体边缘区激发模式的新手段——涡旋波耦合理论。在这一理论模型下，研究发现：1）当电流密度驱动和压强梯度驱动的双涡旋波实现锁相时，ELM 将被激发，等离子体进入 ELM-H 模状态；2）当涡度梯度、电流密度和压强梯度驱动的三涡旋波同时实现锁相时，边界层的高频谐振荡（Edge Harmonic Oscillation, EHO）将被激发，从而使等离子体进入 QH 模状态。郭志彬课题组发现等离子体边缘区的径向电场曲率在选择涡旋波的锁相方式上起着关键作用（如图）：1）降低边界电场曲率，三涡旋波联合模式的不稳定性边界（蓝线）会处在 ELM 边界（黑色）右侧，此时系统将处于 ELM-H 模状态; 2）增加边界电场曲率，直到三涡旋波联合模式的不稳定性边界（红色）移至 ELM 边界（黑色）左侧，此时系统将处于 QH 模状态。这些发现对未来聚变堆先进运行模式物理设计和实验研究具有重要的指导意义。相关研究工作于发表于《物理评论快报》（Phys. Rev. Lett. 2020, 125, 255003）。

II. Progress in High-confinement Mode Research of Magnetically Confined Plasmas

H-mode (H: High performance) is a standard scenario of future nuclear fusion reactor. The ELMy H mode (ELM: Edge Localized Mode) and QH mode (Q: Quiescent) are two principal favorable operating scenarios of future burning plasma devices, e.g., the ITER (International Thermonuclear Experimental Reactor). In the ELMy H mode, the thermal energy is released in a highly transient, episodic way, and the induced heat load may erode plasma facing components and degrade performance. In contrast to the large crash of the pressure profile in the ELMy H mode, the edge pressure profile finds a steady weak oscillatory state in the QH mode, so impurities are expelled effectively and the plasma facing components are not eroded. Thus, the QH mode is an attractive scenario for a fusion reactor. The most challenge issue in QH-mode theory is how to treat the synergetic interaction of multi-free energy sources (current density, pressure gradient, vorticity gradient, etc.). Through a deep analysis of the edge plasma turbulence, Guo’s group proposed a new approach to study edge MHD modes (MHD: Magnetohydrodynamic) by considering the phase coupling of vortex waves produced by different sources. While vorticity dephases radial velocity and displacement, and so is stabilizing, a new finding here is that vorticity gradient tends to synchronize the radial velocity and displacement, and so destabilizes edge MHD mode. As a highlighted result, they analytically demonstrate that vorticity gradient can destabilize an otherwise stable kink mode, and so form a joint vortex- kink mode. The synergetic effects of vorticity and its gradient in edge MHD extend the familiar flow shearing paradigm. This theory thus explains the experimental findings that a deeper vorticity-‘well’ may aggravate edge MHD, and so trigger the formation of the edge harmonic oscillation. This work is published in Physical Review Letters (Phys. Rev. Lett. 2020, 125, 255003).

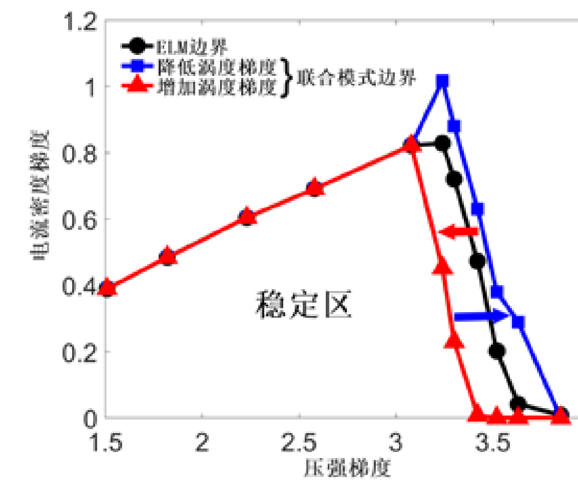

图 1. 涡旋波的发展路径和 QH 状态形成
Figure 1. Path of joint vortex mode and the formation of QH mode

三、“X 射线自由电子激光试验装置”通过国家验收

2020 年 11 月，“十二五”国家重大科技基础设施项目“X 射线自由电子激光试验装置”通过国家验收。该项目由中国科学院上海应用物理研究所和北京大学共同建设。北京大学核物理与核技术国家重点实验室射频超导加速器团队圆满完成了承担的“射频超导加速单元”分总体的建设任务，包括 9-cell 超导腔研制、超导加速单元研制以及超导腔表面处理和垂直测试装置的建设，掌握了射频超导加速单元关键核心技术，取得了一系列重要技术突破，实现了超导腔研制的全国产化。这项建设成果有力地推动了我国自由电子激光领域的发展，为总投资约 100 亿元的“十三五”国家重大科技基础设施项目“硬 X 射线自由电子激光装置”的立项和建设提供了技术储备。

射频超导加速技术是加速器领域的高新技术，是强流高能粒子加速器，特别是连续波 X 射线自由电子激光所必需的技术。超导加速腔是超导加速器的核心部件。射频超导团队在攻克超导腔表面处理关键技术的基础上，研制成功批量大晶粒 9-cell 超导腔（图 1），仅采用缓冲化学抛光处理及高温热处理，6 只超导腔加速梯度全部在 25MV/m 以上，在 16 MV/m（硬 X 射线自由电子激光装置预期运行梯度）和 2 K 温度下，超导腔品质因数在 1.6—2.4×10^{10}（图 2），加速梯度和品质因数在统计意义上均达到了国际先进水平。

自主设计的超导加速单元采用 **2´9-cell** 模组，包括功率耦合器、超流氦两相管道、频率调谐器、热辐射屏、磁屏蔽、低电平控制系统等（图 3）。通过对低温热导、高精度幅相控制和氦压稳定控制等的系统研究，完成了超导加速单元的制造、组装和水平测试，加速梯度达到 21.0—23.5MV/m，静态热损为 7.5 W，漏热、低电平控制和水平测试加

速梯度等技术指标与国际上同类装置相当。本项目建成的垂直测试装置（图 4）在 2K 温度下制冷功率超过 200 W，垂测杜瓦内剩磁小于 5 mG，能够在 2K、1.8 K、1.6 K 温度下对高品质因数超导腔进行低温性能测试。

目前超导加速单元已经投入运行，可提供 10-20 MeV 的电子束，已用于在国内首次产生高重复频率 THz 辐射等实验研究。基于本项目的技术基础，射频超导团队已经为中国工程物理研究院研制了一台 **2´9-cell** 超导加速器，将用于高能 X 射线自由电子激光预制研究。超导腔表面处理和垂测装置也已投入运行，为本单位和中科院上海高等研究院、高能物理研究所、兰州近代物理研究所、中国工程物理研究院等单位开展超导腔高温退火、氮掺杂等前沿研究提供了平台。射频超导加速单元的建设也带动了一批相关高新技术企业的发展，特别是进一步推动了我国的超导腔产业化进程。

图 1. 大晶粒纯铌超导加速腔

Figure 1. large grain superconducting cavities

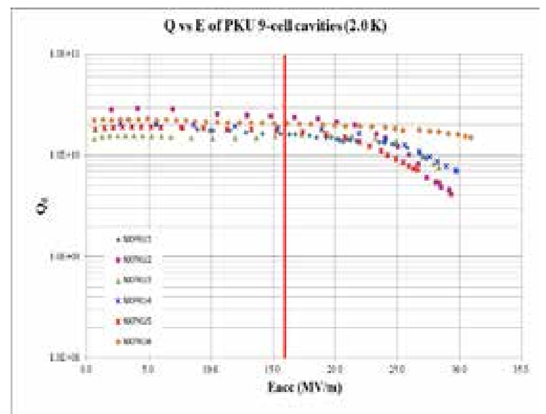

图 2. 超导腔加速梯度与品质因数

Figure 2.Q vs. E_{acc} of 9-cell cavities

图 3. 射频超导加速单元

Figure3. SRF Accelerating Cryomodule

图 4. 超导腔垂测装置

Figure 4. Vertical Test System

III. SXFEL Project Passed National Acceptance

Soft X-ray Free Electron Laser experiment facility (SXFEL) of the national major science and technology infrastructure projects passed the national acceptance in November 2020. SXFEL is constructed by Shanghai Institute of Applied Physics, CAS and Peking University. SRF accelerator group of State Key Laboratory of Nuclear Physics and Technology (Peking University) successfully finished all the research tasks, including development of 9-cell superconducting cavities, SRF accelerating cryomodule, surface treatment device and vertical test system. The group has mastered the key technology of SRF cryomodule, obtained a series of important technical breakthrough and realized full domestic production of SRF cavities. The construction achievements greatly benefit the development of free electron laser facility in China, especially, providing the technology for the hard X-ray FEL Facility (SHINE), one of the national major science and technology infrastructure projects of the 13th five-year plan.

SRF technology is high-tech in the field of particle accelerators and is the indispensable technology for high current and high energy accelerators, especially for continuous wave XFEL. SRF cavity is the key component of superconducting accelerators. SRF group successfully finished a series of large grain 9-cell niobium superconducting cavities by mastering of the critical technology of surface treatment (Figure 1.). After buffered chemical polishing and high temperature treatment, all of the accelerating gradients (Eacc) of six 9-cell cavities are larger than 25 MV/m and the Q_0 values at 2 K are 1.6-2.4×10^{10} at 16 MV/m (the running gradient of hard X-ray free electron laser facility), see Figure 2.. Both E_{acc} and Q_0 reached international advanced level in statistics.

The self-designed SRF cryomodule adopting **2´9-cell** structure, including main power coupler, superfluid helium two phase tube, frequency tuner, thermal shield, magnetic shield and low level RF control system, etc. (Figure 3.). SRF group finished the manufacture, assembly and horizontal test of the SRF cryomodule by systematic researches of low temperature thermal conductivity, high precision amplitude and phase control, stable helium pressure control, etc. The Eacc of cryomodule reaches 21.0—23.5 MV/m and the static heat loss is 7.5 W, which is the same level with the similar device in the world. The vertical test system (Figure 4.) has the cooling capacity of 200 W at 2 K temperature and the remnant magnetic field in the vertical test dewar is less than 5 mGs, which is beneficial for testing of high Q superconducting cavities at 2 K, 1.8 K and 1.6 K.

The SRF accelerating cryomodule has been in operation. It can provide electron beams with energy of 10—20 MeV and is used in the first generating of high repetition THz radiation in China. Based on the SRF technology, SRF group has provided a **2´9-cell** cryomodule for the pre-research of high energy XFEL in China Academy of Engineering Physics. The surface treatment device and vertical test system are also in operation, which provides a platform of high temperature treatment and nitrogen doping researches for Peking University, Shanghai Advanced Institute, Institute of High Energy Physics, Institute of Modern Physics of CAS and China Academy of Engineering Physics. The construction of SRF accelerating cryomodule pushes the development of a series of high-tech companies, especially for the industrialization of superconducting cavities in China.

系所中心研究亮点 | *Highlights*

05 技术物理系 Department of Technical Physics

技术物理系现有教职员工 31 人，其中教授 8 人（含院士 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（含优青 1 人，博雅青年学者 1 人），预聘助理教授 4 人（含博雅青年学者 3 人），副研究员 1 人，高级工程师 1 人，和工程师 6 人。研究方向包括实验核反应与结构、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、探测器研发和核电子学。该系拥有一个亚原子粒子探测实验室、一个核物理教学实验室、北大—兰州联合核物理中心。该系还拥有核技术应用实验室，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，拥有全国唯一的核物理理科基地和核物理国防紧缺专业，并承担多项国家级科研项目。拥有广泛的国内外合作，包括中美“奇特核”理论物理研究所 (CUSTIPEN)；在高能物理方面与欧洲 LHC 和北京 BEPC-BES 的合作；在核物理方面与日本 RIKEN-RIBF、兰州 HIRFL 和北京 CIAE 合作等的合作；在人才培养方面于 2008 年与日本理化所合建的 Nishina School，于 2016 年与美国 MSU 合建的由中国留学基金委支持的 PKU-FRIB 博士后项目等。

There are 31 faculty members in the Department of Technical Physics, 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 1 Boya Young Scholar), 4 tenure-track Assistant Professors (including 3 Boya Young Scholars), 1 associate research fellow, 1 senior engineer, and 6 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, an education laboratory for nuclear physics, and a PKU-Lanzhou joint center for nuclear physics. The department also has nuclear technology application laboratory, which 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. 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 project of defense in nuclear physics. The researchers have undertaken a number of national research projects. 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, and a PKU-FRIB postdoctoral program supported by CSC was established with MSU since 2016.

一、发现丰中子核 ^{16}C 的链状分子结构

不稳定原子核占有核素版图的绝大部分区域，近 20 多年来在实验室中逐步产生出来，表现出一系列新奇的结构和动力学性质，也带来新的应用前景。其中，丰中子原子核奇异的线性链状分子结构已有多年理论预言，但实验发现十分困难，需用多种证据相互印证。此前多个实验组在 ^{14}C 中观察到链状分子态的个别证据。 最近，叶沿林课题组在更加丰中子的 ^{16}C 中，通过反应 Q 值、能级、自旋、特征衰变纲图等多个量的系统性观测，完整确认了 $\pi^2\sigma^2$ 构型的正宇称线性链状分子结构及其转动带。

此项研究的实验探测于 2018 年 04 月在我国的大科学装置兰州重离子加速器 (HIRFL) 上的 RIBLL1 放射性束流线上完成。实验采用每核子 23.5 MeV 的 ^{16}C 次级束流，通过非弹散射将 ^{16}C 激发到集团破裂阈值之上的高激发态。采用精密的零度粒子望远镜和多套大角度的探测器组合，精确测量末态全部三个粒子（图 1）。通过全粒子能动量守恒关系逐事件推知入射粒子能量，避开了放射性次级束流能量弥散的缺陷，首次在弹核碎裂型次级束实验中得到高分辨的 Q 值谱，从而清晰的识别出 ^{16}C 的选择性衰变路径。分析过程采用特殊方法区分了相邻硅微条信号的真假来源，大大提高了最终获得的多重关联真实事件数，从而在足够的统计下通过模型独立的角关联分析获得了分子转动带头号成员的自旋。实验最终确认了价中子处于 $\pi^2\sigma^2$ 构型的正宇称线性链状分子转动带的四个成员：16.5 MeV(0+)、17.3 MeV(2+)、19.4 MeV(4+) 和 21.6 MeV(6+)(图 2)。实验还观察到一个可能的纯 σ^4 构型的分子态（27.2 MeV），为后续实验提供了指引。

相关研究成果发表于《物理评论快报》（Phys. Rev. Lett. 2020, 124, 192501）。

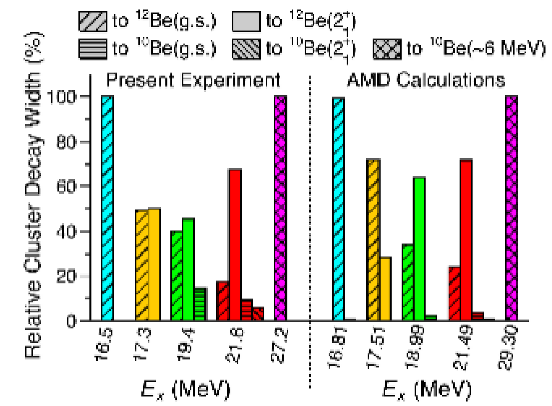

图 1. ^{16}C 线性链状分子带成员的相对集团衰变强度。左、右图分别为实验测量和理论计算结果。

Figure 1. Comparison between experimental and theoretical results for relative cluster decay widths related to each member state.

I. Observation of the Positive-parity Linear-chain Molecular Structure in ^{16}C

Unstable nuclei cover the majority of the nuclear chart. Over the past decades they have gradually been produced in the laboratories and exhibit some exotic structures and dynamic properties, indicating also possible new applications. Among them, the extremely intriguing linear-chain molecular configurations in neutron-rich isotopes have been theoretically predicted for years, whereas their experimental observations seem very challenging due to the required multiple evidences. Previously, individual evidences have been reported by several research groups worldwide. Recently, the Peking University group has selected a more neutron-rich candidate, the ^{16}C, as the target to study the linear-chain structure, by systematically investigating the Q-value, energy level, spin as well as the characteristic decay scheme. A linear-chain molecular structure with positive-parity $\pi^2\sigma^2$configuration has been identified.

An inelastic excitation and cluster-decay experiment 2H (^{16}C, ^{4}He + ^{12}Be or ^{6}He + ^{10}Be) ^{2}H was carried out at HIRFL-RIBLL1 facility. Secondary ion beam of 16C at 23.5 MeV/nucleon and with an intensity of about 1.5*10^{4} pps was produced from a 59.6 MeV/nucleon ^{18}O primary beam impinging on a 4.5 mm thick ^{9}Be target. A triple coincident detection with high efficiency was realized thanks to a multi-layer-silicon telescope at zero degrees combined with eight position-sensitive silicon detectors at larger angles (Figure 1). For the first time, decay-paths from the ^{16}C resonances to various states of the final nuclei were determined, taking full advantages of the well-resolved Q-value spectra obtained from the three-fold coincident measurement. The close-threshold resonance at 16.5 MeV is assigned as the 0+ band head of the predicted positive-parity linear-chain molecular band with $\pi^2\sigma^2$ configuration, according to the associated angular correlation and decay analysis. Other members of this band were found at 17.3, 19.4, and 21.6 MeV based on their selective decay properties, being consistent with the theoretical predictions (Figure 2). Another intriguing high-lying state was observed at 27.2 MeV which decays almost exclusively to ^{6}He +^{10}Be (~6 MeV) final channel, corresponding well to another predicted linear-chain structure with the pure σ-bond configuration.

The results were published at Physics Review Letters (Phys. Rev. Lett. 2020, 124, 192501).

二、离子束技术的新应用：辐照改性摩擦纳米发电机的重要进展

随着物联网的快速发展，亟需大量的传感器和微电子设备来支持这一庞大的信息网络，同时，对移动设备供电系统中的电池与能量收集技术的需求也与日俱增。摩擦纳米发电机（Triboelectric nanogenerator, TENG）自 2012 年问世以来，凭借其通用性，低成本和高效率，逐渐成为能量收集领域的主流技术，也被应用于传感器与微电子设备中来支持庞大的物联网。TENG 的核心要素是摩擦纳米材料，但现有的摩擦纳米材料的界面传输电荷能力不足，极大地限制了其应用。因此，当前研究的重点是如何通过材料表面改性，提高其界面传输电荷能力并提高其稳定性。

付恩刚教授课题组与中国科学院北京纳米能源与系统研究所的陈翔宇研究员和王中林院士课题组进行了离子束新应用方向的合作，首次将载能离子束与摩擦纳米材料相结合，提出了通过低能高密度氦离子的辐照来调控聚合物的摩擦电表面电荷密度的策略和方法，并成功地获得了超强正电性起电材料。相关工作以“Manipulating the triboelectric surface charge density of polymers by low-energy helium irradiation/implantation”为题发表于《能源与环境科学》（Energy Environ. Sci. 2020, 13, 896），并入选高被引论文。研究发现低能离子辐照对目标聚合物微观尺度的表面粗糙度和机械柔性的影响可以忽略不计，但可以稳定地改善材料的起电性能。通过系统地研究离子辐照引起的四种不同聚合物的化学结构变化，深入了解并揭示了不同化学基团与电学性能之间的相互作用规律和机理。他们发现供电子基团与吸电子基团这两种官能团对于摩擦起电过程的传输电荷密度有着重要的影响。其中，聚酰亚胺薄膜在离子辐照改性后表现出了一些前所未有的特性，如高的表面电荷传输密度（332μC/ m^{2}），优良的稳定性和超高的电子给体能力（图 1）。这不仅创造了一个新的起电性能记录，同时也突破了表面结构改性的传统思路，另辟蹊径，为新型起电材料的设计和发展提供了全新的策略和方法，带来了突破性进展，也为从化学基础结构层面调控材料的相应性能提供了指导性模板。同时，这种官能团调控机理也为传统的离子辐照技术开辟了新的应用方向和领域。可以预期，未来会出现众多离子辐照调控的具有不同优异性能的高分子材料，服务于新能源以及其他有特种性能需求的领域中。

II. New Application of Ion Beam Technology: Significant Progress in Irradiation-modified Triboelectric Nanogenerator

With the rapid development of the Internet of Things, a large number of sensors and microelectronic devices are urgently needed to support this huge information network. At the same time, there are growing demands for batteries and energy harvesting technology in the power supply system of mobile devices. Since the advent of Triboelectric nanogenerator (TENG) in 2012, with its versatility, low cost and high efficiency, it has gradually become the mainstream technology in the field of energy harvesting. It has also been applied in sensors and microelectronics to support huge Internet of Things. The core element of TENG is friction nanomaterials, but the existing friction nanomaterials have insufficient interface charge transfer capability, which greatly limits its application. Therefore, the focus of current research is how to improve the interface charge transfer capability and its stability of the materials through surface modification.

The research team led by Professor Engang Fu from the School of Physics of Peking University and the research group of Professor Xiangyu Chen and Academician Zhonglin Wang of Beijing Institute of Nanoenergy and Nanosystems had cooperation on the new application direction of ion beam. They combined energy-carrying ion beams with triboelectric nanomaterials for the first time, proposed the strategy and method of low-energy and high-density helium ion irradiation to control the triboelectric surface charge density of polymers, and successfully obtained super positive electrification materials. Related work was published on Energy & Environmental Science (Energy Environ. Sci.2020, 13, 896) with the title "Manipulating the triboelectric surface charge density of polymers by low-energy helium irradiation/implantation", and was selected as a highly cited paper. The study has found that the impact of low-energy ion irradiation on the micro-scale surface roughness and mechanical flexibility of the target polymer is negligible, but the electrical properties of the polymers could be improved stably. By systematically studying the chemical structure changes of four different polymers caused by ion irradiation, they have deeply understood and revealed the interaction law and mechanism between different chemical groups and electrical properties. They found that the two functional groups, which are electron-donating group and electron-withdrawing group, have an important effect on the transfer charge density of the triboelectric process. Among them, the polyimide film showed some unprecedented properties after ion irradiation modification, such as high surface charge transport density (332μC/m^2), excellent stability and ultrahigh high electron donor ability (Figure 1). This not only creates a new electronic record, but also breaks through the traditional idea of surface structure modification, opens up a new way, provides brand-new strategies and methods for the design and development of new electrification materials, and brings breakthrough progress. It also provides a guiding template for adjusting the corresponding properties of materials from the chemical basic structure level. At the same time, this functional group regulation mechanism also opens up new application directions and fields for traditional ion irradiation technology. It can be expected that in the future, there will be many polymer materials with different excellent properties controlled by ion irradiation, serving new energy and other fields with special performance requirements.

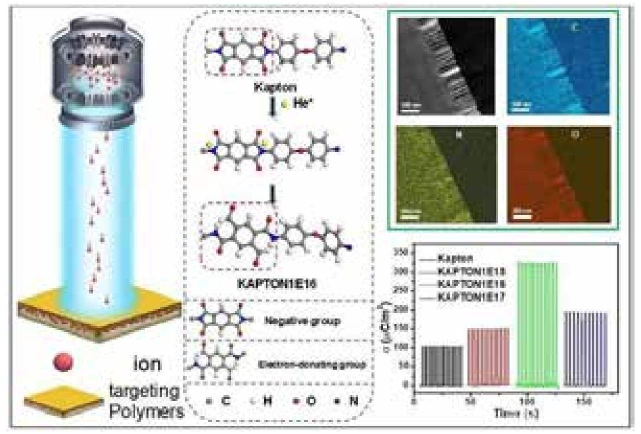

图 1. 离子束辐照改性高分子材料机理与电学性能: (a) 离子束辐照材料示意图; (b) 辐照引起 Kapton 材料供电子官能团形成的示意图; (c) 改性材料的表面结构的透射电子显微镜 (TEM) 和能谱 (EDS) 图; (d) 对比表明，材料经适当剂量的离子辐照后有效电荷传输密度显著提高。

Figure 1. The mechanism and electrical properties of polymer materials modified by ion beam irradiation. (a) Schematic diagram of ion beam irradiated materials; (b) Schematic diagram of the formation of electron-donating functional groups in Kapton materials caused by irradiation; (c) The TEM and EDS images of the surface structure of the modified materials; (d) The comparison shows that the effective charge transport density of the material enhances significantly after appropriate dose of ion irradiation.

三、在 Belle 实验首次测量 Ξ_c^0衰变的绝对分支比

重子，如质子、中子，是组成物质的基本单元，由三个夸克组成。对重子和重子激发态的计算和测量为检验重夸克对称性和轻夸克手征对称性提供了理想的研究平台。粲重子含一个粲夸克和两个轻夸克，是重子家族的重要成员，对粲重子的研究是理解强相互作用和电弱相互作用的重要手段。然而实验上对粲重子弱衰变研究相对较少，尽管最基础的 SU(3) 反三重态粲重子之一的Ξ_c^0已被发现近 30 年，其绝对衰变分支比依旧未知，从而限制了粲重子相关的能谱、产生和衰变等诸多研究。

为了测量 Ξ_c^0衰变绝对分支比，班勇教授课题组与北京航空航天大学、复旦大学、中科院高能物理研究所合作，利用位于日本筑波市的非对称能量电子 - 正电子对撞机 KEKB 的 Belle 实验收集的 772 兆 B 介子对样本，对衰变进行了单举和遍举测量。数据分析中，首次给出了不依赖模型的 $\Xi_c^0 \to \Xi^-\pi^+$，$\Xi_c^0 \to \Lambda K^-\pi^+$和$\Xi_c^0 \to pK^-K^-\pi^+$ 衰变的绝对分支比，这是Ξ_c重子被发现以来对其绝对分支比的首次测量。实验测量的结果将会被广泛应用到与Ξ_c^0衰变相关的测量中去，将为理解强子结构和相互作用提供重要信息。

该测量结果以“First Measurements of Absolute Branching Fractions of the Ξ_c^0 Baryon at Belle”为题发表于《物理评论快报》（Phys. Rev. Lett. 2019, 122, 082001）。

III.First Measurements of Absolute Branching Fractions of the Ξ_c^0 Baryon at Belle

The measurement and calculation of baryons and baryonic excited states are important since they offer an excellent laboratory for testing heavy-quark symmetry or light quarks chiral symmetry. Weak decays of charmed baryons containing one charmed quark provide an useful test of many competing theoretical models and approaches. Up to present, the properties of the Ξ_c baryons, which contains one u or d, one s and one c quark, are still poorly known due to limited experimental data. No absolute branching fractions of Ξ_c decays have been measured yet. A study of Ξ_c baryons will provide important insight of the structure and dynamics in hadron.

In an analysis, Prof Ban Yong’s group, working with collaborators, performed a model independent measurement of the absolute branching fractions of $\Xi_c^0 \to \Xi^-\pi^+$, $\Xi_c^0 \to \Lambda K^-\pi^+$ and $\Xi_c^0 \to pK^-K^-\pi^+$ decays based on 772×10^6 $B\bar{B}$ pairs data collected by the Belle detector at the KEKB asymmetric energy electron-positron collider. These are the first absolute branching fraction measurements since Ξ_c baryons were found 30 years ago. This work is published in Physical Review Letters (Phys. Rev. Lett. 2019, 122, 082001).

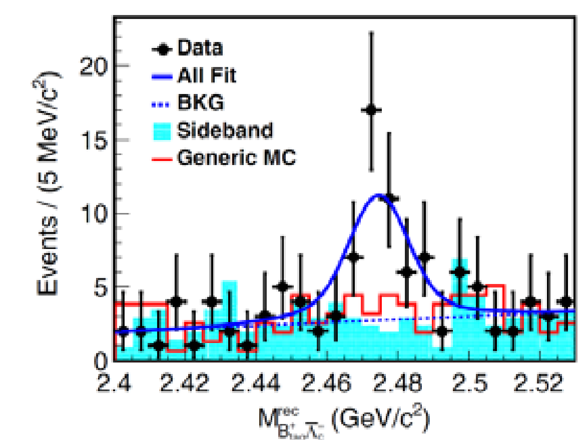

图 1. 从 B+ 衰变中$\bar{\Lambda}_c^-$的反冲质量谱重建出Ξ_c^0重子。

Figure 1.. The Ξ_c^0 baryon was reconstructed with a fit to the recoil mass of $\bar{\Lambda}_c^-$ in tagged B+ decays.

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。最近，北京大学天文学专业入选 2020 年度国家级一流本科专业建设点。天文学系现有全

职教师 7 名，其中教授 3 名，长聘副教授 3 名，助理教授 1 名。该系共有国家杰出青年基金获得者 2 名，国务院政府特殊津贴获得者 1 名，“万人计划”青年拔尖人才 1 名，兼职中国科学院院士 1 名，以及 10 余名来自国内外高校或科研院所的兼职教授。该系还有在站博士后 7 名，博士研究生 85 名，本科生 102 名，办公行政人员 2 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 in 2020. The Department of Astronomy has 7 full-time faculty members consisting of 3 full professors, 3 tenured associate professors and 1 assistant professor. Among them, there are 2 NSFC “Distinguished Youth Award” winners, 1 State Council Government special allowance awardee and 1 “Ten Thousand Talent Program” youth top-notch talent. In addition, the Department of Astronomy has over 10 joint faculty members including one academician of CAS. The Department of Astronomy has 7 postdocs, 85 post-graduate students, 102 undergraduates, and 2 administrative staffs. 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、发现超大质量黑洞生长新途径

一项由陈弦研究员领衔的研究工作表明，太阳系内尘埃粒子的行为可以帮助我们理解类星体中心超大质量黑洞的生长。这项研究成果发表于天文核心期刊《天体物理期刊快报》（Astrophys. J. Lett. 2020, 893, L15），随即得到了《自然》杂志子刊《自然·天文》“研究亮点”栏目（Research Highlight）的报导。

“超大质量黑洞”是指比太阳重一百万倍到一百亿倍的黑洞。从上世纪 70 年代起，人们就意识到超大质量黑洞是解决遥远类星体光源之谜的关键。近二、三十年的天文观测又表明，宁静星系的核心也潜伏着超大质量黑洞，它们很可能是类星体耗尽“燃料”（气体）后留下的残骸。此外，由于星系在不断合并，那么一些大星系的核心就很可能藏着两个超大质量黑洞。这样的双黑洞系统与周围的恒星和气体相互作用，有可能并合成一个大黑洞，同时辐射出能量可观的引力波。

陈弦与合作者注意到除了恒星和气体，光（电磁辐射）是第三类可以与双黑洞作用、导致它们合并的媒质。这一想法源自太阳系中黄道光（zodiac light）的形成机制：黄道面内的尘埃通过散射阳光获得等效的摩擦阻力，因此会逐渐落向太阳（Poynting-Robertson 效应）。这种机制之所以对双黑洞系统起作用，一方面是因为黑洞本身就可能是明亮的光源。根据先前的理论，双黑洞从合并星系获得气体的同时，也获得了新的燃料，因此可以重新“点燃”类星体。另一方面，气体落入黑洞前会先形成一个围绕黑洞的盘状结构，叫做“吸积盘”（图 1）。吸积盘的形成大大提升了黑洞吸收电磁辐射的能力。

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陈弦等人将双黑洞和太阳系做了巧妙的类比，将一个被气体点燃的黑洞看作太阳，另一个带有吸积盘的黑洞当作太阳系中的尘埃粒子，这样就可以用现成的方法计算黑洞受到的阻力。计算结果表明，当两个黑洞的质量相差悬殊时（大约 5 个量级），上述阻力最为有效、可以让双黑洞在气体耗尽前并合。这意味着类星体中的超大质量黑洞有能力清空周围的小黑洞。这一发现也为超大质量黑洞的成长和引力波源的形成找到了一条新的路径。

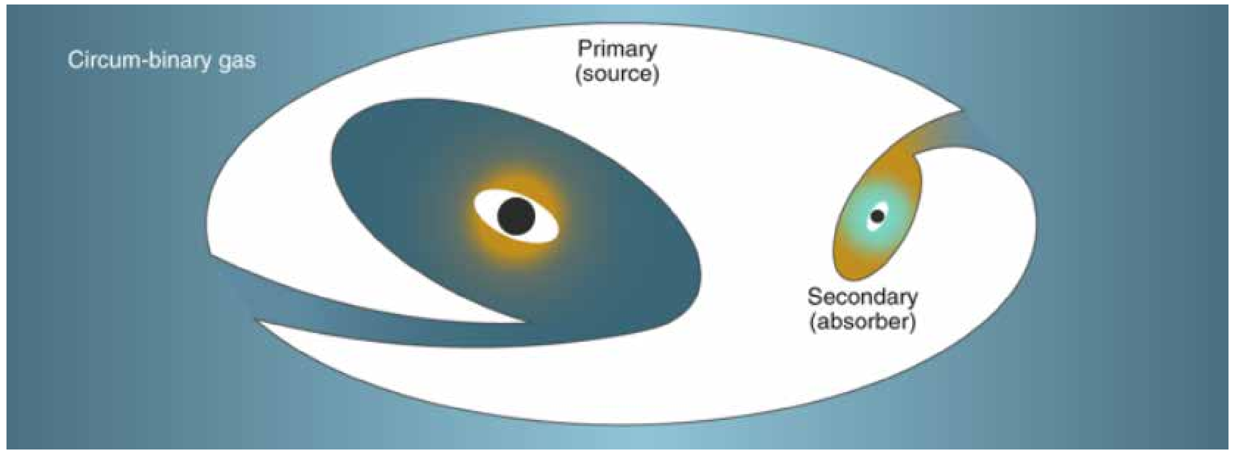

图 1. 主黑洞（Primary）和次黑洞（Secondary）吸积周围气体（Circum-binary gas）。次黑洞的吸积盘作为吸收体（absorber）吸收主黑洞这个光源（source）辐射的电磁波，从而受到一个等效的阻力。（图片来源：《天体物理期刊快报》）

Figure 1. Both Primary and secondary black holes accrete the circum-binary gas. The accretion disk of the secondary, as an absorber, absorbs the light emitted from the accretion disk of the primary, which produces an effective drag force on the secondary. Credit: The Astrophysical Journal Letters.

I. A New Path to Grow Supermassive Black Holes

One recent work lead by Dr. Xian Chen from the Astronomy Department of the School of Physics suggests that the behavior of the dust particles in the solar system could help us understand the growth of the supermassive black holes occupying the centers of quasars. This result was published in the Astrophysical Journal Letters (Astrophys. J. Lett.2020,893, L15), and soon highlighted by Nature Astronomy.

Supermassive black holes are normally a million to a billion times more massive than our Sun. From the 1970s, people had realized that these objects are the central engines of the distant, luminous quasars. Observations in the recent 2-3 decades further discovered that normal, quiescent galaxies also harbor supermassive black holes in their centers, which are likely the relics of exhausted quasars. Since it is known that big galaxies grow by successive mergers, it is likely that two massive black holes would enter the same galaxy. Interaction with the surrounding stars and gas would cause such supermassive black hole binaries to merge, generating the most powerful gravitational wave radiation in the universe.

Xian Chen and his collaborators noticed that besides stars and gas, light (or electromagnetic radiation) is a third medium that could interact with the supermassive black hole binaries and lead to their coalescence. This idea originates from the formation mechanism of the zodiac light in our solar system: the dust particles in the elliptic scatter the light of the sun and, in this way, feel an effect drag force and fall into the sun. This mechanism also applies to binary black holes. On one hand, black hole themselves could be luminous light sources. In fact, the supermassive black holes in merging galaxies could acquire gas from their hosts, igniting quasars. On the other hand, the gas, before falling into a black hole, forms a disk first, called "accretion disk" (See Figure 1). Such a disk significantly enhances the cross section for the black hole to absorb light.

Xian Chen and his collaborators made an interesting analogy. They regard one ignited supermassive black hole as playing the role of the sun, and the other accreting black hole as a dust particle in the solar system. In this way they can calculate the drag force using known formulae. The result shows that the drag force is the most efficient when the masses of the two black holes are very different. The implication is that a supermassive black hole could clear the surrounding small black holes by merging with them, and it happens before the gas in the quasar is exhausted. This finding points to a new path for supermassive black holes to grow and gravitational-wave sources to form.

二、致密物质及其天体物理表现

众所周知，日常生活中的物质由原子、分子构成，而原子核与核外电子组成了原子。如果极端地压缩物质以至于原子核连成一片会怎样？这个问题涉及基本粒子夸克及其间相互作用，自 1930 年代被提出以来，至今仍未有定论。该问题的现实观测意义体现于大质量恒星演化至晚期时产生的超新星爆发及其产物——星核超强的自引力能有效地将物质压缩至原子核密度以上；而残留的致密天体可以表现为能观测到的脉冲星。

脉冲星由宇宙中最致密的物质组成，其物态方程如何，一直以来是天文学和物理学的研究热点，尤其是在发现引力波之后的多信使天文学时代再次成为焦点。一般认为，脉冲星主要由中子构成，即"中子星模型"，然而徐仁新课题组提出的"奇子星模型"在理解大质量脉冲星、磁层辐射及各种爆发现象等方面占有不少优势。徐仁新课题组研究发现，奇子星不仅具有接近三倍太阳质量的极限质量，而且潮汐形变能力低，跟双中子星并合引力波事件 GW170817 观测吻合，这一结果发表于《欧洲物理学报》（Eur. Phys. J. A 2019, 55, 60）。此外，鉴于中子星和奇子星表面束缚特征的差异，徐仁新课题组利用多方模型参数化状态方程，发现极限质量大的中子星往往潮汐变形也大，较难符合 GW170817 的观测结果；而对于奇子星，则不存在这一困难（Mon. Not. R. Astron. Soc. 2020, 499, 4526）。未来观测中，若发现大于 2.3 倍太阳质量的脉冲星将是对奇子星的有力支持。值得一提的是，中国五百米射电望远镜 FAST 提供的高计时精度的观测将能有效地保障脉冲星质量的普查。

II. Dense Matter and its Manifestations in Astrophysics

It is well known that atoms and molecules are the building blocks of normal matter in the daily life, and an atom consists of a nucleus and electron(s) outside. What if this matter is compressed so tightly that atomic nuclei come into close contact? This question has been asked since 1930s, to be relevant to quarks (as fundamental particles) and the interaction in-between, but is yet answered. The practical significance of this problem is related to the rump left behind after a core-collapse supernova of a massive evolved star: the core self-gravity is so strong that dense matter is produced at density as high as the nuclear saturation density, being manifested in the form of pulsars observed.

A pulsar is made of densest matter in the Universe, whose equation of state is a hot topic in both astronomy and physics, particularly in the multi-messenger era after the discovery of gravitational wave. It is conventionally believed that pulsar's matter is neutron-rich (i.e., the neutron star model), however, different manifestations of massive pulsars, magnetospheric activity as well as bursts/flares could be naturally understood in a strangeon star model proposed by Dr. Renxin's group. It is found that the tidal deformability of a strangeon star is low, being consistent with the observation of gravitational wave event GW170817 (Eur. Phys. J. A 2019, 55, 60), though its maximum mass could still be as high as 3 solar masses. In view of the sharp surface difference between neutron and strangeon stars, the authors parameterize the equation of state in a polytropic model (Mon. Not. R. Astron. Soc.2020, 499, 4526), concluding that neutron stars could hardly have small tidal deformability as low as the constraint of GW170817 if its mass-limit is larger than 2.3 solar masses, but a strangeon star has no such difficulty. It is, therefore, strong evidence for strangeon star if one measures a pulsar's mass higher than 2.3 solar masses in the future. Finally, it is worth noting that a census of pulsar mass would effectively be carried out by taking advantage of the China's Five-hundred-meter Aperture Spherical radio Telescope (FAST), with extremely high timing precision.

三、在仙女座大星云 M31 外围发现一颗亮蓝变星

张华伟研究团队与云南大学合作者利用国家大科学装置郭守敬望远镜（大天区面积多目标光纤光谱天文望远镜，英文简称 LAMOST）、中科院国家天文台 2.16 米望远镜、中科院云南天文台 2.4 米望远镜、美国海耳 5 米望远镜的观测数据以及历史观测资料证认了一颗位于仙女座星系（Andromeda Galaxy；也称 M31）外围的亮蓝变星 — LAMOST J0037+4016，这也是目前发现距 M31 中心最远的一颗。

亮蓝变星是大质量（初始质量通常大于 25 个太阳质量）恒星的晚期演化阶段，有着极高的亮度（10^5—10^7 太阳光度），位于赫罗图的左上角顶部。在亮蓝变星演化阶段，恒星通常会有间歇性的质量损失暴，此时恒星的光学波段会变亮 1—2 星等，光谱型从 O/B 型超巨星转变为 A/F 型超巨星。传统的大质量恒星演化模型通常认为，该类恒星是大质量恒星的氦主序星，即是沃尔夫 - 拉叶星的前身星。但近来有观测证据表明亮蓝变星可以爆炸为

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II 型超新星。发现和证认更多的亮蓝变星对于理解大质量恒星的质量损失暴及演化模型至关重要。

此前在 M31 中确定的亮蓝变星只有 6 颗，都集中在旋臂或恒星形成环上（图 1）。新发现的第 7 颗亮蓝变星的位置非常特殊，处于 M31 盘最外围的一个延伸子结构上，使之成为目前发现距 M31 中心最远的一颗亮蓝变星。由于该亮蓝变星的特殊位置，对该星及周围环境的后续研究将为大质量恒星的演化模型提供至关重要的观测约束。

相关研究成果发表在《天体物理期刊快报》（Astrophys. J. Lett. 2019, 894, L7）。

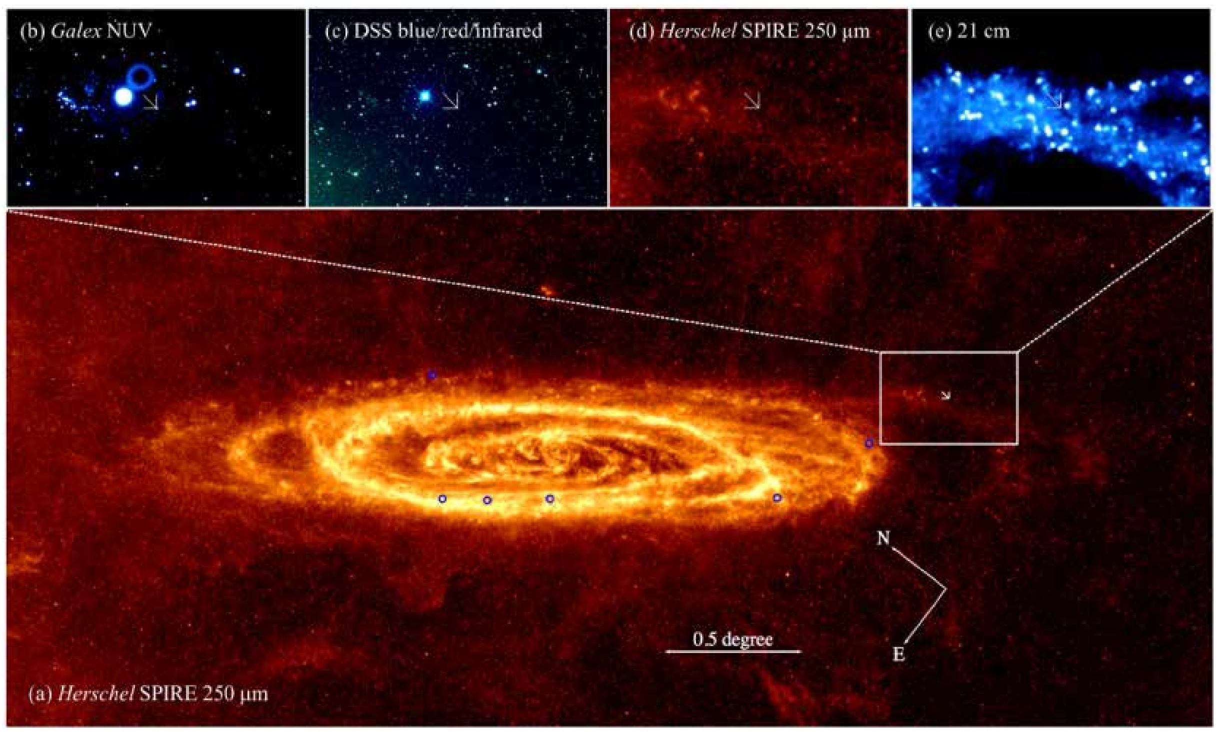

图 1. 不同波段图像中的 LAMOST J0037+4016。a) Herschel SPIRE 250 微米远红外图，图中蓝色圈表示 M31 中已知亮蓝变星位置，白色框为 LAMOST J0037+4016 所处位置；b) Galex 近紫外（NUV）波段放大图像；c) DSS 光学三色合成放大彩图；d）Herschel SPIRE 250 微米远红外放大图；e） 21 cm 波段射电放大图。放大图对应的视场大小与图 a 中白色框相同。

Figure 1. Images in the different bands showing the location and environment of LAMOSTJ0037+4016. Panel a: Herschel SPIRE 250μm image. The image scale is shown near the mid-bottom. The six blue circles mark the locations of the previously known LBVs in M31. The white box of size 20’ ×30’ is centred at this newly discovered LBV. The four images on the top zoom in on the area (of the same size of the white box) of LAMOSTJ0037+4016 in Galex NUV band (panel b); in DSS blue, red and infrared color composite image (panel c); in Herschel SPIRE 250μm image (panel d) and in 21cm line image (panel e).

III.Discovery of a new Luminous Blue Variable in the outskirt of the Andromeda Galaxy

A study by the research group led by Prof. Huawei Zhang from Department of Astronomy, Peking University and collaborators from Yunnan University report the discovery of a new Luminous Blue Variable (LBV) in the outskirt of the Andromeda Galaxy (M31), using data from the LAMOST spectroscopic surveys, the Xinglong NAOC 2.16 m, Lijiang YNAO 2.4 m optical telescopes, Hale 5m telescope, as well as archival data.

LBVs are hot, unstable, massive (> 25 – 30 solar mass) and extremely luminous (10^5 – 10^7 solar luminosity) evolved stars in the upper left parts of the Hertzsprung-Russell (HR) diagram. During the LBV phase, massive stars undergo episodes of eruptive mass-loss (10^{-5} – 10^{-4} solar mass per year), accompanied by spectacular photometric and spectral variabilities, on timescales of years to decades or longer. The origin of the eruptions is not yet well understood, partly due to the limited number of confirmed LBVs and the rareness of the eruptions. From the quiescence to the outburst (or eruptive) stage, the brightness of an LBV increases by 1—2 mag in the visual band and the spectrum type changes from O/early B-type to A/F.

At present, the LBV is either considered as a transition phase between the main sequence massive stars and the Wolf-Rayet stars or is an intermediate precursor of a supernova. More recently, some studies show evidence propose that LBVs could be evolved blue stragglers, i.e. the products of binary evolution, although this is still hot debated. Discovery of new LBVs is therefore of vital importance for understanding the origin of the eruptions and the role LBVs play in stellar evolution.

Currently, only six LBVs are identified and all of them are located in the spiral arms or star forming rings of the M31 disk (see Figure 1). Using the optical light curve, the multi-epoch spectra and the near-infrared color-color diagram, the seventh LBV of M31 are identified. More interestingly, this new LBV is located near the south-western corner of M31 with an unexpectedly large projection distance of 22 kpc from the center. Follow-up observations of this special LBV and its environment may provide vital constraints on the evolutionary status of LBVs.

This result was published in the Astrophysical Journal Letters (Astrophys. J. Lett.2019,894, L7).

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

大气与海洋科学系起源于 1929 年，具有悠久的历史和优良的传统。90 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，未名学者大气科学拔尖学生培养基地入选教育部第二批基础学科拔尖学生培养计划 2.0 基地名单。

本系有 28 名全职教师，包括杰青 3 人、优青 2 人、青年拔尖 2 人。研究方向涵盖极端天气与气候变化、大气物理与大气环境、物理海洋、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 4.7 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 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, fundamental 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 was ranked A+ in the fourth round of disciplinary evaluation by the Ministry of Education. AOS has two second-tier focal disciplines (Meteorology and Atmospheric Physics and Environment), and two more 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 and 2020, AOS was selected as a first-class undergraduate program and a leading Student Training Base in Atmospheric Sciences, respectively, by the Ministry of Education.

AOS employs a total of 28 full-time faculty members with 4 staff. Research fields within AOS include severe weather and climate change, atmospheric physics and environment, physical oceanography, and paleoclimate and planetary atmospheres. AOS actively 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 4.7 SCI papers.

一、海冰流动对太阳系外行星气候与宜居性的影响

杨军研究组的研究表明，在海冰流动的驱动下，潮汐锁相行星的开放海洋面积不断减小，冰雪覆盖区域面积不断增大，导致行星最终进入全球冰雪世界（如图 1）。该工作以“Transition from Eyeball to Snowball Driven by Sea-ice Drift on Tidally Locked Terrestrial Planets”为题发表于《自然·天文》（Nat. Astron. 2020, 4, 58）。

自 1992 年以来，人类已经确认了 4000 多颗太阳系外行星。其中，有 20 颗左右行星的大小与地球相当，接收到的恒星辐射也与地球接近，地表可能可以长期维持液态水存在。液态水是地球上所有生命存在的必需要素，也是判断行星宜居与否的重要依据，因此它们被称为“疑似宜居行星”。这些行星中大部分围绕着质量比太阳小温度比太阳低的红矮星公转，轨道半径只有日地距离的十分之一左右。因此，这类行星所受的潮汐力非常强，进而致使其轨道很容易进入潮汐锁相状态，类似于水星或月球的轨道。对于正圆形的潮汐锁相轨道而言，行星的一个半球永久接收恒星辐射照射，被称为“永久白天”，另一个半球永远接收不到阳光，被称为“永久黑夜”。类似于月球围绕地球公转的轨道，月球永远只有一面朝着地球，另一面永远背向地球。

前人的研究表明潮汐锁相行星的星下点附近可以存在一个开放海洋，而其他区域都被冰雪覆盖，因为只有星下点附近接收到的恒星辐射才能达到使地表温度高于 273 K 的水平。这一开放海洋是光合作用生物的理想生存环境，但是，这些研究都没有严格考虑海冰流动的作用。通过三维耦合的大气—海洋—海冰—陆地模式模拟，杨军等的研究表明，在考虑海冰流动之后，星下点位置的开放海洋无法稳定存在。海冰在背阳面生长，然后被风和海流不断输送到星下点区域，进而通过提高地表反照率和融化吸热过程使地表温度不断降低（图 2），直到使得整个海洋都被冰雪覆盖，进入冰雪世界。

除了海冰流动对开放海域面积的收缩作用，该工作还确认海洋热量输送可以起到相反的作用——扩大开放海域面积。对于接收恒星辐射量较少或者大气中温室气体浓度较低的行星而言，海冰流动的作用占主导。对于接收恒星辐射量较多或者大气中温室气体浓度较高的行星而言，海洋运动的作用占主导。

图 1. 从开放海洋到冰雪世界的转换。白色表示冰雪，蓝色表示海洋。

Figure 1: Transition from open ocean world to snowball world. On the planets, white areas indicate sea ice, and blue areas indicate open ocean.

系所中心研究亮点 | *Highlights*

I. Transition from eyeball to snowball driven by sea-ice drift on tidally locked terrestrial planets

A recent study of Dr. Jun Yang and his team revealed that on tidally locked planets, with the effect of sea-ice drift, the open ocean shrinks and can even disappear, turning the planet into a snowball state, see Figure 1. This work (Transition from eyeball to snowball driven by sea-ice drift on tidally locked terrestrial planets) has been published on Nature Astronomy.

More than 4000 exoplanets have been confirmed since 1992. There are about 20 planets that have similar size and receive similar stellar radiation compared with Earth, indicating that there may exist stable liquid water on such planets. Liquid water is essential for all life on Earth and is also one important criterion of the habitability of a planet, so that these planets are called "potentially habitable planets". Most of the exoplanets that have been found are orbiting around M dwarfs which are smaller and colder than the sun, and they are ten times closer to the host star than the Earth. As a result, the tidal force is very strong for these planets, so that they are likely to get tidally locked to the host star, a situation similar to the moon or Mercury. For 1:1 tidally locked planets, one side of the planets permanently face the host star which is called the "permanent day side", and the other side receives no stellar radiation which is called the "permanent night side", which is similar to the orbit that the moon orbits the Earth.

Previous studies showed that there can be an open ocean area near the substellar point with other regions covered by sea ice, because only the stellar flux near the substellar point can result in a surface temperature higher than 273 K. This open ocean is an ideal environment for photosynthesis. However, these studies did not seriously consider the effect of sea ice dynamics. Using 3-dimensional coupled atmosphere-ocean-sea-ice-land simulations, Jun et al. show that when sea ice drift is taken into consideration, the open ocean near the substellar point cannot be stably sustained. Sea ice forms on the night side and is transported continuously to the day side by wind and ocean currents, decreasing the surface temperature by increasing surface albedo and absorbing heat when it melts near the substellar point (Figure 2), and turning the whole planets into an icy world that the whole ocean is covered by sea ice.

Besides the effect of sea ice dynamics in shrinking the open ocean area, this work also found that ocean heat transport acts in the opposite way-increasing the open ocean area. For planets with smaller stellar radiation or lower greenhouse gas concentration, the effect of sea ice dynamics dominates, while for planets with lager stellar radiation or higher greenhouse gas concentration, the effect of sea ice dynamics dominates.

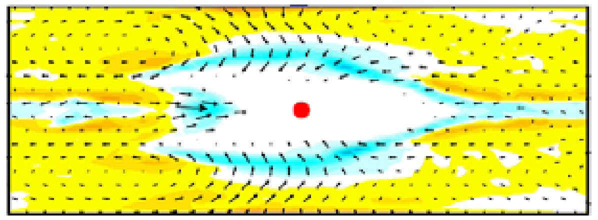

图 2. 海冰流动（箭头）、海冰生长对应的放热（黄色）和海冰融化对应的吸热（蓝色）。

红色点为星下点位置，横轴为经度（0-360），纵轴为纬度（90S-90N）。

Figure 2. Sea ice drift (arrows), heat release from sea ice formation (yellow shading) and heat absorption from sea ice melting (blue shading). The red dot indicates the substellar point. The x-axis is longitude from 0 to 360 and the y-axis is latitude from 90S to 90N.

二、全球变暖下极端降雨响应的区域特征

极端降水天气可以导致洪涝和泥石流等重大气象灾害，给社会经济和生态环境带来极大影响。如 2010 年 7 月巴基斯坦北部连降暴雨引发洪涝，约五分之一的国土和 2000 余万人受灾。在我国，极端降水也是影响最为广泛的气象灾害之一，每年因暴雨洪涝造成的经济损失达气象灾害总损失的 37%，死亡人数占总数的 12%。近年来在气候暖化的气候背景下，全球范围内很多区域的强降雨等极端天气的发生概率或强度也显著增加，对社会的灾害应对能力提出了严峻的挑战。极端降雨的气候响应有着很强的区域特征（图 1），理解这些区域特征及其背后的物理至关重要。

聂绩助理教授课题组近几年深入研究气候变化背景下的极端天气。2020 年 4 月，研究组在《美国科学院院报》上发表题为“Dry and moist dynamics shape regional patterns of extreme precipitation sensitivity”的研究论文（Proc. Natl. Acad. Sci., 2020,117, 8757），阐明了全球变暖下极端降雨响应的区域特征及其机理。该研究使用一种新颖的分析方法将极端降雨气候响应分解为干动力学部分（大尺度扰动强迫）和湿动力学部分（小尺度对流的潜热反馈），并且通过一个理论模型将干 / 湿动力学耦合起来。对多模式模拟结果的集成诊断分析发现：干动力部分在低纬度地区显著减弱、在中高纬度地区增强；湿动力部分则是低纬度增强，随着纬度的增加增幅减小。研究进一步为湿动力学部分构建了一个理论模型，使用一个简单的方程揭示了潜热反馈和大气水汽之间强的非线性关系。此理论模型很好地解释了全球增暖下大气水汽的增多和静力稳定度的变化导致的极端降雨中对流潜热反馈的变化（图 2）。该研究结果为极端降雨气候响应的区域特征提供了定量直观的解释，系统阐明了造成极端降雨气候响应分布特征的机制，有助于改进极端降雨的气候预测。

II. Regional patterns of extreme rainfall sensitivity to global warming

Extreme precipitation weather can cause devastating natural disasters such as floods and landslides, casting great impacts on the social economy and ecological environment. For example, in July 2010, persisting heavy rains in northern Pakistan caused a record-breaking flood, affecting about one-fifth of the country area and more than 20 million populations. In China, extreme precipitation is also one of the most damaging meteorological disasters. Every year, economic losses caused by heavy rains and floods account for 37% of the total losses of meteorological disasters, and the death toll accounts for 12% of the total. In recent years, under global warming, the occurrence probability and intensity of extreme rainfall in many regions of the world have increased significantly, posing a severe challenge to society's disaster response capabilities. The climate response to extreme rainfall has strong regional characteristics (Figure 1), and it is important to understand these regional characteristics and their physical mechanisms.

Assistant Professor Ji Nie led a research group in the Department of Atmospheric and Ocean Sciences, and made significant advances in studying the extreme weathers under the changing climate in recent years.

In April 2020, the research team published a research paper entitled "Dry and moist dynamics shape regional patterns of extreme precipitation sensitivity" on PNAS (Proc. Natl. Acad. Sci., 2020,117, 8757-8763.). Responses of extreme precipitation to global warming are of great importance to society and ecosystems. Although observations and climate projections indicate a general intensification of extreme precipitation with warming on global scale, there are significant variations on the regional scale, mainly due to changes in the vertical motion associated with extreme precipitation. Here, we apply Quasi-Geostrophic diagnostics on climate-model simulations to understand the changes in vertical motion, quantifying the roles of dry (large-scale adiabatic flow) and moist (small-scale convection) dynamics in shaping the regional patterns of extreme precipitation sensitivity (EPS). The dry component weakens in the subtropics but strengthens in the middle and high latitudes; the moist component accounts for the positive centers of EPS in the low latitudes and also contributes to the negative centers in the subtropics. A theoretical model depicts a nonlinear relationship between the diabatic heating feedback (α) and precipitable water, indicating high sensitivity of α (thus, EPS) over climatological moist regions (Figure 2). The model also captures the change of due to competing effects of increases in precipitable water and dry static stability under global warming. Thus, the dry/moist decomposition provides a quantitive and intuitive explanation of the main regional features of EPS.

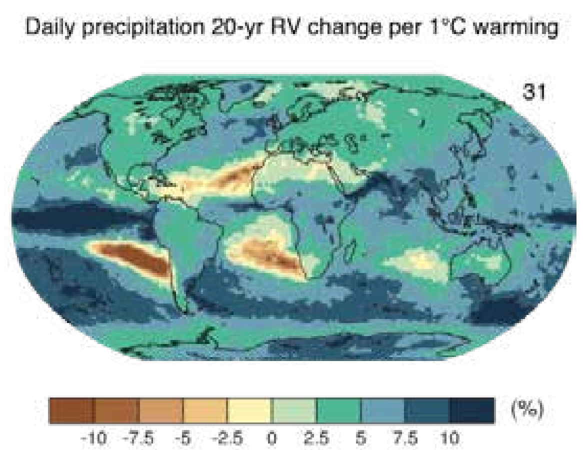

图 1. 极端降雨的气候响应

Figure 1. The regional patterns of extreme precipitation sensitivity to global warming.

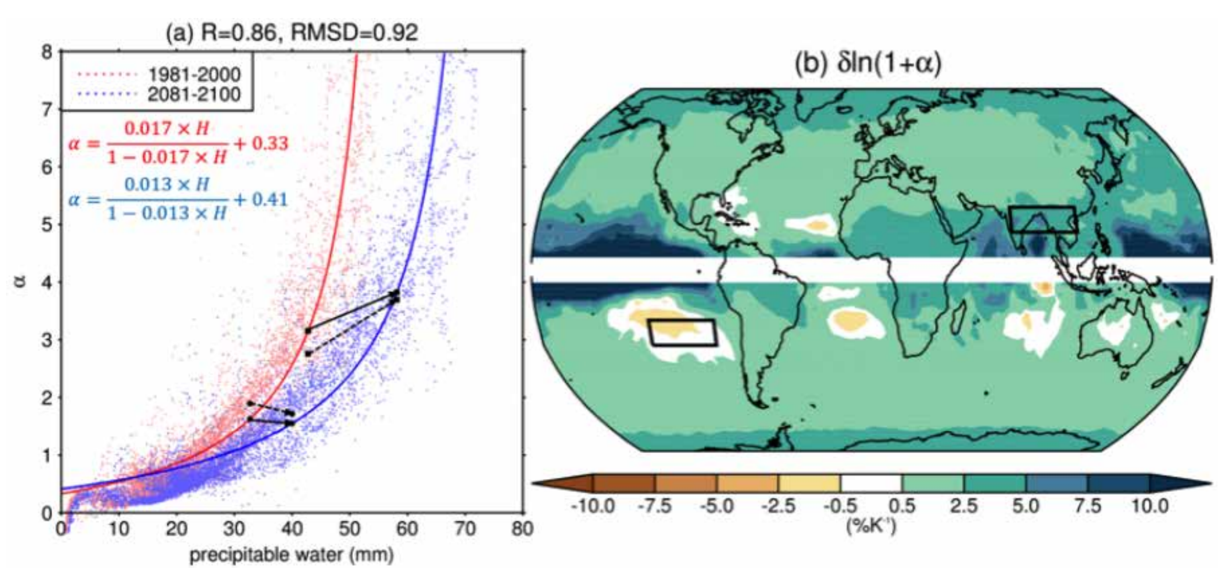

图 2. (a) 理论模型和数据高度吻合。(b) 理论模型解释了潜热反馈在全球暖化下的变化。

Figure 2. (a) The observational data and theoretical curves of diabatic heating feedback math well. (b) The geographic distribution of diabatic heating feedback.

三、冰雪地球事件中赤道附近强季节性温差的形成机制

刘永岗与合作者提出了冰雪地球事件中赤道附近强季节性温差的新形成机制，该工作发表于《科学进展》（Sci. Adv. 2020, 6, 2471）。

现代地球赤道附近太阳辐射的季节性变化较小，因此其季节性温差（最高月平均温度减去最低月平均温度）小于 10 摄氏度。但是，在新元古代晚期，约 7.2 – 6.3 亿年前的全球冰封事件——冰雪地球（Snowball Earth；图 1）事件中，古赤道附近的温差可能很大，超过 20、甚至 30 摄氏度。这是因为人们在与冰雪地球事件关联的地层中发现了很多大型沙楔（图 2），而这些沙楔的形成一般要求有干冷的环境和可能超过 30 摄氏度的季节性温差——在年平均气温比较低的情况下，秋冬季气温快速下降，导致地面收缩而产生的裂缝被沙土充填，年复一年形成了沙楔。在现代地球上主要形成于高纬度地区。

传统上认为，地球上的季节性温差主要是由于地球自转轴相对于黄道平面的倾角造成的，因此有人提出这么大的季节性温差表明当时地球的倾角非常大，超过 54°——即高倾角地球假说（图 1）。当地球倾角很大的时候，不仅赤道附近季节性温差很大，其年平均温度也低于两极，因此高倾角假说认为，虽然在古赤道附近观测到了冰川痕迹，全球平均温度可能并不低，并没有发生冰雪地球事件。这个假说由于无法解释地球倾角是如何演化成现代的大小，其合理性受到巨大质疑。然而，一直没有人能提出高倾角假说之外的其它方式来解释古赤道附近大型沙楔的形成。

刘永岗与合作者注意到，赤道附近的季节性太阳辐射变化还受到地球轨道偏心率的影响。虽然现代地球的轨道偏心率很小，这个影响可以忽略，但是地球轨道的偏心率在0.016 到0.0679之间周期性(有约 10 万年和约 40 万年两个显著周期）变化，有时轨道偏心率比现代大很多，这个影响会变得显著。刘永岗与合作者进行了模拟计算，通过在气候模式中逐渐增大偏心率，发现赤道附近的季节性温差确实可以显著增大。当全球，包括海洋，都被冰封（即硬冰雪地球；图 1）的时候，地表热容很小，季节性温差可达 30 度以上——这样就可以解释观测到的沙楔的形成，而完全不需要高倾角地球假说。另一方面，他们的模拟还表明，如果当时海洋没有被全冰封（即软冰雪地球；图 1），则赤道附近的季节性温差即使在大的偏心率情况下也不会超过 20 度。这是因为非全冰封情况下热带地区比较湿润，地表的热容量较大，导致在季节尺度上不容易产生大的温度振荡。

刘永岗与合作者进一步通过对地面土壤的强度、应力和破裂的计算表明，在硬雪球情况下，由于古赤道附近的温度也非常低，土壤很容易产生脆性破裂，气候模拟得到的季节性温差足以使地面产生很深的裂缝从而形成大型沙楔。然而在软雪球情况下，由于土壤脆性不足，而季节性温差又比硬雪球小很多，则很难形成大型沙楔。因此，他们的研究不仅提出了产生赤道强季节性温差的新机制，强烈支持了硬雪球地球的假说，而且还否定了另外两种假说，对解决冰雪地球各假说之间的争论提供了重要的帮助。

III. Mechanism for the Large Equatorial Seasonal Cycle during Snowball Earth Events

Yonggang Liu and collaborators propose a new mechanism for the large equatorial seasonal cycle during snowball earth events. The work is published by Science Advances (Sci. Adv. 2020, 6, 2471).

Due to the weak seasonal variation of solar insolation, the difference between monthly mean surface temperature of the warmest and coldest months near the equator is less than 10°C on the modern Earth.

However, during the Late Neoproterozoic global glaciation events (i.e., snowball Earth events (Fig. 1), occurred twice between approximately 720-635 million years ago), this temperature difference could have been greater than 20°C or even 30°C. This is because large sand wedges (Fig. 2) have been found near the paleo-equator in the sedimentary layer associated with the snowball Earth events. These sand wedges form in cold and dry regions, mostly in the high-latitude region on the modern Earth. During late autumn and early winter, surface temperature drops quickly and the ground cracks due to thermal contraction. Wind-blown dust will then fill the crack. The crack will open again in the years to follow, and eventually form a large wedge.

Traditionally, seasonal cycle of surface climate is attributed to the obliquity of the Earth's rotational axis. To have large seasonal cycle near the equator, the so-called high obliquity hypothesis proposes that the obliquity of Earth must have been very large (>54°) during that time. When the obliquity is large, the annual mean surface temperature of the paleo-equator would be much lower than that near the poles. Therefore, this hypothesis thinks that the global mean surface temperature was not necessarily very low, and snowball Earth events did not happen. This hypothesis can explain the large equatorial seasonal cycle represented by the sand wedges, but because it cannot provide a mechanism for the returning of Earth's obliquity to present-day value, its validity has been

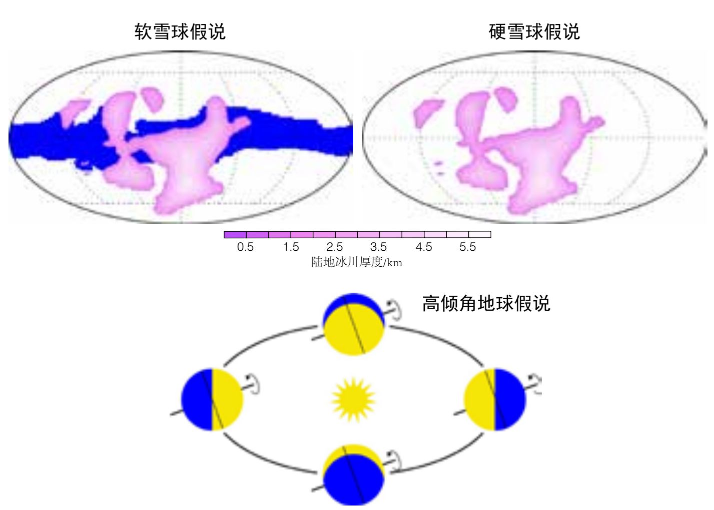

图 1 . 冰雪地球事件的三种假说：软雪球假说、硬雪球假说（和高倾角假说。上面两图中蓝色区域为海洋，粉色区域为冰川覆盖的陆地（约 6-7 亿年前），白色区域为海冰。硬雪球假说中的海冰厚度达到 1000 米左右，全球平均温度低至 -50 摄氏度左右。高倾角地球假说认为赤道地区比两极冷，可以形成陆地冰盖，但两极可能无冰。

Figure 1. Three hypotheses for snowball Earth events: soft snowball Earth (top left; also called waterbelt Earth or slushball Earth), hard snowball Earth (top right) and high obliquity Earth (bottom). White regions in the upper two panels are sea-ice-covered oceans, blue regions are oceans with no ice; pinkish regions are land-ice-covered continents. The thickness of sea ice in a hard snowball Earth is around 1000 m with a global mean surface temperature of about -50 °C. In the high obliquity hypothesis, equatorial region is colder than polar regions; land ice may form near the equator while the polar regions may remain ice free.

under question for a long time. However, no other alternative mechanism has been brought up to explain the formation of sand wedges near the paleo-equator.

In fact, the seasonal cycle of solar insolation near the equator is also significantly affected by the eccentricity of the Earth's orbit. Its influence is often ignored because the eccentricity of present-day Earth orbit is very small. The eccentricity of Earth’s orbit varies with time between 0.016 and 0.0679 on a timescale of approximately 100,000 years, and can thus be much greater than present-day value from time to time. How this variation of eccentricity might affect the seasonal cycle of surface temperature during snowball Earth events was tested by Yonggang Liu and collaborators, using a state-of-the-science climate model. They found that the equatorial seasonal cycle of surface temperature could indeed be greater than 30°C when the eccentricity was large, if the event was a hard snowball Earth (i.e. top right panel of Figure 1). Thus, their study renders the high obliquity hypothesis completely unnecessary. Moreover, their simulations showed that the equatorial seasonal cycle was smaller than 20°C no matter how large the eccentricity was if a soft snowball Earth had occurred (top left panel of Figure 1). This is mainly because the surface was wet and had large thermal inertia in this situation.

Yonggang Liu and collaborators further calculated the soil intensity, stress and cracking of the ground during snowball Earth events. Their results indicated that the simulated seasonal cycle by the climate model was large enough to form deep sand wedges in a hard snowball Earth. In such extreme climate state, the temperature was very low even near the equator, the ground was thus brittle and apt to form deep cracks. For soft snowball Earth, the soil was not so brittle due to its much warmer temperature and seasonal cycle was also weaker, deep cracks were thus very unlikely to occur. Therefore, their study not only provides a more reasonable mechanism for the observed large equatorial seasonal cycle, supporting the hard snowball Earth hypothesis, but also strongly discouraged the other two hypotheses (soft snowball Earth and high obliquity). It helps resolve the debate on the intensity and severity of the glaciation during the Neoproterozoic snowball Earth events.

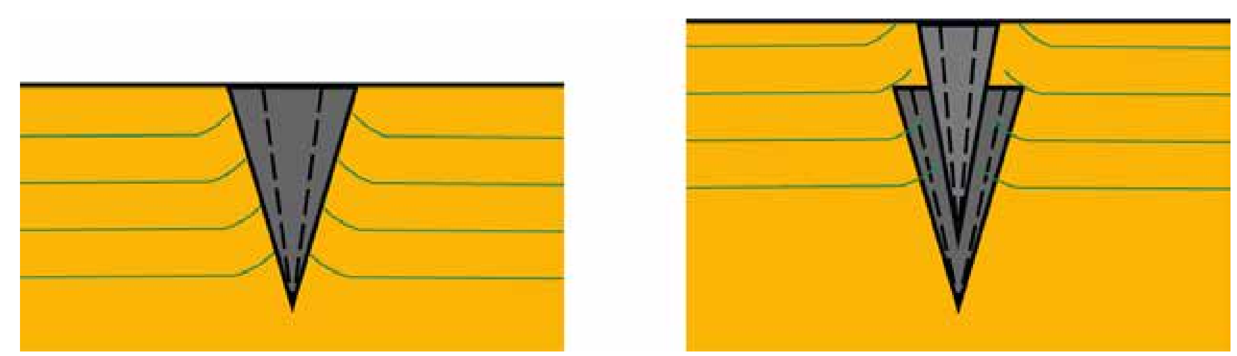

图 2. 地面表层沙楔（灰色区域）的示意图。实际的沙楔只是近似为楔形，在其它过程（比如流水）的作用下常常可以产生复杂的扭曲变形，并且可以形成多重沙楔（如右图）。大的沙楔深度可以达到 3 米以上（比如高倾角假说所指的沙楔），其宽度有时也可以达到 3 米以上，可能需要几百上千年才形成。

Figure 2. Illustration of sand wedges (grey) in sedimentary layers (orange). Actual sand wedges can be distorted into complex shapes due to ground deformation and/or water flow. Sand wedges can form within old ones (left). Both the width and the depth of sand wedges can reach over 3 m, taking hundreds to thousands of years to form.

系所中心研究亮点 | *Highlights*

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教学日常组织管理工作。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 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大普物教学的优良传统，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 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, electrodynamics, thermodynamics and optics, for the sciences major undergraduate students of Peking University. It is also responsible for organizing seminars and arranging foreign 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 old days. As far as the teaching faculties are concerned, except several full-time members, many professors from other departments of School of Physics participate also in teaching general physics. Since these lecturers are experienced researchers, they make their classes more interesting and illuminating 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.

一、 独立提出 ETA 物理认知模型与 ETA 物理教学法

长期以来，国内物理教学法都处于模仿国外的状态，并且物理教学与科研存在一定的脱节现象，这是因为对物理认知的根本规律缺乏认识。

为此，普通物理教学中心的穆良柱老师针对物理认知规律独立研究近 20 年，提出了 ETA 物理认知模型，即完整的物理认知由实验物理认知（E）、理论物理认知（T）和应用物理认知（A）构成。由此模型出发，归纳了物理方法、物理精神，并指出这三者是物理文化的核心内容。

从该模型出发，独立提出了 ETA 物理教学法，即根据认知规律，将物理知识重组为有启发性的认知案例，将教学和科研训练紧密结合，学生学习物理认知的过程就是科研能力的训练过程。该教学法不仅从根本上解决了物理教育教什么、怎么教的问题，还能满足国家经济发展对创新型引领未来人才的急迫需求。

该模型和教学法提出后受到广泛关注和欢迎，已经被特邀做专题报告 30 多次，听众近万人，发表公众号文章 4 篇（"物理与工程"4 篇；"北京大学教务部"1 篇；"老虎物理"2 篇），阅读量超 2 万次，并发表相关文章 4 篇。

相关文章列表：

[1] 穆良柱 . 物理课程思政教育的核心是科学认知能力培养 [J]. 物理与工程 ,2021,31(2).http://kns.cnki.net/kcms/detail/11.4483.o3.20210222.1059.002.html.

[2] 穆良柱 . 什么是 ETA 物理教学法 J. 物理与工程 , 2020, 30(02): 32-36.

[3] 穆良柱 . 什么是 ETA 物理认知模型 J. 物理与工程 , 2020, 30(01): 1-6.

[4] 穆良柱 . 什么是物理及物理文化 ?J. 物理与工程 , 2019, 29(01): 15-24.

I. The ETA Physical Cognitive Model And The ETA Physics Teaching Method Are Proposed

For a long time, domestic physics teaching methods are originated abroad, and the teaching and research of physics have less connection than expected. The reason is the lack of deep understanding of the fundamental laws of the physical cognition.

In order to find the cognition laws, Liangzhu Mu, a teacher from the Center for General Physics Teaching, has independently studied this subject for nearly 20 years, and finally proposes the ETA physical cognitive model. This model is composed of experimental physical cognition (E), theoretical physical cognition (T) and applied physical cognition (A). From the model, physical methods and physicists' spirits are derived. Physical cognition, physical methods and physicists' spirits are the central elements of physical culture.

Based on the model, the ETA physics teaching method is proposed. According to the cognitive law, the physical knowledge is reorganized into enlightening cognitive cases. The teaching process is the same as the research process, in which students get the necessary scientific research training. This pedagogy not only solves the problems of what to teach and how to teach, but also develops a practical way to train innovative talents for the nation.

The model and the method have been widely accepted. More than 30 invited reports have been given in universities and high schools for nearly 10000 audience. Four articles have been written for different WeChat official accounts and have been read more than 20000 times. Four related research papers have been published.

二、《热学》与《电磁学》慕课被评为 2020 年度“首批国家级一流本科课程”

2020 年 11 月 24 日，教育部公布的国家级一流本科课程名单中，由欧阳颀、穆良柱、高原宁和张海君团队建设的《热学》慕课和由王稼军、穆良柱、孟策和陈晓林团队建设的《电磁学》慕课入选了线上一流课程。此外，由陈晓林教授和孟策副教授负责的《电磁学》线下课程被认定为 2020 年度北京市“优质本科课程”。

《热学》慕课不仅介绍热学的基本现象及其解释，还讲授物理学中处理复杂研究对象时的基本方法，同时还介绍应用微积分、统计方法等数学思想来构建物理学认知体系的过程，力求让学生通过热学学习和训练获得科学认知能力。该慕课课程现已开设 4 次，选课人数逾 2 万人。

《电磁学》慕课早在 2018 年就被认定为“教育部国家精品在线开放课程”，而后在王稼军教授的领导下继续改进教学手段、深化课程建设，在 2018-2020 年期间的教学获得了广泛的认可和好评，此次也被认定为“首批国家级一流本科课程”。该慕课课程现已开设 6 次，选课人数逾 2.5 万人。

北京大学物理学院普通物理教学中心将继续推动一流普通物理课程建设工作。

II. Thermophysics and Electromagnetism were honored as national first-class undergraduate courses

The Ministry of Education announced the list of national first-class undergraduate courses on November 24, 2020. The two Moocs, thermophysics (built by Qi Ouyang, Liangzhu Mu, Yuanning Gao, Haijun Zhang) and Electromagnetism (built by Jiajun Wang, Liangzhu Mu, Ce Meng, Xiaolin Chen), were selected as first-class online courses. In addition, the offline course "Electromagnetism" led by Professor Xiaolin Chen and Associate Professor Ce Meng was recognized as the "Excellent Undergraduate Course" in Beijing in 2020.

The Thermophysics Mooc not only introduces the basic phenomena of heat and their explanations, but also teaches the basic methods of dealing with complex objects in physics. At the same time, it also introduces the process of using mathematics, such as calculus and statistical methods, to construct the cognitive system of thermophysics. This course aims to train the student to obtain the scientific cognition ability. The MOOC has been offered four times and attracted more than 20,000 students.

As early as 2018, Electromagnetism MOOC was recognized as the "National Excellent Online Open Course of the Ministry of Education". Later, under the leadership of Professor Jiajun Wang, the course team continued to improve teaching methods and deepen course construction. During the period of 2018-2020, the course was widely recognized and praised, and was once again recognized as a national first-class undergraduate course. The MOOC has been offered six times and attracted more than 25,000 applicants.

The Center for General Physics Teaching will continue to promote the construction of first-class general physics course.

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 8 名（教授 2 名，副教授 6 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. The center undertakes the core course teaching of National Outstanding Courses “General Physics Experiment” and “Modern Physics Experiment”. On the basis of the above, the center constructs the research-oriented “Comprehensive Physics Experiment” and “Frontier Physics Experiment”. At present, there are 8 full-time faculty members (2 professors and 6 associate professors) and 7 laboratory technicians (2 senior engineers and 5 engineers) in the center.

一、“近代物理实验”被教育部认定为首批国家级线下一流本科课程

“近代物理实验”是物理专业高年级学生的一门重要的综合性实验课程。该课程的主要目标是训练学生对物理现象的观察和分析能力，引导他们了解实验物理在物理学中的地位，正确认识新物理概念的产生、形成和发展的过程，培养严谨的科学作风。课程拥有涵盖物理学 10 个领域的近 40 个实验，其中约 1/3 为诺贝尔奖实验，约 1/3 为北京大学物理学院科研成果，约一半的实验为国内最早开出。课程教学团队包括多位杰青、优青和资深教授。

近年来，在北京大学教务部和设备部的大力支持下本课程进行了全面系统的改革建设，硬件方面建成了分子束外延设备、扫描电子显微镜、超高真空扫描隧道显微镜、显微拉曼光谱仪等仪器设备，满足优秀本科生进行研究型实验的需要；实验项目方面增加了高温电阻法研究固态材料成相、约瑟夫森效应、非线性热对流斑图、热噪声和散粒噪声、磁光克尔效应、半导体泵浦固体激光器的调 Q 与光学二倍频等，为北京大学创建国际一流大学培养优秀人才提供了坚实基础。2019 年，课程主持人季航教授率领教学团队参加了国家级线下一流课程的申报工作，以“加强一流本科课程建设与应用，提升本科课程的高阶性、创新性和挑战度”为宗旨，准备了大量视频、文字、图片资料，梳理了本课程历年来的建设与成果，形成了比较能反映课程先进性的申报材料。历时近一年通过公示，北大“近代物理实验”被教育部认定为首批国家级线下一流本科课程。

I. Modern Physics Experiment recognized as the first batch of national first-class undergraduate courses by the Ministry of Education

Modern Physics Experiment is an important comprehensive experimental course for senior physics majors. The main goal of this course is to train students’ ability of observation and analysis of physical phenomena, and to guide them to understand the standing of experimental physics in Physics and to understand the process of the emergence, formation and development of new physical concepts correctly, and eventually to cultivate their rigorous scientific attitude. The course has nearly 40 experiments covering 10 fields of physics, one third of which based on Nobel Prize-winning experiments, and one third from scientific researches of School of Physics at Peking University. About half of the experiments are initiatives in China. The course faculties include bunch of distinguished, excellent and senior professors.

In recent years, our course has been reformed and constructed comprehensively and systematically, with the strong support of the educational administration department and the equipment department of Peking University. Plenty of instruments have been built up and improved in hardware, such as molecular beam epitaxy equipment, scanning electron microscope, ultra-high vacuum scanning tunneling microscope, micro-Raman spectrometer and other equipment to meet the need of excellent undergraduates to carry out research experiments. New experiments have been developed, such as the phase formation of high temperature superconductor, Josephson effect, nonlinear thermal convection pattern formation, thermal noise and scattered particle noise, magneto-optical Kerr effect, Q-switching and the optical frequency doubling of diode-pumped solid-state laser, which provide the solid foundation for Peking University to cultivate excellent students as the world-class university. In 2019, the course Principle Professor Dr. JI Hang led the teaching group to participate in the national first-class curriculum application work to "strengthen the first-class undergraduate curriculum construction and application, enhance the higher-level, innovation and challenging of the undergraduate curriculum" for the purpose, prepared a large number of video, text, and picture materials, sorted out the construction and achievements of the course over the years, and formed the more advanced application materials. Through evaluation and publicity for nearly one year, the Modern Physics Experiment course of Peking University has been recognized by the Ministry of Education as the first batch of national-level first-class undergraduate courses.

二、国际和亚洲物理奥林匹克竞赛国家队的选拔和实验培训

北京大学基础物理实验教学中心负责了 2019-2020 年度的国际和亚洲物理奥林匹克竞赛国家队选拔和培训工作的实验部分。中国国际物理奥林匹克代表队的 5 名队员和亚洲物理奥林匹克代表队的 8 名队员均从全国中学生物理竞赛决赛的金牌获得者中选出。为使有潜能但其所在中学实验条件较弱的同学也能有更公平的机会，实验中心在实验选拔考试前安排了面对全体候选同学的实验培训，并通过精心准备的选拔考试题来全面考察学生的物理实验素养，以确保入选队员都是最优秀的。

由于受到新冠肺炎疫情的影响，原定于 2020 年 7 月在立陶宛举行的第 51 届国际物理奥林匹克竞赛（IPhO）延后。为使各个国家和地区 2020 年度选拔的学生不失去宝贵的参赛机会，俄罗斯主动承担竞赛命题、组织等艰巨工作，使得竞 赛（International Distributed Physics Olympiad, IdPhO2020）得以于 2020 年 12 月 8—15 日在跨越 14 个时区的全球多地举行。作为赛事中国赛区的承办单位，物理学院以最快速度将西楼思源报告厅改装为符合组委会要求的考场，确保中国队顺利取得正式参赛资格。实验中心为使中国队参赛选手们达到最佳比赛状态，安排了多次模拟实验考试。最终中国代表队的五位选手张意飞、孙睿、李世昌、韩永琰和欧阳霄宇全部以高于金牌分数线 50% 以上的突出成绩夺得金牌并包揽前五名；张意飞更以超优异表现勇夺最佳总成绩奖、最佳理论奖、最佳实验奖。

II. Selection and experimental training of national team for the international and Asian physics Olympiad

The Teaching Center for Experimental Physics at Peking University has been responsible for the selection and training of the international and Asian physics Olympiad teams from 2019 to 2020. Five members of the Chinese international physics Olympiad team and eight members of the Asian physics Olympiad team were selected from among the gold medalists in the national physics competition. To make the students with high potential but weak experimental conditions in high school have fair chance, our center arranged the experimental training for all the candidates before the experimental selection, and used the well-prepared exam questions to comprehensively investigate the students' physics experiment level, to make sure that the selected members were the most excellent.

Affected by the COVID-19 epidemic, the 51st international physics Olympiad (IPhO), originally scheduled for July 2020 in Lithuania, was postponed. In order to keep the students selected in 2020 by various countries and regions from losing their precious opportunities to participate, Russia had taken the initiative to undertake the difficult tasks of competition topics and organizations, so that the International Distributed Physics Olympiad (IdPhO2020) could be held in many parts of the world across 14 time zones from 8 to 15 December 2020. As the organizer of the competition in China, School of Physics at Peking University had modified the Siyuan Lecture Hall at the earliest time to meet the requirements of the organizing committee, to ensure the Chinese team successfully qualified for the competition. Our center arranged multiple simulated experimental exams in order to make the Chinese team players reach their best competition status. Eventually all five players from the Chinese team, Zhang Yifei, Sun Rui, Li Shichang, Han Yongyan and Ouyang Xiaoyu, won the gold medals with the outstanding results of 50% higher scores and gained all top five. In particular, Zhang Yifei prominently won the best total score award, best theory award and best experiment award for his super-excellent performance.

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、单原子层六方氮化硼中声子极化激元的直接观测

极化激元是一种在材料界面上进行传输的表面电磁波，它能够突破光的衍射极限，将光的波长压缩到纳米尺度进行操控。二维范德华材料具有特殊的能带结构，可以支持丰富的极化激元模式，例如石墨烯中动态可调的等离激元、氮化硼中低衰减的声子极化激元和过渡金属硫族化合物中的激子极化激元等。它们为上述研究提供了理想的材料选择。特别是单层氮化硼，理论上支持具有最高波长压缩比的声子极化激元，因此对其进行直接测量具有重要的意义。

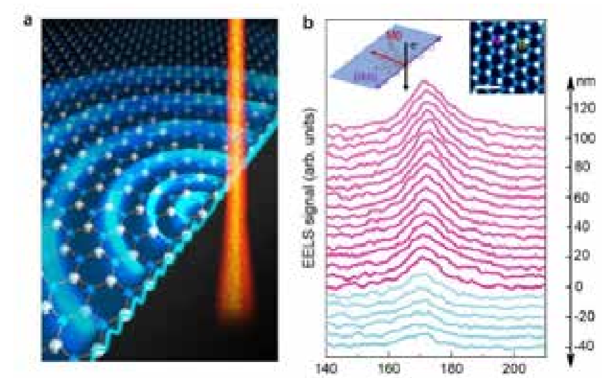

图 1.(a) 电子激发悬空单层氮化硼中声子极化激元的示意图；(b) STEM-EELS 测得的悬空单层氮化硼声子极化激元实验谱线，采集位置沿垂直于样品边缘的方向变化。

Figure 1. (a) Schematic showing swift electrons excite phonon polaritons in the suspended monolayer h-BN. (b) STEM-EELS experimental spectra acquired along a line perpendicular to the sample edge.

然而，普遍使用的光学方法对单层氮化硼 HPhPs 激发效率低，并且结果易受基底影响，导致实验测得的单层氮化硼声子极化激元频率与理论上并不符合。高能电子可提供的动量补偿（>10^8 cm^{-1}）比光学方法（~10^5 cm^{-1}）高约 3 个数量级，因此北大电镜室用透射电子显微镜中的电子能量损失谱（STEM-EELS）对氮化硼材料中的 HPhPs 进行直接探测。利用该方法得到了 h-BN 薄片中近乎完整的上剩余射线带声子极化激元信号，并首次探测到悬空单层氮化硼声子中的超高波长压缩（压缩比超过 487 倍）和超慢群速度（~10^{-5} c）的极化激元信号。此工作在线发表于《自然材料》（Nat. Mater. 2021, 20, 43）。

I. Direct Observation of Highly Confined Phonon Polaritons In Suspended Monolayer Hexagonal Boron Nitride

Phonon polaritons are guided wave modes that propagate at the surface of materials, which can confine and manipulate light at deep subwavelength scales. Hyperbolic phonon polaritons (HPhPs) in two-dimensional (2D) van der Waals materials, such as hexagonal boron nitride (h-BN), can be used to confine and manipulate light at deep subwavelength nanoscales, where they find important applications in subdiffraction imaging, surface-enhanced infrared spectroscopy, nanoscale lasing and integrated optical circuits, among other applications. HPhPs in monolayer h-BN are theoretically expected to reach ultrahigh confinement and ultralow loss.

However, a quantitative measurement of the pristine HPhPs in monolayer h-BN still remains elusive due to the large light–polariton wave vector mismatch, as well as the effects of the supporting substrate. The measured HPhP frequency by optical methods was much lower than the theoretically calculated transverse optical (TO) phonon frequency in free-standing monolayer h-BN. Nevertheless, the momentum transfer provided by swift electrons (>10^8 cm^{-1}) is nearly a thousand times larger than that of optical methods (~10^5 cm^{-1}), which can excite and detect phonon polaritons in monolayer h-BN. Using such a STEM-EELS technique, the research team in Peking University experimentally measured HPhPs in suspended monolayer h-BN and in sub-10-nm-thick h-BN flakes covering nearly the whole upper RS band. They find HPhPs in monolayer h-BN exhibit ultrahigh confinement (>487 times smaller wavelength relative to the wavelength of light in free space) and ultraslow group velocity (~10^{-5} c). This work experimentally demonstrates the existence of high-quality HPhPs when the RS band disappears in monolayer h-BN, thus providing useful insights for the design of optical integrated circuits and sensing and spontaneous emission engineering with enhanced light–matter interactions. This work has been published in Nature Materials (Nat. Mater. 2021, 20, 43).

二、电子显微镜实验室仪器研发工作简报

北京大学物理学院电子显微镜实验室（电镜室）开展了精密科学仪器研制开发工作。在科学技术部、国家自然科学基金委和广东省系列项目支撑下，实验室在电子束曝光系统和阴极荧光系统研发方面不断取得重要进展，并逐步在北京大学推广使用。

电子束曝光系统是微纳加工的重要工具，是利用电子束扫描直写来加工所需的掩膜图形。电镜室参与广东省重点领域研发计划项目（2018B030327001），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。在项目支撑下，已成功搭建 30 kV 电子束曝光系统，目前已开展电子束曝光应用测试工作。同时，电镜室所研发的电子束矢量扫描曝光系统能够配合扫描电子显微镜实现 50 nm 线宽加工，可实现复杂图形的矢量扫描加工，以及曝光写场拼接功能，将在微纳结构和器件加工领域开展重要应用。

阴极荧光系统是利用聚焦电子束扫描所研究物质表面，收集探测具有高空间分辨的荧光强度和光谱信号，以研究微纳尺度下物质的光学和光电特性。电镜室所研制的阴极荧光成像系统可具有近 1mm 的均匀成像视场，在半导体缺陷探测、地质发光样品成像等方面具备应用优势，目前已经面向全校开放使用。阴极荧光光谱探测系统能够实现深紫外至近红外波段的荧光光谱空间分辨探测，在微纳尺度发光材料和器件、纳米光学等领域具有应用价值。

图 1. 项目成功搭建 30 kV 电子束曝光系统

Figure 1. The 30 kV electron beam lithography system established by Electron Microscopic Laboratory.

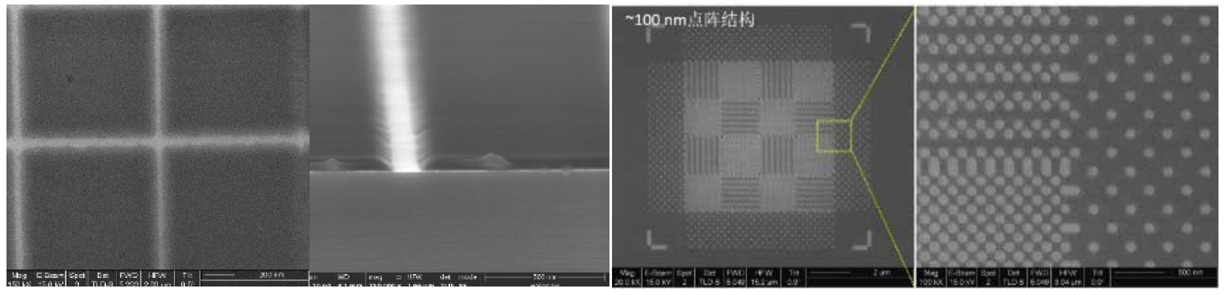

图 2. 利用电子束矢量扫描曝光系统直写加工线条结构（左）与点阵结构（右）

Figure 2. Using the electron beam lithography system, line structures(left) and lattice structures(right) has been processed by direct writing.

系所中心研究亮点 | *Highlights*

II. Electron Microscopic Laboratory: Instrument research and development briefing

Electron Microscopic Laboratory, School of Physics, Peking University has been developing various scientific instruments. With the support of the Ministry of Science and Technology of China, the National Natural Science Foundation and projects of Guangdong Province, the laboratory has made important progress in the development of electron beam lithography system and cathode fluorescence system, which have been gradually on active service in Peking University.

Electron beam lithography system is an important tool in micro-nano fabrication. Electron Microscopic Laboratory participates in the Key Field Research and Development Project of Guangdong Province (2018B030327001), undertaking the tasks of electron beam vector scanning generator, precision laser interferometer sample station and sample chamber. For now, a 30 kV electron beam lithography system has been successfully established, and the application testing of electron beam lithography has been carried out. Besides, the electron beam vector scanning system developed by Electron Microscopic Laboratory has achieved 50 nm linewidth, which can process complex graphics, as well as stitch multiple writing fields, thus supposed to play important roles in nanotechnology. Cathodic fluorescence system that uses focused electron beam to scan the surface of the studied material to collect the fluorescence intensity and spectral signal with high spatial resolution, can probe the optical and photoelectric properties of materials at micro/nano scale. The cathode fluorescence imaging system developed by Electron Microscopic Laboratory has achieved a uniform imaging field of nearly 1 mm, which has advantages in semiconductor defect detection and geological luminescent sample imaging, etc. The system is now open to the university. The cathodic fluorescence spectrum detection system can realize the spatial resolution detection of fluorescence spectrum from deep ultraviolet to near infrared bands, and has application value in the fields of micro-nano luminescent materials and devices, nano optics, etc.

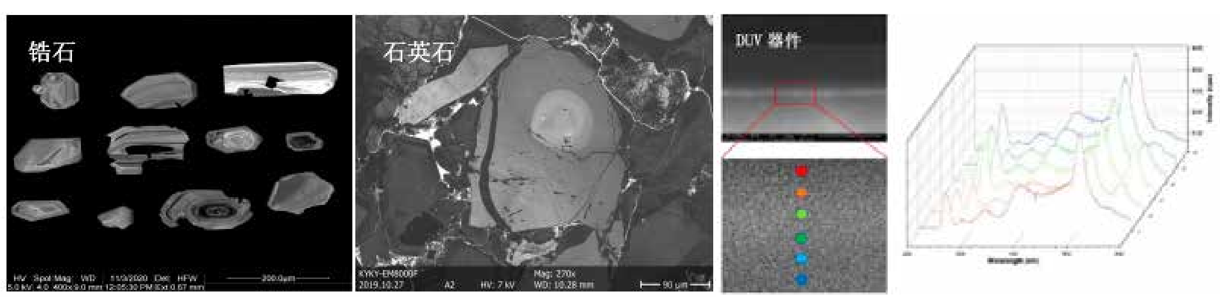

图 3. 利用阴极荧光成像系统研究地质锆石和石英石样品（左）；利用阴极荧光光谱探测系统在纳米尺度表征分析深紫外发光器件的荧光光谱（右）。

Figure 3. Study of geological zircons and quartzite samples using the cathode fluorescence imaging system(left). Analysis of fluorescence spectra of deep ultraviolet emitting devices by using the cathode fluorescence spectroscopy detection system at nanoscale (right).

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

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 2020 年 12 月，已有教研系列人员 30 人 (全职到岗 29 人)，其中特聘讲席教授 1 人，讲席教授 4 人，教授 9 人，长聘副教授 8 人，预聘助理教授 8 人。每名教师建有独立的研究小组，实行独立 PI 制。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”，10 人曾获国家杰出青年科学基金，4 人入选基金委优秀青年基金项目，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，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，目前中心共培养博士后 66 人（目前在站博士后 22 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 175 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 17 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 2020 年 12 月，中心共发表 SCI 论文 1200 余篇，其中多篇发表在 Science，Nature 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40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 3 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、

系所中心研究亮点 | *Highlights*

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 2019, the ICQM faculty members consist of 4 Chair Professors, 9 tenured Full Professors, 8 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 66 postdocs with several of them making important achievements in their research fields. 175 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 17 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 2020 since the establishment of the center in 2010, ICQM has published more than 1200 SCI papers, many of which were published in the most influential scientific journals in the world, such as Science, Nature 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、实验证实二维冰的存在

水是自然界中分布最广泛的物质之一，冰是水分子规则排列形成的常见物态，其结构与成核生长在材料科学、摩擦学、生物学、大气科学等众多领域具有至关重要的作用。经过了近百年的研究和探索，迄今人们已经发现了 18 种三维冰相，其中自然界最常见的冰相为六角结构的 I_h 相。冰在二维极限下是否能稳定存在？此问题在学术界一直存在很大的争议。

量子材料科学中心的江颖、徐莉梅、王恩哥与美国内布拉斯加大学林肯分校的曾晓成合作，利用

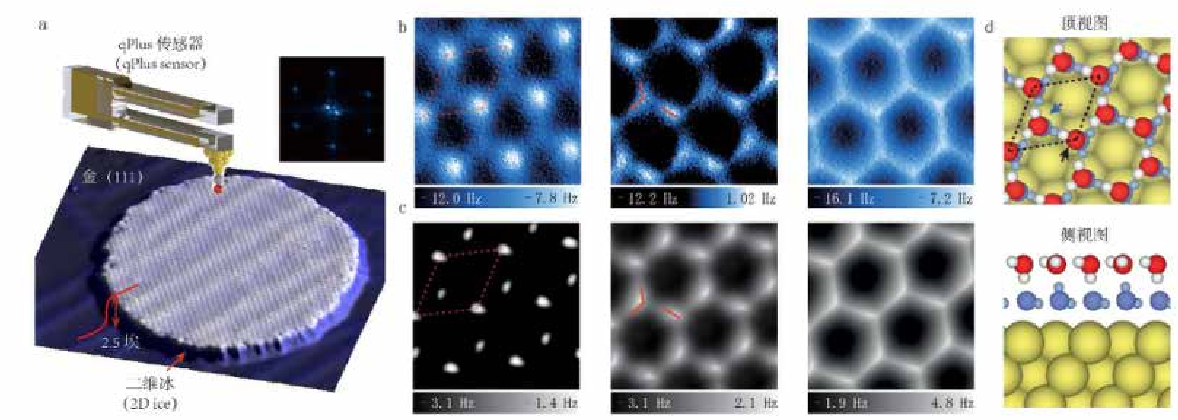

图 1. 实验装置示意图，二维冰 AFM 实验结果与模拟，和二维冰“互锁式”结构的原子模型。

Figure 1. Experimental setup, detailed AFM images of 2D bilayer ice and the corresponding structural model.

自行研发的高分辨原子力显微镜技术（图 1），以原子级分辨率捕捉到了二维冰的形成过程，并结合计算模拟揭示了其独特的生长机制（图 2），首次证实了二维冰的真实存在。研究人员把实验中拍摄到的二维冰命名为二维冰 I 相，以对比大自然中广泛存在的三维冰 I_h 相。二维冰的发现改变了一百多年来人们对冰相的传统认识，开启了探究二维冰家族系列的大门，为冰在低维和受限条件下的形态和生长提供了全新的图像。

该工作以“Atomic imaging of the edge structure and growth of a two-dimensional hexagonal ice”为题于 2020 年 1 月 2 日发表于《自然》（Nature 2020, 577, 60），得到国内外专家的高度评价，被《自然综述—化学》、英国物理学会《物理世界》、美国科学促进会 EurekAlert、美国 Science Daily、《科学通报》、《中国科学》、《科技日报》等二十多个国内外期刊杂志和科技媒体广泛评述和报道。

I. Experimental verification of the existence of two-dimensional ice

Water ices are ubiquitous in nature. The structure and growth of ice play critical roles in an incredibly broad spectrum of materials science, tribology, biology, atmospheric science. For nearly 100 years, enormous experiments and theoretical calculations have led to the discovery of eighteen three-dimensional crystalline phases, among which the hexagonal ice (Ice Ih) is the most common ice. However, whether the ice can exist at two dimensions (2D) has been under longstanding debate. The teams led by Prof. Ying Jiang, Prof. Limei Xu and Prof. Enge Wang of International Center for Quantum Materials (ICQM) of Peking University, in collaboration with Prof. Xiao Cheng Zeng of Department of Physics of University of Nebraska-Lincoln, revealed the structure and growth processes of a genuine 2D ice with an atomic resolution. This research group has achieved the following major scientific breakthroughs and discoveries:

(1)By carefully tuning the temperature and water pressure, a single-crystal 2D ice can be grown on Au(111), and fully wets the surface with a thickness of around 2.5 Å, corresponding to two water overlayers.

(2)With the non-invasive atomic force microscopy (AFM), the details of 2D ice can be revealed with submolecular resolution. The atomic-scale images combined with density functional theory (DFT) calculations reveal that the 2D ice corresponds to an interlocked bilayer-ice structure. It is the first genuine 2D ice confirmed by theory and experiment, i.e., named 2D ice I (Figure 1).

(3)To understand the ice growth mechanism, the AFM was employed to image edges of the 2D ice island. It contains the original zigzag edge and reconstructed armchair edge. Combining with DFT calculations and molecular dynamics simulations, very distinct ice growth behaviors were found, namely "collective bridging mode" for zigzag edge and "local seeding mode" for armchair edge (Figure 2).

This work, entitled "Atomic imaging of edge structure and growth of a two-dimensional hexagonal ice", is published in Nature on January 2, 2020（Nature 2020, 577, 60）. It is the first experiment to yield the atomic-scale information of 2D ice growth in real space, which may renovate our conventional understanding of the formation and melting of low-dimensional ices on surfaces. Technologically, the 2D ices also have many potential applications. For example, the 2D ice on the surface can promote or inhibit the formation of 3D ice, which may provide a new guide for designing anti-icing materials. As all H bonds of water molecules in the 2D ice are saturated, the interaction with the surface is minimal. Such a property can lead to super-lubrication and be used to reduce friction between materials.

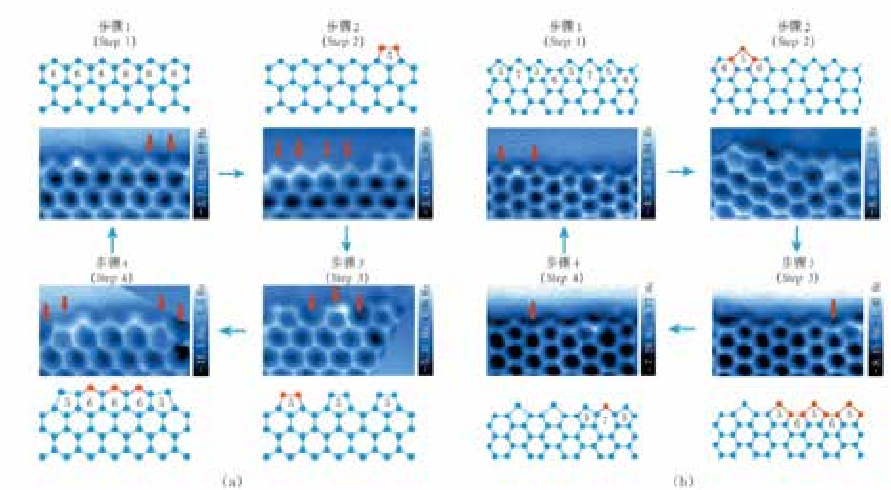

图 2. 二维冰锯齿状边界的“搭桥”式生长和扶椅状边界的“播种”式生长机制

Figure 2. Proposed growing process for zigzag and armchair edges.

二、高温超导体系中二维反常金属态的证实

2015 年凝聚态物理最高奖 Buckley 奖颁发给四位美国物理学家，以表彰他们在二维超导体系中发现超导—绝缘体相变现象，该相变被认为是量子相变的范例。所谓量子相变，是指在绝对零度下系统处于量子基态时随着参数（如无序、磁场和门电压等）变化而发生的相变。在超导—绝缘体相变中，理论上只有两种基态，零电阻的超导态和无法导电的绝缘态。然而，三十多年前，科学家在研究超导—绝缘体相变时，发现某些薄膜在极低温下会表现出新奇的物理特性：随着温度降低，薄膜的电阻先迅速下降然后趋于一个较小的非零常数，类似金属特性，被称为“反常金属态”。在过去的三十多年里，各国科学家们陆续在许多二维超导体中观察到所谓反常金属态的迹象，似乎表明二维体系中存在第三种量子基态反常金属态（亦称为“量子金属”）。然而，最近的实验表明上述观测可能存在着严重的问题。研究者用滤波器过滤了测量线路中的高频噪声信号，惊奇地发现原本有限电阻的反常金属态居然变成了零电阻的超导态。因此，二维反常金属态是否存在成为了一个充满争议的物理难题和前沿课题。

王健研究组与电子科技大学李言荣、熊杰以及美国布朗大学 James Valles 教授等合作在宏观面积的高温超导 YBCO 纳米多孔薄膜（超导转变温度高达 80K）中证实了反常金属态的存在。超导转变温度的提升和薄膜面积的增加大大提高了超导体

系的稳定性，不易受外界噪声的干扰。滤波器对比实验也表明，是否过滤测量线路中的高频噪声对于实验结果的影响几乎可以忽略不计，这是成功探测反常金属态的一个关键因素。在 YBCO 薄膜中，研究团队通过系统的极低温电输运实验，观测到低温下的电阻饱和，霍尔效应消失，巨磁阻，线性伏安特性和库珀对的量子振荡等多项实验证据，证实了反常金属态的存在。由于选用了高温超导体系，反常金属态出现的温度高达 5K，这一温度远超过之前的报道。库珀对的量子振荡等实验现象首次证实了反常金属态的载流子为玻色子，反常金属可被称为玻色金属。该工作为国际上争论了三十多年的反常金属态的存在提供了有力的证据，并为研究反常金属态提供了新思路。

研究成果以“超导—绝缘相变中的玻色金属态”为题，于 2019 年 12 月 20 日发表于《科学》(Science 2019, 366, 1505）。这一重要发现迅速得到了国际学术界的广泛关注，玻色金属理论的提出者美国伊利诺伊大学 Philip W. Phillips 教授在《科学》上以“终获自由: 玻色金属“猛兽出笼””为题发表“观点”（Perspective）文章高度评价了这一重要工作，并指出王健团队的工作使得“学术争议结束，玻色子可以像金属一样存在” (Science 2019, 366, 1450)。美国科学院院士斯坦福大学 Steven A. Kivelson 教授在《凝聚态物理期刊俱乐部》（Journal Club for Condensed Matter Physics）上发表评论文章指出反常金属的证实“对量子材料的理解具有基础性的重要意义”。

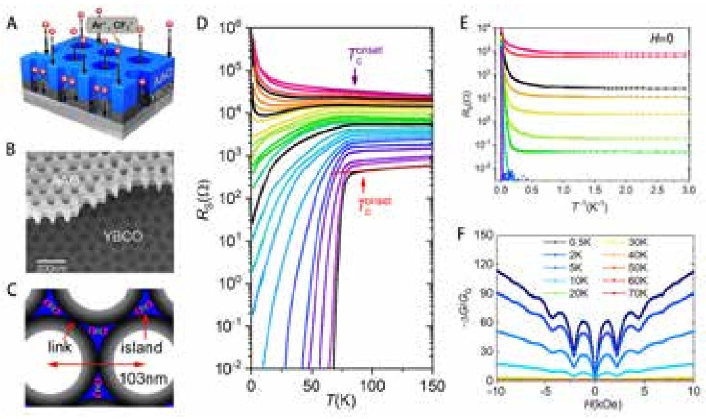

图 1. 钇钡铜氧（YBCO）纳米多孔薄膜中的量子相变与反常金属态。(A) 用多孔氧化铝（AAO）模板蚀刻法制备 YBCO 纳米多孔薄膜的工艺示意图。(B) YBCO 纳米多孔薄膜扫描电镜（SEM）图像。(C) YBCO 纳米多孔薄膜的几何结构示意图。(D) 不同刻蚀时间下 YBCO 纳米多孔薄膜的电阻对温度的依赖关系。随着刻蚀时间的增加，薄膜发生了无序调控的超导 - 反常金属 - 绝缘体相变。(E) 反常金属态薄膜和超导薄膜的输运曲线。其中低温下电阻的饱和行为为量子金属态的特征。(F) 反常金属态的磁导周期性振荡，揭示了反常金属态的载流子为库珀对。

Figure 1. The quantum phase transition and anomalous metal in nanopore modulated YBCO thin films. (A) Illustration of the fabricating process of nanopore modulated YBCO thin films by reactive ion etching through AAO mask. (B) The scanning electron microscope (SEM) image of nanopatterned YBCO films. (C) Illustration of the nanopatterned YBCO films (D) Temperature dependence of resistance for the nanopatterned YBCO films for different etching times. With increasing etching time, the films undergo a disorder-induced superconductor-anomalous metal-insulator transition. (E) The temperature dependence of resistance of the films in superconducting state and anomalous metallic state. The resistance saturation with decreasing temperature in the low temperature regime is the main characteristic of anomalous metallic state. (F) Magnetoconductance periodic oscillations of an anomalous metallic state film, revealing that the charge carriers of the anomalous metallic state are Cooper pairs (bosons).

II. The demonstration of two-dimensional anomalous metallic state in high-temperature superconducting systems

The 2015 Oliver E. Buckley prize (the most important prize in condensed matter physics) was awarded to four American scientists for their discovery and pioneer investigations of the superconductor-insulator transition (SIT) in two-dimensional (2D) superconducting systems, a paradigm of quantum phase transitions. The quantum phase transition is a continuous transition at absolute zero temperature from one ground state to another tuned by a non-thermal parameter (e.g. disorder, magnetic field or gate voltage). In the SIT, theoretically there are two ground states, the superconducting and insulating states. More than thirty years ago, scientists found new physical characteristics of thin films at ultralow temperatures when studying the SIT. With decreasing temperature, the resistance of the films drops rapidly and then saturates to a small constant, similar to the metallic behavior (named anomalous metallic state). Possible signature of this “anomalous metallic state” has been widely observed in various 2D superconductors over the past thirty years, which may indicate another quantum ground state (the anomalous metallic state or quantum metallic state). However, recent experiments indicate that there might be serious problems in the aforementioned observations of the anomalous metallic state. It is reported that the “anomlous metallic state” with finite resistance at low temperatures becomes superconducting state with zero resistance in both crystalline and amorphous superconducting films when the high frequency noise is filtered in the measurements. Therefore, whether two-dimensional anomalous metallic state can exist is a controversial issue and a frontier topic in Physics.

Prof. Jian Wang at Peking University, in collaboration with Prof. Yanrong Li, Prof. Jie Xiong at University of Electronic Science and Technology of China and Prof. James M. Valles Jr. at Brown University, demonstrated the existence of anomalous metallic state in macroscopic high-temperature superconducting YBCO thin films patterned with an array of holes. The superconducting critical temperature of the 2D YBCO films is around 80 K. The relatively high critical temperature and macroscale significantly increase the stability of the superconducting system and reduce the influence of external noise. A control experiment indicates that whether filtering the high frequency noise or not, the experimental results remain almost the same, which is a key to detect anomalous metallic state. By performing systematic transport measurements, resistance saturation at low temperatures, zero Hall resistance, large magnetoresistance, linear voltage-current characteristic and quantum oscilations of Cooper pairs are simultaniously detected in the YBCO thin films, demonstrating the existence of anomalous metallic state. Because of high superconducting critical temperature, the anomalous metallic state appears at 5K, much higher than that in previous works. The quantum oscillations of Cooper pairs for the first time demonstrate that the charge carriers of the anomalous metallic state are Cooper pairs (bosons). Thus, the anomalous metal can also be called Bose metal. This work not only provides solid evidence of anomalous metallic state, which is under intensive debate for over thirty years around the world, but also paves a new way for further investigating the origin of anomalous metallic ground state.

The paper entiled “Intermediate bosonic metallic state in the superconductor-insulator transition” was published in Science on December 20, 2019 (Science 2019, 366, 1505). Prof. Philip W. Phillips at University of Illinois published a perspective paper in Science (Science 2019, 366, 1450) with a title of “Free at last: Bose metal uncaged”. He spoke highly of this work by saying that “the teasing is over. Bosons can exist as a metal.” Prof. Steven A. Kivelson at Stanford University gave high evaluation on this work and wrote a commentary in Journal Club for Condensed Matter Physics. In the commentary, Prof. Kivelson pointed out that “this conclusion (the demonstration of anomalous metallic state) is of fundamental importance for our understanding of quantum materials.”

三、超冷原子中三维拓扑能带的表征和观测

超冷原子在过去数年里广泛开展了一维和二维拓扑物相的量子模拟研究，然而在三维拓扑物相方面长时间没有进展。一个关键困难在于，超冷原子物理中长期以来缺乏有效的方案表征和观测三维物性，如能带结构、三维拓扑相等。冷原子中的主要观测方案包括利用时间飞行和光成像作探测，这类方案只能探测冷原子的二维信息，而第三个方向在成像中被叠加而无法准确探测。比如，在制备拓扑态后，为了探测拓扑能带，让冷原子做自由飞行，然后拍摄照片探测原子的动量空间中涵盖拓扑特性的（赝）自旋极化纹理（spin texture）。由于拍照把与成像面垂直的方向的空间维度积分掉，只能得到剩下的二维空间上自旋极化分布。因此，在长时间里冷原子中未能实现在实验上观测三维拓扑物理。

刘雄课题组与合作者在理论上提出了一种等效探测三维拓扑能带的技术，并以此技术方案成功在冷原子中实现对三维节线（nodal line）半金属拓扑能带的实验观测。工作发表于 2019 年的《自然·物理》（Nat. Phys. 2019, 15, 911）。这项三维拓扑探测方案适用于一大类具有某些对称特性（如磁群、镜像等）的三维量子体系。基本思想如下。由于对称性，可证明该类三维量子系统存在一些特定的二维对称面，并且除了对称面上的自旋分布，对称面上下侧的其他面的自旋极化分布会相互抵消。因此，沿对称轴积分叠加后呈现的总二维自旋分布等同于二维对称面上的自旋结构。进一步，通过调控量子体系的参数，使得体系中的二维对称面沿对称轴有效平移，最终覆盖整个对称轴。如此，通过一系列参数调控的二维测量，可实现对整个三维能带自旋结构的表征和观测。基于这个方案，他们开展实验，成功实现由北大理论组之前提出的三维节线拓扑半金属，并实现对该系统三维能带拓扑和节线的准确观测。

这项工作中提出的探测三维拓扑能带的技术方案具有广泛的适用性，包括任何具有磁群对称性、镜面对称性、或其他类似对称特性 (包括演生对称特性) 的三维系统。这项工作推动了冷原子中高维系统测量技术的发展，为冷原子中高维拓扑物理的研究开辟了新道路。尤其需要指出，刘雄军组进一步发展了这项探测方案，《中国科学》（Sci. Bull. 2020, 65, 2080），并和中国科技大学合作首次基于超冷原子实现了三维最理想外尔半金属能带的探测《科学》（Science 2021, 372, 271-276）。这是超冷原子近期的一项新突破。

系所中心研究亮点 | *Highlights*

III. Quantum Simulation of 3D Topological Matter with Ultracold Atoms

Complex topological matter has become the focus of both academic and industrial research because it is seen as a way to pave the way to making information and computation devices more noise free and robust. Exploring the topological quantum states with quantum simulators like ultracold atoms can enable the precise studies of every aspect of the exotic states, and broaden the understanding of the fundamental phases of nature. For this the quantum simulation of 1D and 2D topological phases has been widely explored in ultracold atoms. Nevertheless, little progress was made toward the study of 3D topological states for ultracold atoms, since it is hard to characterize and resolve 3D topological physics based on the conventional schemes of detection in experiment.

Physicists from Peking University (PKU) and the Hong Kong University of Science and Technology (HKUST) have proposed and successfully realized for the first time a 3D simulation of topological matter consisting of ultracold atoms. The proposed and realized a technique called virtue-slicing imaging to reconstruct and characterize the 3D band topology in atomic systems. This breakthrough also paves an opening to further examining new topological matter that cannot be well realized in solids. Such never-before-done engineering artificial material with ultracold atoms may allow physicist to model unusual phases of matter.

This work was led by Xiong-Jun Liu, a Professor from the School of Physics at PKU, and Gyu-Boong Jo, an Associate Professor from the Department of Physics at HKUST. They created an artificial crystal lattice structure, which was previously proposed by the PKU group, to model ultracold atoms prepared at 30 billionths of a degree above absolute zero. This new synthetic quantum matter is a 3D spin-orbit coupled nodal-line topological semimetal, which exhibits an emergent magnetic group symmetry. With such emergent symmetry the researchers proved in theory that the 3D band topology can be resolved by only imaging 2D spin patterns on the parameter-tuned symmetric planes, and further successfully observed the 3D topological semimetal in experiment. The detection technique proposed and used here can be generally applied to exploring all 3D topological states of similar symmetries when those become available.

This work signifies a breakthrough progress for quantum simulation with ultracold atoms. In particular, the technique reported in the work enables the experimental investigation and observation of nontrivial phases of all physical dimensions, including various insulating, semimetal, and superfluid phases with nontrivial topology in ultracold atoms. As result, this development expands the ability to explore complex topological matter in 3D, and will open up a promising avenue for quantum simulation with ultracold atoms.

The research was recently published online in Nature Physics(Nat. Phys. 2019, 15, 911).

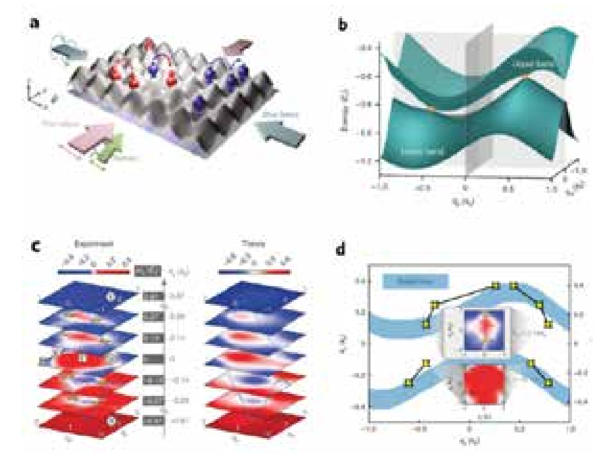

图 1. a 三维拓扑节线半金属的实现示意图。b 动量 的二维子空间能谱存在狄拉克点。这些狄拉克点沿着 方向分布形成节线。c 基于虚拟分层探测方案实现三维拓扑结构的重建。d 拓扑节线分布。
Figure 1. a Sketch of the realization of 3D nodal line semimetal. b The 2D band with Dirac points for fixed The Dirac points extending along direction form nodal lines. c The reconstruction of 3D band topology from virtue-slicing imaging technique. d The topological nodal lines.

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，以英语为工作语言。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) 引力与高能天体物理 ;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。

除了追求科学上的卓越，研究所也致力于构建中国天文界与国际天文界的桥梁。研究所 20% 的全职教师、50% 的博士后是外籍。除了接待来自国内外科研院所的访问学者，研究所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。

研究所现任所长为何子山，副所长为吴学兵、Gregory J. Herczeg, 协调人为陈建生。国际科学顾问委员会在学术活动、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。研究所教师中包括 1 位千人计划和 10 位青年千人计划入选者，2 位科技部创新人才推进计划入选者和 1 名万人计划科技创新领军人才。研究所与天文学系合作密切，人员互聘，资源共享，联合开展科学研究和人才培养。经与天文学系和其它天文单位联合聘用，研究所目前有 25 位教师，约 35 位博士后，多位访问学者和 5 位行政人员。

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.

In addition to supporting scientific excellence, KIAA also serves as an interface between the Chinese and international astronomy communities; 20% of the full-time faculty and 50% of the postdoctoral researchers are foreigners, in addition to regular visitors and partnerships between PKU astronomy and a wide network of universities and astronomy centers in China and abroad. KIAA regularly sponsors thematic workshops, conferences, and a range of other academic activities to facilitate scientific exchanges with the domestic and international astronomy community.

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, ten youth thousand-talent program awardees, two MOST innovative talent promotion program awardees, and a ten-thousand program innovative talent program awardee. 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 25 professors, approximately 35 postdoctoral fellows, many visiting scholars, and five administrative staff members.

一、确定快速射电暴辐射机制

快速射电暴（Fast Radio Burst, FRB）是偶发宇宙无线电暴发事件。几毫秒时间内，它们所释放的无线电波的能量相当于全世界几百亿年的发电量总和。快速射电暴的核心问题包括：高强度射电辐射的辐射机制是什么？快速射电暴来源于何种天体？

快速射电暴相干辐射可能来自于中心天体磁层内的物理过程，也可能来自远离中心天体的相对论性激波的作用过程。2019 年，依托于中国天眼 FAST，李柯伽课题组和合作者监测到快速射电暴 FRB180301 的 15 次重复暴发。在其中 7 次暴发中探测到射电辐射的偏振多样性（图 1）。这个观测支持磁层辐射起源，否定传播机制的辐射模型。

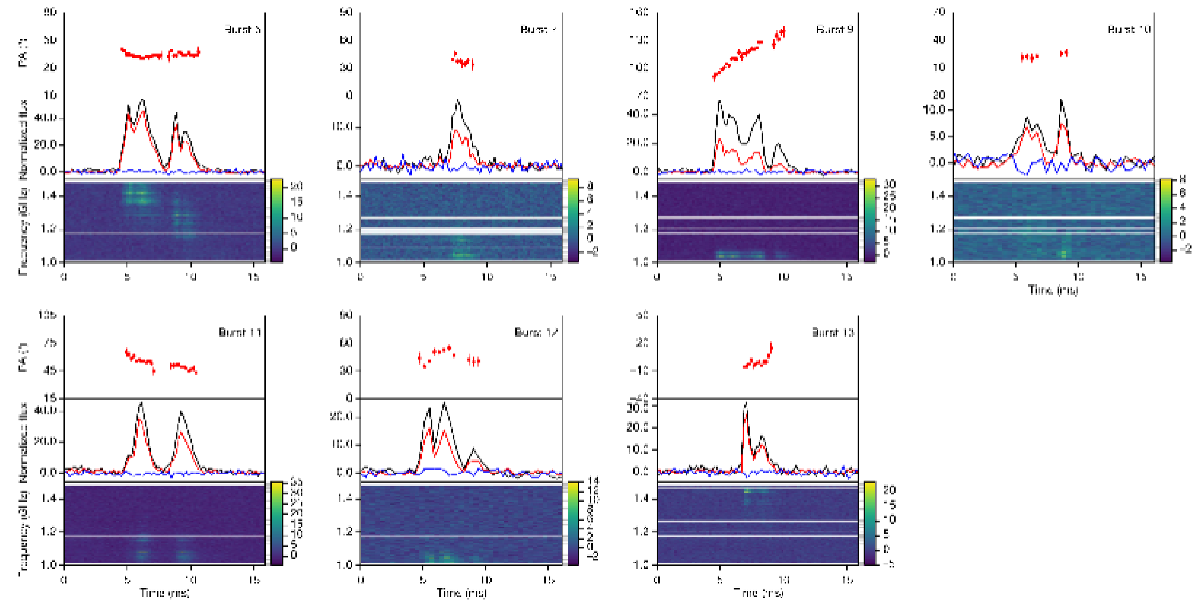

图 1. FAST 观测到来自 FRB180301 重复脉冲的偏振多样性

Figure 1. The polarisation diversity of FRB 180301 detected by FAST.

这项研究首次确定磁层是快速射电暴的产生地。该成果于 2020 年 10 月 28 日发表于《自然》（Nature 2020, 586, 693）。

虽然 FAST 的观测说明快速射电暴的辐射产生于磁层内，但是其中心天体仍旧未知。 2020 年 4 月 28 日，国际上两台射电望远镜独立发现了一例快速射电暴（FRB200428），并确认其来自银河系内正处于活跃期的磁星 SGR J1935+2154。在 FAST 监测期间，磁星释放出 29 个 X 射线暴发，李柯伽课题组和合作者在对应的射电数据中排除了来自磁星的显著信号。FAST 的观测对磁星的射电辐射给出了迄今最严格的流量限制，并且表明快速射电暴与磁星高能暴发的相关性非常弱。该结果对快速射电暴起源于磁星的相关研究给出了非常强的限制和推动作用。该成果于 2020 年 11 月 4 日发表于《自然》（Nature 2020, 687, 63）。

I. Nail down the radiation mechanism of fast radio bursts

Fast radio bursts (FRBs) are the cosmological radio bursts, which occur randomly. The energy of radio waves radiated in a few milliseconds surpasses tens-of-billion-year world total electricity final consumption. The key questions are, what is the radiation mechanism of radio waves from the FRBs, and what are the sources of FRB?

In astronomical context, the coherent radiation may come from magnetosphere or interaction of relativistic shock waves. In 2019, Kejia Lee's research team and collaborators monitored FRB 180301 using Five-hundred-meter spherical radio telescope (FAST). Fifteen bursts were detected, and 7 of them manifest a diversity in polarization properties (Figure 1). The observation supports the magnetospheric origin, and disfavors the propagation-like models. The study (published by Nature on 28th Oct. 2020; Nature, 2020, 586, 693) had firstly identified the magnetosphere being the birth place of FRBs.

Although FAST observation indicated that the FRBs were generated inside magnetosphere, the exact type of central objects were still unknown. 28th April 2020, two international radio telescopes independently identify FRB 200428 coming from an active magnetar in the Milkyway, SGR J1935+2154. During FAST observation, 29 X-ray bursts were recorded with high energy instruments, yet, Kejia Lee's research team and collaborators detected no radio pulsation using FAST. This provided the most stringent upper limits for the flux of radio pulse from SGR J1935+2154 in its active window. It shows that the correlation between FRB and high energy activities is rather weak. The study (published on 4th Nov. 2020, Nature 287, 63) constrains the FRB radiation theory and project the questions for FRB trigger mechanism.

系所中心研究亮点 | *Highlights*

二、光谱证实 134 亿光年外最遥远天体

江林华领衔的国际团队探测到一个 134 亿光年外星系的光谱，证实了该星系为人类迄今发现的最遥远天体。团队同时还捕捉到来自该星系持续数分钟的暴发信号，疑似与星系中一个伽马射线暴有关。该成果对理解宇宙早期星系和恒星形成有重要意义。该成果的两篇论文均发表在 2020 年 12 月 14 日的《自然·天文》（Nat. Astron. 2021, 5, 256）和（Nat. Astron. 2021, 5, 262）。

根据现有理论和宇宙学数值模拟，第一代恒星形成于宇宙大爆炸后约 1.5 亿年，而第一代星系在随后的 1 亿年左右形成。同时，最早的大质量黑洞种子也开始诞生和成长。这些天体发出的电离光子重新“点亮”宇宙，即宇宙再电离。该电离过程持续数亿年，是宇宙演化的最重要时期之一。研究再电离和探测宇宙“第一缕曙光”是下一代地面和空间大型光学红外望远镜的主要科学目标之一。但就目前能使用的望远镜而言，探测这些遥远天体的光谱非常困难。

江林华团队所研究的天体是一个称为 GN-z11 的星系。已有数据显示 GN-z11 的宇宙学红移可能为 11 左右，或至少是 10 以上。一般认为，在下一代红外望远镜运行之前，很难准确测量该星系的红移。该团队利用十米口径的凯克（Keck）望远镜，在近红外波段对 GN-z11 进行了深度光谱观测，并基于光谱分析出该星系的准确红移为 10.957，证实其为 134 亿光年之外的星系（图 2），对应的宇宙年龄为 4 亿年。这是目前人类通过光谱证实的最遥远天体。光谱显示有三条发射线，由碳和氧的二次电离气体发出，表明该星系中已有丰富的金属成分（指非氢和氦元素）。这也意味着该星系不是宇宙中第一代星系，即几乎没有金属成分的星系。

团队在观测 GN-z11 时还探测到来自该星系方向的一次暴发。该暴发显示出一条明亮的近红外光谱，持续时间短于三分钟。光谱包含明显的大气吸收成分，表明暴发信号来自地球大气层外。经详细分析，基本排除该暴发信号来自地球上人造物体和太阳系天体等来源。进一步理论计算表明，该光谱可能来自 GN-z11 的一次伽马射线暴，为伴随该伽马射线暴的（静止坐标下）紫外辐射。若该解释成立，那么这是人类已知的最遥远天体爆发，表明大爆炸后 4 亿年左右宇宙就可能大量产生伽马射线暴。

以上成果为研究宇宙极早期天体打开了一扇窗口，也表明现有大型天文设备有能力探测到部分早期星系的光谱，具有重要科学意义。

图 1. 艺术想象图 – 最遥远星系及其中疑似伽马射线暴（图片制作：北京天文馆喻京川）。

Figure 1. An artist's conception of the most distant galaxy with a Gamma-ray burst (credit: Jingchuan Yu).

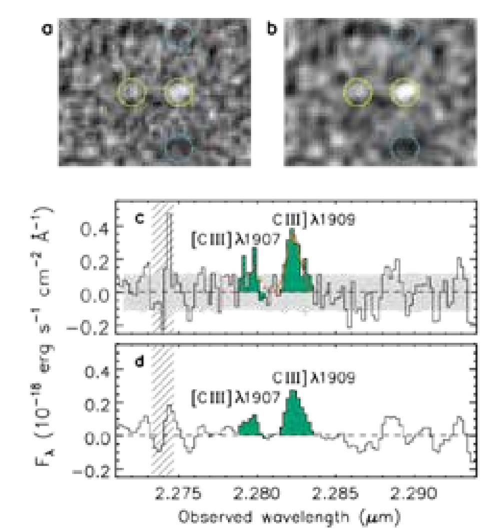

图 2. 星系 GN-z11 的部分二维和一维光谱，表明其红移为 10.957。图 b 和 d 分别是图 a 和 c 平滑后的光谱。

Figure 2. Part of the 2D and 1D spectra of GN-z11, indicating its redshift of 10.957. Panels b and d show the smoothed version of the spectra in panels a and c.

II. Spectroscopic confirmation of the furthest galaxy 13.4 billion light-years away

An international team of astronomers, led by Linhua Jiang at the Kavli Institute for Astronomy and Astrophysics, obtained near-infrared spectra and successfully measured the redshift of a faint galaxy 13.4 billion light-years away, the most distant astrophysical object known to date. Meanwhile, the team also detected a burst signal with a duration of minutes from the galaxy, which can be explained as an ultraviolet flash associated with a gamma-ray burst (GRB). These results are important to understand the formation of stars and galaxies in the very early Universe (Figure 1). Two papers based on the results were published in Nature Astronomy on Dec 14, 2020 (Nat. Astron. 2021, 5, 256; Nat. Astron. 2021, 5, 262).

Based on the current theory and cosmological simulations, the first stars formed about 150 million years after the Big Bang, and the first galaxies formed roughly 100 million years later. This is also the epoch when the seeds of the first supermassive black holes started to form and grow. These astrophysical objects gradually re-ionized the Universe. This “cosmic reionization” lasted several hundred million years and represents one of the most important phase transitions of the Universe. One of the main scientific goals of the next generation telescopes is to understand reionization and detect light from the first objects. But for current astronomical facilities, it is very difficult to detect optical/infrared spectra from such distant galaxies.

Using the 10m Keck I telescope, Jiang’s team carried out deep spectroscopic observations of the galaxy “GN-z11” in the near-infrared. Based on the existing data, GN-z11 is generally believed to be a very distant galaxy at a redshift around 11, or at least greater than 10. But its accurate redshift has remained unclear. From the spectra obtained from Keck, the team detected three emission lines from GN-z11 and determined a redshift 10.957, meaning that GN-z11 is a galaxy with a distance of 13.4 billion light-years (Figure 2), when the Universe was only 400 million years old. This is the most distant astrophysical object known to date. The three emission lines are produced by gas with doubly ionized carbon and oxygen, suggesting a high metal abundance (elements other than hydrogen and helium) in this galaxy. It further means that GN-z11 is not one of the first-generation galaxies, which would contain almost no metals.

During their observations on Keck, the team members also serendipitously caught a bright flash from GN-z11. This flash showed up as a compact continuum spectrum in one image with a duration shorter than 3 minutes. The spectrum exhibits prominent telluric absorption features, indicating that it arose from above the atmosphere. The team members performed a comprehensive analysis of the origin of the flash, and ruled out the possibility that the flash was from any known sources such as man-made satellites or moving objects in the Solar system. They concluded that GN-z11-flash was likely produced by a GRB in GN-z11, as the spectrum, brightness, and duration of the flash are consistent with such an interpretation. This result may imply that GRBs can be largely produced as early as 400 million years after the Big Bang.

The above results have opened a new window to study the earliest objects in the Universe. They also suggest that the largest telescopes currently available are capable of detecting spectra from some of the furthest galaxies.

三、首次实现分辨微引力透镜双像

一个多世纪前，爱因斯坦基于广义相对论预言了微引力透镜现象，即背景恒星的光在经过观测者视线方向的一个天体时会受到其引力作用发生偏折而成为两个像。近年来，东苏勃研究员领导国际团队在天体微引力透镜研究中取得了突破，使用位于智利的欧洲南方天文台的甚大望远镜光干涉阵（VLTI）的 GRAVITY 仪器，第一次成功地分辨了微引力透镜双像，并精确测量了爱因斯坦角半径这个关键参数。该研究成果为利用微引力透镜法测量天体质量开辟了一个新途径，可用于未来搜寻银河系中孤立的恒星级黑洞。

这项成果以“First Resolution of Microlensed Images”为题 2019 年发表于《天文物理期刊》（Astrophys. J. 2019, 871, 70）。东苏勃研究员为第一及通讯作者，团队还包括来自欧洲、美国、新西兰等国的合作者。

1936 年，在业余科学家曼德尔（Rudi Mandl）的再三敦促下，爱因斯坦不太情愿地在《科学》(Science) 杂志上发表了微引力透镜的理论。其实，爱因斯坦的笔记表明，他早在 1912 年就完成了相关的计算。他发现，根据广义相对论，在观测者的视线方向上，如果一个前景的天体（透镜）与一颗背景的恒星（源）的角距离很近，源的光线经过透镜附近时会发生偏折进而成像。若观测者、透镜和源处于完美的三点一线上，会呈现环状像，称爱因斯坦环；更普遍的情况是，光线会被偏折为位于爱因斯坦环附近的两个弧状像。对于银河系中的微引力透镜现象，爱因斯坦环的角半径只有毫角秒的量级（1 个毫角秒等于三百六十万分之一度）。

爱因斯坦之所以不情愿发表论文，原因是他对实际观测到微引力透镜现象的前景非常不看好。他断言，“没有希望能直接观测到这个现象”，并给出了两个主要理由：首先，产生微引力透镜现象的条件是前景和背景的两颗恒星需要对齐在极小的角度里（就是在爱因斯坦环内），而对于银河系中某颗恒星，该几率不超过百万分之一；另外，他预期不会有任何仪器可以直接分辨相距毫角秒的双像，所以能观测到的效应仅是作为背景源的恒星增亮。

从 1993 年起，凭借大视场望远镜和 CCD 相机，时域巡天项目的发现远超出了爱因斯坦悲观的预期：通过对银河系中心核球区域数以亿计的恒星的亮度变化进行反复不断的监测，天文学家们已经发现了数万个微引力透镜事件。在微引力透镜事件中，当透镜天体以每年数个毫角秒的相对运动速度经过背景恒星的视位置时，恒星的光度在数周时间内产生变化。通过研究微引力透镜事件，人们已经作出诸多天体物理发现，包括发现近 100 颗太阳系外行星。

然而，20 多年间，就像爱因斯坦预期的那样，人们一直没能实现直接分辨开微引力透镜的双像。直到 2017 年 11 月，东苏勃团队才使用有长达百米基线的 VLTI 光干涉阵观测微引力透镜事件 TCP J0507+2447，首次成功分辨了双像。通过测量双像的角间距，研究团队还以 2% 的高精度测量了爱因斯坦环的角半径（1.87±0.03 毫角秒）。从光干涉阵分辨双像的观测中得到的信息可用于打破微引力透镜事件分析中的参数简并，直接测量透镜质量，从而释放出微引力透镜方法的一项独特潜力——发现银河系中的孤立恒星级黑洞。

2015 年以来，LIGO 引力波天文台发现了多个双黑洞合并事件，这些令人震惊的发现引出了一个重要问题：这些数十个太阳质量的黑洞是如何形成的？无论是大质量恒星演化的终点还是发源于宇宙早期的奇特物理过程，理论都预言大量的孤立（单）黑洞必然存在。而单、双黑洞族群的相对比例可为黑洞形成机制提供重大线索。然而，受到现有观测方法的限制（引力波、X 射线双星及视向速度），现在所有已知恒星级黑洞都发现于双星之中。

微引力透镜是唯一已知的可发现孤立恒星级黑洞的方法，有望探索这片未知的“新大陆”。根据理论估算，在已探测到的微引力透镜事件中，已有约数百个是由黑洞引发的。但是，时至今日，人们仅

发现了几个微引力透镜黑洞的候选体，但由于光变曲线的分析中存在的透镜质量—距离的参数简并，无法确定性地区分黑洞与低质量恒星。而通过光干涉阵分辨双像，就能够测量到爱因斯坦环角半径这个关键参数来打破该简并，得以直接测量透镜天体质量，从而确定性地认证黑洞。

2001 年，Delplancke 等人提出了利用 VLTI 光干涉阵分辨微引力透镜双像的可能性，然而该方法极具挑战性，十几年来，人们进行了多次失败的尝试。主要的困难是光干涉观测需要足够明亮的观测目标。东苏勃团队对 J0507+2447 的成功观测汇聚了多个有利因素。2017 年 10 月底，日本业余天文学家 T. Kojima 偶然在反银心方向发现了一颗恒星增亮，全天全自动超新星巡天网络（东苏勃为核心成员）的监测数据表明，这是一个微引力透镜事件。TCP J0507+2447 源的距离仅是绝大多数在银心方向发现的微引力透镜事件的十分之一，达到了 VLTI 观测所需的亮度。团队立即向欧洲南方天文台成功申请到台长机动时间，在发现后不到一个星期内获得了宝贵的、世界上最先进的光干涉仪器 VLTI GRAVITY 的观测时间。观测时，目标的亮度接近 VLTI GRAVITY 的极限能力，而绝佳的大气条件使得团队把握住了这个稍纵即逝的机遇，成功得以观测。

目前，在北京大学的经费支持下，东苏勃课题组在中科院新疆天文台南山观测站建设了全天全自动超新星巡天网络的新节点“天山”，正式观测后预计将提高该望远镜网络在明亮微引力透镜事件上的发现和观测能力。东苏勃团队正在利用 VLTI/GRAVITY 光干涉阵对更多的微引力透镜事件进行系统观测，以期搜寻银河系中的孤立恒星级黑洞。

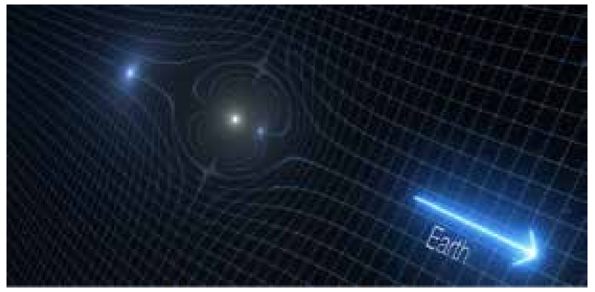

图 1. 微引力透镜示意图（图片制作：欧洲南方天文台）

Figure 1. An Artist Depiction of Gravitational Microlensing (Image Credits: ESO)

III. When the Stars Align — the First Resolved Microlensed Images

Using the GRAVITY instrument on The Very Large Telescope Interferometer (VLTI) of European Southern Observatory (ESO), an international team led by Professor Subo Dong (Kavli Institute for Astronomy and Astrophysics, Peking University) have resolved the two images of a microlensed source star for the first time, more than a century after Einstein first predicted that such image splitting could be caused by the gravity of another (lens) star along the line of sight to the source. This detection fills in the key missing ingredient that yields the mass and distance of the lens star. This technique could be applied in the future to measure the mass of isolated stellar-mass black holes, whose definitive detections have so far remained elusive.

The result is published in the Astrophysical Journal (Astrophys. J.2019,871,70). The following essay describing the research is published in the ESO Messenger (Msngr, 2019, 178, 45).

In 1936, after persistent prodding by the amateur scientist Rudi Mandl, Albert Einstein reluctantly published the idea of gravitational microlensing (Einstein, 1936), which was “a little calculation” he had carried out 24 years earlier. According to general relativity, when an object (i.e., a lens) aligns closely with a background star (i.e., a source) along the line of sight of the observer, the light rays from the source are bent when passing by the lens and subsequently form images. In the ideal case of perfect alignment, the bent light rays form a ring-like image (called the Einstein ring); more typically, there are two arc-shaped images with a separation on the scale of the Einstein ring. For microlensing in the Galaxy, the angular radius of the Einstein ring (the angular Einstein radius) is on the order of only a milliarcsecond.

Einstein’s reluctance to publish was because he saw little in the way of observational prospects; he asserted that “there is no hope of observing this phenomenon directly”. He had two reasons for thinking this, both of which relate to the minuscule angular size of the Einstein ring. First, for microlensing to occur, two stars need to align within the Einstein ring, and the probability of this is tiny, no greater than one in a million towards any star in the Galaxy. Second, he anticipated that no instruments could resolve the images, and thus the only observable effect would be the brightening of the source.

Since 1993, armed with wide-field telescopes and CCD cameras, time-domain surveys have vastly exceeded Einstein’s pessimistic expectation and found tens of thousands of microlensing events so far by photometrically monitoring almost a billion stars in dense stellar fields (primarily the Galactic bulge). During these events, the brightness of the

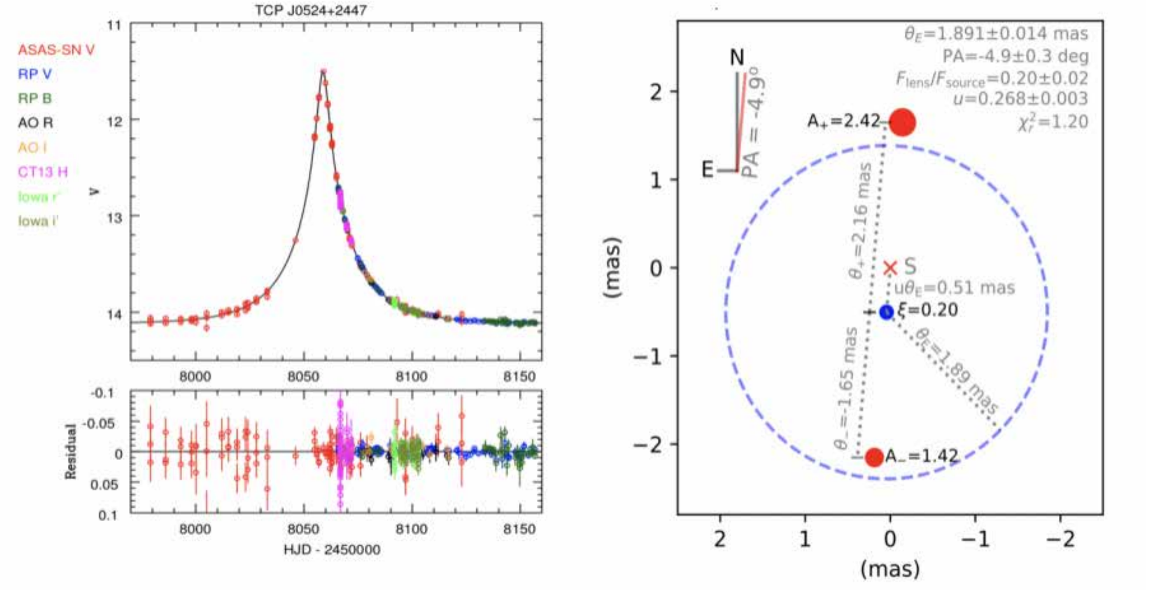

图 2. 左：微引力透镜事件 TCP J0524+2447 的光变曲线，描述其亮度随时间（以天为单位）的变化。右：微引力透镜的模型（以毫角秒为单位）。两个红点表示两个像的视位置，点的大小示意像的亮度。“x”符号标示未经透镜效应放大前的源的视位置。 蓝点代表透镜位置，蓝色虚线表示爱因斯坦环。

Figure 2. Left: Light curves of the microlensing event TCP J0524+2447, showing how its brightness changes as function of time (in the units of day). Right: Microlensing model (in the units of milliarcsecond). The two red dots are the major and minor images — the sizes of the dots do not represent the actual apparent sizes of the images, but rather an indication of their respective fluxes. The “x” symbol is where the unlensed source would be (labelled “S”). The blue dot is the lens position with its flux, and the blue dashed circle is its Einstein ring. Flux is expressed in fractions of unlensed source flux.

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source usually varies over a few weeks as the lens star moves with a relative proper motion of several milli-arcseconds per year. Microlensing events have yielded rich astrophysical results, including the discovery of nearly a hundred extrasolar planets.

It was not until November 2017 that microlensed images were successfully resolved for the first time (Dong et al., 2019), defying Einstein' s dismissal. Our team achieved this by observing the microlensing event TCP J05074264+2447555 (hereafter "TCP J0507+2447" for brevity) with the GRAVITY instrument (GRAVITY Collaboration, 2017) on the Very Large Telescope Interferometer (VLTI). Our observations allow us to measure the angular Einstein radius at 2% precision: 1.87 ± 0.03 milliarcseconds (see Figure 1). Interferometric resolution of images can unleash microlensing' s unique potential to find isolated stellar-mass black holes (BHs) lurking in the Galaxy by lifting the degeneracy between mass and distance in the analysis of microlensing light curves.

LIGO/VIRGO' s astonishing discoveries of merging BHs (Abbott et al., 2016) have raised an important open question: how to form BHs with a few tens of solar masses? Whether they are the end points of massive stars or have exotic origins in the early universe, theories predict that isolated (single) BHs must exist. The relative frequency between the single and binary BH populations can provide crucial clues to the formation mechanism. However, limited by the detection techniques, all known stellar-mass BHs are found in binaries.

Microlensing holds great promise in probing the important yet uncharted parameter space of isolated BHs. Estimates by Gould (2000) suggest that, amongst the microlensing events detected to date, many hundreds may involve BH lenses. But thus far only a few BH candidates have been reported. This is due to the mass-distance-velocity parameter degeneracy, which makes it impossible to definitively distinguish BHs from low-mass stars. All existing BH candidates have relatively long event timescales, which can be due to the large Einstein radii of BH lenses with high masses. But a large Einstein radius can also be produced by a low-mass stellar lens at a close distance. Alternatively, a slow relative proper motion between the lens and source stars may induce a long timescale even with a moderate Einstein radius.

To completely break the degeneracy, two additional observables are required besides the microlensing event timescale. One is called the "microlensing parallax", which depends on the Einstein radius projected onto the observer' s plane. It can be constrained for long events from the distortion of the light curves induced by the acceleration of the Earth while it orbits the Sun or by comparing the ground-based observations with simultaneous light curves from a space telescope in heliocentric orbit. The angular Einstein radius measured from the VLTI resolution of microlensed images is the other missing ingredient that can yield unambiguous determination of the lens mass and thereby definitively identify a BH lens.

The lens of TCP J0507+2447 is not a BH but a low-mass star. Nevertheless, it can serve as a testbed for the above-mentioned approach of lens mass determination. In an independent effort, another research team has measured the lens flux with Keck adaptive optics images, and by combining this with our precise VLTI angular Einstein radius measurement, they find that the lens is a dwarf star of 0.58 +/- 0.03 $M_\odot$ (Fukui et al., 2019). Our team (Zang et al., 2020) has measured the microlens parallax using the Spitzer light curves, and by combining the VLTI angular Einstein radius, the lens is found to be 0.50 +/- 0.06 $M_\odot$. The good agreement between the results of these two approaches demonstrates the robustness of our method. Remarkably, around the peak of the light curve of TCP J0507+2447, there was a short-lived anomaly lasting a few hours, suggesting that the lens star has a 20-Earth-mass planet at around 1 AU (Nucita et al., 2018; Fukui et al., 2019).

The possibility of using the VLTI to resolve microlensing images was first proposed by Delplancke et al. (2001), but it had proven to be extremely challenging, with numerous failed attempts prior to our observations. The major challenge had been the difficulty of identifying a sufficiently bright target for the interferometric observations. A confluence of lucky circumstances facilitated our success. Unlike the vast majority of microlensing events found by professional wide-field surveys towards the Galactic bulge, TCP J0507+2447 was serendipitously discovered by the Japanese amateur astronomer T. Kojima, and the source is at 800 pc towards the Galactic anti-centre, making it one of the closest microlensing events ever found. Our DDT proposal (2100.D-5031) was quickly accepted, and an ongoing VLTI run allowed our GRAVITY observations to be conducted within about a week of the initial discovery. And thanks to the exceptional site conditions, we were able to observe it near the magnitude limit of VLTI/GRAVITY at a relatively high airmass of ~ 1.5.

The exceptional sensitivity of VLTI/GRAVITY and the advent of all-sky bright transient surveys such as ASAS-SN and Gaia provide an unprecedented opportunity to obtain more resolved microlensing images. We hope to carry out a systematic survey towards the first definitive identification of an isolated stellar-mass black hole.

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 14 人，万人计划人才 8 人，教育部新世纪 / 跨世纪人才 12 人，青年长江学者 4 人，国家优秀青年科学基金获得者 14 人。

实验室有国家基金委创新研究群体 3 个，主持承担了 200 多项国家级科研项目，包括牵头多项国家重点研发计划和重大科学研究计划，以及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。

近 5 年来，承担经费超过 5 亿元，发表 SCI 论文 900 余篇，其中，有 12 篇刊登于 Nature（8 篇）和 Science（4 篇）；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 110 余项。

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, 14 winners from the China National Funds for Distinguished Young Scientists, 8 winners from the National special support program for high-level personnel recruitment, 12 winners from the New Century Excellent Talents in University, 4 Young Yangtze Scholar and 14 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, and has undertaken more than 200 national-level scientific research projects in the past five years, including 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 Society of Photo-Optical Instrumentation Engineers（SPIE）, 3 Fellows of Chinese Optical Society（COS）, 2 Fellows of the Optical Society of America（OSA）, and 1 Fellow of Institute of Physics（IOP）.

In the past five years, the laboratory has obtained grants more than 500 million yuan; published more than 900 SCI papers, many of which were published in the most influential scientific journals in the world, such as Science/Nature series journals, Physical Review Letters, etc., including 8 Nature papers and 4 Science papers; more than 110 patents were granted.

一、微腔非线性光学及超宽谱集成光频梳

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。人工微结构和介观物理国家重点实验室、纳光电子前沿科学中心肖云峰教授和龚旗煌院士领导的课题组在超高品质因子微腔非线性光学研究中取得系列重要进展。

在非线性谐波光源高效产生方面，课题组首次实现了有机分子修饰的二氧化硅光学微腔的高效三次谐波产生，三次谐波转换效率达到 1680%/W^2，比此前报道的二氧化硅微腔转换效率提高了四个量级，成果被《物理评论快报》以封面及编辑推荐形式亮点报道（Phys. Rev. Lett. 2019, 123,

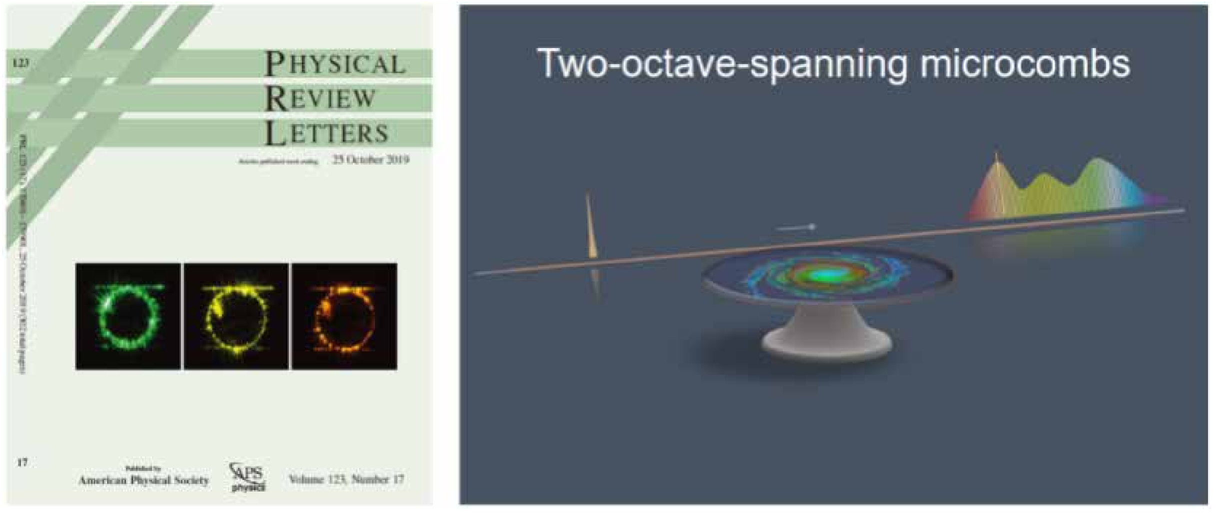

图 1 微腔非线性光学及双倍频程展宽集成光频梳

Figure. 1. Microcavity nonlinear photonics and two-octave-spanning integrated microcombs

173902）。在非线性光场调控方面，研究人员首次在回音壁微腔中实现了可重构、超低阈值的自发对称破缺的手征拉曼激光激射，《自然·通讯》（Nat. Commun. 2020, 11, 1136）。课题组还在实验上研究了混沌光学微腔中的光子输运，揭示出初态敏感的光子演化路径，为光场调控提供了新工具，成果发表于《物理评论快报》（Phys. Rev. Lett. 2019, 123, 173903）。

在集成光频梳方向，课题组实现了覆盖两个倍频程的超宽谱片上光梳的激发与高效率收集，打破了国际微腔光梳谱宽记录。实验上，研究人员首先在二氧化硅微芯圆环腔中，通过四波混频过程在红外的泵浦光（1550 nm）附近产生光梳；之后利用表面对称破缺诱导的二阶非线性和二氧化硅本征的三阶非线性效应实现跨波段的可见、近可见光梳产生；最终形成覆盖两个倍频程（450-2000 nm）的超宽谱光梳。此外，利用预先设计的非对称腔体形状提供的混沌诱导动量变换通道，实现了微腔与耦合波导的宽带有效耦合，从而极大地增强了宽谱光梳在全波段的收集效率。此项工作首次将变形度作为一个新的自由度引入到微腔光梳的研究中，为混沌物理与时间孤子相结合的物理研究新方向提供了可能性。相关研究成果发表于《自然通讯》（Nat. Commun. 2020, 11, 2336）。

I. Microcavity nonlinear photonics and integrated broadband optical frequency combs

Optical microcavity is capable of confining light in a small volume for a long time, therefore greatly enhancing the light-matter interaction. For decades, optical microcavity is a pivotal platform for fundamental physics researches and pioneering applications. Recently, the group led by professor Yun-Feng Xiao and Qihuang Gong made a series of important advances on the nonlinear optics in microcavities with ultra-high-quality factors. The group is attached to the State Key Laboratory for Mesoscopic Physics and Frontiers Science Center for Nano-optoelectronics, School of Physics, Peking University.

First, the group realizes high-efficient third harmonic generation in an organically functionalized silica microsphere. The efficiency of third harmonic generation reaches 1680%/W^2, which is four orders magnitude larger than the previous works reported in silica microcavities (Phys. Rev. Lett. 2019, 123, 173902, front cover paper, Editor' s Suggestion). Next, the group demonstrates reconfigurable and ultra-low threshold spontaneous symmetry broken chiral Raman laser emission in a whispering gallery mode microcavity (Nat. Commun. 2020, 11, 1136). Besides, the group also studies the chaotic photon transport and experimentally demonstrates the distinct pathways of photon evolution. Such research of chaotic dynamics paves the way for high-efficient integrated nonlinear optical devices(Phys. Rev. Lett. 2019, 123, 173903, editor' s suggestion).

Moreover, the group demonstrate two-octave-spanning broadband chip-scale microcomb generation, which breaks worldwide record for the bandwidth of microcombs. In the experiment, the researchers pump the microcomb at 1550 nm band with the process of four-wave mixing and the successive comb lines at the visible band is stimulated with surface-induced second order nonlinearity and bulk third order nonlinearity for a silica microcavity. The comb lines cover the range of 450-2000 nm over two-octave spanning. Besides, the efficient collection of the broadband comb signal is realized in the chaotic channel induced by a deformed microcavity. This work introduces a new degree of freedom, cavity deformation, to the microcomb studies, the combination of temporal solitons and chaos in deformed cavity in the future may provide new possibilities for optical soliton physics studies and microcomb applications (Nat. Commun. 2020, 11, 2336).

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、等离子体物理和高能量密度物理五个学科，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研究所。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88人，其中中科院院士4人，长江特聘教授4人，国家杰出青年基金获得者13人，1个国家自然科学基金创新研究群体。在站博士后约50人，研究生约300人。2019-2020年实验室承担科研项目约150项，包括牵头主持3项国家重点研发计划项目，1项国家自然科学基金重大项目，1项国家重大科研仪器设备研制专项等国家级科研任务。年均到账科研经费约2.8亿元，研究成果发表高水平论文约120篇。实验室正积极推进两项“十四五”国家重大科技基础设施项目立项，包括本实验室有深度参与的“激光驱动多束流装置（LMBF）”以及与中国原子能科学院联合提出的“北京在线同位素分离丰中子束流装置（BISOL）”。

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14C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。实验室建设有多个实验平台，包括亚原子粒子物理实验室、射频超导实验室、激光加速器实验室和核技术应用实验室，正在建设国内首个激光核谱学实验室，并在怀柔综合性国家科学中心建设交叉研究平台“北京激光加速创新中心”。

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至今）；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CERN、日本RIKEN、美国ANL和NSCL、中国原子能科学院、中国科学院近物所等实施实验研究计划。

The State Key Laboratory of Nuclear Physics and Technology at Peking University 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, and 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 lab include the Hadron physics, Radioactive nuclear beam physics, Accelerator physics and techniques and Nuclear technique applications.

The lab is composed of 88 key researchers, including 4 academicians of the Chinese Academy of Sciences, 4 special professors of Yangtze River, 13 National Outstanding Young Scientists and 1 NSFC Innovation Research Groups. In 2019 and 2020, the lab has about 50 postdocs and 300 PhD students. About 150 research projects including 3 National Key Research and Development Plans, 1 NSFC Major Program and 1 National Major Scientific Instruments and Equipment Development Project are undertaken by this lab. The lab has an annual budget of about 280 million RMB from the competitive funding resources and published more than 120 high level papers per year. The lab is actively promoting the establishment of two“14th Five-Year”National Major Science and Technology Infrastructure Construction Projects, one is the“Laser-Driven Multi-Beam Flow Device (LMBF)” in which the lab has deeply involved, and the other is the“Beijing Isotope-Separation-On-Line Neutron-Rich Beam Facility (BISOL)” proposed jointly with Chinese Academy of Atomic Energy.

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 2×6 MV tandem accelerator, the 4.5 MV Van De Graaff accelerator, the 2×1.7 MV tandem accelerator and the compact accelerator for 14C AMS. The lab also has a number of experimental platforms, including the Subatomic Particle Physics Laboratory, the Radio Frequency Superconducting Laboratory, the Laser Accelerator Laboratory and the Nuclear Technology Application Laboratory. The first lab of Laser Nuclear Spectroscopy in China is under construction, and the construction of Beijing Laser Acceleration Innovation Center in Huairou Comprehensive National Science Center is in progress.

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 CERN in Europe, RIKEN in Japan, ANL and NSCL in USA, CIAE and IMP in China and so on.

一、激光加速研究系列将在怀柔科学城激光加速创新中心展开

为了开展激光加速前沿研究，北京市政府批准建设北京激光加速创新中心 (BLAIC)。该中心位于怀柔科学城核心区，总建筑面积 30000 平米，具备基础科学研究、大型设备技术研发、研究生培养、国际学术研讨等功能，将为辐射医学、前沿物理、核能持续、先进材料等领域重要科学问题的研究提供研究条件，成为我国下一代先进加速器和先进光源研究的科学研究前沿阵地，最终成为学科交叉的国际级影响力的大型综合科学创新平台。2020 年，经过多次讨论，北京激光加速创新中心确定了整体最终设计，其中 A 区已经完成了结构封顶。目前土建完成了工作量 40%；关键水冷、辐射防护，真空等辅助设备完成招标和采购工作。预计 2021 年 4 月中心建筑结构全部封顶，2021 年底具备竣工验收条件。

在科技部重大仪器专项的支持下，北京大学牵头的“拍瓦激光质子加速器装置研究与应用示范”项目在 2019 年获批并基建落户怀柔科学城。项目拟建成基于重频拍瓦激光器的激光质子加速器，研制开发稳定可靠的激光质子放射治疗系统。2020 年，激光等离子体研究团队完成了拍瓦激光质子加速器（CLAPAII）的设计工作，为实验样机的建立奠定了基础。项目组与法国 Thales 公司合作，共同完成了 2PW 飞秒激光系统设计；同步进行 PW 国产激光系统的研制，已实现 100mJ, 50fs, 2TW 输出，为未来国产化奠定基础；自主完成加速真空腔体系统的物理设计；完成了重频打靶系统初步设计，可实现＞ 1Hz 重频打靶，载靶量＞ 500 发；建立束流动力学模型并做出了分析与改进，完成了垂直与水平两条传输线的设计；完成了磁体设计程序的开发，掌握了基于 CCT 超导磁体的关键技术和工艺路线；提出了治疗头系统的物理设计方案；与此同时，还针对激光质子加速器开的需求，完成了自动化控制系统的方案设计。2024 年，第一台可加速产生百 MeV 质子束的拍瓦激光加速器的实验样机将在激光加速创新中心建成。

在激光加速理论研究方面，高能量密度物理研究团队近期开展了粒子加速和辐射的系列理论和实验研究，提出了多个新的离子加速和阿秒辐射新方案，如新型级联冲击波加速、少周期离子光压加速和单周期离子加速等。乔宾教授与合作者提出了通过双色激光与薄靶相互作用获得孤立的高强度阿秒辐射脉冲光的新方案，该成果 2020 年发表于《物理评论快报》（Phys. Rev. Lett. 2019, 124, 114802）。该团队研究发现双色光与薄靶作用时会发生完全不同于单色光作用下的非线性动力学过程，纳米靶中的电子层在突变周期内被全部推出靶外，加速、压缩形成高密高能的纳米电子层，电子层在透明激光场中发生强相干同步辐射，不仅实现了在反射和透射方向都获得孤立阿秒脉冲光，而且脉冲强度达到单色光作用下的近 40 倍。

图 1. 基于拍瓦激光质子加速器的质子放疗系统

Figure 1.Proton Radiotherapy System Based on Petawatt Laser Proton Accelerator

I. Laser Acceleration Researches Will be Launched at Beijing Laser Acceleration Innovation Center in Huairou Science City

Beijing Laser Accelerated Innovation Center (BLAIC) in Huairou Science City is under construction. BLAIC is supported by the Beijing municipal government and has a total construction area of 30000 square meters. It has the functions of basic scientific research, large-scale equipment technology research and development, postgraduate training, international academic research and so on. It will provide research conditions for important scientific issues in radiation medicine, frontier physics, nuclear energy, advanced materials and other fields, and become the next generation of advanced accelerator and advanced light source in China, which will become a large-scale comprehensive scientific innovation platform with international influence and interdisciplinary. After a year of effect in 2020, the overall final design of BLAIC is determined. Up to now, 40% of the work of civil engineering was completed and the structural capping of area A has been completed. The investment and purchasing work of the auxiliary equipment (vacuum, radiation protection, cooling system) are completed. It is estimated that all the structures will be capped in April 2021, and the conditions for completion and acceptance will be met by the end of 2021.

With the support of the Ministry of science and technology of the PRC, the project of "The research of PW laser proton accelerator and application demonstration" led by Peking University was approved in 2019 and the project kick-off meeting was held in Peking University on June 12, 2020. The project aims to build a laser proton accelerator based on repetitive PW laser system, develop a stable and reliable laser proton radiotherapy system, and carry out the application demonstration

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research around tumor treatment. After clinical testing and medical certification, the project will complete the prototype of laser proton radiotherapy product meeting the needs of hospital treatment, and gradually realize industrialization to benefit the society and the people.

In 2020, the laser plasma research team has successfully completed the design work of PW laser proton accelerator, which laid the foundation for the establishment of the experimental prototype. In cooperation with Thales, the laser plasma research team has completed the design of 2PW laser system. At the same time, it is also developing domestic PW laser system, which has realized the output of 2TW with energy of 100mJ and pulse duration 50fs, laying the foundation for future localization. The project team has independently completed the physical design of the accelerating vacuum chamber system, and completed the preliminary design of the high repetition target system, which can achieve >1Hz repetition shooting frequency up to 500 shots. In the aspect of laser accelerated ion beam transmission, on the basis of comprehensive analysis and optimization of the beam dynamics model, the team has designed both the vertical and horizontal transmission lines, developed the magnet design program, and mastered the key technology and process route of superconducting magnet based on CCT. The physical design scheme of the treatment head system has been proposed. At the same time, according to the requirements of the laser proton accelerator, the automatic control system is also designed. In the coming years of 2024, the experimental prototype of the first PW laser accelerator that can generate 100 MeV proton beam will be built in BLAIC.

In the meantime, the high energy density physics research team has carried out a series of theoretical and experimental studies on particle acceleration and radiation, and proposed a number of new ion acceleration and attosecond radiation schemes, such as new cascade shock wave acceleration, few cycles ion light pressure acceleration and single cycle ion acceleration. Professor Qiao Bin and his collaborators have proposed a new scheme to obtain isolated high-intensity attosecond radiation pulses through the interaction between two-color laser and thin target, which was published in Physical Review Letters (Phys. Rev. Lett. 2019, 124, 114802).

图 2 北京激光加速创新中心建筑效果图和实际建筑照片

Figure 2.The architectural drawing and the actual building photo of BLAIC

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

北京大学高能物理研究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，9 位青年学者，12 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 being the director, the Center for High Energy Physics at Peking University now has 8 senior fellows from abroad, 9 research associates, 33 junior fellows and 12 postdocs. The research interests include: cosmology, quantum field theory, particle physics phenomenology, and hadronic physics.

一、LHC 能区 p-Pb 碰撞小系统 QGP 信号研究

夸克胶子等离子体（QGP）是强相互作用物质的解禁闭相，它曾经存在于早期的宇宙，也有可能存在于中子星内部。高能核核碰撞可以在瞬间产生 QGP 所需的极端条件，揭示高温高密下强相互作用物质的相变和性质，并帮助人们近一步认识宇宙极早期的演化。在传统的相对论重离子碰撞中，例如 200 A GeV 的 Au-Au 碰撞中，强耦合的 QGP 已经被产生和发现，其中的三个重要证据为：强的集体流，椭圆流的价夸克标度律和喷注淬火效应。

在 RHIC 和 LHC 能区的 p-Pb、p-p 等碰撞小系统是当前高能核核碰撞的一个重要前沿领域，从中寻找和确认 QGP 信号可以帮助人们了解和认识自然界在费米尺度下可能存在的最小流体及其集体运动的机制。然而，由于较小的系统尺度，与 QGP 形成相关的喷注淬火信号尚未在 p-Pb 等碰撞小系统中被直接观测到。另一方面，在低横动量区所测量到的小系统各向异性流的形成机制也尚在探讨中。

基于这个现状，宋慧超副教授与学生及合作者建立了“流体—重组合—碎裂”混合模型，并用它着重研究了 LHC 能区 p-Pb 碰撞小系统在中等横动量区椭圆流的价夸克标度率。在重组合机制的框架下，他们首次定量地解释了最近 CMS、ATLAS 和 ALICE 大型国际合作组在中等横动量区所观测到的 v2 准价夸克标度率，发现低横动量区部分子的集体流及重组合对定量解释该标度率起到了关键的作用。此外，还发现相变附近随温度变化的组分夸克质量对定量描述中等横动量区可分辨粒子的产额很重要。这项工作强烈地暗示了高多重数质子—铅核碰撞小系统已出现部分子自由度，并很可能已产生 QGP。

这项工作发表于《物理评论快报》（Phys. Rev. Lett. 2020, 125, 072301）。博士生赵文彬为该论文的第一作者，宋慧超副教授为通讯作者，其它的合作者有北京大学物理学院刘玉鑫教授，华中师范大学秦广友教授和德州农工大学 Che Ming Ko 教授。

I. The QGP signals for the small p-Pb collision system at the LHC

The Quark Gluon Plasma (QGP) is the de-confinement state of the strong interacting matter. It once existed in the very early university and also possibly exists inside the neutron stars. High-energy nucleus-nucleus collisions aim to create the QGP, explore the QCD phase transition and study the properties of the hot QCD matter. In traditional heavy ion collisions, such as 200 A GeV Au-Au collision at RHIC, the strongly coupled quark-gluon plasma sQGP has been created and discovered. The three important evidences are: strong collective flow, the valence quark scaling of the elliptic flow and jet quenching.

Currently, small collision systems, such as p-Pb and p-p collisions at the LHC, are hot and important research topics in high-energy nucleus nucleus collisions. The search and confirmation of its QGP signals can help us understand the smallest fluid at the Fermi scale and reveal the mechanism of its collective behavior. However, due to the small system size, jet quenching has not been directly observed. On the other hand, the mechanism of the observed anisotropic flow is still under debates.

Considering such situation, Huichao Song, together with her students and collaborators, developed the "hydro-coal-frag" hybrid model, and used it to study the particle yields and collective flow at intermediate transverse momentum regime for p-Pb collisions at the LHC. For the first time, they quantitatively explained the valence quark scaling of v2 observed by the CMS, ATLAS, and ALICE Collaborations, and found that the quark coalescence procedure plays an essential role. They also found that the mass of the constituent quark that varies with temperature near the phase transition is crucial for a quantitatively description of the particle yields at the intermediate transverse momentum regime. Their calculation, together with the observed valence quark scaling of v2, strongly indicates the existence of partonic degree of freedom, and possible formation of the QGP in the high multiplicity p-Pb collisions at the LHC.

This work was published on Physical Review Letters (Phys. Rev. Lett. 2020, 125, 072301). Wenbin Zhao, a doctoral student, is the first author, and Huichao Song is the corresponding author. Other collaborators include Professor Liu Yu-Xin from Peking University, Professor Qin Guangyou from Central China Normal University, Professor Che Ming Ko from Texas A&M University..

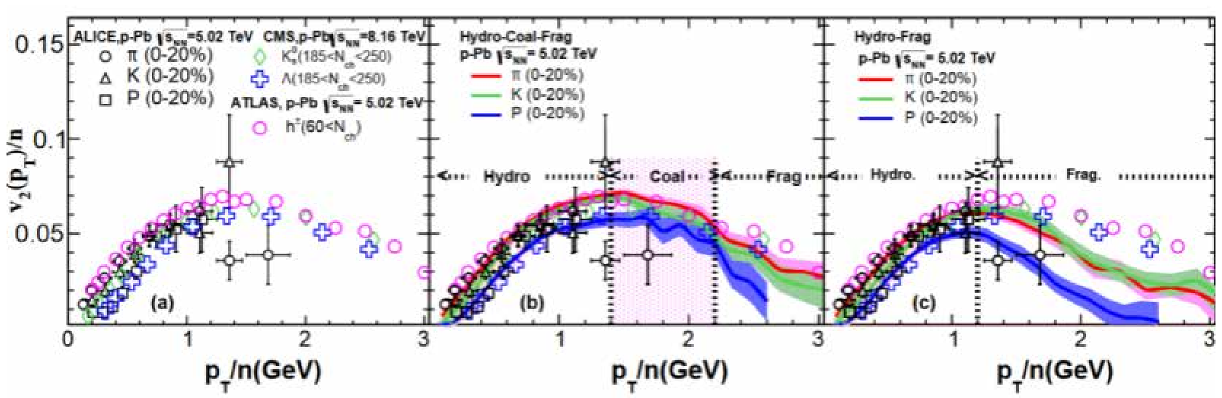


图 1.（左）CMS、ATLAS 和 ALICE 等大型国际合作组在 5.02 TeV p-Pb 碰撞小系统 高多重数事件中观测到的椭圆流准价夸克标度率；（中）流体—重组合—碎裂模型的计算结果与实验结果比较；（右）流体—弦碎裂模型的计算结果与实验结果比较。

Figure 1. Differential elliptic flow in high multiplicity p-Pb at 5.02 TeV measured by CMS, ATLAS and ALICE Collaborations (left); The comparison between the Hydro-Coal-Frag model calculations and the experimental measurements (middle); The comparison between the Hydro-Frag model calculations and the experimental measurements (right).

学生活动
Students

为增强学生身体素质，物理学院学生会、研究生会组织同学参加学校新生杯、北大杯、硕博杯、春秋季运动会等体育赛事，策划“动量杯”系列体育比赛。2019 年春季运动会物理学院获得甲组校本部第一名。

In order to enhance students' physical fitness, the students participated in sports events such as the Freshmen's Cup, Peking University Cup, Masters Cup, and the Spring and Autumn Games, and designed a series of "Momentum Cup" games. In 2019, the School ranked first in sports competitions.

2019 年 5 月，物理学院 2017 级 2 班获得北大班集体最高荣誉“班级五四奖杯”；2015 级博士生曹启韬获得北大学生最高荣誉“学生五·四奖章”。

In May 2019, Class 2, Grade 2017 of the School of Physics won the "Class Wusi Medal", the highest collective honor of Peking University; Cao Qitao, the 2015 PHD student, won the " Youth Wusi Medal", the highest honor of Peking University students.

2019 年 5 月、2020 年 10 月，物理学院先后举办了第十七届和第十八届“北京大学钟盛标物理教育基金”研究生学术论坛，基金捐赠人钟赐贤先生及夫人夏晓峦女士来校参加颁奖典礼。该学术论坛平均每年参加论坛学生百余人，报名专业涵盖物理学院全部九个学科。

In May 2019 and October 2020, The 16th and 17th "Peking University Zhong Shengbiao Physics Education Fund" postgraduate academic forum was successfully held. Mr. Cixian Zhong and his wife, Ms. Xiaoluan Xia, attended the award ceremony. The academic forum has more than 100 students participating every year.

2019 年 6 月 30 日，物理学院 2019 年毕业典礼在百周年纪念讲堂隆重举行；2020 年 6 月 28 日，物理学院 2020 年毕业典礼受疫情影响在物理学院举办并进行线上直播。

On June 30, 2019, the 2019 Graduation Ceremony of the School of Physics was held in the Peking University Hall; on June 28, 2020, the Graduation Ceremony was held in the College of Physics and lived online due to the influence of the epidemic.

学生活动 | ***Students***

2019 年 9 月 17 日，物理学院在英杰交流中心阳光厅举行 2019 年开学典礼。

On September 17, the School of Physics held the opening ceremony.

2019 年 8 月，物理学院 2019 级本科生参加军训。

In August 2019, the 2019 undergraduates participated in military training.

2019 年 10 月 1 日，物理学院师生参加庆祝新中国成立 70 周年群众游行方阵和志愿服务工作。

On October 1, 2019, teachers and students participated in the mass parade and volunteer service to celebrate the 70th anniversary of the founding of People's Republic of China.

2019 年 11 月，物理学院、国际关系学院和环境科学与工程学院组织联合团校，邀请原任国资委企业改革局副局长贾小梁讲授开学第一课，促进学生骨干全面发展。

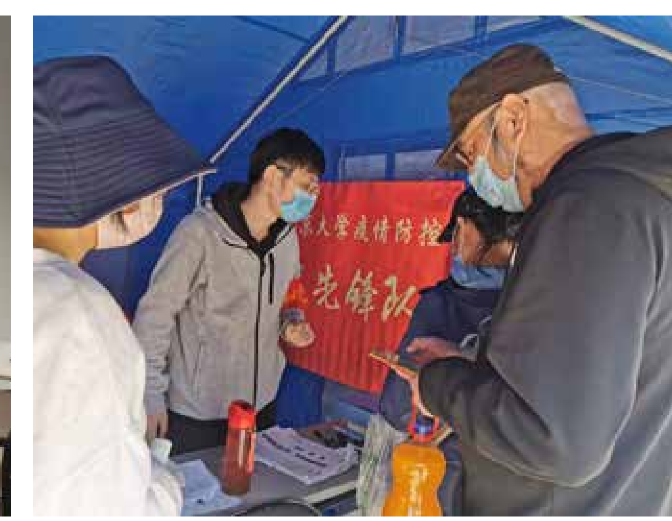
In November, 2019, School of Physics, School of International Studies and College of Environmental Science and Engineering organized a joint Youth League School to invite Jia Xiaoliang, former Deputy Director of Enterprise Reform Bureau of The State-owned Assets Supervision and Administration Commission of the State Council (SASAC), to give the first class to promote the comprehensive development of student backbone.

2019 年 12 月，学院学生自发组织新年晚会，以独具特色的节目迎接新年的到来。

In December 2019, students organized a new year's party to welcome the New Year with unique programs.

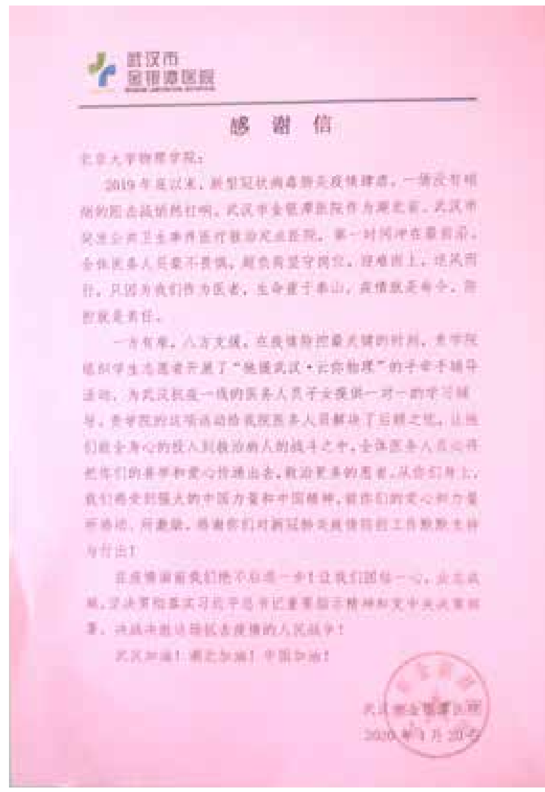
2020 年 2 月，物理学院为湖北疫区同学寄送口罩、明信片等慰问物资，关心疫区同学身心健康。居家同学主动参与社区防疫志愿服务，为疫情防控贡献力量。

In February 2020, the School sent masks, postcards and other consolation materials to the students in the epidemic area of Hubei Province to show their concern for the physical and mental health of the students.



2020 年 4 月，物理学院学生自发组织为武汉医务人员子女开展线上学业辅导，学院收到金银潭医院的感谢信。

In April 2020, the students of College of Physics spontaneously organized online academic counseling for the children of Wuhan medical staff, and the College received a letter of thanks from Jinyintan hospital.



武汉市金银潭医院

感 谢 信

武汉加油！湖北加油！中国加油！

2020 年 5 月，物理学院组织师生参加第二届五四青春长跑。

In May 2020, the School of Physics organized teachers and students to participate in the 2nd Youth long distance race.

2019 年 5 月、2020 年 5 月，物理学院组织第八届、第九届本科生小型科研项目训练比赛。同年 8 月，物理学院学生代表参加 CUPT，取得全国二等奖的佳绩。

In May 2019 and May 2020, the School held the 8th and 9th undergraduate small scientific research project training competition. In August, student representatives won the second prize in the Chinese College Student Physics Academic Competition.

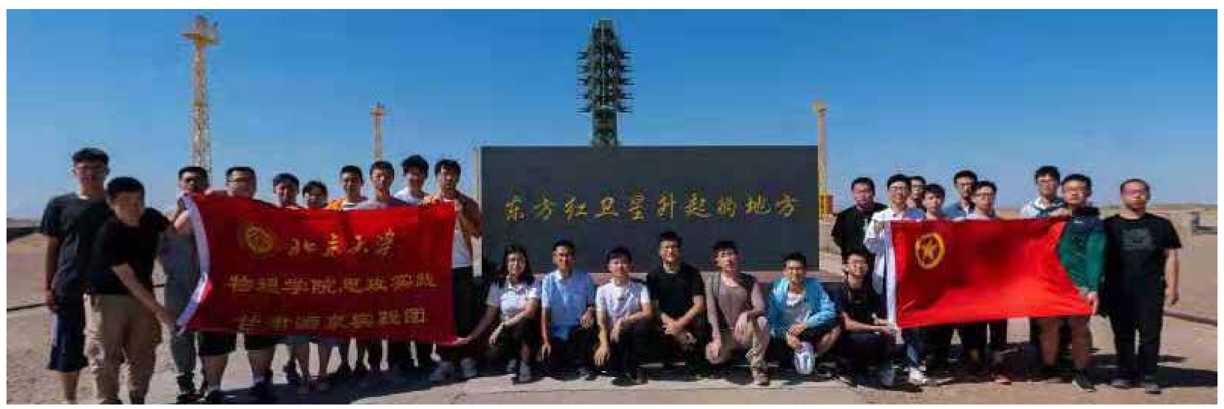
2020 年 6 月，物理学院院长高原宁、党委书记杨金波迎接第一批湖北返校毕业生。

In June 2020, Gao Yuanning and Yang Jinbo welcomed the first batch of returned graduates from Hubei Province.

学生活动 | ***Students***

2020 年 7 月—8 月，物理学院组织学生开展思政实践活动。学生到酒泉卫星发射中心、郭永怀事迹陈列馆等地开展实践调研。

From July to August 2020, the school of Physics organized students to carry out ideological and political practice activities. Students went to Satellite Launch Center, Guo Yonghuai Memorial Hall and other places to carry out practical research.



2020 年 8 月，物理学院欢送本科入伍同学。

In August 2020, School of Physics sends off undergraduate enlisted students.

2020 年 9 月，物理学院院长高原宁为 2020 级本科新生讲授开学第一课；物理学院组织 2020 级新生素质拓展活动。

In September 2020, Gao Yuanning, Dean of the School of Physics gave the first lesson for the freshmen of Grade 2020; the School organized the quality development activities for the 2020 undergraduates.

2020 年 10 月，本科生和研究生举行迎新晚会。

In October 2020, undergraduate and graduate students held a welcome party for new students.

为了促进学院学生的就业发展，学院每年定期组织企业参访和举行“青藤计划”校友专场招聘会。图为第四届“青藤计划”招聘会。

In order to promote the employment development of students, the School regularly organizes corporate visits and holds "Ivy League" alumni job fairs every year.

2020 年 12 月，物理学院新生代表在北京大学 2020 年新生“爱乐传习”项目暨纪念“一二·九”运动 85 周年师生歌会上演唱《星河》，获得甲组二等奖和最佳编排奖。

In December 2020, freshmen representatives from the School performed chorus "Xinghe" at Peking University's 2020 freshman "Philadelphia" project and a memorial event, won the 2nd prize of group A and the best arrangement award.

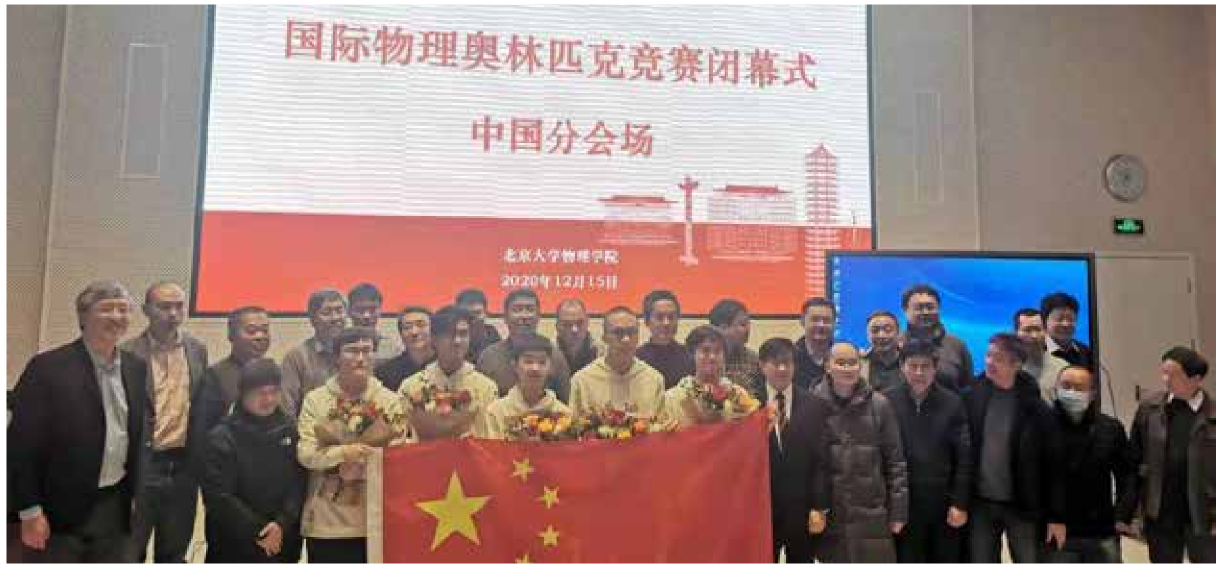
学生活动 | *Students*

2020 年 12 月，物理学院参加第七届“五校联盟博士生学术论坛”，5 人获得论坛一等奖，取得优异成绩。

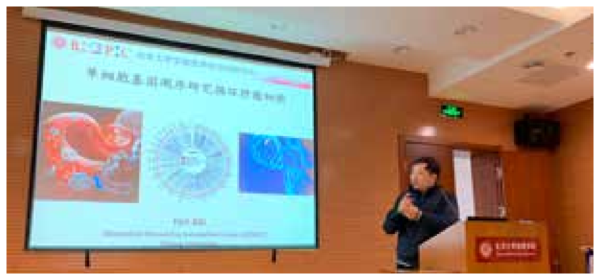
In December 2020, the School of Physics participated in the 7th PHD Academic Forum of Physics Five Universities, there were five students won the first prize of the forum.

2020 年 12 月，中国代表队包揽国际物理奥林匹克竞赛前 5 名。

In December 2020, the Chinese team took the top five in the International Distributed Physics Olympiad, IdPhO2020.



校友与基金
Alumni and Funds



2019 年 1 月 5 日，物理学院 2019 年校友新年论坛在学院西楼 202 报告厅召开。本届论坛以“物理与生命科学”为主题，白凡研究员、李鹏副研究员两位主讲嘉宾从基因测序与癌症检测、传染病防控中的应用等方面，带领大家探索生命科学的奥妙。

On January 5, 2019, the school held the Alumni New Year Forum. with the theme of "physics and life sciences". Researcher Bai Fan and associate researcher Li Peng led us to explore the mysteries of life sciences from the aspects of gene sequencing and cancer detection, as well as the application of infectious disease prevention and control.

2019 年 4 月 4 日，我国两弹　星元勋郭永怀先生诞辰 110 周年纪念日。物理学院应邀至山东荣成参加纪念活动，深切缅怀先生，感悟先生功绩。

April 4, 2019 is the commemoration of the 110th Birth Anniversary of Professor Guo Yonghuai, the Two Bombs and One Satellite of China. Teachers and students representatives of School of Physics were invited to attend the commemoration activities in Rongcheng, Shandong Province, to deeply cherish the memory of Mr. Guo and appreciate his achievements.

校友与基金 | *Alumni and Funds*

2019 年 5 月 4 日，北京大学技术物理系 1959 级校友入学六十周年庆祝聚会。

On May 4, 2019, the 60th Anniversary Celebration Gathering of 1959 Alumni of the Department of Technical Physics was held.

2019 年 5 月 18 日，物理学院校友会联合北京大学金融校友联合会、南燕沙友会举办此次校友论坛。学院校友会邀请了 1979 级校友、物理学院院长高原宁教授做《粒子物理和大科学工程》主题报告；黄震嘉宾由北京大学金融校友联合会邀请，报告题目为《金融科技赋能实体经济》。

On May 18, 2019, the Alumni Association of School of Physics, together with the financial Alumni Association of Peking University and the Nanyansha Alumni Association, held the alumni forum. Gao Yuanning, Alumni of Grade 1979 and Dean of the school of physics, was invited to give a speech with the theme of “Particle Physics and Great Science Gngineering”; Huang Zhen was invited by the Financial Alumni Association to give a speech with the theme of “Financial Technology Enabling Real Economy".

2019 年 6 月 15 日，北京大学物理学院第二届校友代表大会在思源报告厅隆重召开。

On June 15, 2019, the 2nd Alumni Congress of School of Physics was solemnly held.

2019 年 10 月 26 日，北京大学物理学院第三届校友企业专场招聘会在物理学院思源报告厅举行。

On October 26, 2019, the 3rd alumni enterprise job fair of School of Physics of Peking University was held.

2019 年 10 月 9 日，物理学院校友会、学工办看望“北京大学物理学院陈互雄物理教育基金”捐赠人陈敬熊先生、常菊芳女士。

On October 9, 2019, the school visited Mr. Chen Jingxiong and Ms. Chang Jufang, the donors of the “Chen Huxiong Physics Education Fund”.

2019 年 10 月 22 日，物理学院校友会看望西安交通大学校友，并了解校友发展情况。

On October 22, 2019, the school visited the alumni of Xi'an Jiaotong University and learned something about their development.

2019 年 11 月 17 日，物理学院校友会举办上海校友活动。

On November 17, 2019, the school held activities for Shanghai alumni.

2019 年 11 月 27 日，物理学院校友会、学工办看望“北京大学物理学院张文新物理教育基金”捐赠人张文新先生。

On November 27, 2019, the school visited Mr. Zhang Wenxin, the donor of "Zhang Wenxin Physics Education Fund ".

2019 年 11 月 30 日至 12 月 1 日，北京大学校友会第九届理事会第三次会议、北京大学第十三次校友工作研讨会在湖北武汉召开。56 级物理系校友李维楠、78 级物理系校友于芳、82 级技物系校友郭俊杰、85 级物理系校友杨三文、88 级技物系校友徐红星、03 级校友郭宇铮等校友代表与来自全球的 300 余位校友代表共同研讨校友工作。

From November 30 to December 1, 2019, the third meeting of the ninth Council of Peking University Alumni Association and the 13th Alumni Work Seminar of Peking University were held in Wuhan, Hubei Province. Li Weinan, Yu Fang, Guo Junjie, Yang Sanwen，Xu Hongxing, Guo Yuzheng and other alumni representatives, attended the meeting to communicate alumni work with more than 300 alumni representatives from all over the world.

校友与基金 | *Alumni and Funds*

2019 年 11 月 29 日，学院校友会秘书处组织了在武汉工作校友聚会，与来自华中科技大学、武汉大学、华中师范大学等单位工作的校友共忆燕园情谊。

On November 29, 2019, the Secretariat of the school Alumni Association organized a gathering of alumni in Wuhan to recall the friendship of Yanyuan, with alumni from Huazhong University of science and technology, Wuhan University and Central China Normal University.

2019 年 12 月 15 日，物理学院 2020 年校友新年论坛在西 213 举行。本次论坛邀请北方华创微电子副总裁、首席科学家刘韶华校友、中国长江三峡集团总部特聘分析师黄俊灵校友带来分享报告。

On December 15, 2019, the school held the Alumni New Year Forum. Liu Shaohua, Vice President and Chief Scientist of NAURA Microelectronics, and Huang Junling, special analyst of China Three Gorges Group Headquarters, were invited to deliver reports.

2019 年 12 月 25 日，物理学院校友会秘书处看望厦门大学校友。

On December 25, 2019, the school visited the alumni of Xiamen University.

2020 年 3 月 26 日，物理学院校友会举办主题为“助力科研成长，练就过硬本领”的优秀校友在线交流分享会。

On March 26, 2020, the school held an online meeting for outstanding alumni with the theme of "Helping Scientific Research Growth and Cultivating Excellent Skills".

2020 年 4 月 4 日，物理学院校友会举办海外科研校友交流会。

On April 4, 2020, the school held an overseas scientific research alumni meeting.

2020 年 4 月 18 日，物理学院校友会举办创业校友交流会。

On April 18, 2020, the school held an exchange meeting for entrepreneurship alumni.

2020 年 5 月 4 日，物理学院校友会举办校友论坛，邀请吴国盛、毛有东、王超龙三位校友带来学术报告。

On May 4, 2020, the school held an alumni forum. Wu Guosheng, Mao Youdong and Wang Chaolong were invited to deliver academic reports.



2020 年 6 月 20 日，物理学院校友会第十一次理事会议在线举行，校友会理事、各年级联络人四十余人参会。

On June 20, 2020, the 11th Council meeting of the Alumni Association was held online, more than 40 Alumni Association directors and contact persons of all grades participated in the meeting.

2020 年 6 月 28 日，张德明校友参加物理学院 2020 年毕业典礼并致辞。

On June 28, 2020, alumni Zhang Deming attended and delivered a speech at the 2020 Graduation Ceremony of School of Physics.

2020 年 12 月 14 日，物理学院校友举办 2021 年校友新年论坛，邀请北京大学科维理科维理天文与天体物理研究所东苏勃研究员带来报告。

On December 14, 2020, the school held the Alumni New Year Forum. Dong Supo of the Institute of Astronomy and Astrophysics of Department of Science and Technology in Peking University was invited to deliver a report.

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 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 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

校友与基金 | *Alumni and Funds*

设立时间 Time of Establishment	项目名称 Project Title	捐赠人 Donators
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 alumni (Ms. Fang Jing, Mr. Lei Yi'an and 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 11978 级校友胡铭 The 1978 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
2013	北大合伙人基金 PKU Partnership Fund	北大物理 2012 级研究生李骥、宗华、付建波 The 2012 physics graduates Li Ji, Zong Hua and Fu Jianbo
2013	1978 级核物理校友奖励基金 1978 Nuclear Physics Class Fund	北大原子核物理 1978 级校友（纪力强先生等） The 1978 alumni (Mr.Ji Liqiang et al.)

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 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 Liabrary 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 Buidling 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 PKU Physics 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

合作与交流
Exchange & Cooperation

一、学术讲座 Lectures

I 北京大学百年物理讲坛
The Centennial Physics Lectures

2019年，举办“北京大学百年物理讲坛”第二十二至二十六讲。第二十二讲邀请美国匹兹堡大学杰出教授、粒子物理与天体宇宙学中心的所长韩涛教授来校作了题为“探索万物之源：高能物理五十年”的公开演讲，并与师生交流。

In 2019, the school held the 22nd and 26th sessions of The Centennial Physics Lectures. The 22nd lecture “Quest for Nature: Fifty Years of Discoveries in High Energy Physics” was given by Pittsburgh University distinguished professor Han Tao, who presently serves as the founding director of the Pittsburgh Particle Physics, Astrophysics and Cosmology Center (PITT PACC).

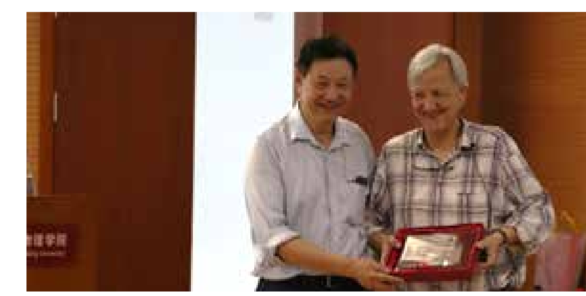
合作与交流 | *Cooperation*

第二十三讲邀请到1985年诺贝尔物理学奖获得者、德国马克斯 - 普朗克固体物理研究所前任所长 Klaus von Klizting 教授来校报告访问。

The 23rd lecture “Quantum Hall Effect and the New International System of Units” was given by the 1985 Nobel Laureate in Physics Professor Klaus von klizting, who is the former director of the Max Planck Institute for solid state physics, Germany.

第二十四讲邀请到德国著名物理学家、维尔茨堡大学教授 Laurens W. Molenkamp 教授来校报告访问。

The 24th lecture “Topological Insulator: a new state of matter” was given by professor Laurens W. Molenkamp, a famous German physicist and professor of University of Würzburg.



第二十五讲邀请到美国普林斯顿大学荣誉教授 Robert J. Cava 教授来校交流。

The 25th lecture “Superconductivity: Where we are and where we are going” was given by professor Robert J. Cava, Honorary Professor of Princeton University.

第二十六讲邀请到奥地利国际著名理论物理学家 Peter Zoller 教授来校交流。

The 26th lecture “A Quantum Leap in Quantum Information---- Building Quantum Computers and Quantum Simulators with Cold Atoms and Ions” was given by professor Peter Zoller, University of Innsbruck, and Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences.

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

2020 年，物理学院学术论坛开讲。首讲邀请到中国科学技术大学“严济慈”讲习教授、国际功能材料量子设计中心联合主任张振宇教授作公开演讲。

In September 2020, the Distinguished Colloquium of School of Physics was launched. The 1st lecture “Predictive Discoveries of 2D Materials for Topological Superconductivity and High-Tc Superconductivity” was given by professor Zhenyu Zhang, who is a Distinguished Chair Professor at University of Science and Technology of China and serves as co-founding Director of International Center for Quantum Design of Functional Materials.

第二讲邀请到未来生命研究所所长、美国麻省理工学院教授 Max Tegmark 作公开演讲。

The 2nd lecture “AI for physics & physics for AI” was given by professor Max Tegmark, a professor doing physics and AI and physics research at MIT as part of the Institute for Artificial Intelligence & Fundamental Interactions and the Center for Brains, Minds and Machines; serves as president of the Future of Life Institute.

第三讲邀请到中国科学院半导体研究所黄永箴教授作公开演讲。

The 3rd lecture was given by professor Yongzhen Huang, Institute of Semiconductors.

第四讲邀请到中国科学院国家天文台副台长、银河系三维结构团组首席研究员、中国科学院大学天文与空间科学学院副院长刘继峰作公开演讲。

The 4th lecture “In search of X-ray quiet stellar black holes” was given by Jifeng Liu, deputy director-general of NAOC, deputy chair for the School of Astronomy and Space Sciences at UCAS.

二、学术访问 Academic Exchange

2019 年 9 月，中东技术大学副校长 Mehmet Zeyrek 一行 6 人访问北京大学。物理学院副院长徐莉梅教授，技术物理系冒亚军教授、李强副教授与代表团在临湖轩亲切会谈。本次会议进一步推动了双方开展实质性合作，初步计划在粒子物理、凝聚态与量子材料科学等领域加强师生互访和交换，与博士后来华推荐。

In September 2019, Vice President of the Middle East Technical University Mehmet Zeyrek, and his delegation visited Peking University, and had a cordial talk at linhuxuan with delegation of School of Physics, The Associate Dean of School of Physics Professor Xu Limei, and Professor Mao Yajun and Associate Professor Li Qiang of the Department of Technical Physics. This talk promoted the development of substantive cooperation between the two parties: strengthen the visits and exchange of teachers and student in the fields of particle physics, condensed matter and quantum materials science, ect., and recommend post doctors to work in China.

11 月，未来科学大奖与北京大学联合学术报告会“中微子与宇宙”在北京大学英杰交流中心阳光厅举行。2019 未来科学大奖物质科学奖获得者、加州大学伯克利分校物理系教授陆锦标先生，2019 未来科学大奖物质科学奖获得者、中国科学院高能物理研究所所长王贻芳教授和中国科学院高能物理研究所理论物理室主任邢志忠教授先后以“中微子与宇宙”为主题作了精彩演讲。

In November 2019, The Joint Symposium of Future Science Prize and Peking University was held in the Overseas Exchange Center of Peking University. Professor Lu Jinbiao (2019 Future Science Prize Winner of Material Science Prize, Professor of Physics Department of University of California at Berkeley), Professor Wang Yifang (2019 Future Science Prize Winner of Material Science Prize, director of Institute of high energy physics of Chinese Academy of Sciences) and Professor Xing Zhizhong (director of theoretical physics Division of Institute of high energy physics of Chinese Academy of Sciences) gave wonderful speeches themed as “ Neutrinos and the universe".

2020 年 1 月，诺贝尔物理学奖得主 Gérard Mourou 教授访问北大，并参加“激光驱动多束流国家重大科技基础设施（筹）”专家咨询委员会聘任仪式及前沿学术研讨会。Mourou 教授此次来访深入参与了北京大学激光多束流设施建设国际研讨，讨论和完善建设方案，组建优势团队。

In January 2020, Professor Gérard Mourou, the Nobel Laureate in physics, visited Peking University and participated in the Expert Advisory Committee Appointment Ceremony and Frontier Academic Seminar of "National Major Science and Technology Infrastructure for Laser Driven Multi-Beam". During his visit, Professor Mourou deeply got involved in the international seminar on the construction of laser multi beam facilities in Peking University, discussed and improved the construction scheme, and established an excellent team.

三、学术会议 Academic Conferences

2019 年 5 月 25—26 日，继北京大学大气科学学科建立 90 周年庆祝大会之后，大气与海洋科学系顺利举办了气候与大气环境变化国际研讨会。本次研讨会邀请了国内外30余位专家学者就“气候、大气成分、海洋、热带”等专题作前沿报告。

From May 25 to 26, 2019, following the 90th anniversary celebration of the establishment of atmospheric sciences at Peking University, The Department of Atmospheric and Oceanic Sciences successfully held the International Symposium on Climate and Atmospheric Environmental Changes. This seminar invited more than 30 domestic and foreign experts to give Frontier Reports on topics of climate, atmospheric composition, ocean, and tropics.

6 月 3 日，由北京量子信息科学研究院和北京大学共同主办的第七届量子霍尔现象国际研讨会在北京顺利举行，来自 9 个国家 18 个国际知名大学和研究机构的专家学者（包括 14 位外籍）作特邀报告。

On June 3rd, the 7th International Symposium on Quantum Hall Phenomenon, co-sponsored by Beijing Academy of Quantum Information Sciences and Peking University, was successfully held in Beijing. Experts and scholars (including 14 foreign nationals) from 18 internationally renowned universities and research institutions gave invitation report.

7 月 1—7 月 5 日，“环形正负电子及质子对撞机”物理探测器国际工作会议在北京大学举行。

From July 1st to 5th, the International topical workshop on the CEPC Physics and Detector was held in Peking University.

8 月 21 日—8 月 24 日，第二届 DRHBc 原子核质量表研讨会在北京大学举行。

From August 21 to 24, the 2nd Symposium on DRHBc Mass Table was held in Peking University.

奖励与荣誉
Awards & Honors

2019 年度
In 2019

- “物理学”入选 2019 年度国家级和北京市一流本科专业建设点。
  "Physics" was selected as one of the national and Beijing first-class undergraduate construction majors in 2019.
- “未名学者物理学拔尖学生培养基地”入选2019年度教育部(首批)基础学科拔尖学生培养计划2.0基地。
  " Weiming-scholar Top-notch Undergraduate Training Base of physics " was selected as one of the bases for the Top-notch Undergraduate Training Scheme 2.0 of Ministry of Education in 2019 (the first batch).
- 穆良柱获第三届北京市高等学校青年教学名师奖。
  Mu Liangzhu won the 3rd Young Teaching Teacher Award of Beijing high education schools.
- 马伯强主持的“数学物理方法”教学团队入选北京高校优秀本科育人团队。
  Ma Boqiang and his "Methods of Mathematical Physics" teaching team was selected as one of the Excellent Undergraduate Education Teams of Beijing high education schools.
- 刘玉鑫主持的“热学”入选北京高校优质本科教材课件重点项目。
  "Thermal Science" of Liu Yuxin was selected as a key project of quality undergraduate teaching materials and courseware of Beijing high education schools.
- 路裕、许昭鉴、刘越、潘书航完成的论文入选 2019 年北京市普通高等学校优秀本科生毕业设计（论文），肖云峰、朱瑞、冯济、史俊杰获优秀毕业设计（论文）指导教师。
  The theses completed by Lu Yukun, Xu Zhaojian, Liu Yue, Pan Shuhang, respectively, were selected as the Outstanding Undergraduate Graduation Designs (theses) of Beijing high education schools in 2019; Xiao Yunfeng, Zhu Rui, Feng Ji and Shi Junjie won the Outstanding Graduation Design (thesis) Supervisor.

奖励与荣誉 | *Awards & Honors*

- 北京大学参与完成的项目“脉冲强磁场国家重大科技基础设施”获 2019 年度国家科学技术进步一等奖（单位排名：3/10）。
  The project "High Magnetic Field National Large Research Infrastructures" completed by Peking University was awarded the First prize National Science and Technology Progress Award in 2019 (Peking University ranked 3/10).

- 江颖、王恩哥、徐莉梅等完成的项目“揭示水合离子的原子结构和幻数效应”入选 2018 年度中国科学十大进展。（2019 年 2 月揭晓）
  The project "The effect of hydration number on the interfacial transport of sodium ions" completed by Jiang Ying, Wang Enge, Xu Limei, et al., was selected as one of the Top Ten Advances in Chinese Science in 2018. (Revealed in February 2019)

- 江颖、王恩哥、徐莉梅等完成的项目“科学家首次揭示水合离子微观结构”入选 2018 年度中国十大科技进展。（2019 年 1 月揭晓）
  The project completed by Jiang Ying, Wang Enge, Xu Limei, et al., "The effect of hydration number on the interfacial transport of sodium ions" was selected as one of the Top Ten Chinese Science and Technology Progress in 2018. (Revealed in January 2019)

- 王恩哥、江颖、李新征、孟胜、徐莉梅完成的项目“原子尺度下水的复杂形态与全量子化效应研究”获 2019 年度高等学校科学研究优秀成果奖（科学技术）自然科学一等奖。
  The project completed by Wang Enge, Jiang Ying, Li Xinzheng and Xu Limei was awarded the First Prize of Natural Science Award of High Education Science Research Excellent Achievement (Science and Technology) in 2019.

- 傅宗玫、张霖、赵春生、旷烨完成的项目“我国大气气溶胶的来源反演解析及物化特性研究”获 2019 年度高等学校科学研究优秀成果奖（科学技术）自然科学二等奖。
  The project completed by Fu Zongmei, Zhang Lin, Zhao Chunsheng and Kuang Ye was awarded the Second Prize of Natural Science Award of High Education Science Research Excellent Achievement (Science and Technology) in 2019.

- 杨金波、韩景智、杨云波、刘顺荃、王常生完成的项目“强各向异性纳米晶永磁材料研究”获 2019 年度北京市科学技术奖自然科学奖二等奖。
  The project completed by Yang Jinbo, Han Jingzhi, Yang Yunbo, Liu Shunquan, Wang Changsheng was awarded the Second Prize of Beijing Natural Science Award in Science and Technology in 2019.

- 高原宁、汤超当选中国科学院数学物理学部院士。
  Gao Yuanning and Tang Chao were elected as Academicians of the Chinese Academy of Sciences (Department of Mathematics and Physics).

- 江颖当选美国物理学会会士。
  Jiang Ying was elected as American Physical Society Fellow.

- 孟智勇当选美国气象学会会士。
  Meng Zhiyong was elected as American Meteorological Society Fellow.

- 颜学庆获全球加速器大会 2019 年度 Hogil Kim 加速器奖。
  Yan Xueqing won the Hogil Kim Prize of the International Particle Accelerator Conference in 2019.

- 杨晓菲获国际纯粹与应用物理联合会青年科学家奖。
  Yang Xiaofei won the Young Scientist Award of International Union of Pure and Applied Physics.

- 李婧获 Richard M. Goody 奖。
  Li Jing won the Richard M. Goody Award.

- 刘运全当选中国光学学会会士。
  Liu Yunquan was elected as Chinese Optical Society Fellow.

- 江颖获第十五届中国青年科技奖。
  Jiang Ying won the 15th China Youth Science and Technology Award.

- 江颖获 2019 年度北京市杰出青年中关村奖。
  Jiang Ying won the Beijing Outstanding Youth Zhongguancun Award in 2019.

- 王健获 2019 年度高等学校科学研究优秀成果奖（科学技术）青年科学奖。
  Wang Jian won the Young Scientific Award of High Education Science Research Excellent Achievement (Science and Technology) in 2019.

- 刘雄军获亚太物理学会联合会 - 亚太理论物理中心杨振宁奖。
  Liu Xiongjun won the AAXPPS-APCTP C.N. YANG Award.

- 肖云峰、朱世琳、孙庆丰分别获中国物理学会饶毓泰物理奖、王淦昌物理奖、周培源物理奖。
  Xiao Yunfeng，Zhu Shilin and Sun Qingfeng won the Rao Yutai Physics Prize, Wang Jianchang Physics Prize, and Zhou Peiyuan Physics Prize of the Chinese Physical Society, respectively.

- 王剑威获中国光学学会饶毓泰基础光学二等奖。
  Wang Jianwei won the Second Prize in Rao Yutai Fundamental Optics of the Chinese Optical Society.

- 高鹏第十三届中国硅酸盐学会青年科技奖。
  Gao Peng won the 13th Youth Science and Technology Award of the Chinese Ceramic Society.

- 楼建玲获胡济民教育科学奖。
  Lou Jianling won the Hu Jimin Education Science Award.

- 邵立晶入选第四届中国科学技术协会青年人才托举工程。
  Shao Lijing was Selected for the 4th Young Talents Support Project of China Association for Science and Technology.

2020 年度
In 2020

- “天文学”入选 2020 年度国家级一流本科专业建设点。
  "Astronomy" was selected as one of the national first-class undergraduate construction majors in 2020.

- “未名学者大气科学拔尖学生培养基地”入选 2020 年度教育部（第二批）基础学科拔尖学生培养计划 2.0 基地。
  " Weiming-scholar Top-notch Undergraduate Training base of atmospheric science" was selected as one of the bases for the Top-notch Undergraduate Training Scheme 2.0 of Ministry of Education in 2020 (the second batch).

- 欧阳颀主持的“热学”入选国家级线上一流本科课程，季航、马伯强主持的“近代物理实验”“数学物理方法”入选首批国家级线下一流本科课程。
  "Thermal Science" hosted by Ouyang Qi was selected as one of the national online first-class undergraduate courses, while "Modern Laboratory Physics" and "Methods of Mathematical Physics" hosted by Ji Hang, Ma Boqiang, respectively, were selected as the first batch of national offline first-class undergraduate courses.

- 孟策主持的“电磁学”入选北京高校优秀本科课程。
  "Electromagnetism" hosted by Meng Ce was selected as one of the outstanding undergraduate courses in Beijing universities.

- 亓瑞时、曾耀萱、李嘉轩完成的论文入选 2020 年北京市普通高等学校优秀本科生毕业设计（论文），高鹏、杨军、何子山获优秀毕业设计 (论文) 指导教师。
  The theses completed by Qi Ruishi, Zeng Yaoxuan, Li Jiaxuan, respectively, were selected as the Outstanding Undergraduate Graduation Designs (theses) of Beijing high education schools in 2020; and Gao Peng, Yang Jun, He Zishan won the Outstanding Graduation Design (thesis) Supervisor.

- 吴桃李完成的论文“北京大学物理学科拔尖优秀毕业生跟踪调查研究”获北京高校第十一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 11th Basic Teaching Skills Competition (Thesis Competition) for Young Teachers in Beijing high education schools.

- 刘运全、吴成印、彭良友、龚旗煌完成的项目“原子分子动力学超快光场成像和调控”获 2020 年度高等学校科学研究优秀成果奖（科学技术）自然科学一等奖。
  The project completed by Liu Yunquan, Wu Chengyin, Peng Liangyou and Gong Qihuang was awarded the First Prize of Natural Science Award of High Education Science Research Excellent Achievement (Science and Technology) in 2020.

- 李柯伽与合作者完成的研究成果“中国天眼确定快速射电暴的起源”入选 2020 年度中国十大天文科技进展。
  The research completed by Li Kejia and his co-workers was selected as one of the Top Ten Astronomical Science and Technology Advances in China in 2020.

- 李柯伽与合作者完成的研究成果“首次发现快速射电暴源的辐射具有丰富偏振特征”入选 2020 年中国重大科学进展。
  The research completed by Li Kejia and his co-workers was selected as one of major scientific advances in China in 2020.

- 刘开辉与合作者完成的研究成果“实现尺寸最大、晶面指数最全单晶铜箔库的可控制备” 入选 2020 年中国重大技术进展。
  The research completed by Liu Kaihui and his co-workers was selected as one of major technological advances in China in 2020.

- 马仁敏与合作者完成的研究成果“通讯波段的高性能钠基等离激元纳米激光器”、刘开辉与合作者完成的研究成果“米级高指数晶面单晶铜箔库制造”入选 2020 年度（首届）中国半导体十大研究进展。
  Cooperative research works of Ma Renmin and Liu Kaihui, respectively, were selected as the Top Ten China Semiconductor Research Advances in 2020.

- 马仁敏与合作者完成的基础研究成果“金属钠：助推等离激元光子器件走向应用”、高鹏与合作者完成的基础研究成果“单层氮化硼声子极化激元的直接观测”和肖云峰、龚旗煌等完成的应用研究成果“双倍频程展宽的芯片级光频梳” 入选 2020 年度中国光学十大进展。
  The research works of Ma Renmin and his co-workers, Xiaoyunfeng and Gong Qihuang, respectively, were selected as the top ten advances in optics in China in 2020.

- 李焱当选中国光学学会会士。
  Li Yan was elected as Chinese Optical Society Fellow.

- 高原宁获 2020 年度陈嘉庚科学奖（数理科学奖）。
  Gao Yuanning won the Tan Kah Kee Science Award (Mathematics and Physics).

- 颜学庆获 2020 年度何梁何利科学与技术进步奖（物理学奖）。
  Yan Xueqing won Ho Leung Ho Lee Award for Progress in Science and Technology (Physics).

- 吴月芳获中国天文学会第十五届张钰哲奖。
  Wu Yuefang won the 15th Zhang Yuzhe Award of the Chinese Astronomical Society.
- 江颖获第八届仁科芳雄亚洲奖。
  Jiang Ying won the 8th Nishina Asia Award.
- 江颖教授获 2020 年度全球华人物理与天文学会亚洲成就奖。
  Jiang Ying won the Achievement in Asia Award (AAA)，Robert T. Poe Prize of International Organization of Chinese Physicists and Astronomers.
- 肖云峰获第十六届中国青年科技奖。
  Xiao Yunfeng won the 16th China Youth Science and Technology Award.
- 杨晓菲获第十七届中国青年女科学家奖。
  Yang Xiaofei won the 17th Chinese Young Women Scientist Award.
- 肖云峰获 2020 年度陈嘉庚青年科学奖（信息技术科学奖）。
  Xiao Yunfeng won the Tan Kah Kee Youth Science Award (Information Technology Science).
- 东苏勃获第二届科学探索奖。
  Dong Subo won the 2nd Science Discovery Award.
- 刘灿入选 2020 年度未来女科学家计划。
  Liu Can was selected for Future Women Scientists Programme in 2020.