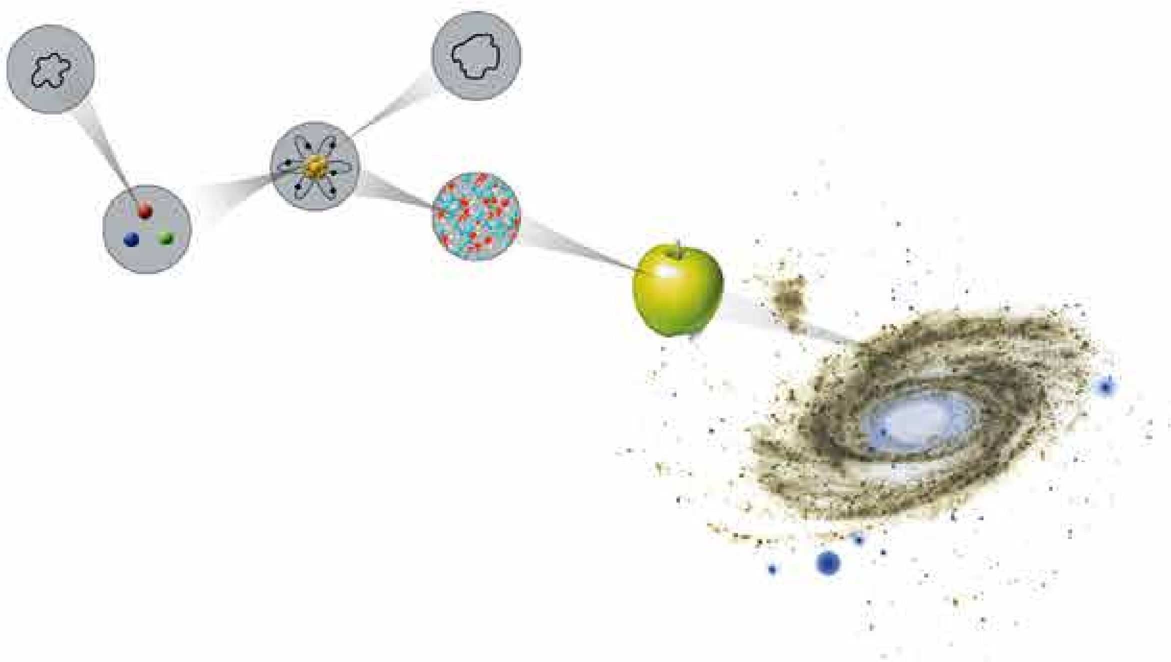

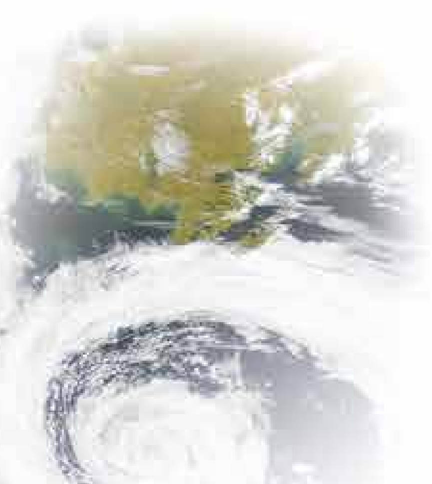

2015-2016 年报

Bi-annual Report

北京大学物理学院

SCHOOL OF PHYSICS, PEKING UNIVERSITY

# 2015-2016 年报

Bi-annual Report

# 前言
# *The Dean's Address*


北京大学是中国近代最早进行物理教育和研究的高等学府。自 1913 年设立物理学门起，北大物理已经走过将近一个世纪的风雨历程。近百年来，我们经历了创业初期的步步艰辛，创造出西南联大时的鼎盛辉煌；既目睹过国家解放后的蓬勃发展，更见证着改革开放以来的巨大进步。几代北大物理学人筚路蓝缕，矢志不移，苦心耕耘，艰难玉成，以自己的远见卓识、坚韧不拔和惟实创新铸就了中国物理乃至中国现代科学教育与研究的根基。时至今日，北京大学物理学院已经发展成为享誉海内外的物理学研究重镇和顶尖人才培养摇篮。

纵观世界一流的物理教育科研机构，无不都有历经久远、点滴积淀的独特传统，引领方向、特色鲜明的目标宗旨，科学合理、规范高效的管理体制，国际顶尖、各有所长的人才群体，宽松自由、协同共进的学术氛围，严谨缜密、执着求真的科学品质，追求卓越、开拓进取的创新精神以及所有这些因素的有机联系与共同作用。站在一个新的历史起点上，北京大学物理学院正向更高、更远的目标不断奋进。

科学研究是物理学院的立院之本。在我对北大，甚至对许多国内外大学的了解中，并不多见一个学院的科学研究领域在空间和时间的尺度上能像我们物理学院这样宽广——大到宇宙与星系，小到原子和夸克；快到阿秒，慢至亿年。北京大学物理学院始终面向国际一流、探索科学前沿；我们既鼓励原创性基础研究，也积极推进具有潜力的应用研究，更提倡不同学科之间的交叉拓展。我们努力寻求和把握物理研究的趋势和方向，期待在未来的竞争和发展中持续突破、有所作为。

物理学院一切工作的中心在于凝聚和培养人才。我们一直致力于发现、吸引、培养和使用具有国际竞争力的拔尖创新人才，他们不仅包括才华横溢的教授学者，还有壮志凌云的青年才俊和莘莘学子。我们为卓越人才全力准备的，不仅是良好的科研条件、完备的基础设施和优厚的生活保障，更在于自由活跃的学术气息、轻松愉悦的人文氛围和广阔持续的发展空间。我们深信，对浩瀚无际的未知世界的痴迷、执着和探求，是每个北大物理学人真正的生命意义与价值所在。

格物致知，薪火相传；百年物理，继往开来。今日的北京大学物理学院，将继续秉承近百年来积淀的优良传统，发扬“勤奋、严谨、求实、创新”的卓越精神，脚踏实地、同心同德、积极进取；努力向“将学院建设成为在国内物理学界起到骨干引领和带头示范作用，在国际物理学界具有重要影响的教学科研中心”的目标不断坚实迈进！

**谢心澄**
**北京大学物理学院院长**

Peking University is the first institute of higher learning in modern China to conduct physical education and research. It has been nearly a hundred years since Peking University established its physics division in 1913. One hundred years on, we have experienced the hardships of pioneering, the prime time of the National Southwest Associated University period, the vigorous development at the foundation of the new country, and the huge progress brought by the execution of the Reform and the Opening Up policy. Generations of scholars here have consolidated the foundation for the education and research of physical science and modern science in general in China with their combined vision, perseverance and innovation. Today, the School of Physics, Peking University has become a highly renowned research and talent cultivation center for physics.

As it embarks on its second century, the Peking University School of Physics establishes its new goal of developing into the world' s first-class institution of physical education and academia. In order to achieve this goal, we will carry out our distinguished traditions, identify the specific target purpose, construct a scientific and sustainable mechanism, attract and train the outstanding talent groups, create a free and corporative environment, develop a rigorous and truth-seeking academic attitude, and cultivate an exceeding and innovative scholarly spirit.

The root of our work lies in promoting physical research. Based on my understanding of many colleges and universities at home and abroad, there are quite few whose fields of study can be as broad as ours—both spatially and temporally—as big as universes and galaxies, small as atoms and quarks, and as fast as attoseconds, slow as billion years. Research in the School of Physics is not only devoted to the frontiers of fundamental physics but also to the innovation of advanced technology as well as to the exploration of interdisciplinary collaborations. We strive to follow the development trend of physical research and expect to make continuous breakthroughs in the future.

The center of our work is attracting and cultivating talents. We have been engaging ourselves in discovering, attracting and training leading innovative talents, including distinguished scholars and outstanding young men and students. We seek to provide for them favorable research and living conditions, a free and friendly working environment and a sustainable room to develop. It is our belief that the true meaning of our lives here at Peking University the School of Physics lies in the infatuated and persistent exploration into the infinite world of the unknown.

To study the nature of things in order to acquire knowledge is a mission that the School of Physics, Peking University has undertaken for nearly a hundred years. Today, our school will continue to extend our great scholarly tradition of “Diligence, Rigorousness, Truth, and Innovation”, make down-to-earth, united and active efforts in order to build our school into a leading institute of physical education and research that not only plays a leading role in China but also exerts an important impact on all over the world.

Xincheng Xie
Dean of School of Physics, Peking University





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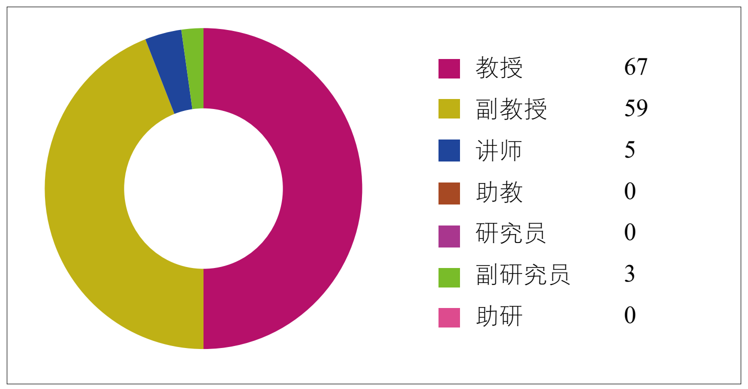


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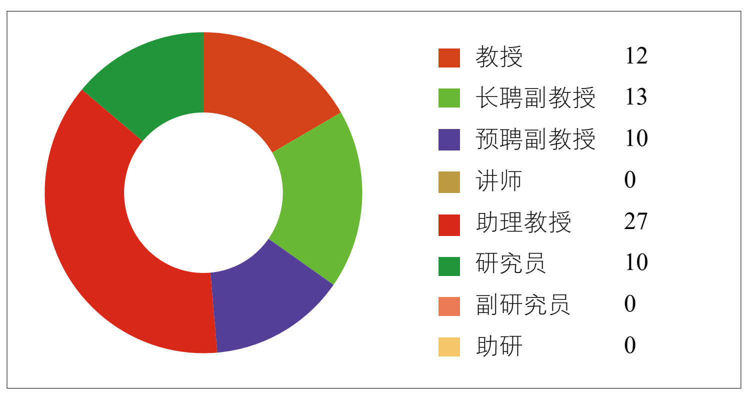


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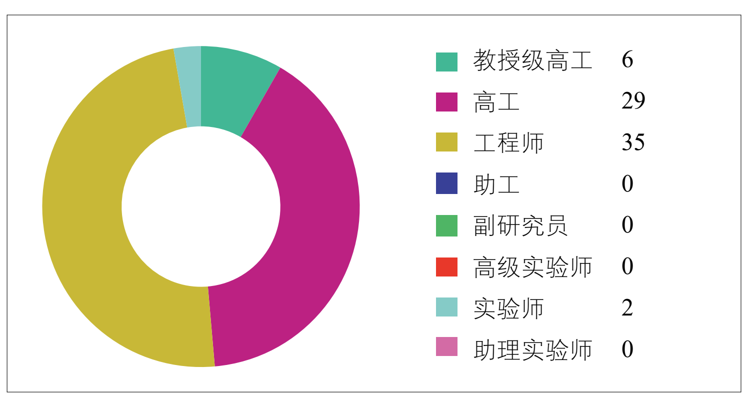


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# 下属机构
# *Divisions*

- 理论物理研究所 Institute of Theoretical Physics
- 凝聚态物理与材料物理研究所 Institute of Condensed Matter and Material Physics
- 现代光学研究所 Institute of Modern Optics
- 重离子物理研究所 Institute of Heavy Ion Physics
- 等离子体物理与聚变研究所 Institute of Plasma Physics and Fusion Studies
- 技术物理系 Department of Technical Physics
- 天文学系 Department of Astronomy
- 大气与海洋科学系 Department of Atmospheric and Oceanic Sciences
- 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
- 电子显微镜专业实验室 Peking University Electron Microscopy Laboratory
- 量子材料科学中心 International Center for Quantum Materials
- 北京大学科维理天文与天体物理研究所 Kavli Institute for Astronomy and Astrophysics
- 人工微结构和介观物理国家重点实验室 State Key Laboratory for 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
- 高能物理研究中心 Center of High Energy Physics

# 系所中心研究亮点
# *Highlights*

## 01 理论物理所 Institute of Theoretical Physics

理论物理研究所现有教职工 19 人，其中教员（含教授、副教授、研究员等）18 人，办公行政 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，涉及了自然界从宇观到介观直至微观基本粒子的各个尺度。

There are 19 members in the institute with 18 faculty members and one administrative staff. The research fields include string and cosmology, particle physics theory, hadronic physics, nuclear physics, condensed matter and statistical physics that cover from the scale of the universe down to microscopic scales of elementary particles.

### 一、自旋单态粲偶素 ηc 产生的研究

2014 年， LHCb 实验组在大型强子对撞机 LHC 上测量了 ηc 的产生，这是对自旋单态粲偶素产生的首次测量，对于揭示重夸克偶素的产生机制具有重要意义。我们利用重夸克极限下的自旋对称性，建立自旋单态 ηc 和自旋三重态 J/ψ 产生过程之间的关系，在非相对论量子色动力学（NRQCD）框架下进行了次领头阶（NLO）计算，发现可以很好地解释实验测量的 ηc 产生截面。此前，我们对 J/ψ 产生过程系统的 NLO 研究发现， 通过确定包括 S 波自旋单态、S 波自旋三重态和 P 波自旋三重态在内的 3 个色八重态长程矩阵元的 2 个独立线性组合，可以解释强子对撞机 Tevatron 和 LHC 上测量的 J/ψ 产生截面， 同时可以解释 J/ψ 产生的极化现象，从而为强子对撞机上粲偶素产生机制研究中长期存在的极化疑难问题提供了解决的途径。在自旋对称性的假定下，ηc 的产生实验对 J/ψ 的长程矩阵元的取值提出了新的限制条件，有可能把 J/ψ 的 3 个矩阵元完全确定下来。 未来需要更多的实验进一步缩小这些矩阵元的取值范围，检验重夸克自旋对称性的成立条件，这对理解重夸克偶素的产生机制是十分重要的。该结果发表在物理评论快报上：Hao Han（韩浩）, Yan-Qing Ma（马滟青）, Ce Meng （孟策）, Hua-Sheng Shao（邵华圣）， Kuang-Ta Chao （赵光达）， ηc production at LHC and implications for the understanding of J/ψ production, Phys. Rev. Lett.114, 092005 (2015)

### I. The study of spin-singlet charmonium ηc production

The LHCb collaboration measured the ηc production at the Large Hadron Collider in 2014. As the first measurement of spin-singlet charmonium production, it is very important for revealing the mechanism of heavy quarkonium production. Based on spin symmetry in the heavy quark limit, we established a relation between the production of spin-singlet state ηc and spin-triplet state . Then in the framework of nonrelativistic quantum chromodynamics (NRQCD), we performed the next-to-leading order calculation of ηc production and found that the measured cross section can be well described. In our previous study, by including the next-to-leading order effect, we found that both cross section and polarization of the  measured at hadron colliders Tevatron and LHC can be explained by two linear combination of three color-octet long-distance matrix elements, including spin-singlet S-wave, spin-triplet S-wave and spin-triplet P-wave states, which provides a solution for the long-standing polarization puzzle of charmonium production at hadron colliders. Under the assumption of spin symmetry, the measurement of ηc production provides a new constraint for long-distance matrix elements of , which may fully determine all three of them. It will be important for future experiments to further constrain these long-distance matrix elements, to test the heavy quark spin symmetry, and to fully understand the production mechanism of heavy quarkonium. This result is published in Physical Review Letters 114, 092005 (2015).

### 二、在强子对撞机上量子色动力学次次领头阶和重求和效应

通常，在深度非弹散射实验和在欧洲核子中心的大型强子对撞机的实验上，量子色动力学（QCD）对于精确理论预言至关重要。 由于目前实验测量精度不断提高，为了使得理论预言和实验测量精度相匹配，现在迫切需要计算对撞机过程的高阶量子色动力学修正。高阶的量子色动力学修正可通过计算耦合常数固定阶展开和对于红外敏感区域的大对数项的重求和。 长期以来，国际上已有大量的研究致力于该领域的研究。在 2015-2016 年，李重生教授课题组在该研究领域研究中取得重要进展，有关工作分别发表于美国《物理评论快报》和欧洲《高能物理学报》以及美国《物理评论 D》 上，其代表性的工作结果归纳如下。

对于固定阶的量子色动力学修正，李重生课题组首次计算了在深度非弹实验中带电流诱导粲夸克产生的 QCD 次次领头阶微分散射截面，并在计算中包含了完整的粲夸克质量依赖。他们的结果表明，量子色动力学次次领头阶修正在某些相空间区域较次领头阶结果可降低截面约 10%。该结果可用于改进核子中奇异夸克的部分子分布函数的抽取，并可部分解释 ATLAS 实验和深度非弹散射实验所测得奇异夸克分布的差异。此项工作已发表于 Phys. Rev.Lett.116,212002 (2016) 。

对于量子色动力学的重求和效应，李重生课题组研究了在大型强子对撞机上矢量玻色子对 + 零喷注产生过程的重求和效应。该研究结果与 CMS 对 Z 的测量数据符合非常好，相差在 2σ 置信范围以内，这很好地解释了实验精确测量结果与 QCD 次领头阶理论预言之间的偏离。该工作发表于 Phys.Rev.D 93,094020 (2016) 。李重生课题组还研究了在大型强子对撞机上离壳希格斯粒子产生并衰变 () 的背景和信号的干涉结果的重求和效应。该工作可用于改进实验测量希格斯粒子的衰变宽度以及希格斯粒子与其它粒子之间的耦合常数。在 8 TeV 和 13 TeV 强子对撞机上，软胶子重求和将 QCD 近似次次领头阶预言提高了 10% 左右。在该工作发表于 JHEP 1508, 065 (2015)， 已被国际理论与实验同行引用 40 余次。

## II. QCD NNLO and resummation effects on the observables at hadron colliders

In general, quantum chromodynamic (QCD) controls the precision of the theoretical prediction in deep inelastic scattering and at the CERN large hadron collider (LHC). In order to compare with more precise experimental measurements, it is imperative to provide the predictions for the process with high order QCD corrections. The precision prediction can be achieved by obtaining the high fixed-order expansion of or the resummation of the logarithmic terms in the infrared sensitive phase space region to all order in . A tremendous effort has been devoted to the studies of perturbative QCD calculations. In 2015-2016, Prof Chong Sheng Li' s group has made significant progress on this research region and have published one paper in Physical Review Letters and several papers in Journal of High energy Physics and Physical Review D, respectively. The selective achievements are introduced as following.

For the fixed order calculations, Prof. Chong Sheng Li' s group present a fully differential next-to-next-to-leading order calculation of charm quark production in charged-current deep-inelastic scattering, with full charm-quark mass dependence. The next-to-next-to-leading order corrections in perturbative QCD can reduce the next-to-leading order cross sections by 10% in certain kinematic regions. The results can be used to improve the extraction of the parton distribution function of a strange quark in the nucleon in the intermediate-x region, and relieve the tention of strange-quark distributions extracted from ATLAS and DIS experiments .The work was published in Phys. Rev.Lett. 116, 212002 (2016).

The resummation effects for vector boson pair production with a jet veto at the LHC was investigated by Prof. Chong Sheng Li' s group. Their results agree very well with the CMS data for Z productions within 2 σ C.L. at √ S = 8 TeV, which can explain the 2 σ discrepancy between the CMS experimental results and theoretical predictions based on NLO calculation with parton showers. The work was published in Phys. Rev. D 93, 094020 (2016). The threshold resummation effects for the signal-background interference process of , which can be used to constrain the Higgs boson decay width and to measure Higgs couplings to the SM particles. The soft gluon resummation can increase the approximate NNLO result by about 10% at both the 8 TeV and 13 TeV LHC. After published in JHEP 1508, 065 (2015), this work has been cited about 40 times.

## 三、顶夸克对产生过程微分截面的精确预言

顶夸克事例正被位于欧洲的大型强子对撞机（LHC）上的实验家们大量观测到。目前，顶夸克的很多性质已经被实验家们测量得非常精确了，这对于检验标准模型和探索超出标准模型以外的新物理非常重要。实验方面的进展也同时对理论计算的精度提出了更高的要求。特别是人们发现，即使在计算到微扰量子色动力学的次次领头阶之后，对顶夸克对产生微分截面的理论预言仍然对于重整化标度和因子化标度的选取方案有很大的依赖性。而原则上一个物理可观测量不应该依赖于这些标度的选取。此外，微分截面的实验结果和次次领头阶的理论结果无法在所有运动学区域达成一致。这些问题促使人们开始考虑更高阶的量子色动力学效应。最近，杨李林课题组在这一问题上取得重大突破。

为了计算更高阶的量子色动力学效应，杨李林课题组采用了他们针对高能顶夸克对产生过程发展的一套软胶子重求和框架。高能顶夸克对产生过程是一个非常特殊的过程，在微扰计算中会出现大的对数项，导致微扰展开的收敛性很差。杨李林课题组采用的重求和方法能够重新组织微扰级数的各项，从而可以把高阶的对数项考虑进来。计算结果表明，重求和效应极大地改善了理论预言对于标度选取方案的依赖性。另外，重求和的结果在整个相空间与实验结果符合得非常好，从而缓解了理论与实验之间的冲突。这些结果发表在物理评论快报（Physical Review Letters 116, 202001, 2016)上。此后，杨李林课题组与计算顶夸克对产生过程次次领头阶结果的课题组合作，给出结合两方面结果的理论预言，发表在高能物理杂志（Journal of High Energy Physics 1805, 149, 2018）上。这代表了当前国际上对这一过程微分截面最为精确的理论预言。

## III. Precision predictions for top quark pair production

The top quark is being copiously produced and observed at the CERN Large Hadron Collider (LHC). This allows precision measurements of many important properties of the top quark, which are crucial for testing the Standard Model of particle physics and searching for possible new physics at higher energy scales. The progress on the experimental side imposes high demands on the accuracies of theoretical calculations. Especially, one finds that even at the next-to-next-to-leading order (NNLO) in perturbative Quantum ChromoDynamics (QCD), the theoretical predictions for differential cross sections of top quark pair production still have large dependence on the choice of unphysical renormalization and factorization scales. In addition, the experimental results for the differential cross sections cannot agree with the NNLO theoretical predictions in all kinematic regions. These issues call for higher order QCD effects to be incorporated. Recently, the group of Li-Lin Yang made significant progress on this problem.

To calculate higher order QCD effects, the group of Li-Lin Yang employed a soft gluon resummation framework which they developed earlier. The high energy top quark pair production process is a very special one. Large logarithms appear in perturbative calculations, making the perturbative expansion badly convergent. The resummation method can reorganize the terms in the perturbative series such that higher order logarithmic terms can be incorporated. The result shows that the resummation effects significantly reduce the dependence of the theoretical prediction on the scale choices. Moreover, the results agree well with the experimental measurements in the whole phase space, and the conflict between theory and experiment is largely alleviated. These results were published in Physical Review Letters 116, 202001, 2016. Afterwards, the group of Li-Lin Yang collaborates with the NNLO group to give more complete theoretical predictions combining ingredients from both sides. These were published in Journal of High Energy Physics 1805, 149, 2018, which represents the state-of-the-art QCD predictions for the differential cross sections in top quark pair production.

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

凝聚态物理与材料物理研究所现有教职工 63 人，其中，长聘教授 5 人，长聘副教授 3 人，预聘制助理教授 7 人，老体制教授 17 人，副教授 16 人，工程技术人员 15 人。 研究队伍中包括，院士 5 人，长江特聘教授 4 人，国家杰出青年 5 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，表面物理与扫描探针显微学，高温超导体及其相关材料、物理与器件，纳米结构和低维物理，软凝聚态物理，以及磁性物理和新型磁性材料。

There are 63 faculty members in the institute, consisting of 5 tenured professors, 3 tenured associate professors, 7 tenure-track faculty members, 17 full professors, 16 associate professors, and 15 engineering technicians. Among the senior researchers are 5 academicians of the CAS, 4 Chang Jiang scholar professors, and 5 national distinguished young scholars. The research fields covering a wide range include Devices and Physics of Wide-gap semiconductors, Condensed Matter Physics, Nanosized Semiconductors and Optoelectronic Physics, Surface physics and Scanning Tunneling microscopy, Physics and Devices of High Temperature Superconductors, Low-dimension Nanostructure and Physics, Soft Condensed Matter Physics, and Physics of Magnetism and Advanced Magnetic Materials.

## 一、创造石墨烯单晶生长速度世界纪录

自石墨烯被发现以来，其优越的物理性能使其备受瞩目，科学家们一直在寻找合适的合成方法来实现石墨烯的工业化生产与应用，而大单晶石墨烯的生长是实现石墨烯高端应用的基础。利用化学气相沉积法在商用铜箔上生长石墨烯是获得大单晶石墨烯的突破口之一，现有实现大单晶生长的方法主要是通过复杂的表面处理及极低的碳源来降低形核密度，该方法的生长速率普遍低于 0.4 μm/s，生长时间长达几十小时。石墨烯成核是一个量子概率事件，在极长的生长过程中必然会有新核产成，因此极慢的生长速率无法实现超级大单晶的生长。如果能够实现石墨烯的超快生长，一旦形核，石墨烯就可以在极短的时间内迅速长大，从而实现石墨烯大单晶的可控制备。因此，提高石墨烯的生长速率，对获得石墨烯超级大单晶具有重要意义。

近日，北京大学物理学院王恩哥院士、俞大鹏院士、刘开辉研究员及其合作首次将大单晶石墨烯的生长速度提高了 2-3 个数量级，达到了 60 μm/s，并接近理论极限值。成果以“Ultrafast growth of single-crystal graphene assisted by a continuous oxygen supply”为标题发表在《自然 • 纳米技术》上 (Xiaozhi Xu et al. Nature Nanotechnology 11, 930–935 (2016))。研究人员从表面科学出发，利用氧化物表面存在的悬键在高温下会释放出氧这一特性，实现了在商业铜箔上高质量大单晶石墨烯的超快生长：合成 0.3 mm 大小的单晶石墨烯晶畴仅需要 5 s。该工作发现，高温下氧化物衬底所释放出的氧可以大大加快碳源的分解，保证有充足的碳源参与到石墨烯生长，从而实现了石墨烯的超快生长，速度达到了 60 μm/s, 相比之前的速度提高了 2-3 个数量级。该工作提出了一种简单有效地提升石墨烯生长速率的技术，利用该项技术可以在很短的时间内合成大面积高质量石墨烯薄膜，提高了生产效率，降低了生产成本，为石墨烯超级大单晶的工业化生产铺平了道路。





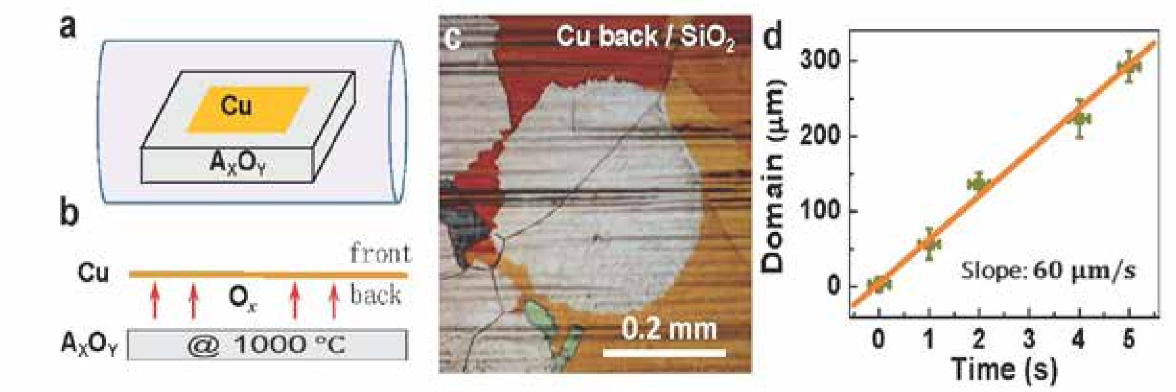



图 1. 大单晶石墨烯的超快生长设计示意图和生长速率曲线。

Figure 1. Schematic diagrams of the setup and the domain size evolution with growth time.

## I. New world record of graphene growth rate

Graphene has a range of unique physical properties and could be of use in the development of a variety of electronic, photonic and photovoltaic devices. For most applications, large-area high-quality graphene films are required and the chemical vapour deposition (CVD) synthesis of graphene on copper surfaces has been of particular interest due to its simplicity and cost efficiency. However, CVD graphene growth rates on copper are less than 0.4 μm/s, and therefore the synthesis of large, single-crystal graphene domains takes at least a few hours.

Recently, Prof. E. G. Wang, Prof. D. P. Yu and Prof. K. H. Liu from Peking University and other collaborators found a new way to realize the ultrafast growth of sub-millimeter-sized single-crystal graphene on copper foil with record growth rate of 60 μm/s, which is several orders of magnitude faster than previous record. This work has been published in Nature Nanotechnology by "Ultrafast growth of single-crystal graphene assisted by a continuous oxygen supply" (Xiaozhi Xu et al. Nature Nanotechnology 11, 930–935 (2016)).

The high growth rate is achieved by placing the copper foil on an oxide substrate with a gap of ~15 μm between them. The oxide substrate provides a continuous supply of oxygen to the copper catalyst surface during the CVD growth, which significantly lowers the energy barrier to carbon feedstock decomposition and increases the growth rate. With the approach, they are able to grow single-crystal graphene domains with a lateral size of 0.3 mm in just 5 seconds. The ultrafast growth enables a potential of growing inch-sized single-crystal graphene wafer in a few minutes for scalable high quality graphene applications.

## 二、高输出功率电子束泵浦深紫外光源的制备

AlGaN 基紫外光源是一种高效环保型光源，是目前替代汞灯的唯一固态光源解决方案，在消毒杀菌、空气 / 水净化、生化检测、紫外固化等领域有重要应用前景。但深紫外发光器件的光效随

发光波长变短而大幅度降低，其主要原因是深紫外发光器件对应高 Al 组分 AlGaN，由于其材料 p 型掺杂困难导致空穴注入效率较低，其发光模式趋于 TM 模式不利于沿 c 轴的光提取。宽禁带半导体中心王新强、沈波研究组在实验中采用电子束泵浦方法有效避免 p 型掺杂的难题，同时设计了新型有源区多量子阱结构，该结构中势垒为 $Al_{0.75}Ga_{0.25}N$ 材料，势阱为准二维（Quasi-2D）GaN 数字合金结构，该结构至少具有 3 个优点：增强载流子局域化有利于辐射复合发光、GaN 共格生长提高材料生长质量、量子阱压应变增强 TE 出光模式提高光提取。

实验中有源区准二维 GaN 结构通过分子束外延（MBE）方法精确控制生长，STEM 测试表明准二维 GaN 为共格生长。多量子阱结构生长于高质量 AlN/ 蓝宝石复合模板（位错密度 $4\times10^9$ $cm^{-2}$），变温 PL 测试其室温内量子效率为 34%。偏振 PL 测试其发光为 TE 模式占主导。实际设计的电子束泵浦紫外光源为倒装芯片模式（Flip chip），为了增加光提取效率，设计了周期性表面划痕和高反射 Al 膜结合的方法，一方面通过划痕抑制侧面出光，另一方面通过高反射 Al 膜抑制正面出光。电子束泵浦器件测试结果为：室温发光波长为 285 nm，最大脉冲（pulse）输出功率约为 160 mW（电子束能量 20 keV，聚焦），最大连续（CW）输出功率约为 39 mW（电子束能量 15 keV，非聚焦）。本工作展示了准二维 GaN 量子结构在实现高输出功率深紫外发光器件中的优异特性，在紫外杀菌和净化领域有广阔应用前景，相关结果发表在 Advanced Materials [2016, 28, 7978-7983]。相关研究工作得到了科技部战略性先进电子材料专项、自然科学基金和人工微结构和介观物理国家重点实验室的支持。

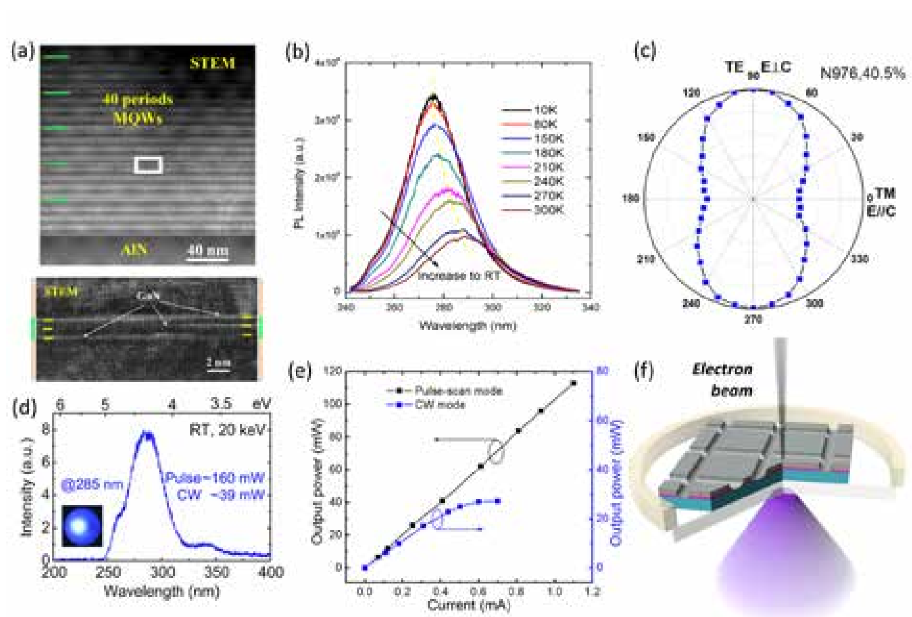



图 1.（a）有源区准二维 GaN 量子结构截面 STEM 图（b）变温 PL 测试（c）偏振 PL 测试（d）电子束泵浦紫外器件发光光谱（e）脉冲和连续激发下器件输出功率（f）电子束泵浦器件示意图。

Figure 1. (a) STEM images of the MQWs structure and the inserted quasi-2D GaN layers. (b) Temperature-dependent PL spectrum. (c) Radiation and polarization properties of the sample. (d) E-beam pumped emission spectrum in CW regime. (e) The dependence of output power on e-beam current in pulse-scan mode and CW mode. (f) The pumping scheme of the MQWs structure by an electron beam.





## II. High-output-power e-beam pumped ultraviolet light source

$Al_xGa1-_xN$-based UV light sources are currently considered as excellent candidates to replace excimer and mercury lamps, showing unique advantages of high-efficiency and environmentally friendly sources. UV light sources with high performance are of great importance because they are promising for a wide variety of applications such as water/air purification, biological/chemical analysis, surface modification and so on. However, the output power and emission efficiency of deep-UV light sources are still much poorer because they suffer from several inherent issues, in particular the difficulty in p-type doping for high-Al-content AlGaN layers, and the transverse magnetic (TM, E//c) polarized emission involvement. To avoid the difficulty in p-type doping, we adopt an electron-beam (e-beam) pumping method instead of conventional electrical injection. Also, we propose a novel active region, i.e. quasi-two-dimensional (quasi-2D) GaN layers inserted in $Al_{0.75}Ga_{0.25}N$ matrix. In comparison with conventional MQWs, such quasi-2D GaN layers show the following advantages: (1) The carrier localization is greatly promoted both in vertical and lateral directions; (2) The crystalline quality should be pretty good since the quasi-2D GaN layers are coherently grown on the AlGaN layers and hence free of misfit dislocations and (3) The UV light emission along c-axis (TE, E ⊥ c) is predicted to be dominant. The designed structure of quasi-2D GaN wells was grown by plasma-assisted MBE. The periodic ultrathin quasi-2D GaN layers are clearly recognized in the STEM image and the coherent growth of the GaN is confirmed. The quasi-2D GaN structure was deposited on a AlN/c-sapphire template. The TDD in the AlN template is estimated by XRD measurement to be around $4\times10^9$ $cm^{-2}$. The estimated IQE at RT is about 34% from the temperature-dependent PL measurements. The TE polarized light emission is dominate with a measured polarization degree of 40.5%. A flip chip e-beam pumped UV light source was fabricated. To increase the UV light extraction efficiency through the sapphire/AlN interface we made a network of grooves on the wafer surface in two orthogonal directions before coating the Al mirror. The e-beam pumped emission spectrum in the CW pumping mode at room temperature was measured with the emission centered at 285 nm. The maximum output power is ~160 mW (~39 mW) in the pulse-scan (CW) regime pumped at the electron energy of 20 keV (15 keV). Our work demonstrates that the quasi-2D GaN layers are promising for fabrication of high-output-power deep UV light sources. This research work is partially supported by the MOST of China, the NSFC and the State Key Laboratory of Artificial Microstructure and Mesoscopic Physics.

## 三、光控低维纳米材料激子等离激元耦合过程研究

二维材料是一类具有原子级别尺寸厚度的超薄材料，自石墨烯被发现以来，大量的二维材料被生长和制备，其中过渡金属硫族化合物（TMDs）受到了科学家们广泛的关注。单层二硫化钼（$MoS_2$）就是 TMDs 家族的典型代表，它与体材料 $MoS_2$ 相比，在光学性质上展现出许多独特的性质，如直接带隙光吸收、多激子发光、谷偏振荧光现象等。然而，超薄的尺寸又影响了材料光与物质的相互作用

过程，单层 $MoS_2$ 在可见光波段仅有 8% 左右的吸收效率，限制了它在光电子器件方面的应用和发展。因此，探究单层 $MoS_2$ 光与物质的相互作用过程的研究具有重要意义。表面等离激元纳米结构可以诱导金属纳米结构中电子的集体震荡，并在近场实现局域电磁模式，产生等离激元与激子的耦合模式。又由于其丰富的结构和动态调控的光学性质，是一种实现低维纳米材料光学性质调控的重要手段。

近日，北京大学物理学院方哲宇课题组，探究了光控低维纳米材料等离激元激子耦合过程，解释了低维材料界面处的电子转移过程机理。研究人员利用金属纳米颗粒的局域表面等离激元作用，激发热电子对单层 $MoS_2$ 的掺杂，并通过吸收光谱和荧光光谱对其进行了表征和分析。发现改变金属颗粒的浓度、激发波长和激光强度可实现灵活的光谱调控。相关成果以“Active Light Control of the $MoS_2$ Monolayer Exciton Binding Energy”为标题发表《美国化学学会 • 纳米》上 (ACS Nano, 9, 10158-10164 (2015) )。为了实现大面积均匀的电子掺杂效果，并权衡材料成本问题，研究人员创新性地制备 GQD/$MoS_2$ 异质结构，利用石墨烯量子点的等离激元隧穿效应，实现了一种新的高效光控界面掺杂，并进一步发现掺杂效应可以对单层 $MoS_2$ 的谷偏振度进行有效调控。相关成果分别以“Graphene Quantum Dots Doping of $MoS_2$ Monolayers”为标题发表《先进材料》上 (Advanced Materials, 27, 5235-5240 (2015))。该工作阐述了表面等离激元对材料物性的调控机理，探究了等离激元纳米结构和低维材料的界面电荷转移过程，为新型低维异质结材料在生物医学传感、光电探测器件和光控发光器件等方面提供了新的思路。

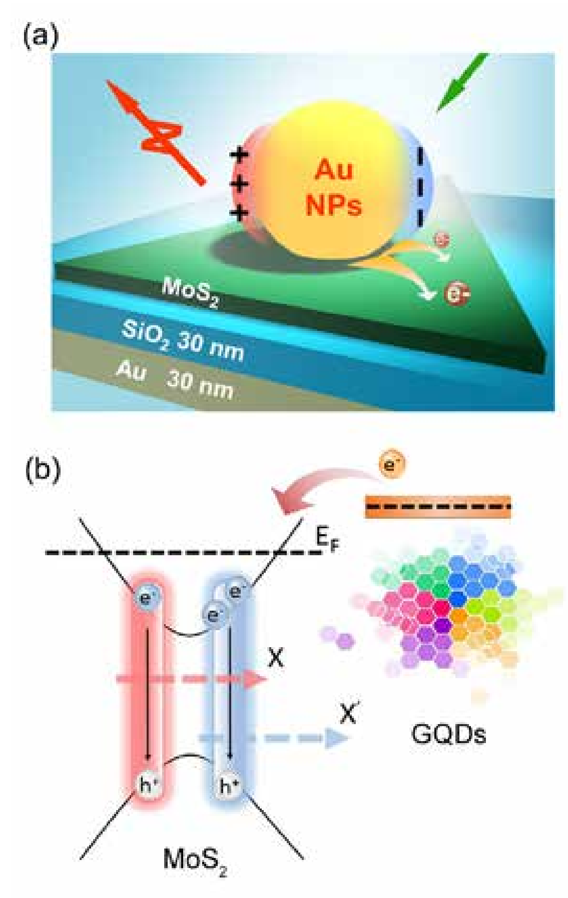



图 1. (a) 低维纳米材料等离激元激子耦合过程。(b) 低维材料的界面电荷转移过程

Figure 1. (a) Exciton-plasmon interaction of low-dimensional materials. (b) Charge transfer at the interface of low-dimensional materials.

## III. Light control of exciton-plasmon interaction in low-dimensional materials

Two-dimensional materials (2D) is a family of atomically thin low-dimsional materials. Since graphene was prepared, more and more 2D materials are synthesized. The family of transition-metal-dichalcogenides (TMDs) attract great attention among the group of materials scientists. Monolayer $MoS_2$ is a member of this family, it shows unique optical properties compared with bulk materials, such as direct band-gap, multi-exciton photoluminescence (PL) and valley-polarized PL. However, the ultra-thin thickness limits the light-matter interaction of materials, which only absorbs less than 8% light in the visible range. Plasmonic nanostructure induced near-field modes can couple with exciton forming exciton-plasmon modes, which helps to realize the light control of exciton-plasmon interaction in low-dimensional materials.

Recently, the group of Prof. Z. Y. Fang from Peking University explored the process of exciton-plasmon interaction by fabricating plasmonic nanostructures on monolayer $MoS_2$. They ultilized plasmonic hot electrons doping $MoS_2$ monolayers, and the doping effect changes the dielectric constant of $MoS_2$ resulting in spectral change. This spectroscopic tuning was further investigated by using different Au nanoparticle concentrations, excitation laser wavelengths and intensities. This work has been published in ACS Nano by “Active Light Control of the $MoS_2$ Monolayer Exciton Binding Energy” (ACS Nano, 9, 10158-10164 (2015) ). To realize homogeneous doping in a large area, they fabricated GQD/$MoS_2$ heterostructures, and realized an active controlled optical doping process. The doping effect is arising from the charge tunneling of localized surface plasmon of GQDs. GQDs doping effect was further used to modulate the degree of circular polarization of $MoS_2$ monolayers. The work has been published in Advanced Materials by “Graphene Quantum Dots Doping of $MoS_2$ Monolayers” (Advanced Materials, 27, 5235-5240 (2015)). This work has demonstrated the charge transfer process at the interface of low-dimensional materials, which paves the way for applications in biological sensing, photodetectors and light-emitting devices.

## 四、生物振荡精确性与自由能耗散的关系

生命系统为物理学家提供了许多在非平衡态系统中进行信息处理的范例。生物振荡网络是生命体的计时器，调节如细胞周期、心脏律动、昼夜节律等各种与时间信息相关的重要生命过程。但是在微米尺度的细胞环境中，分子噪声和环境噪声会使得振荡的相位发生涨落，从而使振荡过程变得非常不精确。虽然各种生物振荡网络的分子机制已大致明确，但人们对于生物振荡网络如何控制噪声，以及控制噪声的热力学代价等问题知之甚少。

为了研究生物振荡网络的热力学原理，欧阳颀教授研究组与美国 IBM 沃森研究中心的涂豫海教授展开合作，首次从理论上系统阐述了生物振荡网络中相位扩散与自由能耗散的关系。

已知的分子生物振荡网络一般都以三种基元网络结构之一为核心结构。研究发现，在这三种基元网络结构中，振荡相位的扩散系数与自由能耗散之间都呈相同的反比关系。该研究进一步从一个简单模型中解析的得到了相位扩散系数与自由能耗散的反比关系。从微观上看，振荡过程实际由多个自由能驱动（例如 ATP 水解）的反应环路构成。消耗的自由能越多，振荡的相位精确性也就越高。相关实验数据分析也进一步验证了这个反比关系的普适性。

该工作从理论上证明了生命系统以耗散自由能的方式来保证调控功能和有序度的维持。工作以“The free energy cost of accurate biochemical oscillations”为题发表在 Nature Physics 杂志（Nature Physics 2015,11,772–778）。

### IV. The free energy dissipation in biological oscillations

Biological systems provide excellent examples for physicists studying information processing in non-equilibrium systems. The relationship between biological regulatory functions and non-equilibrium thermodynamics has been an active research area in biophysics. In particular, biological oscillation serves as a clock for living systems by regulating time-related processes such as the cell cycle, the cardiac rhythm, and the circadian clock. However, in the micron-scale cellular environment, phase fluctuations in biological oscillations can be overwhelming due to molecular noise and environmental stochasticity. Although the molecular mechanisms underlying many biological oscillations have been elucidated over the past years, how noise is controlled and the thermodynamic cost of noise reduction have remained elusive.

To understand the thermodynamic principles of biological oscillations, Professor Qi Ouyang' s research group and Professor Yuhai Tu from IBM Watson Research Center (a joint Changjiang Professor in the School of Physics and the Center for Quantitative Biology at Peking University) collaborated on a work to lay the first theoretical grounds for the relationship between phase diffusion in biological oscillations and the free energy dissipation.

All known oscillatory systems share three basic oscillation motifs as their core molecular network structure. The work found that across the three oscillation motifs, the diffusion constant of the phase of oscillation maintains an inverse relationship with the free energy dissipated per period. This relationship and its range of validity were further shown analytically in a simple model of noisy oscillation. Microscopically, oscillations are driven by multiple irreversible cycles that hydrolyze fuel molecules such as ATP. The more free energy consumed per period, the more periods the phase of oscillation remains coherent. Experimental evidence in support of this general relationship and testable predictions were also presented in the work.

The work provided theoretical evidence that life, as an open system, invests free energy to maintain its regulatory functions and remain highly ordered. It was published in Nature Physics with the title "The free energy cost of accurate biochemical oscillations" (Nature Physics 2015, 11, 722–778)

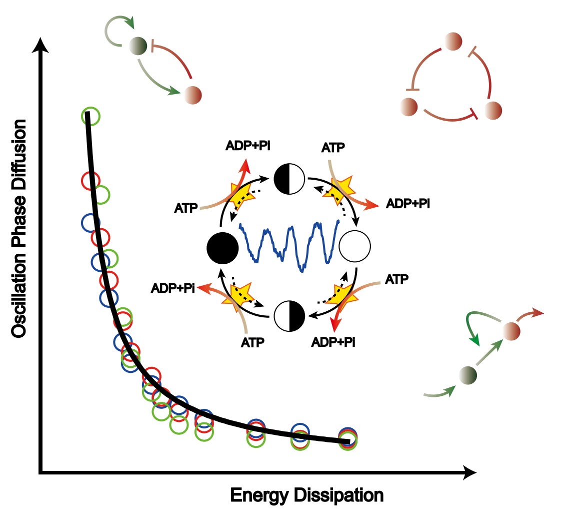



图 1：在三种产生振荡的生物网络中，振荡相位扩散系数与能量耗散呈反比关系。从微观上看，振荡由多个自由能驱动的反应环路构成。自由能消耗越高，振荡相位的精确性也越高。

Fig. 1: In three biological networks that drives oscillations, the phase diffusion constant is inversely proportional to the free energy dissipation. Microscopically, oscillations are driven by multiple irreversible cycles that consume energy. The more free energy consumed per period, the more accurate the phase of oscillation remains.



系所中心研究亮点 | *Highlights*

## 03 现代光学研究所 Institute of Modern Optics

北京大学现代光学研究所是在北京大学原物理系光学专业的基础上于 2000 年 5 月成立的，现任所长由中科院院士、长江特聘教授 龚旗煌 教授担任。北大现代光学研究于 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。目前北京大学光学学科是“211 工程”和“985 工程”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”的主要支撑学科之一。以现代光学所为基地，北京大学还与中科院联合成立了“中科院—北京大学超快光科学和激光物理联合中心”。

现代光学所以队伍建设为核心，通过培养和引进一批优秀青年学者，十多年来发展迅速。现代光学研究所现有固定人员 24 人，其中教研人员 20 人，实验技术人员 4 人。教研人员中正教授 9 人，副教授 5 人，Tenure 正教授和副教授各 1 人，Tenure-track 助理教授 4 人。实验技术人员中包括高级工程师 1 人，工程师 3 人。现代光学研究所拥有国家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，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 2 人，杰出青年基金获得者 5 人，优秀青年基金获得者 5 人，教育部新世纪优秀人才 7 人，北京市科技新星 1 人。经过近十年的发展，光学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，学科成员当选美国光学学会（OSA）和英国物理学会（IoP） Fellow, 部分光学所成员担任 Optics Letters、Chemical Physics Letters 等国内外重要杂志编委、副主编和 Nonlinear Optical Phenomena and Applications （SPIE）， Asian Conference on Ultrafast Phenomena 等学术会议主席等职。

龚旗煌教授获得 2016 年度 “何梁何利基金科学与技术进步奖”电子信息技术奖，刘运全教授入选第二批国家“万人计划”科技创新领军人才，2016 年龚旗煌教授主持的国家重大科研仪器研制项目“飞秒 - 纳米时空分辨光学实验系统”正式启动，肖立新教授、陈志坚教授、王树峰副教授、曲波副教授、龚旗煌院士的研究成果“高效有机蓝光材料及其介观结构发光器件研究”获得 2015 年度高等学校科学研究优秀成果奖自然科学一等奖。

现代光学研究所站在国际科学研究前沿，开拓新的光学研究领域，已形成飞秒科学与强场光物理、介观光学与纳微光子学、光电功能器件与量子信息等主要研究方向，在国内外的影响力日益增加，已经逐步成为具有国际竞争力的光学科研和教学的重要基地。

The Institute of Modern Optics (IMO) was established in May 2000 based on the previous Optics discipline of Department of Physics in Peking University (PKU). The present director is professor Qihuang Gong, who is an academician of the Chinese Academy of Science and distinguished professor fellowship of Changjiang Scholar Program. Historically, professor Yutai Rao and professor Ta-You Wu initiated research of modern optics at Peking university in the 1930s and developed it into a comprehensive optics discipline. At present, the optics discipline at IMO is a National Key Discipline, and also one of Key Construction Contents of "211 Project" and "985 Project". IMO constitutes one of the two research branches in the State Key Laboratory for Artificial Microstructure and Mesoscopic Physics. IMO has also established several joint research initiatives such as the

CAS-PKU Ultrafast Optics & Laser Physics Center and PKU Opto-Electronics Center.

IMO acted the team building as the core and has developed rapidly in the past ten years through training and introducing a lot of outstanding young scholars. Currently, IMO has 24 faculty members (including 20 academic faculty members and 4 engineers). There are 9 professors, 5 associate professors, 1 tenure professor, 1 tenure associate professors, 4 tenure-tracking assistant professor, 1 senior engineer and 3 engineers. IMO possesses one Innovation Group of Optics Discipline of Mathematical and Physics Department in the National Natural Science Foundation of China, and one Innovation Team in Key Areas of Ministry of Science and Technology. There are 1 academician of the Chinese Academy of Science, 3 distinguished professor fellowship of Changjiang Scholar Program, 2 chief scientists of 973 projects, 2 leading talents in scientific and technological innovation of Ten thousand people project. 5 faculties won the National Science Foundation of China (NSFC) support for Distinguished Young Scholars and 5 others won the Excellent Young Scholars from NSFC. There are totally 7 faculties elected into the Program for New Century Excellent Talents in University from the Ministry of Education of China. One faculty won Beijing Science and Technology New Star. Many faculties have received great achievements and obtained great recognitions in their research fields. One faculty was elected to the American Optical Society (OSA) and the British Physical Society (IoP) Fellow. Many faculty members were elected as editorial committee or vice editor-in-chief of the journals including Optics Letters, Advanced Optical Materials, Chemical Physics Letters, and China Series G. Many faculty members were elected as president of the international academic conferences including Nonlinear Optical Phenomena and Applications （SPIE）， Asian Conference on Ultrafast Phenomena.

In 2016, professor Qihuang Gong won Electronic Information Technology Award of "He Liang He Li Foundation Science and Technology Progress Award". Yunquan Liu won the second batch Leading Talents in Science and Technology Innovation under the National "Ten Thousands Project". Professor Gong Qihuang presided over the national major scientific research instrument development project "femtosecond-nanometer space-time resolution optical experimental system", which officially launched in 2016. Research achievements in the project of “Study on High Efficiency Organic Blue Light-emitting Materials and Mesoscopic Structural Light-emitting Devices” carried by Professor Qihuang Gong and Lixin Xiao’ s groups won the first prize of High Education Natural Science Award of China.

Since inception, IMO has committed itself to explore new frontiers in optics and tackle global challenges in optical science. The institute has established well recognized research directions including femto-science and intense optical physics, mesoscopic optics and nano-photonics, functional opto-electronic devices and quantum information. With its increasing impact in global optical society, IMO has become globally competitive institute for research and education in optical science.



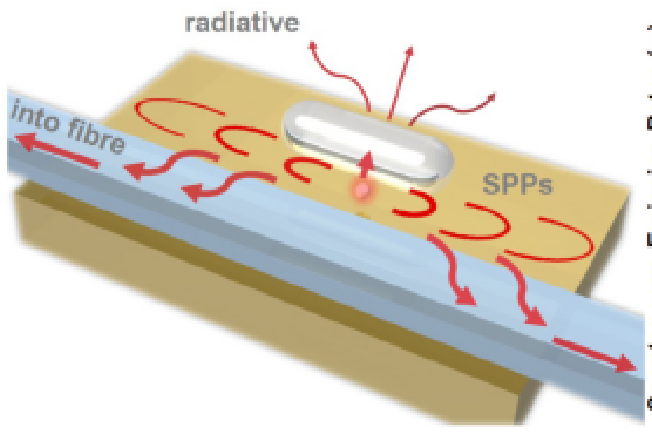


## 一、微纳尺度上的高效方向性单光子发射

北京大学现代光学所龚旗煌院士团队的古英教授研究组，通过将量子体系放入纳米金属棒与纳米金属膜之间的纳米量级的间隙中，理论实现了有效的单光子发射和纳米尺度一维低损传导，朝着实现芯片单光子源迈出了重要的一步。该研究结果题为《基于间隙表面等离激元的有效单光子发射与收集》，刊登在2015年5月15号的《物理评论快报》上。详细信息请参考：Efficient Single Photon Emission and Collection Based on Excitation of Gap Surface Plasmons,PRL 114, 193002 (2015),DOI:10.1103/PhysRevLett.114.193002，http://dx.doi.org/10.1103/PhysRevLett.114.193002。

单光子发射是腔量子电动力学、单光子源和基于腔的激光等领域的重要问题。基于“珀塞尔效应”的原理，通过改变电磁场的局域态密度可以增强自发辐射速率。为了实现光学器件芯片化，多种微纳光子学结构被提出来调控光的自发辐射和收集。克服了介质纳米结构光子自发辐射速率低的弱点，表面等离激元结构极大地提高光子发射速率。本工作通过结合间隙表面等离激元结构中超高的光子发射率与低损耗光纤有效的提取，从理论上在金属纳米棒 - 纳米膜结构中提出了有效的单光子发射与一维纳米尺度的传导（图 1）。他们发现总的光子发射加快和表面等离激元通道的光子衰减速率变快可以达到只有金属纳米膜时的几十倍。特别的，他们利用波矢匹配光纤将表面等离激元通道的单光子导出，在波导中光的衰减速率可以达到真空中的290~770 倍。这种新的机制将会对基于金属的光学腔、芯片上的超亮单光子源、和芯片上的基于表面等离激元的纳米激光器等研究领域有重要影响。

上述研究得到国家自然科学基金重大研究计划“培育项目”、“创新群体项目”和“面上项目”，以及科技部“973 项目”、北京大学人工微结构和介观物理国家重点实验室支持。



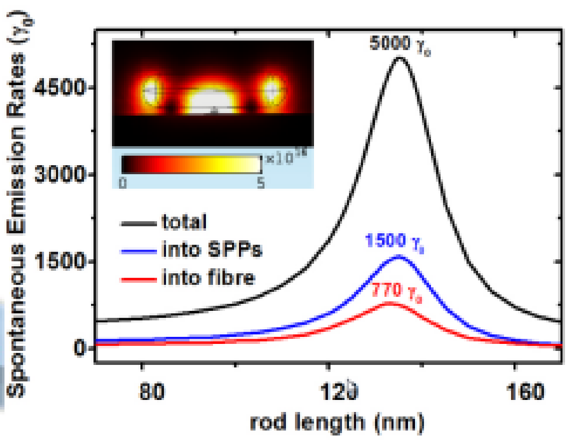




图 1：量子发射体与纳米棒 - 纳米金膜间隙表面等离激元体系耦合，并与波矢匹配光纤结合。

图 2：自发辐射速率加快随着纳米棒尺寸变化。

Fig. 1: The schematic diagram of the emitter-plasmon coupling system.

Fig. 2: Spontaneous emission rates with varying the size of metallic nanorod.

## I. High-efficiency emission and collection of single photons at micro/nano scale

By putting the quantum emitter into the nanoscale gap formed by metallic nanorod and nanofilm, Prof. Ying Gu' s group in the team of Academician Qihuang Gong theoretically demonstrated the high-efficiency emission and collection of single photons at micro/nano scale, which makes a substantial step to the on-chip single photons sources. The work was published in Phys. Rev. Lett. 114, 193002 (2015) entitled "Efficient Single Photon Emission and Collection Based on Excitation of Gap Surface Plasmons". The detailed information can refer to the website: http://dx.doi.org/10.1103/PhysRevLett.114.193002.

The study of single photon emission is of fundamental interest for research in cavity quantum electrodynamics, single photon sources, and cavity-based lasing processes. For the requirement of on-chip devices,based on the principle of the Purcell effect, various nanophotonic structures have been proposed to tailor the emission rates and the collection efficiency of radiated light. Overcoming the limit of weak spontaneous emission of quantum emitter in dielectric structures, plasmon nanostructures were proposed to greatly enhance the emission of single photons. Here, through combining the advantages of gap surface plasmon polaritons with the low-loss nanofibers, they demonstrated theoretically the efficient photon emission of a single dipole emitter and one-dimensional nanoscale guiding in metallic nanorod-coupled nanofilm structures coupled to dielectric nanofibers (Fig. 1). They found that total decay rates can be larger more than one order of that in metallic nanofilms. For the requirement of practical applications, propagating single photons with decay rates of 290 $\gamma$ 0–770 $\gamma$ 0 are guided into the phase-matched low-loss nanofibers. The proposed mechanism promises to have an important impact on metal-based optical cavities, on-chip bright single photon sources and plasmon-based nanolasers.

The work was supported by the Creative Research Group project of the National Science Foundation of China, and the National Basic Research Program of China.

## 二、强场原子分子超快动力学的理论研究

在 2015-2016 两个年度里，物理学院现代光学研究所在强场原子分子超快动力学的理论研究方面取得了多方面的进展。首先，彭良友副教授和龚旗煌院士领导的团队对隧穿电离的非绝热问题进行了系统研究。他们采用激光强度可比拟的正交双色光场实现了在二维方向上对电子波包干涉的相干操控；同时，通过对比绝热模型、非绝热模型与精确数值求解含时薛定谔方程等三种方法所得到的电子动量谱分布，他们发现在通常的很多实验条件下，电子隧穿的非绝热效应是不可忽略的，非绝热效应同时体现在隧穿电离率和隧穿电离初始条件的准确估计两方面。该研究结果对于强场物理实验上光强的标定以及研究电子隧穿的基本问题都具有很重要的意义。该研究成果发表于《物理评论快报》【Phys. Rev. Lett. 115, 193001 (2015) 】。

氦原子是一个典型的微观三体体系，其在远紫外光作用下发生双光子双电离的过程是当前理论和实验研究中的一个具有挑战性的问题。最近，研究团队在氦原子双光子双电离总截面的计算中取得重要进展。他们基于二阶含时微扰论、通过弱化电子关联作用来构建物理模型，给出了计算氦原子双光子双电离总截面的解析表达式，解析模型的预测与精确数值求解高维含时薛定谔方程的结果完美相符。他们的研究表明电子关联在氦原子双光子双电离总截面的计算中并不重要，解决了长久以来的争议。该研究成果发表在《物理评论快报》【Phys. Rev. Lett. 115, 153002 (2015)】。

强场物理的另外一个重要课题是强中红外激光作用下的电离动力学和谐波产生。其中，随着波长的增长时谐波产率随着波长的变化标度律是阿秒脉冲产生的重要问题之一。研究团队与俄罗斯及其它国家的科学家通力合作，对这个问题进行了系统的解析和数值研究，发现谐波产率随着波长具有一个普适的标度律，指出了前人所认为的在长波长下有一个更有利的标度律的错误。该研究工作发表于《物理评论快报》和《物理评论 A》【Phys. Rev. Lett. 114, 069301 (2015); Phys. Rev. A 92, 023409 (2015)】。

最后，因为近几年取得的一些重要进展，彭良友副教授和龚旗煌院士应著名物理综述期刊《Physics Reports》编辑的邀请，为该刊撰写了强场和阿秒物理方面的综述文章。在这个长篇综述里，他们系统总结了自阿秒激光在 2001 年诞生以来阿秒物理在各方面的研究进展，具体内容涉及理论和计算方法、阿秒光源、单电子运动的探测和控制、光电效应的时间延迟、双电子关联动力学的探测和控制以及未来展望等【Physics Reports 575, 1 (2015)】。

## II. Theoretical Studies on Ultrafast Dynamics of Atoms and Molecules in Laser fields

In the years of 2015-2016, important progress on several topics has been made in the ultrafast dynamics of atoms and molecules in laser fields by our faculties in the Institute of Modern Optics. First of all, the team led by Prof. Liang-You Peng and Prof. Qihuang Gong investigated the nonadiabaticity in the electron tunneling ionization of atoms. They carried out a systematic study on this issue by using orthogonally polarized two-color fields with comparable intensities and are able to steer the coherent interferences of different electronnic wavepackets ionized at different times. Through comparative studies by an adiabatic model, a nonadiabatic model, and the exact solution to the time-dependent Schrödinger equation, they found that nonadiabtic effects do exist in the differential momentum distributions of the ionized electrons. The work is published in Phys. Rev. Lett. 115, 193001 (2015)。

Helium is the simplest three-body system and its double ionization of He by xuv pulses is a challenging problem in both the theoretical and the experimental study. The same team made progress in evaluation of the total two-photon double ionization cross section by an analytical model based on the second-order time-dependent perturbation theory, neglecting the final-state electron correlation. In both the sequential and nonsequential regime, the results of the model agree with the ab initio simulation by the numerical solution to the two-electron time-dependent Schrödinger equation. Their studies show that, the final-state correlation is not important in the evaluation of the total double ionization cross section, but only in the differential ionization cross section. This work is published in Phys. Rev. Lett. 115, 153002 (2015).

Another interesting topics is the ionization and harmonic generation of atoms in strong mid-infrared laser fields. A key issue is the scaling law of the harmonic yield against the increase of the wavelength, which is crucial for the generation of the attosecond pulse. The team collaborated with international colleagues and found a universal scaling law in a wide range of the wavelength, clarifying the misled claim in some previous work. These important results were published in Phys. Rev. Lett. 114, 069301 (2015) and Phys. Rev. A 92, 023409 (2015).

Finally, because of important progress in recent years made by the team lead by Prof. Peng and Prof. Gong in strong field and attosecond physics, they were invited by the Editor of Physics Reports to contribute a review article. In the 71-page review, they summarized main results in different topics in this field, such as theoretical and computational methods, attosecond light sources, the probe and control of the electronic motion and the electron-electron correlation, photoionization time-delay, and perspectives of attosecond physics, etc. This review was published at Physics Reports 575, 1 (2015).

## 三、多路光子器件集成

微纳光子器件的芯片上集成是实现超宽带超高速信息处理芯片的基础，其基本要求是统一材料平台、超低能耗、超快响应、片上触发，这也是光子集成所面临的一个重大挑战。

北京大学人工微结构和介观物理国家重点实验室、物理系胡小永教授和龚旗煌院士等提出利用复合增强非线性实现近红外和光通讯波段超快大非线性纳米复合材料新方法，制备出多组分纳米复合材料 nano-Au:(IR140:PDTP-DFBT)，进一步提出将表面等离激元的场增强效应和介电光子学低损耗的优势相结合，以具有强光场局域和场增强效应的表面等离激元纳米复合腔作为开关单元，以超低损耗氮化硅狭缝光波导作为连接波导，制备出由氮化硅狭缝光波导连接 4 个表面等离激元纳米复合腔阵列所构成的片上 2×2 全光交换器件，利用上层控制波导的倏逝场触发开关单元来实现片上触发的全光交换的功能。将全光交换的控制光阈值光功率降低 4 个数量级，控制光强降低到 450 kW/cm$^2$，同时保持 63 ps 的超快时间响应。这样实现了超低能耗、超快响应、片上触发、多波长操作的全光交换器件。论文发表在重要期刊 Advanced Optical Materials 上（Advanced Optical Materials 4，1159（2016）），并被选为同期的封面文章。工作还被 WILEY 出版集团科技网站 Materials Views China 以“表面等离激元与光子学融合：芯片上超快全光交换新突破”为题进行专题评述“这项研究工作为克服集成光子器件研究所面临的材料瓶颈难题提供了一条新思路，有助于推动超大规模片上集成全光交换的实用化研究，而且为实现超高速三维集成光子逻辑处理功能芯片提供了一种途径”。还提出表面等离激元辐射模式到非辐射模式的单向耦合实现超材料巨大群速度减慢的新方法，利用金纳米棱镜对作为超材料分子，通过调控金纳米棱镜对中的两个金纳米棱镜间距，将群折射率提高到4000，提高了一个数量级，获得了光通讯波段巨大慢光效应。在此基础之上，利用复合增强非线性方法将透明窗口的全光调制的阈值泵浦光强降低到 1.5 kW/cm$^2$，将阈值泵浦光功率降低了 6 个数量级，同时保持 42.3 ps 的超快时间响应，实现超低能耗超快响应的全光可调超材料感应透明。相关工作发表在重要期刊 Light: Science & Applications 上（Light: Science & Applications 4，e302（2015））。相关工作还被 National Science Review 期刊以“New development in integrated photonic devices”为题专题评述“……为非线性光学和量子光学的研究提供了一个平台”。





a b c

图：a）片上触发全交换。b）Wiley 出版集团科技网站 Materials Views China 专题评述。c）National Science Review 期刊专题评述。

Figures: a) On-chip triggered all-optical switch. b) Thematic evaluation by the science and technology website ‘Materials Views China’ of Wiley Publishing Group. c) Thematic evaluation by the journal of National Science Review.

## III. Multi-channel photonic devices integration

The on-chip integration of micro-nano photonic devices is the basis for the realization of ultrawide-band and ultrahigh-speed information processing chips. Its basic requirements are unified material platform, ultralow energy consumption, ultrafast response, and on-chip trigger. This is also a major challenge for photon integration.

Xiaoyong Hu and Qihuang Gong proposed a new mechanism to realize ultrafast and large third-order nonlinear nanocomposite materials in the near-infrared and optical communication range by using compound enhancement of nonlinearity, and fabricated multi-component nanocomposite nano-Au:(IR140:PDTP-DFBT). Furthermore, they combined the advantages of field-confinement effect of plasmonics and low-losses properties of dielectric photonics to construct on-chip 2x2 all-optical switch. Plasmonic nanocavities having strong light localization and field confinement effect were used as the switching units, and the low-loss SiN slot waveguides were used as the access waveguides. The on-chip 2x2 all-optical switch was constructed by four plasmonic nanocavities interconnected with SiN slot waveguides. The evanescent field of the upper control waveguides was used to trigger the switching units so as to realize the optical switch function. The threshold pump light power was reduced by 4 orders, and the threshold pump light intensity was reduced to 450 kW/cm$^2$. An ultrafast response time of 63 ps was maintained simultaneously. Thus, an on-chip-triggered all-optical switch with an ultralow energy consumption, ultrafast response, and multiple operating wavelengths was realized. This work was published in Advance Optical Materials (Advanced Optical Materials 4, 1159 (2016)), and was selected as the Cover Article. The scientific web Materials Views China of WILEY publishing group thematically evaluated this work using the title ‘Fusion of surface plasmons and photonics: new breakthroughs in ultrafast all-optical switching on the chip’ as: “This work provides a new way to overcome the bottleneck problem of material faced by integrated photonic devices, help to promote the practical research of ultralarge-scale integrated on-chip optical switching, but also provides a way for the realization of ultrahigh speed three-dimensional integrated photonic logic processing chips".

They also proposed a new method to realize giant metamaterial induced transparency based on unidirectional coupling of surface plasmon radiation modes to non-radiation modes. Gold nanoprism dimer was used as the meta-molecule. The group refractive index was increased to 4000, which is enlarged by one order, through adjusting the spacing between two nano-prisms. Moreover, the threshold pump light intensity for the all-optical tunable transparency window was reduced to 1.5 kW/cm$^2$, which means that the threshold pump light power was reduced by six orders. An ultrafast response time of 42.3 ps was maintained simultaneously. Therefore, an ultrafast all-optical tunable metamaterial induced transparency with ultralow energy consumption was realized. This work was published in the journal of Light: Science & Applications（Light: Science & Applications 4，e302（2015））. This work was thematically evaluated by the journal of National Science Review using the title "New development in integrated photonic devices" as: "this work provides a platform for the study of nonlinear optics and quantum optics".

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

北京大学核科学前身为物理教研室，是新中国第一个核学科培养基地，60 多年来培养了大量的高级专业人才（其中包括 15 位两院院士）。重离子物理研究所目前是该学科的依托单位，它根据自身特点同时面向科学前沿和国家重大需求，不断调整学科方向，开展高水平前沿研究，同时完善研究生课程设置，优化研究生培养方案。北京大学重离子物理研究所目前拥有核技术及应用、医学物理与工程、等离子体物理、高能量密度物理和先进加速器系统（专业硕士）五个学科培养方向。重离子物理研究所目前拥有一支高水平的科学研究和工程技术队伍，历年来研究所有多名学术带头人在国际和国内学术组织中担任各种职务，多人在大型国际学术会议上做特邀报告，在国内外学术界具有重要的影响力。目前研究所有在职人员 46 人，其中中科院院士 2 人（陈佳洱、张维研（双聘）），国家海外高水平学者 4 人、国家杰出青年基金获得者 2 人，北京大学百人计划研究员 6 人，教授 12 人，副教授（含高工）15 人，博士生导师 27 人。

The discipline of nuclear science and technology at Peking University has been grown up from the Physical Laboratory which was founded in 1955 (Renamed to Department of Technical physics later). In past several decades, more than ten thousands talents have been cultivated including 15 academicians. It insists developing science and engineering simultaneously, developing interdisciplinary and serving to the national vital demand for a long time and has become an important unit for research and talent cultivation of nuclear science and technology in China. Institute of Heavy Ion Physics has established a high-level faculty team with reasonable age structure. There are 46 staff members, in which here are 2 academician of Chinese Academy of Sciences, 4 scholar of "high level Experts overseas", 6 outstanding young scientists of "Hundred young talents plan of Peking University", 12 professors and 27 doctoral supervisors.





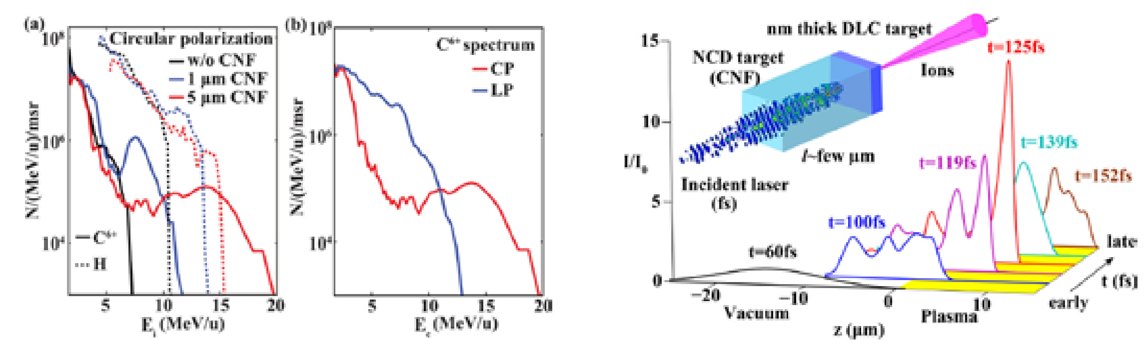
### 一、首次利用碳纳米管实现相对论光强下等离子透镜

光场强度高于 10$^{18}$W/cm$^2$ 的超强激光与等离子体相互作用时，可产生场强高达 10$^{12}$V/m 的加速电场，比常规加速器至少高出千倍以上。基于此原理的激光加速器可产生具有超短脉冲长度、超高束流密度的高能离子束，有望在离子放疗、高能量密度物理等领域得到广泛应用。目前激光离子加速领域的研究热点是如何利用现有的飞秒脉冲激光，在有限的激光能量下获得高能量、高品质的离子束。

颜学庆教授率先在理论上提出可利用一片超薄的临界密度等离子体作为"激光等离子体透镜"来提高光场强度，陡化脉冲前沿 [PRL 107, 265002,(2011)]。经过透镜后的飞秒脉冲激光与另一个超薄的纳米靶相互作用，可以大幅度提高离子的加速效率，获得高能离子 [PHYSICS OF PLASMAS 20, 013101 ,( 2013)]。马文君研究员利用单壁碳纳米管在国际上首次制备出了平均密度仅为固体密度的 1%-5% 的位于临界密度区的超薄薄膜，并将其用于离子加速实验中。实验结果证实了临界密度等离子体对激光脉冲的自聚焦与自整形效应。采用等离子透镜后，圆偏振光照射下获得了 20MeV/u 的碳离子，相比不采用等离子透镜的情况能量提高了三倍，打破了利用飞秒脉冲激光获得的最高碳离子能量记录。质子能量提高了 1.5 倍。

该工作 ["Ion Acceleration Using Relativistic Pulse Shaping in Near-Critical-Density Plasmas"[PRL 115, 064801, (2015)] 作为 Editor Suggestion 发表在国物理评论快报后，引起了广泛关注。APS 专门撰写了"Bringing Ions up to Speed"的专题报道。Science Daily，MedicalPhysicsWeb 也分别作了题目为"Focused laser power boosts ion acceleration"及"Nanotubes energize laser-accelerated ions"的专题报道。

这项工作得到了科技部重大科学问题导向性项目（973A），核物理与核技术国家重点实验室和北京大学应用物理与技术研究中心的支持。德国 Joerg Schreiber 教授研究组及英国的卢瑟福实验室作为国际合作方提供了实验条件。




激光在纳米管等离子体透镜中的整形过程（左）和离子能谱图（右）

Laser shaping process in the carbon nanotube plama lens (left) and energy spectra of ions (right).

### I. Realizing plasma lens at relativistic intensity with carbon nanotubes for the first time

When a laser pulse with intensity above 10$^{18}$W/cm$^2$ interacts with the plasma, the generated electrostatic field could exceed 10$^{12}$V/m, which is higher than the field in conventional accelerator at least by a factor of 1000. Laser-driven ion accelerators based on such high field can delivery exceptional ultrashort and ultradense high-energy ion bunches for the applications in hadron therapy and high-energy-density physics. The current focus of laser ion acceleration is to generate high-energy and high-quality ion beam with limited laser energy supported by state-of-art laser technology. Prof. Yan firstly propose that a “plasma lens”, made of ultrathin near-critical-density plasma slab, can lead to a higher laser intensity at focus spot and meanwhile steepen the pulse (PRL 107, 265002, (2011)). When the laser pulse passing through the plasma lens interacts with an ultrathin foil, the energy of generated ions can be greatly enhanced (PHYSICS OF PLASMAS 20, 013101 ,( 2013)). Dr. Ma, a young assistant professor in PKU, succeeded to produce such plasma lens for the first time by employing carbon nanotube foam (CNF). The density of such foam lies in the range of 1%-5% solid density, e.g., in the critical density region. The experiments by using such foam confirmed the self-focusing and self-steepening effect of plasma lens. Energetic carbon ions with energy of 20MeV/u were generated by irradiating CNF-DLC double-layer targets with circular polarized pulses. The carbon and proton energy was boosted by a factor of 3 and 1.5 respectively.

This work of “Ion Acceleration Using Relativistic Pulse Shaping in Near-Critical-Density Plasmas” [PRL 115, 064801, (2015)] was published on Physical Review Letters as Editor Suggestion and aroused great interests. A news titled as “Bringing Ions up to Speed” was reported by APS. Science Daily, MedicalPhysicsWeb also reported this work.

This work was supported by the guiding projects for key scientific problems (973A), national key lab for nuclear physics and technology. The team of Prof. Joerg Schreiber and Rutherford Appleton Laboratory are the collaborators.

## 二、基于 DC-SRF 注入器成功开展高重频 THz 辐射和 UED 研究

射频超导（SRF）注入器可产生高平均流强连续波（CW）电子束，在国际上有多家实验室在开展相关研究。由射频超导与自由电子激光课题组自主研发的 DC-SRF 光阴极注入器，成功地解决了光阴极与超导腔的兼容性问题，已实现稳定载束运行，其输出电子束能量约为 3 MeV，平均流强约为 1 mA，并具有高重复频率、低发射度、短脉冲等特点，有着广泛的应用前景。

在对 DC-SRF 光阴极注入器束流动力学进行深入研究的基础上，结合速度压缩和能量优化，课题组设计搭建了仅由一台十周期永磁波荡器、一个螺线管透镜、一组自制四极线圈所组成的紧凑 THz 辐射源 [X. Wen et al., NIMA 820, 75~79 (2016)]。实验中通过优化 DC-SRF 注入器的加速相位和电子束传输元件参数，获得了宏脉冲内平均功率最大为 4.4 mW、中心频率在 0.24-0.42 THz 范围内可调、带宽约为 15% 的 THz 超辐射（如图 1 所示）。

利用 DC-SRF 注入器提供的高品质电子束，课题组还开展了国际上首次兆赫兹（MHz）重复频率、MeV 能量的超快电子衍射（UED）实验 [L. Feng et al., Appl. Phys. Lett. 107, 224101 (2015)]，如图 1 所示。这一原理验证实验展示了 DC-SRF 注入器产生的高重复频率电子束在 UED 应用方面的优势。需要强调的是，高重频为反馈系统提供了更大的控制带宽，因此 MHz MeV UED 装置产生的电子束具有极高的时间和能量稳定性，这对于将 UED 分辨率推进至数十飞秒或更快是至关重要的。





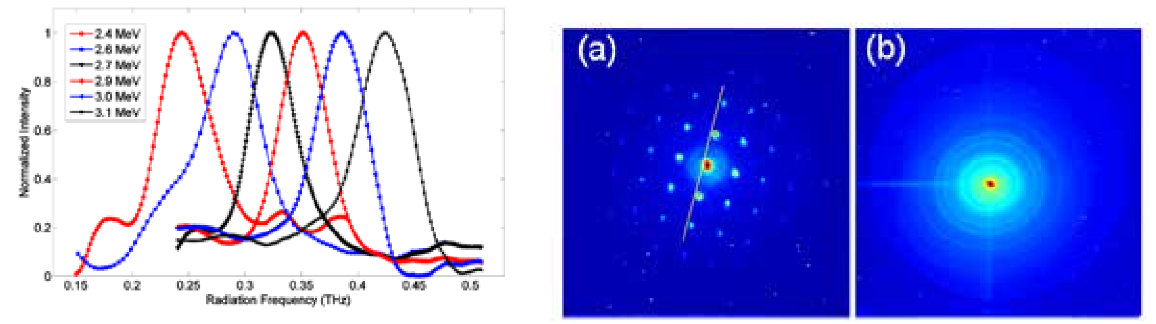



图 1 基于 DC-SRF 注入器产生的高重频电子束流，开展 THz 波荡器超辐射和 UED 实验研究。左图：在不同电子束能量下测得的波荡器超辐射频谱，电子束重复频率 27 MHz。右图：(a) 单晶金箔的电子衍射图样；(b) 多晶铝箔的电子衍射图样。电子束重复频率 812.5 kHz，衍射图样采样时间 200 ms。

Fig. 1. THz superadiant radiation and UED experiments with the high-repetition-rate electron beam from the DC-SRF photoinjector. Left: measured THz superadiant undulator radiation spectra with different electron beam energies. Right: measured electron diffraction patterns from a single-crystalline Au foil (a) and a polycrystalline Al foil (b) taken at 812.5 kHz repetition rate with an integration time of 200 ms.

## II. High-repetition-rate THz radiation and UED study based on the DC-SRF photoinjector

Superconducting radio-frequency (SRF) photoinjector has the potential to deliver high average current, continuous-wave (CW) electron beam and has been developed in several laboratories worldwide. At Peking University, SRF’s group proposed and developed the DC-SRF photoinjector, which successfully avoids the contamination of semiconductor photocathode material in the SRF cavity. Now it can produce stable electron beam with the average current of ~1 mA and normalized emittance ~1.5 mm-mrad. It is widely believed that this kind of injector is one of the most hopeful SRF photoinjector to provide electron beam with high average current, low emittance, and short pulse duration.

Based upon a detailed study of the beam dynamics for the DC-SRF photoinjector, and in combination with velocity bunching and electron energy optimization, SRF’s group designed and built a very compact THz radiation source, comprising only a 10-period permanent-magnet undulator, a solenoid, and a set of self-made quadrupole coils [X. Wen et al., NIMA 820, 75~79 (2016)]. Through optimizing the SRF cavity phase and the parameters for the electron beam optics, SRF’s group obtained in experiments THz superradiant radiation with a maximum average power of 4.4 mW (in the macro pulse), the central frequency tunable from 0.24 THz to 0.42 THz, and a bandwidth ~15% (as shown in Fig. 1).

Using the high-quality electron pulses from the DC-SRF photoinjector, SRF’s group have also experimentally demonstrated MeV electron diffraction at MHz repetition rate for the first time, as shown in Fig. 1 [L. Feng et al., Appl. Phys. Lett. 107, 224101 (2015)]. This proof-of-principle experiment shows the potential of high repetition rate pulses from the DC-SRF photoinjector for applications in ultrafast electron diffraction (UED). It is worth pointing out that the high repetition rate provides a large control bandwidth for the feedback system, and therefore, the MHz MeV UED facility allows to produce an electron beam with very high timing and energy stability, crucial for pushing the temporal resolution to the tens of femtoseconds regime.

## 三、北大强流直流质子源长时间运行稳定性和可靠性创新纪录

离子源是为加速器等离子束设备提供离子流的装置，是整个设备的源头。离子源的束流能力，稳定性和可靠性直接影响着整个设备的正常运行和工作效率。对于需要长时间稳定运行的直流离子束装置来说，这些问题更为重要。因此，关注前沿研究的 973 计划（No.2014CB845500）提出了研制一台高品质强流直流 2.45GHz ECR 质子源的目标。该离子源不仅要能产生 100mA 质子束，而且能实现 50 mA@50keV 直流质子束 300 小时的稳定运行，稳定运行期间瞬时中断的次数小于 5 次。北京大学彭士香老师领导的离子源团队承担了此项研究任务。

国际上，法国 CEA/Saclay 研制的直流质子源可以产生 140mA 的质子束，在 75mA@95keV 下运行时其最长束流不间断记录为 113 小时 (R. Gobin, EPAC 2002, 1712-1714(2002))；美国 LANL 研制的直流质子源在 60-75mA@47keV 下连续运行了 170 小时，最长不打火间隔仅为 5 小时 (J. Sherman,IEEE 1996,867-870)。因此，研制一台能输出 50mA@50keV 直流质子束且离子源连续 300 小时稳定运行的直流质子源是一个很有挑战性的科学问题。

彭士香老师课题组在深入探究引起离子源高压打火和等离子体稳定性的原因和抑制方法之后，于 2015 年 1 月首次实验就得到了国际上首条直流质子源 50mA@35keV 连续运行 300 小时、且无打火或等离子体不稳定导致束流中断的记录 (S. X. Peng, CPB Vol. 24(7) (2015) 075203), (S. X. Peng, RSI 87, 02A706 (2016)]。五次束流中端均是由于冷却水机故障导致。在此基础上，团队进一步研究离子源中的物理机理，优化运行环境，并在 2016 年 6 月获得了直流质子源 50mA@50keV 连续 300 小时间稳定运行无任何束流中断的实验记录（如图 1 所示）。束流的稳定性、可靠性和束流可利用率均达到 100%。束流的归一化均方根发射度为 0.186 π mmmrad. 完成实验后我们对离子源进行了详细的检查，未发现任何损坏。随后我们重新开机，并在 50kV 下引出了 130mA 的质子束。研究结果发表在 Chin. Phys. B 上（S. X. Peng, CPB, 26(2): 025206(2017)）


图 1. 北大 2.45GHz ECR 直流质子源 300 小时稳定运行记录 ( 图中引出电压，及时束流、累计运行时间 )。

Fig. 1. Screenshot of the monitor computer at the end of longevity test. Top: extraction voltage, instantaneous current, and counting hours. Bottom: beam current versus elapsed time.





## III. PKU high intensity DC proton source creates a new record for long-term stability and reliability

Ion source is the very front section that delivers ion beam for a facility, such as an accelerator. The beam generation ability, stability and reliability of an ion source and its beam availability are extremely significant for the entire equipment. These issues are even more important especially for those DC ion beam devices that require long-term stable operation. Therefore, the 973 Program (No. 2014CB845500), which focuses on cutting-edge research, proposes the goal of developing a high-quality, high-current DC 2.45 GHz ECR proton source. The ion source not only has the ability of generating a 100 mA proton beam, but also achieves a stable operation of 50 mA @ 50 keV DC proton beam for 300 hours, and the number of transient interruptions during stable operation is less than 5 times. The ion source team led by Peking University's Peng Shixiang took on this research task.

Only CEA/Saclay, France and LANL, USA launched this kind of research in the World. The 2.45GHZ ECR ion source developed by CEA/Saclay group that named as SILHI has the ability to deliver 140 mA proton beam and the longest non-interrupted CW running period is 113 hours operation at 95keV with 75mA H+ in late 1999 （EPAC 2002, 1712-1714(2002). To qualify the ECR ion source for LEDA project at Los Alamos, a 170-hour continuous run of their 2.45 GHz ECR source with 60–65 mA H+ beam at 47 keV was performed in 1996. Ion beam downtime caused by sparks in the high voltage column of extraction system and one gas flow control problem appeared and the longest uninterrupted run time was five hours (J. Sherman, IEEE 1996, 867-870). Therefore, developing a 2.45GHz ECR ion source that has the ability to produce a stability 50mA@50keV CW proton beam within 300 hours continuous operation with limited beam-offs is a big challenge.

To meet the requirement, attentions were paid on eliminating the uncertainties that may caused beam trips or sparks. A DC proton beam of 50–55 mA with energy of 35 keV has been run for 306 hours continuously at the beginning of 2015. Total beam availability, defined as 35-keV beam-on time divided by elapsed time, is higher than 99%. No plasma generator failure or high voltage breakdown was observed. All beam offs downtime were caused by the failure of water cooling machine problem. The longest uninterrupted run time is 122 hours. After some new improvements, a 300 hours long term 50mA@50keV CW proton beam experiment was carried out in June 2016. The total running time is 300.5 hours, including near 6 hours ion source preparation and 294 hours non-disturb continuous operation. Within the continuous 13 days operation, no beam-off happened, no spark was observed, no beam drop appeared, no interrupting action was needed, and only a few beam fluctuations caused by the air conditional failure occurred. Beam stability, availability and reliability within the 294 hours is 100%. The root-mean-square (RMS) emittance of this 50 mA@50 keV CW proton beam is about 0.186 π mmmrad. A careful inspection of the ion source was done after this long term operation and no obvious damage was found. The restart experimental results obtained after the ion source inspection prove the high repeatability of PKU PMECRIS. In addition, a 130-mA H+ beam was obtained at 50 kV with duty factor of 10% (100 Hz/1 ms) with this source. The result was published on PBC(S. X. Peng, CPB, 26(2): 025206(2017)).

# 05 等离子体物理与聚变研究所
# Institute of Plasma Physics and Fusion Studies

等离子体物理与聚变研究所于 2008 年 12 月 26 日正式成立，王晓钢教授任所长。目前等离子体物理与聚变研究所共有 6 人，包含中科院院士（双聘）1 人，“北大百人”3 人。目前在读博士生 28 名、硕士生 4 名。

等离子物理与聚变研究所成立以来，主要在磁约束等离子体、空间等离子体方向开展理论分析、大规模数值模拟，以及实验数据分析等研究。最近还在聚变诊断方法方面开展工作。相关研究成果在 Nature Physics、Physics Review Letters、Nuclear Fusion、Physics of Plasmas、Journal of Geophysics Research 等国际主要学术刊物上发表论文 40 余篇。我所先后承担和参与科技部国家磁约束聚能专项、课题、国家自然科学基金委重点项目和面上项目、教育部博士点基金等近 20 项。2015 年北京大学提出的托卡马克极向磁场诊断新方法——“激光离子束轨迹探针”项目获得国内同行的大力支持，团队成员、物理学院重离子所林晨研究员获得国家磁约束聚变能发展研究专项的人才项目资助，并担任 2015 年度国家磁约束聚变能发展研究专项人才项目 " 磁约束聚变物理前沿基础问题研究”项目首席科学家。

等离子物理与聚变研究所与相关北大研究单位（北京大学聚变模拟中心、应用物理中心、科维理天文与天体物理研究所、地空学院等）、及国内外聚变与等离子物理研究人员建立长期有效的合作关系，近年来等离子物理与聚变研究所在研究生培养方面成绩斐然，在国内外已有初步影响。林志宏教授指导的包健同学 2015 年在第 24 届国际等离子体数值模拟会议做大会邀请报告。李博研究员受邀在 2016 年的美国物理学会等离子体物理分会年会上做大会邀请报告。

根据物理学院安排，2017 年等离子体物理与聚变研究所并入重离子物理研究所。

Institute of Plasma Physics and Fusion Studies (IPPFS) at Peking University (PKU) was established on in December 2008 with Professor Xiaogang Wang serving as the director. Currently there are 6 staff members and more than 30 graduate students at IPPFS. The main research topics of IPPFS include magnetic fusion energy, laser plasma interaction, and space plasma physics. Researchers at IPPFS have published more than 30 referred papers in Nature Physics, PRL, Nuclear Fusion, Physics of Plasmas, etc. Plasma physics is one of the major research fields in the State Key Lab for Nuclear Physics and Technology.

IPPFS has also established fruitful collaborations with researchers at other PKU research centers (including Fusion Simulation Center, Center for Applied Physics, KIAA, and School of Earth and Space etc), and with major national and international fusion energy and plasma physics programs.





## 一、聚变诊断新方法——“激光离子束轨迹探针”初步研究

托卡马克中的极向磁场直接反映环向电流、q 剖面，是维持托卡马克等离子体平衡的零级物理量之一；径向电场与等离子体约束与输运密切相关，是托卡马克等离子体研究的关键物理参数之一。现有的托卡马克极向磁场、径向电场诊断方法在诊断数据精度、鲁棒性、时空分辨率等方面均远不能满足当前聚变等离子体不断深入的物理研究和不断进步的工程技术的研究需要。

北京大学研究团队提出激光离子束轨迹探针（LITP）这一诊断二维极向磁场和径向磁场的全新原理和方法，充分利用激光加速离子束的大能散、大速度散角、超短脉冲，离子多价态等特点，有望实现对环形磁约束聚变装置中极向磁场、径向电场和电子密度的二维诊断。

LITP 的基本思路如图 1 所示：激光束通过托卡马克装置窗口到达真空室内壁的靶上，通过激光加速原理产生高能离子束。新产生的离子束随即在环向磁场的作用下发生轨迹偏转，这些离子的轨迹可以利用分布在真空室内壁另一侧的探测器来确定，得到出射离子的极向位置和飞行时间。由于极向磁场会使得离子产生环向位移，而径向电场会使得离子产生极向位移，通过测量这些环向位移和极向位移，就可以利用层析等方法重构出极向磁场和径向电场的剖面；类似于重离子束探针的原理，还可以得到电子密度的二维分布。

为了实现激光离子束轨迹探针的诊断，我们提出了激光离子束轨迹探针的基本原理，完成了激光离子束轨迹探针线性理论和非线性理论的推导，对关键的层析问题发展了基于偏微分方程数值求解的层析方法，并使用数值计算程序对激光离子束轨迹探针的基本原理，反演方法进行了初步的验证。

在完成理论和模拟研究的同时，实验工作同步开展。在北京大学等离子体实验装置（PPT）上，用于验证激光离子束轨迹探针基本原理，提高反演方法，解决工程问题的实验系统已完成搭设。系统的主要部分：离子源，极向场线圈，探测器和反演程序等。这些组成部分均先后进行了单独调试。在初步实验中我们使用潘宁离子源代替激光离子加速器，首次在实验中验证了激光离子束轨迹探针的正向反演原理。进一步在托卡马克环境下的原理验证实验正在计划安排中。

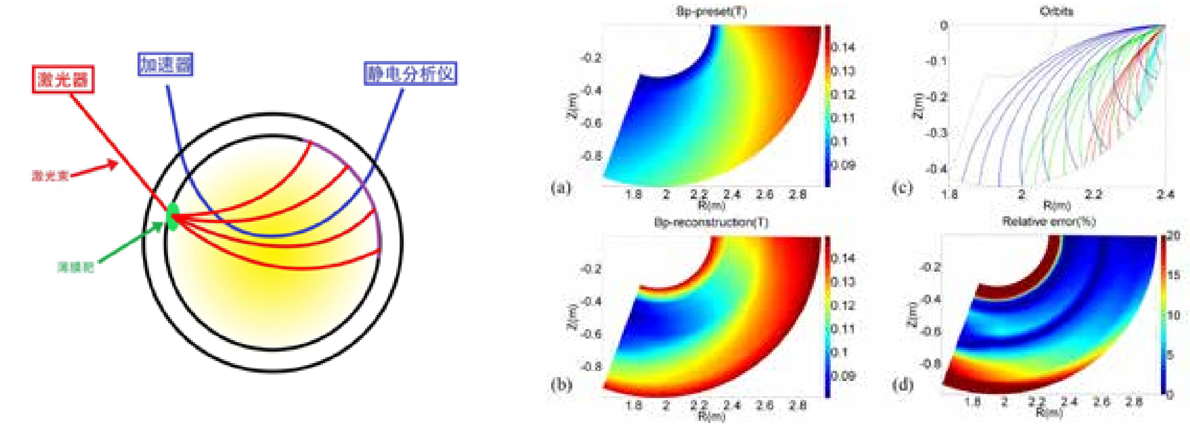



图 1： 激光离子束轨迹探针（LITP）系统示意图（左），以及 LITP 反演托卡马克极向磁场的理论结果。

FIG. 1， A schematic drawing of Laser-accelerated Ion-beam Trace Probe (LITP), and 2D reconstruction results of the poloidal magnetic field in tokomaks by LITP。

### I. The Laser-accelerated Ion-beam Trace Probe (LITP): a New Diagnostics method of 2D profiles of the poloidal magnetic and radial electric field in tokomaks

Poloidal magnetic field is one of the basic parameter in the magnetic-confined fusion (MCF) studies. Basic equilibrium profiles in plasma are determined by the poloidal magnetic profile. Plasma potential or electric filed is another important parameter in MCF. Electric field determines perpendicular motion of guiding centers, including zonal flow, streamer, and drift waves. The radial electric field in the pedestal region is one of the key point of the L-H transition. And plasma potential plays an important role in the turbulent plasma transport. So electric field diagnostic can contribute to plasma turbulence and transport importantly.

Some diagnose methods of poloidal magnetic file and radial electric field, such as the motional stark effect (MSE) and the polarimeter, are the popular poloidal magnetic field diagnose method, and the cross-polarization scattering is a method for magnetic field perturbation diagnostic. The Heavy Ion Beam Probe (HIBP) is a directly diagnose method of the plasma potential field. While all of the diagnostic method mentioned has a limited temporal and spatial revolution and are difficult for a 2D diagnose, which prevent the development of physics understanding and engineer technology. So a 2D magnetic field and electric field diagnostic with high temporal and spatial resolution are in need.

Recently, the plasma research group in Peking University and their collaborators propose a new method, named as the Laser-driven Ion-beam Trace Probe (LITP), to diagnose both the poloidal magnetic field and radial electric field. By taking use of four characters of the laser-driven ion beam: large energy spread, large pinch angle distribution, extremely short pulse and multiple charge state, the LITP can diagnose a 2D profile of both poloidal magnetic field and radial electric field. In the LITP method, ion beams are generated in the vacuum chamber and then injected into plasma. The ion traces are influenced by the the magnetic field and electric field. So the poloidal magnetic field can cause a toroidal displacement, yet the radial electric field can cause a poloidal displacement. By measuring the ion’s trace displacements, the poloidal magnetic field and radial electric field profiles can be reconstructed using tomography method.

We have finished the calculations of the basic principle of LITP, some preliminary simulation results, and experimental preparation to test the basic principle of LITP. (Rev. Sci. Instru., 2014, 85(11): 11E429., 11D860., Rev. Sci. Instru., 2016, 87(11): 11D608)





## 06 技术物理系 Department of Technical Physics

技术物理系现有教职员工 28 人，其中：教授 8 人（其中杰青 3 人），教授级高级工程师 1 人，副教授 7 人，北京大学长聘副教授 2 人（其中优青 1 人），预聘助理教授 3 人，高级工程师 1 人，讲师 1 人，工程师 5 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、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，该实验室拥有包括电弧熔炼、2×1.7 MV 串列加速器、透射电子显微镜和 X 射线衍射仪等在内的新型核能材料的制备、辐照、表征和测试平台，主要用于应用核物理研究（核能材料与核技术应用）；技术物理系是“核物理与核技术国家重点实验室”的重要组成部分，拥有全国唯一的核物理理科基地和核物理国防紧缺专业；承担 973 项目和多项基金重点项目；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)；高能物理方面与欧洲 LHC-CMS 和北京 BEPC-BES 合作；核物理方面与日本 RIKEN-RIBF、兰州 HIRFL 和北京 CIAE 合作等；人才培养方面 2008 年起与日本理化所合建了 Nishina School，2016 年与美国 MSU 建立了由中国留学基金委 CSC 支持的 PKU-FRIB 博士后项目等等。

There are 28 faculty members in the department, including 8 full professors(including 3 National Outstanding Young Scientists), 1 professorship engineer, 7 associate professors, 2 tenured Associate Professors (including 1 National Outstanding Junior Young Scientist), 3 tenure-track Assistant Professors (including 2 “National Young QianRen Project” research professor), 1 senior engineer, 1 lecturer and 5 engineers. The research fields cover experimental nuclear reaction and structure, theoretical nuclear structure, experimental high-energy physics, theoretical intermediate and high-energy physics, applied nuclear physics, radiation protection, detector technique and nuclear electronics. The department is an important part of the State Key Laboratory of Nuclear Physics and Technology. 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. 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 researches are supported by 973-project and several key projects from national natural science foundation (NSFC). 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-CMS 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.

系所中心研究亮点 | ***Highlights***

## 一、新型强子态 XYZ 研究

夸克模型描述的常规强子态有夸克 - 反夸克组成的介子态和三夸克组成的重子态，而强相互作用理论量子色动力学描述的强子态并不局限于此，理论上还存在例如多夸克态、分子态、混杂态和胶球态等新型强子态（又被称为 XYZ 强子态）。寻找与研究这些奇特强子态是 BESIII 实验的主要物理目标之一，这其中 X(1835) 被认为是赝标量胶球的可能候选者，$Z_c(3900)$ 被认为是四夸克态的候选者，引起了理论与实验研究者的广泛研究兴趣。冒亚军教授团队的主要研究进展如下：1) 与高能物理研究所金山团队合作利用 BESIII 获取的约 13 亿 J/ψ 数据样本，通过 $J/\psi \to \gamma K_S^0 K_S^0 \pi^0$ 衰变过程，在 $K_S^0 K_S^0 \pi^0$ 不变质量谱上以 12.9 倍标准偏差的统计显著性首次观察到 X(1835) 到该末态的衰变模式，利用分波分析给出 X(1835) 的质量、宽度、分支比、自旋和宇称等特性，为我们理解 X(1835) 的性质提供了重要实验证据。此外，还以 8.9 倍标准偏差的统计显著性观察到另一个自旋宇称为 0-+ 的共振态 X（1560）。该工作发表于 Phys. Rev. Let. 115, 091803 (2015)，我校博士生秦瑶同学为通讯作者。2）与中国科学院大学吕晓睿团队合作利用 BESIII 采集的 $1092fb^{-1}$ 的 4.226GeV $e^+e^-$ 对撞数据和 $826fb^{-1}$ 的 4.256GeV $e^+e^-$ 对撞，首次通过双 D 介子标记方法，通过分析 $e^+e^- \to (DD^*)^0\pi^0 + c.c.$ 过程，在 $(DD^*)^0$ 质量阈附近以 10 的标准偏差的统计显著性发现一个中性结构。对这个结构的细致分析，并对比带电 $Z_c(3885)$ 的衰变性质，表明这是一个中性 $Z_c(3885)$ 且与其带电伴随粒子一起组成了同位旋三重态。这为我们深入理解 $Z_c(3885)$ 粒子的性质提供了重要的实验证据。该工作发表于 Phys. Rev. Lett. 115, 222002 (2015)，我校博士生单葳同学为通讯作者。3）与中国科学院大学吕晓睿团队合作利用 BESIII 采集的 $1092fb^{-1}$ 的 4.226GeV $e^+e^-$ 对撞数据和 $826fb^{-1}$ 的 4.256GeV $e^+e^-$ 对撞数据，通过我们发展出的独特的部分重建技术，研究了 $e^+e^- \to (D^*\bar{D}^*)^0\pi^0 + c.c.$ 过程。首次在 $(D^*\bar{D}^*)^0$ 不变质量谱 4.025GeV/$c^2$ 附近观测到了一个新的结构，并将之命名为 $Z^0c(4025)$ 粒子。新发现的粒子的质量、宽度及反应截面与 BESIII 之前发现的 $Z_c^{\pm}(4025)$ 粒子在误差范围内均一致，这预示着三个粒子很有可能为同位旋三重态。Zc(4025) 被认为是继 Zc(3885) 后的另一个重大发现，其原因是它们可能是我们寻找多年的四夸克态粒子。该工作发表于 Phy. Rev. Lett. 115, 182002 (2015)，我校博士生刘兰雕同学为通讯作者。

## I. Study of New Forms of Hadron State

The conventional hadron states in quark model consist of mesons, which are quark and anti-quark bound states, and baryons, which are bound states with three valence quarks. Quantum Chromodynamics (QCD) tells us that there is no particular reasons why only mesons and baryons should exist as bound states of quarks. There should be new forms of hadron such as multiquark states, molecular states, hybrids and glueballs, also called as exotic or XYZ states. Search for those exotic hadron states is one of the major physics targets of BESIII experiment, espcially the X(1835) state as a candidate of psudeo-scalar glueball and $Z_c(3900)$ as a candidate of tetra-quark state. The team of Professor Yajun Mao has made following progress on above exotic hadron states: 1) Observed the X(1835) in $K_S^0 K_S^0 \pi^0$ final state through radiative decay of $J/\psi \to \gamma K_S^0 K_S^0 \pi^0$ with about 1.3 billion J/ψ events collected by BESIII detector. The significance is about 12.0 standard deviation. A partial wave analysis is performed and the mass, width, branch ratio, spin and parity of X(1835) are obtained. The experimental results are very important to understand the property of X(1835). In addition, a new $0^{-+}$ structure is also observed with a significance of 8.9 standard deviation. The study is collaborated with Professor Shan Jin' s team in Institute of High Energy Physics. The final results are published in Phys. Rev. Let. 115, 091803 (2015) and the corresponding author is Yao Qin, a PhD student of PKU. 2）First observation of neutral $Z_c(3885)$ in $e^+e^- \to (DD^*)^0\pi^0 + c.c.$ process with $1092fb^{-1}$ data at 4.226GeV $e^+e^-$ collision energy and $826fb^{-1}$ data at 4.256GeV $e^+e^-$ collision energy. The significance is about 10 standard deviation with a analysis technique of double D tagging which provides great suppression power on backgrounds. Further study shows that the newly observed neutral $Z_c(3885)$ is the isospin partner of charged ones. The study is collaborated with Professor Xiaorui Lv' s team in Universtiy of Academic of Science.. The final results are published in Phys. Rev. Let. 115, 222002 (2015) and the corresponding author is Wei Shan, a PhD student of PKU. 3）First Observation of neutral $Z_c(4025)$ in $e^+e^- \to (D^*\bar{D}^*)^0\pi^0 + c.c.$ process with $1092fb^{-1}$ data at 4.226GeV $e^+e^-$ collision energy and $826fb^{-1}$ data at 4.256GeV $e^+e^-$ collision energy, with analysis techniques of double D tagging, partial reconstruction and g veto, etc. The mass, width and Born cross-section of the newly observed neutral $Z_c(4025)$ agree well with that of its charged partners within 1.5 standard deviation, consistent to the assumption of triple-isospin states. The study is collaborated with Professor Xiaorui Lyu' s team in Universtiy of Academic of Science.. The final results are published in Phys. Rev. Let. 115, 182002 (2015) and the corresponding author is Landiao Liu, a PhD student of PKU.

## 二、原子核中隐含的赝自旋和自旋对称性及其起源

发现新的对称性并揭示其基本物理意义在物理学中往往意味着重大科学突破。1969 年，Arima、Harvey 和 Shimizu 以及 Hecht 和 Adler 这两个科学家小组独立提出了原子核的赝自旋对称性（见图 1）。随后，包括诺贝尔奖获得者 A. Bohr 和 B. Mottelson 在内的许多科学家对这种对称性的起源进行了多年的探索。直到 1997 年，才由美国科学家 Ginocchio 发现这种对称性是 Dirac 哈密顿量的相对论对称性。他从极限情况出发，阐明赝自旋对称性成立的条件是核子 Dirac 方程的标量势和矢量势之和为零，即，但这一条件在实际原子核中并不成立。

孟杰及其合作者从 1991 年开始研究原子核的赝自旋对称性问题，在该领域取得了一系列重要成果。（1）他们严格证明，只要 Dirac 方程的标量势和矢量势之和的导数为零，即，原子核单核子谱就具有赝自旋对称性；并指出在实际原子核中，赝自旋对称性的破缺程度由赝自旋—轨道耦合势与赝离心势的竞争所决定。由于随着中子数的增加，势场的弥散度逐渐增大，在近中子滴线原子核中将出现更好的赝自旋对称性。（2）根据赝自旋对称性的成立条件，他们提出了一个不仅严格满足该条件，而且存在单核子束缚态的相对论模型，因而可用来深入研究赝自旋对称性极限以及实际原

子核中的对称性破缺机制。通过精确求解该模型，他们讨论了严格满足赝自旋对称性成立条件的单核子能谱结构、赝自旋伙伴态波函数之间的关系以及闯入态的赝自旋伙伴态等问题。（3）相对论Dirac运动方程不仅存在正能量解，也存在负能量解，而核子Dirac方程的负能量解对应着反核子态。通过考察Dirac方程的反核子态，他们提出原子核的反核子谱存在一种新的对称性——自旋对称性，并指出该对称性的起源与核子谱的赝自旋对称性起源相同。在实际原子核中，与核子谱的赝自旋对称性破缺相比，反核子谱的自旋对称性破缺更小，是一种几乎严格保持的对称性。（4）他们还结合超对称量子力学、微扰理论和相似重整化群方法，提出了解决赝自旋对称性起源的可能方案等。

由于上述贡献，孟杰等受物理学界顶尖综述期刊《Physics Reports》邀请，为该刊撰写了题为《原子核中隐含的赝自旋和自旋对称性及其起源》的综述文章。文章系统总结了自1969年以来原子核赝自旋对称性的主要研究进展，内容涉及各种系统和势场下核子谱的赝自旋和反核子谱的自旋对称性，包括稳定原子核和奇特核、非约束势和约束势、定域势和非定域势、中心势和张量势、束缚态和共振态、核子谱和反核子谱、核子谱和超子谱、球形原子核和变形原子核等。同时，文章还讨论了该领域尚未解决的问题，包括核子谱的赝自旋和反核子谱的自旋对称性的微扰特征、结合相似重整化群方法的超对称表示以及闯入态之谜等。文章自发表以来，已被引用50余次，入选ESI高被引论文，对原子核中隐含的赝自旋和自旋对称性的研究起到了重要的推动作用。

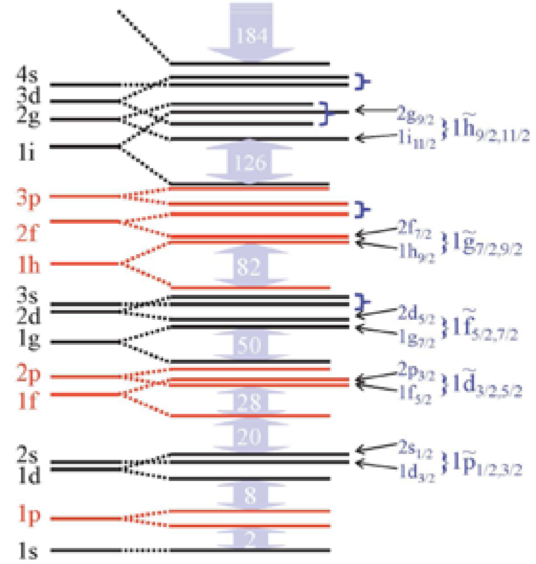



图 1. 原子核单核子能谱的示意图。一方面，自旋伙伴态 之间的强自旋轨道劈裂给出了传统的幻数。另一方面，括号内的一对单核子态 和 近似简并。它们被称为赝自旋伙伴态，相应的对称性称为赝自旋对称性。

Fig. 1. Schematic nuclear single-nucleon spectrum. On one hand, the strong spin–orbit splittings between the spin doublets lead to the traditional magic numbers. On the other hand, pairs of single-nucleon states in braces, and are quasi-degenerate. They are defined as the pseudospin doublets , and the pseudospin symmetry is introduced for such near degeneracy.

## II. Hidden pseudospin and spin symmetries and their origins in atomic nuclei

Discovering new symmetry and revealing its fundamental physical meaning always lead to significant scientific breakthroughs in physics. In particular, for the pseudospin symmetry (PSS, see Fig. 1) in nuclear single-nucleon spectra discovered independently by the group of Arima, Harvey, and Shimizu as well as the group of Hecht and Adler in 1969, many scientists (including Nobel Laureates A. Bohr and B. Mottelson) perused intensive investigations. The origin of this symmetry was unknown until the American scientist Ginocchio pointed out in 1997 that it is a relativistic symmetry of the Dirac Hamiltonian. Starting from a symmetry limit, he showed that the condition for the exact PSS is that the sum of the scalar and vector potentials in the single-nucleon Dirac equation equals to zero, i.e., However, such a condition can never be fulfilled in realistic nuclei.

Jie Meng and his collaborators have been working on the topic of PSS since 1991, and have made a series of important achievements. (1) They proved rigorously that the PSS can be fulfilled as long as the derivative of the sum of the scalar and vector potentials equals to zero, i.e., . Moreover, they pointed out that the PSS breaking in realistic nuclei depends on the competition between the pseudospin-orbit potential and the pseudo-centrifugal barrier. In nuclei near neutron drip line, a better conserved PSS is expected because the diffuseness of potential increases with the neutron number. (2) Based on the condition of PSS, they proposed a new relativistic model which not only exactly fulfills the PSS condition but also has bound single-nucleon states. This model therefore paved a way to explore the limit of this symmetry, as well as the corresponding symmetry breaking in realistic nuclei. By solving this model analytically, the single-nucleon spectra under the condition of the PSS, the relation of the wave functions between pseudospin partners, and the puzzle of intruder states were investigated. (3) For a Dirac equation, there are the single-particle states not only with positive energies but also with negative energies. The latter are interpreted as antiparticle states under charge conjugation. By examining the anti-nucleon states in the Dirac equation of atomic nuclei, they revealed a new symmetry in the anti-nucleon spectra—the spin symmetry (SS), and pointed out that this new symmetry shares the same origin as the pseudospin symmetry in the nucleon spectra. In realistic nuclei, the SS in the anti-nucleon spectra is much better conserved than the PSS in the nucleon spectra. (4) They also discussed the origin of PSS in a quantitative way by combining the supersymmetric quantum mechanics, perturbation theory and similarity renormalization group.

Due to the above contributions, Jie Meng et al. were invited by Physics Reports to write a review article "Hidden pseudospin and spin symmetries and their origins in atomic nuclei" [Physics Reports 570 (2015) 1-84]. In this review, the progress on the investigations of pseudospin and spin symmetries in atomic nuclei were summarized systematically, including extensions of the PSS and SS study from stable to exotic nuclei, from non-confining to confining potentials, from local to non-local potentials, from central to tensor potentials, from bound to resonant states, from nucleon to anti-nucleon spectra, from nucleon to hyperon spectra, and from spherical to deformed nuclei. Open issues in this field are also discussed in detail, including the perturbative nature, the supersymmetric representation with similarity renormalization group, and the puzzle of intruder states. The paper has been cited more than 50 times and recognized as an ESI Highly Cited Paper. It has substantially motivated and advanced the relevant studies on the hidden pseudospin and spin symmetries in atomic nuclei.



系所中心研究亮点 | *Highlights*

## 三、$^{14}$C 的集团结构研究

原子核的集团结构一直是核物理研究领域的一个奇特且重要的方面。集团结构不同于通常的独立粒子图像，对宇宙中元素的形成有重要影响。在不稳定核中，价核子与集团核心可以有很多组合，所以可以形成不同的集团（分子）构型。不同于 Be 同位素中的双 α 中心，C 同位素中的三 α 中心使其可以形成三角形，线形构型等不同的奇异结构，如图 1 所示。线性构型作为集团结构中最奇特的构型，一直被理论与实验关注。理论预言，由于 $^{14}$C 中价中子所处轨道的不同，存在两种不同构型的线性结构（图 1）。这两种构型有不同的衰变模式，且衰变到不同末态的分支比不同。

近期，北大实验核物理团队利用 45 MeV 的 $^{9}$Be 束以及集团转移反应 $^{9}$Be（$^{9}$Be, $^{14}$C$^{※}$ → α +$^{10}$Be）$^{4}$He，完成了 $^{14}$C 集团结构研究的实验。这个反应道的 Q 值非常大，容易占据理论预言的具有集团结构的高激发态，并可以利用各种衰变碎片来很好地区分反应末态。利用前冲的 $^{10}$Be + α，重建了 $^{14}$C 的大量共振态，如图 2 所示。由于 Q 值谱的分辨很好，清楚地区分了 $^{10}$Be 的末态，即基态，第一激发态以及 6 MeV 左右的态。图 2 中所示的大部分共振态都和文献结果一致。发现了一个激发能为 22.5（1）MeV 的共振态，主要衰变到子核 $^{10}$Be 的 6MeV 左右的激发态，这与理论预言的 σ-band 线链分子带的带头的独特性质一致。提取了这个态的相对衰变分支比，也与理论预言一致，意味着这个态具有“3α 成线性排列”的线链超形变结构的特性。另外，还新发现了一个激发能为 23.5 MeV 的共振态，这个态主要衰变到子核 $^{10}$Be 的第一激发态。

相关实验结果发表在 Physical Review C (Rapid communication)、Chinese Physics C 等学术刊物，在 OMEG2015、INPC2016、WNCP2016 等学术会议作邀请报告。该项研究得到了 973 计划和国家自然科学基金的资助。

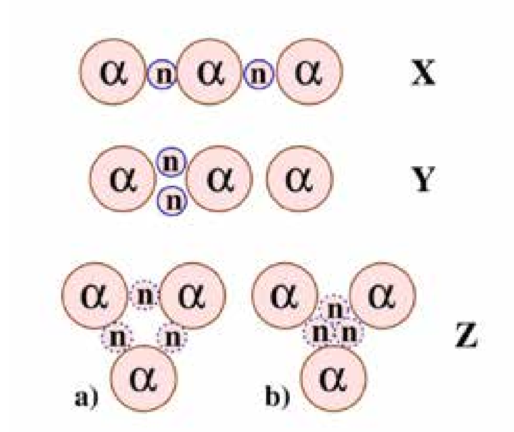



图 1, $^{14}$C 中可能存在的集团结构。X（σ-bond）和 Y（π-bond）是两种不同的线性分子链构型，Z 为三角形构型。

Figure 1, Possible cluster configurations in $^{14}$C. X（σ-bond）and Y（π-bond） are two different linear-chain configurations, while Z is the triangle configurations.

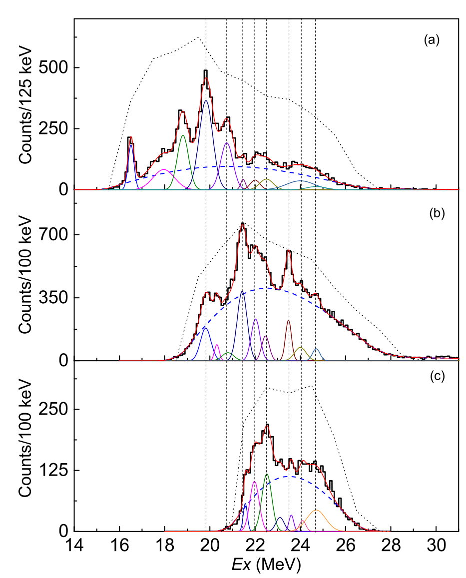



图 2, 利用衰变碎片 $^{10}$Be + α 构建的 $^{14}$C 的激发能谱。利用高分辨的 Q-value 谱区分了 $^{10}$Be 的基态（a），第一激发态（3.4 MeV, 2+）（b），以及 6 MeV 左右的激发态（c）。

Figure 2, $^{14}$C excitation energy spectrum reconstructed from $^{10}$Be + α fragments, gated on the high-resolution Q-value peaks for events decaying to the ground state (a), first excited state (3.4 MeV, 2+) (b), and states at around 6 MeV excitation (c), in $^{10}$Be.





## III. Study of cluster structures in $^{14}$C

Nucleon clustering inside a nucleus is an intriguing and important phenomenon which has given rise to an alternative view of the basic structure of a nucleus and also generated significant impact on the formation of elements in the universe. It has been recognized that a much larger number of cluster (molecular) configurations can be formed in an unstable nucleus, owing to numerous combinations of valence nucleons with the cluster cores. Unlike the α+α rotor in the Beryllium isotopes, the α+α+α configurations in the Carbon isotope make it possible to have more different configurations, such as triangle and linear-chain clusters, as shown in Figure 1. Linear-chain configurations, the most peculiar ones in cluster structures, have attracted a lot of attention from both theoretical and experimental sides. Two different linear-chain configurations, σ-bond and π-bond, have been predicted by the AMD model. Different decay patterns and branching ratios decaying to different final states of these two configurations have also been suggested by the theoretical calculations.

Recently, the experimental nuclear physics group at PKU has carried out a cluster-transfer experiment $^{9}$Be ($^{9}$Be, $^{14}$C$^{※}$ → α + $^{10}$Be)$^{4}$He using an incident beam energy of 45 MeV. This reaction channel has a large Q value that favors populating the high-lying states in $^{14}$C and separating various reaction channels. A number of resonant states (Figure 2), are reconstructed from the forward-emitting $^{10}$Be + α fragments with respect to three sets of well-discriminated final states in $^{10}$Be, most of which agree with the previous observations. A state at 22.5(1) MeV in $^{14}$C is found to decay predominantly into the states around 6 MeV in $^{10}$Be daughter nucleus, in line with the unique property of the predicted band head of the σ-bond linear-chain molecular states. A new state at 23.5(1) MeV is identified which decays strongly into the first excited state of $^{10}$Be.

The results were published recently in Journals such as Physical Review C (Rapid communication)、Chinese Physics C, and reported at conferences such as OMEG2015、INPC2016、WNCP2016. This work has been supported by the 973 program and the NSFC projects.

# 07 天文学系 Department of Astronomy

北京大学天文学系成立于 2000 年，前身为 1960 年在地球物理系成立的天文专业，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，北大天体物理学科被评为全国重点学科。天文学系现有全职教师 9 名，其中教授 5 名， 副教授 4 名。 共有长江学者特聘教授 1 名，国家杰出青年基金获得者 3 名， 并有兼职中国科学院院士 2 名，另外还有 19 名来自国内外高校或科研院所的兼职教授。在站博士后 9 名，博士研究生 62 名，本科生 118 名，办公行政人员 1 名。主要研究领域包括宇宙学与星系形成、高能天体物理、星际介质和恒星与行星系统、粒子天体物理等，涉及各种天文尺度及极端天体环境。

The Department of Astronomy (DoA) was founded in 2000, based on the Astronomy Division in the Department of Geophysics established in 1960. It became a family 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. DoA has 9 full-time faculty members consisting of 5 professors and 4 associate professors. Among them, there are 1 Cheung Kong Scholar chair professor and 3 NSFC "Distinguished Youth Award" winners. DoA has 19 joint faculty members including 2 academicians. Moreover, DoA has 9 post-doctors, 62 post-graduate students, 118 undergraduates and 1 secretary. The main research fields include Cosmology and Galaxy Formation, High Energy Astrophysics, Interstellar Medium, Stellar and Planet System, and Astroparticle Physics, involving astronomical phenomena and astrophysical processes at all scales and various astrophysical environments.

## 一、发现宇宙早期最亮、中心黑洞质量最大的天体

利用国内望远镜首先发现，并得到国外望远镜观测的证实，北京大学吴学兵教授领导的以中国天文学家为主的国际团队宣布发现了一颗距离地球128亿光年、发光强度是太阳的430万亿倍、中心黑洞质量约为120亿太阳质量的超亮天体，它是目前已知的宇宙早期发光最亮、中心黑洞质量最大的天体。这一研究成果发表在2015年2月26日出版的国际顶级科学期刊《自然》上（Wu et al., 2015, Nature, 518, 512–515）。该期杂志把此发现的论文作为四篇封面推荐文章之一，还为此作了题为"井喷式快速成长的年轻黑洞"（Young black hole had monstrous growth spurt）的新闻发布，并邀请德国科学家在同期杂志的新闻与观测（News & Views）栏目发表题为"年轻宇宙里的巨兽"（A giant in the young Universe）专文介绍了这一发现。国内外数百家新闻媒体，包括美国有线电视新闻网(CNN)，时代周刊，华盛顿邮报，洛杉矶时报，国家地理，发现频道，科学美国人，英国路透社，卫报，德国明镜周刊，图片报，以及中央电视台，新华社，人民日报，光明日报，中国日报，中国科学报等，都把该发现作为重要新闻进行了报道。

类星体是在光学波段看起来形状与银河系里的恒星类似、但实际上却非常遥远而明亮的一类特殊天体，其巨大能量来自于中心大质量黑洞吸积周围物质释放出的引力能。近年来，吴学兵领导的研究团队发展了一套基于光学和红外波段天文测光数据选取红移大于5的类星体候选体的有效方法，并利用多个望远镜的光谱观测发现了许多高红移类星体，其中最高红移的是一颗名为SDSS J0100+2802的类星体。它的第一个光学波段光谱是在2013年12月29日利用中国科学院云南天文台的2.4米丽江望远镜拍摄的，吴学兵等初步判定它是一颗红移高于6.2的类星体。随后一年里他们联合美国、智利等国的天文学家利用国外的多镜面望远镜(MMT)、大双筒望远镜(LBT)、双子座望远镜(Gemini)和麦哲伦(Magellan)望远镜所作的后续观测进一步确认它是红移为6.3的类星体。利用观测到的光谱数据，他们估计出该类星体的发光强度超过太阳光度的430万亿倍，比目前已知的距离最远(离地球130亿光年)的类星体还亮7倍。而且其中心黑洞的质量达到了120亿个太阳质量，使得它成为目前已知的高红移类星体中光度最高、黑洞质量最大的类星体。这一宇宙早期最亮天体的发现为研究宇宙早期的结构提供了难得的机遇，同时其中心高达120亿个太阳质量黑洞的存在对现有的宇宙早期黑洞的形成与增长理论以及星系的演化理论提出了挑战。

该研究得到国家自然科学基金重点项目和面上项目，中国科学院先导B专项和科技部973项目的支持。



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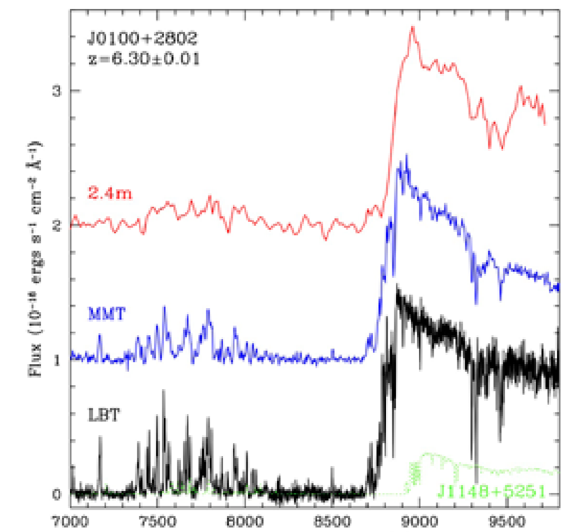


图1：利用中国科学院云南天文台2.4米丽江望远镜和美国MMT、LBT望远镜拍摄的该类星体光谱及其与以前最亮类星体J1148＋5251光谱的比较（2.4米和MMT光谱向上有移动）。

Figure 1: Comparisons of the spectra of the new quasar, J0100+2802, taken with the 2.4 m Lijiang telescope at Yunnan Observatory, the MMT, and the LBT, with the spectrum of the most luminous high-redshift quasar previously known, J1148+5251 (the spectra of the 2.4m and the MMT have been shifted up by 2 units and 1 unit, respectively).

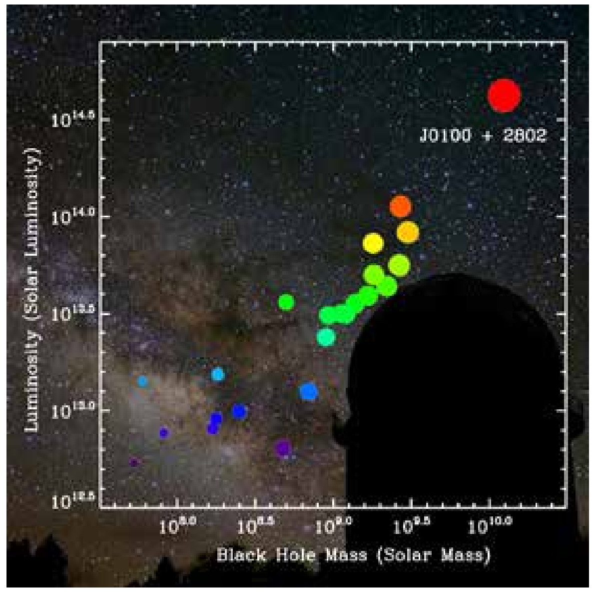


图2: 新发现类星体J0100+2802与其它已知红移5.7以上类星体的黑洞质量和光度的比较（背景为丽江2.4米望远镜圆顶和天空）.

Figure 2: Comparison of the black hole mass and luminosity of the new quasar, J0100+2802, with those of other, previously known z > 5.7 quasars (the background photo is the 2.4 m Lijiang telescope dome and the sky at that location).

## I. Discovering the most luminous object with the most massive black hole in the early Universe

Based on initial observations with a domestic telescope and follow-up observations using several telescopes outside China, an international team led by Prof. Xue-Bing WU from Peking University announced the discovery of an ultra-luminous object containing the most massive black hole in the early Universe. It is located at a distance of 12.8 billion light-years from the Earth, and has a power that is 430 trillion times greater than the power of the Sun.

In the center of this object, there is a giant black hole with a mass of 12 billion solar masses. The paper was published in Nature on 26 February 2015 and was highlighted as one of the four papers on the issue's cover. Nature issued a press release entitled "Young black hole had monstrous growth spurt" on 25 February 2015 and invited a German scientist to write a News and Views article, "Young black hole had monstrous growth spurt" in the same issue to introduce the discovery. Hundreds of news media, including CNN, Time, the Washington Post, the LA Times, National Geographic, Discovery Channel, and Scientific American in the USA, Reuters and the

Guardian in the UK, Der Spiegel and Bild in Germany, as well as CCTV, Xinhua Net, the People’s Daily, Guangming Daily, China Daily, and China Science Daily, all reported this discovery as important news.

This object belongs to a class of quasars, which look very similar to the stars in our Milky Way in optical morphology, but are actually very distant and luminous objects. Their huge power comes from the released gravitational energy of the matter surrounding the massive black holes in the centers of quasars. In recent years, a team led by Prof. Wu has developed a new method to select candidates of quasars with redshifts greater than 5 based on optical and infrared photometric data and discovered many high-redshift quasars using spectroscopic observations with several telescopes. Among them, SDSS J0100+2802, is the quasar with the highest redshift in their program. The first spectrum of it was taken on 29 December 2013 with the 2.4m Lijiang telescope of Yunnan Observatory, Chinese Academy of Sciences, and it was identified as a quasar at a redshift higher than 6.2. Follow-up observations done with the MMT, the Large Binocular Telescope (LBT), and the Gemini and Magellan telescopes (outside China) confirmed that it is a quasar at a redshift of 6.30. Using spectroscopic data, the team estimated that the luminosity of this new quasar is 430 trillion times greater than the solar luminosity and seven times higher than the luminosity of the most distant quasar (at a distance of 13 billion light-years from the Earth). The central black hole mass was estimated at 12 billion solar masses, making it the most luminous quasar with the most massive black hole in the early Universe. The discovery of this ultra-luminous object provides us with a unique chance to study the structure of the early Universe. The existence of such a black hole with a mass of 12 billion solar masses at redshift 6.3 presents challenges to theories of black hole formation and growth and the evolution of galaxies in the early Universe.

This work was supported by NSFC key and general grants, the pilot-B program of the Chinese Academy of Sciences, and the 973 program of the Ministry of Science and Technology in China.

## 二、利用弱引力透镜效应峰值统计限制引力性质

大量的观测证据表明，我们的宇宙正处在加速膨胀的状态，这对我们理解宇宙提出了极大的挑战。为解释宇宙的加速膨胀，我们需要 1) 在广义相对论的框架下，引入未知的具有“负压”性质的“暗能量”成分；2) 或者在宇宙尺度上修改引力理论。二者均会极大地影响我们对宇宙的认知。

在众多用于解释宇宙加速膨胀的修改引力理论当中，非常具有代表性的是所谓 f(R) 理论。不同于通过弯曲时空以使曲率标量 R 最小化的广义相对论，f(R) 理论额外引入一个曲率标量 R 的函数，并使 R+f(R) 整体最小化。构建恰当的 f(R) 模型，该理论解释宇宙的加速膨胀，同时可以通过所谓变色龙机制，满足太阳系引力检验。然而，在宇宙学尺度，该理论所预言的结构形成与演化过程将不同于广义相对论的预言。因此，大尺度结构的观测将对人们理解宇宙加速膨胀的本质、加深对基本物理和宇宙的认识至关重要。

宇宙大尺度结构产生的引力效应改变时空性质，造成光的传播路径发生偏折，这使得所观测到的远处星系的形状和亮度发生微小改变，这个效应称为弱引力透镜效应（见图 1 左上），是公认的最重要的宇宙学探针之一。基于 Canada-France-Hawaii Telescope Lensing Survey (CFHTLenS, http://www.cfhtlens.org) 的弱引力透镜观测数据，北京大学物理学院天文系范祖辉教授领导的宇宙学研究团组与英国杜伦大学、国家天文台和上海师范大学合作，通过进行详尽的弱引力透镜峰值统计分析，对一个具有代表性的修改引力理论“Hu-Sawicki f(R) 修改引力理论”给出了非常严格的限制。

在弱引力透镜分析中，利用测量到的星系的形状，可以构建宇宙中的物质分布，而其中的高峰区域与视线方向上的大质量暗晕相关。图 1 左下显示了一个从 CFHTLenS 数据构建出来的弱引力透镜会聚场的例子。图中，可以清楚地看到其中的高峰区域，它们与黑色圆圈标注的已知星系团存在很好的对应关系。因此，高峰值数目的多少密切地依赖于暗晕的形成与演化过程，是检验引力理论的敏感的探针。与其他星系团的研究相比，弱引力透镜峰值统计方法具有很独特的优势，即其为纯引力效应，受复杂的重子物理过程的影响弱。另一方面，弱引力透镜分析有自己的系统误差，如何正确地预言弱引力透镜峰值分布对宇宙学的依赖一直是该领域重要的前沿问题。近年来，该研究团组在建立理论模型、模拟校准分析、开发快速计算程序等方面开展了深入的研究，已建立了利用弱引力透镜峰值统计进行宇宙学研究的系统分析方法。

在本工作中，结合最新的宇宙微波背景观测结果，该研究团队对 CFHTLenS 弱引力透镜观测数据进行了详尽的分析，首次利用弱引力峰值统计方法对“Hu-Sawicki f(R) 修改引力理论”给出了严格的限制。图 1 右上显示了 CFHTLenS 的峰值分布，而右下则显示对应得到的对 log|fR0| 参数的限制。结合 Planck 宇宙微波背景的观测结果，在 2σ 置信度上给出限制为 log|fR0|<5.16，这是目前为止在宇宙学尺度上得到的最强的限制之一，结果显示没有探测到偏离广义相对论的证据。

该工作明确证实了利用弱引力透镜峰值统计方法区分不同引力理论的可行性。未来的弱引力透镜观测数据量将大大增加，我们期待利用弱引力透镜峰值统计方法将对不同引力理论及宇宙学重要参数给出更加强有力的限制。与此同时，大大降低的统计误差将对精确宇宙学的系统误差控制提出了更高的要求，该研究团队已经并将继续对不同系统误差展开深入研究，进一步改进现有的峰值统计理论模型。除此之外，利用源星系的红移信息，他们还将对弱引力透镜峰值进行分层分析，以进一步挖掘弱引力透镜峰值统计在未来宇宙学研究中的巨大潜力。

相关发表文章：

Liu, Xiangkun; Li, Baojiu; Zhao, Gong-Bo; Chiu, Mu-Chen; Fang, Wei; Pan, Chuzhong; Wang, Qiao; Du, Wei; Yuan, Shuo; Fu, Liping; Fan, Zuhui, Physical Review Letters, (2016), 117, 051101

Constraining f(R) Gravity Theory Using CFHTLenSWeak Lensing Peak Statistics

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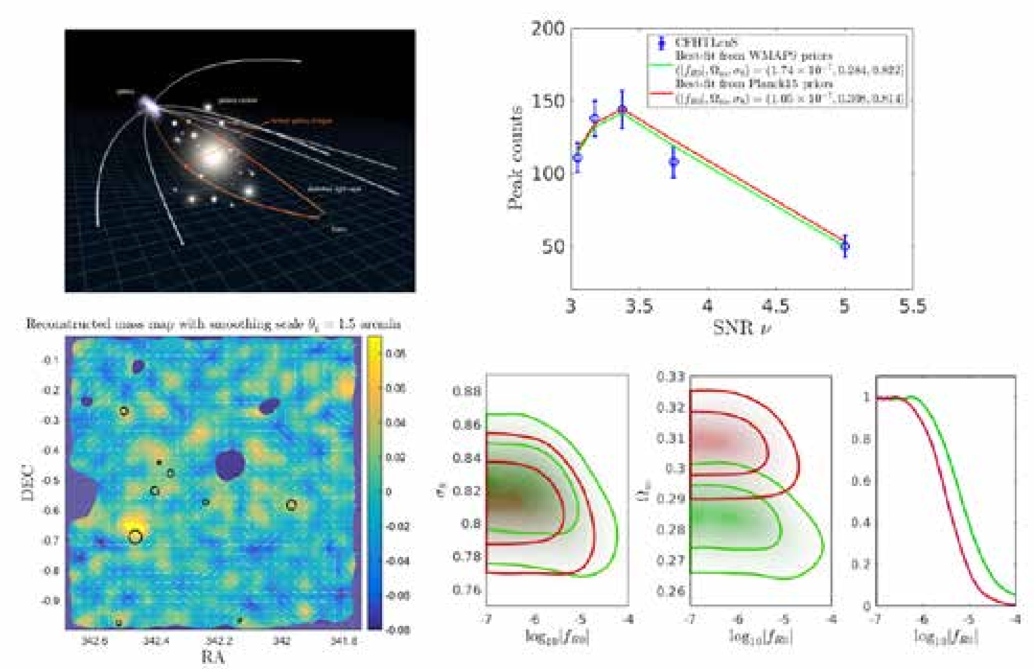


图 1 左上：引力透镜系统示意图；左下：一个从 CFHTLenS 重构得到的物质分布示例；右上：CFHTLenS 峰值分布；右下：对应得到的对于 log|fR0| 的限制。

Fig.1 Upper left: an illustration of the gravitational lensing effect; Lower left: a reconstructed convergence map from CFHTLenS; Upper right: peak counts distribution from CFHTlenS; Lower right: the derived constraints on log|fR0|

## II. Constraining modified gravity from weak lensing peak statistics

The observed cosmic acceleration has posed a great challenge to our understanding about the Universe. It requires either introducing a dark energy component, which possesses an equivalent negative pressure, into the matter content of the Universe, or modifying the general relativity theory of gravity on cosmological scales. Either one can have profound impact physically and cosmologically.

Among different theories of modified gravity attempting to explain the accelerating expansion of the Universe, f(R) theory is a representative one. Unlike in general relativity where the space-time bends to minimize its curvature R, in f(R), an extra function of R is introduced and the minimization is done for R+f(R). With the suitable choice of f(R), this theory might explain the cosmic acceleration while still passing the solar system tests on the law of gravity owing to the chameleon effect. However, the structure formation on cosmological scales can be affected significantly. Therefore observations of large-scale structures are critical in scrutinizing the underlying mechanism driving the global cosmic acceleration, and thus deepening our view of fundamental physics and cosmology.

Arising from the light deflection by large-scale structures in the Universe, as illustrated in the upper left panel of Fig.1, the weak lensing (WL) effect has been recognized as one of the key cosmological probes. With CFHTLenS WL observations (http://www.cfhtlens.org), a team, led by Prof. Zuhui Fan of Peking University and consisting of members from Peking University, Durham University (UK), National Astronomical Observatories, Chinese Academy of Sciences, and Shanghai Normal University, carried out detailed WL peak analyses and obtained stringent constraints on the Hu-Sawicki f(R) gravity theory.

High peaks in WL maps are closely related to massive halos along lines of sight. The lower left panel of Fig.1 shows an example of the WL convergence map we obtained from CFHTLenS data. Peaks are seen very clearly there, and they have good correspondences with known clusters shown in black circles. Their abundance is therefore sensitive to halo formation and evolution, which in turn is sensitive to the law of gravity. Comparing to cosmological studies using optical, X-ray or Sunyaev-Zeldovich clusters, which rely heavily on baryonic observable–mass relations, WL peak statistics are much less affected by baryonic physics, the major systemic effect concerned in normal cluster studies. On the other hand, WL peak studies have their own systematics. How to predict accurately the cosmological dependence of WL peak abundance is a challenging task. Considering carefully the noise effect arising from intrinsic shapes of source galaxies, we have developed an analyzing pipe line for cosmological studies using WL high peaks, from theoretical modeling, mock simulation calibrations, to a fast computing platform.

By applying it using CFHTLenS with priors from WMAP and Planck CMB observations, the team has derived tight constraints on the Hu-Sawicki f(R) theory, for the first time, from WL high peak abundance. In the right panels of Fig.1, we show the peak counts from CFHTlenS in the upper, and the constraints on the log|fR0| parameter in the lower. We obtain a tight constraint with log|fR0|<5.16 (2 σ and Planck prior). No derivations from the general relativity theory are detected.

Our study demonstrates clearly the promising potential of WL peak analyses. With on-going and future large observations with much improved data quantity and quality, we expect WL peak analyses will result in much better cosmological constraints. Low statistical errors in future observations ask for tighter systematic controls in cosmological observables. We have been continuously working toward improving our theoretical modeling and studying carefully different systematic effects. We are also exploring more information from WL peak analyses by incorporating the redshifts of source galaxies tomographically in order to fully realizing the power of WL peak statistics in future cosmological studies.

Published paper:

Liu, Xiangkun; Li, Baojiu; Zhao, Gong-Bo; Chiu, Mu-Chen; Fang, Wei; Pan, Chuzhong; Wang, Qiao; Du, Wei; Yuan, Shuo; Fu, Liping; Fan, Zuhui, Physical Review Letters, (2016), 117, 051101

Constraining f(R) Gravity Theory Using CFHTLenSWeak Lensing Peak Statistics

News：

http://www.sciencemag.org/news/2016/07/attempt-explain-away-dark-energy-takes-hit

系所中心研究亮点 | *Highlights*

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

北京大学大气与海洋科学系起源于 1929 年，具有悠久的历史和优良的传统。近 90 年来，大批杰出学者先后在此执教或学习，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，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"。

本系现有 28 名全职教师，包括杰青 3 人、优青 2 人、青年拔尖 1 人。研究方向涵盖天气、气候、大气物理、大气化学与环境、物理海洋及行星大气，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 90 万元，人均每年发表 SCI 论文 3.5 篇（其中北大第一署名的 2.3 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 has two second-tier focal disciplines (meteorology, atmospheric physics and atmospheric 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".

AOS employs a total of 28 full-time faculty members, including 3 National Outstanding Early-Career Scientists, 2 National Outstanding Early-Career Scientist, 1 Qing Nian Ba Jian Scholar, and 5 Early-Career Thousand-Talent Scholars. Research fields within AOS cover meteorology, climatology, atmospheric physics, atmospheric chemistry, environmental science, physical oceanography, 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 900,000 RMB research funds and published 3.5 SCI papers (including 2.3 papers with Peking University as the first affiliation).

## 一、全球化大气污染的气候强迫影响

2016 年，大气与海洋科学系林金泰长聘副教授等人在《自然 - 地球科学》发表研究论文（Article），首次揭示了全球贸易与全球大气输送引起的气溶胶污染转移对区域和全球气候强迫的影响。

产品消费需要的生产及相关交通运输、电力生产等经济活动导致大量的污染物排放。通过大气输送过程，区域排放影响全球污染状况，并进一步影响气候系统的辐射平衡。在经济全球化的背景下，国际贸易意味着产品的消费地和生产地分离，相应的污染物排放地区从消费地区转移到生产地区，改变了全球污染物排放的空间分布及区域污染、污染输送和气候强迫特征。因此，全球经济贸易和大气输送的耦合对气溶胶的气候强迫具有重要影响。

自 2014 年以来，由林金泰共同领导的一个国际合作团队发表了一系列研究工作，揭示了经济贸易及其与大气输送的耦合对空气质量、人群健康和气候强迫的影响。其 2014 年开创性的工作（Lin et al., PNAS, 2014）首次揭示了国际贸易和大气输送过程的耦合对全球化大气污染转移的影响，发现中国作为"世界工厂"生产了大量产品满足国外消费，同时也承受了严重的空气污染。该论文获得 Cozzarelli 奖，迄今已被下载超过 18 万次。

在 2016 年发表的《自然 - 地球科学》论文中，林金泰等人进一步将研究范围扩展到全球，首次揭示了全球多边经济贸易活动与大气输送过程的耦合导致的全球化气溶胶污染对大气层顶直接辐射强迫的影响。如图 1 所示，林金泰等人发现，东亚地区（主要是中国）是最大的产品出口地区，2007 年东亚地区的消费引起的二次无机气溶胶（SIOA）和一次有机气溶胶（POA）的全球辐射强迫（RFc）比该地区的生产引起的辐射强迫（RFp）小 18%，而该地区的黑碳 RFc 比 RFp 小 10%。作为对比，西欧作为产品的净进口地区，其 SIOA+POA 的 RFc 是 RFp 的 2 倍，其黑碳 RFc 是 RFp 的 1.7 倍。整体来说，发达地区是产品的净进口国，其 RFc 远高于 RFp，而发展中地区是产品的净出口国，其 RFc 小于 RFp，也就是说，辐射强迫从发达地区转移到发展中地区。由于气溶胶在大气中停留的时间较短，任一个地区的 RFc 与 RFp 的差值存在显著的空间变化，这种辐射强迫差异对于气候系统的响应有重要影响（图 2）。这一成果被 NSFC 期刊《Science Foundation in China》作为亮点报道，并被众多主流媒体报道（http://www.phy.pku.edu.cn/~acm/acmNews.php）。基于这项工作，林金泰荣获中国新锐科技人物突出贡献奖（http://www.phy.pku.edu.cn/news/news17/170114.xml）。

林金泰等人的一系列研究表明，大气污染物的全球化转移和气候环境影响不仅与全球的经济生产有关，也与全球的消费行为有密切关系，这对于厘清经济 - 贸易 - 排放 - 污染 - 气候环境的关系、制订有效的全球环境政策和协同减排方案具有重要意义。

论文：


Lin, J.-T. #*, Tong, D. #, Davis, S., Ni, R.-J., Tan, X., Pan, D., Zhao, H., Lu, Z., Streets, D., Feng, T., Zhang, Q. *, Yan, Y.-Y., Hu, Y., Li, J., Liu, Z., Jiang, X., Geng, G., He, K., Huang, Y. *, and Guan, D.: Global climate forcing of aerosols embodied in international trade, Nature Geoscience, doi: 10.1038/NGEO2798, 2016（链接：https://www.nature.com/articles/ngeo2798）

Lin, J.-T. #*, Pan, D. #, Davis, S. J., Zhang, Q. *, He, K. *, Wang, C., Streets, D. G., Wuebbles, D. J., and Guan, D.: China's international trade and air pollution in the United States, PNAS, 111, 1736-1741, doi:10.1073/pnas.1312860111, 2014（链接：http://www.pnas.org/content/111/5/1736?tab=metrics）

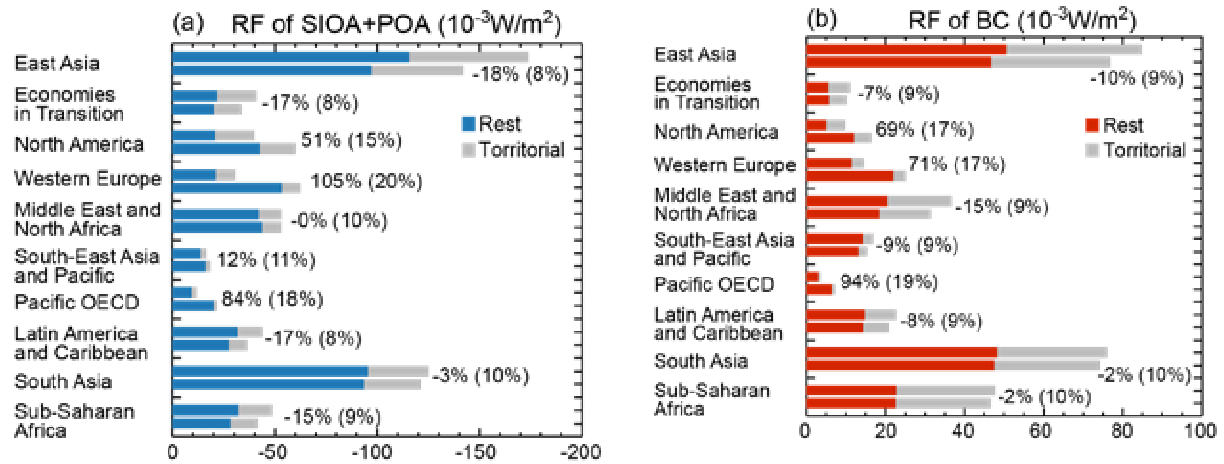


图 1：2007 年全球各地区的 RFp（上柱）与 RFc（下柱）。对于任一个地区，蓝色（红色）和灰色分别表示 SIOA+POA（BC）在地区上空及地区外的辐射强迫，对应的数字表示 RFc 与 RFp 的相对差异及其 2σ 误差。

Figure 1. Global production- and consumption-based radiative forcing of SIOA+POA (a, scattering aerosols) and BC (b, absorbing aerosol) for 10 source regions. For any region, RFp (upper bar) and RFc (lower bar) are summed from the RF imposed above (grey) and outside (blue in a and red in b) their territories. For any region, the percentage value indicates the relative change from RFp to RFc, and the value in the parenthesis is the associated error (2σ). Source: Lin et al., Nature Geoscience, 2016.

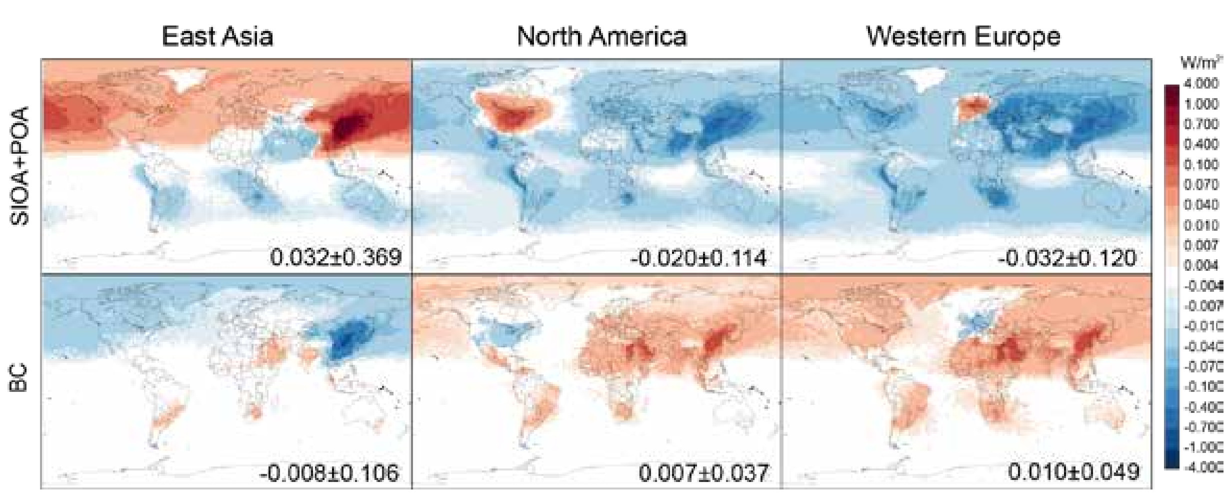


图 2：2007 年主要地区的 RFc 与 RFp 的差异的水平分布。

Figure 2. Global differences between consumption- and production-based radiative forcing (RFc – RFp) in 2007. Source: Lin et al., Nature Geoscience, 2016.



系所中心研究亮点 | *Highlights*

## I. Globalizing air pollution and climate forcing

Production of goods for consumption and associated economic activities (transportation, power generation, etc.) result in tremendous amounts of air pollutant emissions. And atmospheric transport of air pollutants allow regional emissions to have a global impact, a well-recognized environmental problem. Furthermore, international trade allows a country to import goods from other countries; therefore it alters the location of production and thus affects the spatial distribution of emissions. As the amount of emissions from production of a particular product differs significantly between countries, due to differences in economic structure, energy structure and emission control levels, economic trade may also change the total amount of global emissions. The coupling of trade and atmospheric transport not only means substantial re-distribution of air pollution at the global scale, but it also has a major impact on regional contributions to climate forcing and climate change.

Since 2014, an international team co-led by Professor Jintai Lin has published a series of studies quantifying the impacts of pollution transfer associated with trade and atmospheric processes on ambient air quality, public health and climate forcing on a regional or global scale. In their pioneering work (Lin et al., PNAS, 2014) that won the prestigious PNAS Cozzarelli Prize and has been downloaded by over 180,000 times, the team first presented the coupling effect of trade and atmospheric processes on China's pollution and its global impacts. They revealed tremendous influences of economic trade in relocating pollution, much more than the effect of atmospheric transport alone. They also showed that the U.S. outsourcing manufacturing to China reduced emissions produced in the United States with a significant increase in emissions produced in China and thus an increase in pollution transported from China. The two factors compensated for each other, resulting in an improvement in sulfate air quality over the eastern United States with reductions in China and the western United States.

In this new study (Lin et al., Nature Geoscience, 2016), the team further analyzed the trade-pollution relation from a global trade perspective. They revealed the overall impacts of global multi-lateral economic trade and atmospheric processes on global air pollution, geographic transfer, and, for the first time, the top-of-atmosphere direct radiative forcing of aerosol pollution. The work was done by integrating a series of calculations on trade-related emissions, pollution transport and radiative processes. As shown in Fig. 1, they found that East Asia (mostly China) is the largest net exporter of goods, and in 2007 the aerosol radiative forcing due to East Asian consumption of goods (RFc) was smaller than the forcing due to its production (RFp) by 18% for scattering aerosols (secondary inorganic aerosols SIOA and primary organic aerosol POA together) and by 10% for black carbon. By contrast, Western Europe is a giant net importer of goods, and its RFc in 2007 was twice as much as its RFp for SIOA+POA and was 1.7 times its RFp for black carbon. Overall, the developed countries were net importers of goods, and their RFc exceeded RFp, with the opposite story being true for the developing countries – in other words, there was net transfer of radiative forcing from the developed to the developing countries. Due to the short lifetime of aerosol pollutants, the difference between any region's RFc and RFp has substantial spatial variability (Fig. 2), with important impactions for climate responses. This paper points to the complexity of regional attributions of climate forcing and climate change and the need of global cooperative thinking and actions to combat this serious problem. It was featured by the NSFC magazine Science Foundation in China, and was reported by many news media (http://www.phy.pku.edu.cn/~acm/acmNews.php). Based on this study, Professor Lin won the Rising Scientist Outstanding Contribution Award (http://www.phy.pku.edu.cn/news/news17/170114.xml).

Overall, the works by Lin et al. depict the global connections among consumption, production, air pollution, human health and climate forcing and suggest that both the costs and benefits of policy efforts to reduce air pollution may thus be shared globally and supported by international cooperation. Their studies also call for better integration of atmospheric and trade processes in pollution transfer analyses to improve the understanding and mitigation of globalizing air pollution.

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## 二、过去 21000 年东亚夏季风与冬季风的相互关系

决定中国气候基本面貌的东亚夏季风（EASM）和东亚冬季风（EAWM）在经典气候学中被认为彼此呈反向变化关系，即夏季风强时冬季风弱，反之亦然。这种未经充分证实的先验假设关系，却一直被用来解释现代气候变化和古气候演化的诸多问题。近些年随着几个“违反常识”的新观测证据的出现，气候学界迫切需要重新审视这一古老问题：东亚夏季风和冬季风真的一直是反相关吗？

大气与海洋科学系的闻新宇、刘征宇及其合作者使用 CCSM 气候模式对 LGM 以来（约 21,000 年前）的气候演化进行全强迫连续模拟，再辅以 4 个单强迫敏感性试验（轨道强迫、淡水通量强迫、陆地冰盖强迫、和温室气体强迫）进行比对，以从模式角度给出了到目前为止对这一问题最为完整的回答。结果表明：东亚季风主要在两种物理机制作用下演化：1）在 21,000 年慢变的轨道尺度上，主要强迫是岁差，冬季风和夏季风呈现同向变化，即冬 - 夏季风同强（中国东部冬冷夏热，夏季降水偏多）或同弱（中国东部冬暖夏凉，夏季降水偏少），具体而言在早中全新世时期，冬 - 夏季风同强，而在冰消期和全新世后期，冬 - 夏季风同弱。2）在冰消期快变的千年尺度上，主要强迫是北大西洋淡水通量，冬季风和夏季风呈现反向变化，每当一次北大西洋淡水注入后，冬季风加强，夏季风减弱，这在 H1-BA-YD 时期特别清楚。除此之外，东亚季风对陆地冰盖和温室气体强迫也有所反应，但处于次要地位。

总之，闻新宇等使用先进气候模式，系统研究了东亚地区冬 - 夏季风之间的关系——这一古气候学界的经典问题。他们的研究结果从多种时间尺度及背后物理机制的角度统一了对这一问题的不同认知，为近 21,000 年以来的东亚季风研究提供了来自模式的基准证据，并为未来全球变暖背景下的东亚季风预估提供了科学依据。

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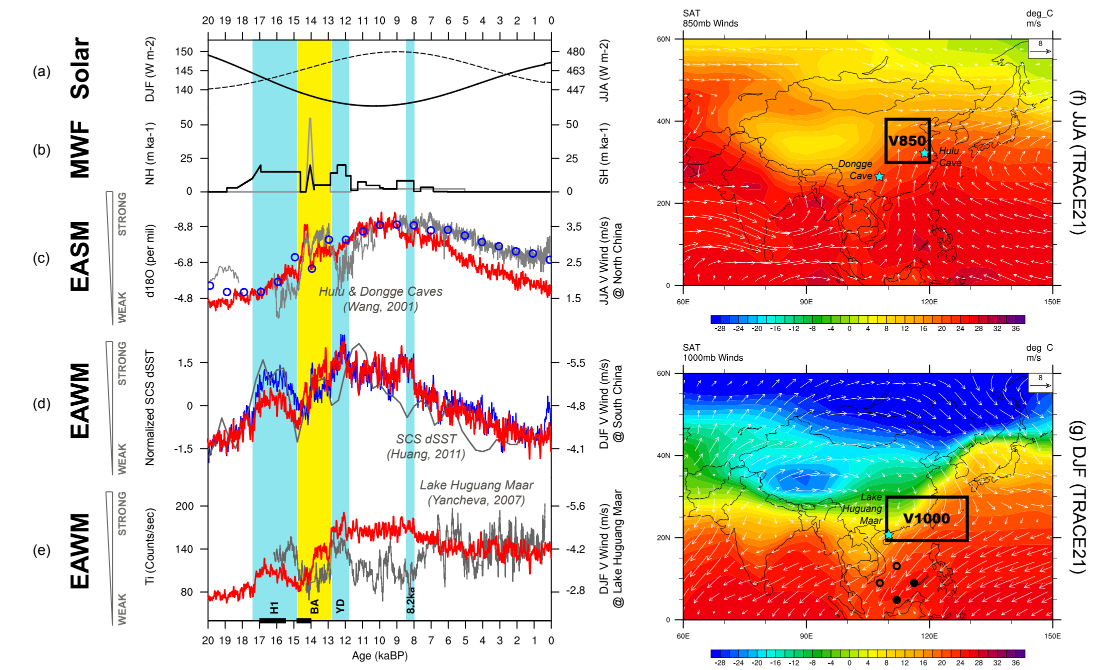
Wen, X., Z. Liu, S. Wang, J. Cheng, and J. Zhu. 2016: Correlation and anti-correlation of the East Asian summer and winter monsoons during the last 21,000 years. Nature Communications, 7, 11999, doi: 10.1038/ncomms11999




图．20,000 年来观测与模拟的东亚季风指数和相关物理参数的演化 . (a) 北半球 45N 的冬夏季太阳辐射; (b) 北半球和南半球的淡水通量；(c) 观测 EASM 指数（Wang, et al., 2001）（灰）、模拟 EASM 指数（定义见 f）（红）、模拟 d18O 变化（蓝圈）；(d) 观测 EAWM 指数（Huang, et al. 2011）（灰）、模拟的海温梯度指数（蓝）、模拟 EAWM 指数（定义见 g）（红）；(e) Yancheva et al. (2007) 观测 EAWM 指数（灰）和模拟的按照 Yancheva 定义计算的 EAWM 指数（红）；(f) 模式中东亚夏季风的气候态风场；(g) 模式中东亚冬季风的气候态风场 .

Figure. Variability of EASM, EAWM, and associated climatic variables in the past 20,000 years. (a) Solar insolation at 45N; (b) Fresh water fluxes in NH and SH; (c) Observed EASM index (Wang, et al., 2001, grey), Simulated EASM index (red, definition see f), and Simulated d18O (blue circle); (d) Observed EAWM index (Huang, et al., 2011, grey), Simulated SST gradient index (blue), Simulated EAWM index (red, definition see g); (e) Observed EAWM index (Yancheva, et al., 2007, grey) and Simulated EAWM index followed Yancheva et al. (2007) (red); (f) Climatology of EASM in model; (g) Climatology of EAWM in model.

## II. Revisiting the Co-variability of EASM and EAWM in the Past 21,000 Years

The correlation between EASM and EAWM are traditionally considered as negative within the climate community, i.e. stronger EASM means weaker EAWM, and vice versa. However, this assumption, unclear and unapproved though, was widely used to explain a mass of modern and paleo climate problems in the past decades. In recent years, with a couple of proxy findings that challenge this assumption, people tend to re-consider the old question: Are EASM and EAWM always negatively correlated?

Dr. Xinyu Wen and Prof. Zhengyu Liu, from the Department of Atmospheric and Oceanic Sciences, lead a team to re-investigate this issue by performing a 21,000-year consecutive simulation with complete forcing and four sensitivity runs with single forcing for each (orbital; fresh water flux; ice; and greenhouse gases). It is shown that the long-term variability of Asian monsoons are dominated by two key processes: 1) slow varying procession, resulting in positively correlated variations among EASM and EAWM at low-frequency band; and 2) fast varying fresh water input over North Atlantic ocean, so-called AMOC events, leading a strengthened EAWM and weakened EASM, which is much clear during H1-BA-YD deglaciation interval. Moreover, EAWM and EASM are also influenced by the long-term variations of land ice-sheet and greenhouse gases during the past 21,000 years, but subtle.

Wen and Liu el al. (2016), from modeling point of view, re-investigate the relations between EASM and EAWM, two dominant system in determining China's climate, with focus on multiple timescales and associated physical processes. The results, by providing a spatial-temporal unified benchmark for long-term variability of EASM and EAWM, reconcile the current debate on Asian monsoon's co-variability and improve our understandings of monsoon's role in the context of future climate change.

Reference：

Wen, X., Z. Liu, S. Wang, J. Cheng, and J. Zhu. 2016: Correlation and anti-correlation of the East Asian summer and winter monsoons during the last 21,000 years. Nature Communications, 7, 11999, doi: 10.1038/ncomms11999

## 三、气候变暖将加重地面臭氧污染

物理学院大气与海洋科学系百人计划研究员傅宗玫研究组在《自然—气候变化》（Nature Climate Change）上发表论文，题为"Positive but variable sensitivity of August surface ozone to large-scale warming in the southeast United States"。该研究发现气候变暖将导致植被密集地区的地面臭氧浓度增加，危害人体及生态系统健康。此外，臭氧随气候变暖增加之幅度有很大的年际及年代际变化，并与大尺度气候系统年代际变异有关。这些结果解决了国际大气化学界关于臭氧对气候变暖响应方向的长期争论，并对东亚（包括中国）、南亚、西欧、美国东南部等地空气污染的长期治理及政策规划有重要意义。

地面臭氧是一种重要的空气污染物，危害人体及生态系统健康。地面臭氧系由挥发性有机物在日光照射下、受氮氧化物催化的光化学反应生成。即使在人为活动污染物（挥发性有机物、氮氧化物）排放不变的情况下，气候变暖也可能改变地面臭氧浓度。特别是在东亚（包括中国）、南亚、西欧、美国东南部等受污染的植被密集区域，夏季地面臭氧可能对气候变暖极为敏感。这是由于植被排放的有机物（主要是异戊二烯）是臭氧的重要前体物，





且其排放强度与气候条件成非线性相关。但是长期以来，国际大气化学界对气候变暖究竟将造成受污染的植被密集地区地面臭氧增加还是减少，一直未达成共识。其主要原因是异戊二烯光化学反应中吸收氮氧化物的效率，存在很大的不确定性。

傅宗玫研究组通过分析及模拟 1988-2011 年美国东南部地面臭氧观测，确定了气候变暖将导致地面臭氧浓度增加。研究方法的关键创新之处，是他们发现 1988-2011 年美国东南部 8 月份气温的年际变化，主要反应全美大陆尺度的气温振荡。因此，通过分析此期间地面臭氧对年际尺度温度变化的敏感性，可以诊断地面臭氧对未来大尺度气候变暖的敏感性。

该研究发现，在 1988-2011 年间，美国东南地面臭氧对大尺度气候变暖的敏感性始终为正值，但是此敏感性具有很大的年际变化。傅宗玫等通过一系列模式实验，发现区域大气环流的年际变异对臭氧输送有很大的影响，使地面臭氧对大尺度气候变暖的敏感性可变化三倍。这表示有些年份气候变暖 1 K 将造成地面臭氧增加 2.4 ppb，但有些年份气候变暖 1 K 臭氧增幅可达 7.1 ppb。傅宗玫等进一步发现，在更长时间范围内（1948-2012 年），区域大气环流的年际变异导致臭氧输送对气温变暖的敏感性符号正负交替变化，并且可能与北大西洋年代际振荡（Atlantic Multidecadal Oscillation，AMO）等气候系统本身的年代际变异现象有关。

该研究结果表明，国际上现有的气候 - 化学耦合模型无法正确预测未来空气污染强度，因此亟需发展能正确预测 AMO 等气候系统年代际变异的气候 - 化学耦合模型。此外，为管理未来区域空气质量所制定的中长期减排政策，需要考虑空气污染对气候变暖敏感性的年际及年代际变化，才能保证未来持续达成空气污染标准。

本研究主要由傅宗玫研究员及其本科生郑一琦（现为美国耶鲁大学博士生）完成，另有美国哈佛大学及普林斯顿大学多名研究人员参与。本研究得到国家重点基础研究发展计划（973 计划）、国家自然科学基金优秀青年项目及面上项目的经费支持。

Reference:

Fu, T.-M.*, Y. Zheng, F. Paulot, J. Mao, and R. M. Yantosca (2015), Positive but variable sensitivity of August surface ozone to large-scale warming in the southeast United States, Nature Climate Change, 5, 454-458, doi:10.1038/nclimate2567.

## III. Positive but variable sensitivity of August surface ozone to large-scale warming in the southeast United States

Dr Tzung-May Fu and her colleagues at the Department of Atmospheric and Oceanic Sciences, School of Physics recently published a paper entitled "Positive but variable sensitivity of August surface ozone to large-scale warming in the southeast United States" on Nature Climate Change. This study shows that climate warming will lead to increased surface ozone levels over polluted forested areas, threatening the future health of humans and ecosystems. In addition, the sensitivity of ozone to climate warming shows great interannual and interdecadal variability with potential links to large-scale climate interdecadal variability. These findings resolve a long-standing debate among the atmospheric chemistry community regarding with the response of ozone to climate warming. These findings also have important implications for the prediction and management of future ozone air quality over regions like East Asia (including China), South Asia, Western Europe, and the southeast U.S.

Surface ozone, a major air pollutant toxic to human and ecosystems, is produced by the photochemical oxidation of volatile organic compounds (VOCs) in the presence of sunlight and nitrogen oxides (NOx). Even in the absence of changes in anthrpogenic emissions of VOCs and NOx, climate warming may affect surface ozone levels, especially over polluted forested areas (e.g., East Asia, South Asia, Western Europe, and the southeast U.S.) in summer. This is because forests emit a particular compound, isoprene, which is an important precursor to ozone. The flux of isoprene from forests is non-linearly dependent on climate conditions. However, for a long time the atmospheric chemistry community have not reached a consensus on whether climate warming will increase or decrease surface ozone levels over these polluted forested areas. This lack of consensus is mainly due to the high uncertainty related to the NOx-sequestration efficiency during the photochemical cascade of isoprene oxidation.

Fu and her colleagues used observations and simulations to diagnose the surface ozone levels over the southeast United States during 1988-2011. They showed that climate warming will lead to increases in surface ozone levels. A key to their discovery was recognizing that the interannual variation of August surface temperatures over the southeast U.S. during 1988-2011 was mainly a manifestation of a large-scale temperature oscillation in which almost the entire North American continent was in the same phase. Thus, during 1988-2011 and on the interannual timescale, August surface ozone over the southeast U.S. was perturbed by large-scale temperature variations, which offers a unique opportunity to diagnose the sensitivity of ozone to large-scale warming.

The study found that the sensitivity of ozone to large-scale warming over the southeast U.S. was consistently positive during 1988-2011. However, that sensitivity varied interannually by a factor of three (2.4 to 7.1 ppb/K). Fu and her colleagues found that such variability was mainly driven by the variability in ozone transport by regional atmospheric circulation. They further showed that, over a longer timespan (1948-2012), the sensitivity of regional ozone transport to temperature changed signs on interannual and interdecadal timescales, with potential links to the Atlantic Multidecadal Oscillation.

This study showed that prediction of future ozone changes will require climate-chemistry models with more realistic representations of climate variability and its drivers, such as models initialized with observed ocean conditions. Long-term management of ozone air quality must consider the variability of the sensitivity of ozone to climate warming to ensure consistent attainment of ozone air quality standards in the future.

This work was mostly conducted by Dr. Tzung-May Fu and her undergraduate student Ms Yiqi Zheng (now PhD student at Yale University), in collaboration with researchers from Harvard University and Princeton University. This work was funded by the Ministry of Science and Technology of China and the National Natural Science Foundation of China.

Reference:

Fu, T.-M.*, Y. Zheng, F. Paulot, J. Mao, and R. M. Yantosca (2015), Positive but variable sensitivity of August surface ozone to large-scale warming in the southeast United States, Nature Climate Change, 5, 454-458, doi:10.1038/nclimate2567.





## 09 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、2014 年 10 月，钟锡华教授出版了教材《电磁学通论》，出版者为北京大学出版社

本书系经典电磁学的一本教材，内容共八章： 静电场，静电场中的导体和电介质，恒定电流场和

直流电路，恒定磁场，磁介质，电磁感应，交流电路以及麦克斯韦电磁场理论。配置习题 218 道，其中五成系新编；特设讨论题 32 道，品种各异，系课程内容的深化和延伸，尤其适用于小班讨论课。

本书系钟锡华教授的又一本力作，四度沉淀，心力所至。散度旋度，贯穿全书；边值关系，大有作为；余弦型球面电荷和正弦型球面电流成为两个新典型，其球内均匀场与其球外为偶极场，两者相映成趣。平实无华，无奇有新意，是本书的品格。论述阐述深刻富有思想性，分析推演简捷有独到之处，物理图象丰富清晰，语言明净生动，是本书的显著特色。

**I. In October of 2014, Prof. Xi-Hua Zhong published one textbook titled "A General Course in Electromagnetism". The publisher is Peking University Press.**

As a textbook, this book consists of eight chapters, which include
(1) Electrostatics;
(2) Conductor and Dielectric in electrostatics;
(3) Stationary current and circuits;
(4) Magnetostatics;
(5) Magnetic materials;
(6) Law of induction;
(7) Time-varying current and circuits;
(8) Maxwell equations.
The book contains also 218 problems for home assignments. More than one half of them were made by the author. Especially, 32 special topics were proposed, too. They should be useful to the leaders of discussion sessions.
On this book, the author, who has taught this course for many years during four periods, spent a great amount of time. In particular, the author emphasizes the importance of concepts of divergence and curl of vector fields as well as the boundary-value problems from the beginning chapters of this book. For example, the fields produced by the electric charge distribution and current density of sinuous type rather than the conventional uniform ones on a sphere are calculated. These changes may seem minor. However, they do make this book more illuminating to students. As readers will see, in general, the author gives a quite intuitive physical picture and motivation before he solves a concrete problem. Therefore, the arguments presented in the following analyses are very easy to understand. Indeed, the author of this book is very capable of explaining difficult concepts and techniques by simple languages.

## 10 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，并开设研究型的“综合物理实验”和“前沿物理实验”选修课。目前在岗专职教师 9 名（教授 2 名，副教授 6 名，讲师 1 名），实验技术人员 7 名（高级工程师 1 名，工程师 6 名）。





The Teaching Center for Experimental Physics at Peking University is a national demonstration center of experiment teaching. It is mainly engaged in teaching of “General Physics Experiment” and “Modern Physics Experiment”, which are of high-quality nationwide and belong to “National Outstanding Courses”. Besides, the center gives research courses called “Comprehensive Physics Experiment” and “Frontier Physics Experiment” to students who are willing to investigate some experimental problems. Now there are 16 faculty members in the center, in which are 2 professors, 6 associate professors, 1 lecturer, 1 senior engineer, 6 engineers.

### 一、“多功能拉曼光学显微镜”荣获全国高校物理实验仪器评比一等奖

2016 年 7 月 20 日，在教育部物理学与天文学教学指导委员会、中国高校实验物理教学研究会主办、青海大学承办的第九届全国高校物理实验教学研讨会实验仪器评比上，基础物理实验教学中心的“多功能拉曼光学显微镜”荣获一等奖，并在 7 个一等奖中排名第一位。该仪器由中心教师张朝晖、刘国超等研制，具有以下三个方面的基本功能：

（1）配合一台光谱仪，可形成完整的拉曼光谱系统，实现显微拉曼光谱检测和拉曼光谱扫描成像（Mapping）。

（2）配合一台电流电压源表，可形成独特的光电综合测试探针台，实现纳米材料及器件的场效应特性检测和光电流扫描成像。

（3）综合使用以上两种配置，可实现纳米材料光谱和光电性能的同步原位逐点综合检测。

这些功能不仅适用于近代物理实验、研究型综合物理实验、前沿物理实验的教学，也可满足纳米材料测试与表征的基本科研需求。

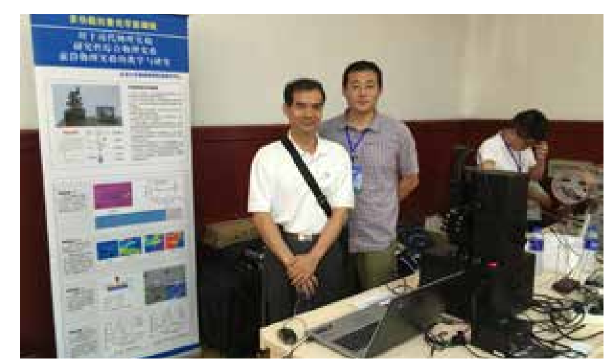


图 1：参评现场的张朝晖老师和刘国超老师

Fig 1: Zhao Zhaohui and Liu Guochao at the instrument evaluation.

图 2：多功能拉曼光学显微镜的实物照片

Fig 2: Multifunctional Raman Optical Microscope.

### I. The “Multifunctional Raman Optical Microscope” won the first prize of national college physics experimental instrument evaluation

In July of 2016, the instrument of “Multifunctional Raman Optical Microscope”, developed by Zhang Zhaohui and Liu Guochao in Teaching Center for Experimental Physics, won the first prize at the ninth session of national college physics experimental instrument evaluation and was ranked first in the seven winners. This instrument evaluation was sponsored by the Directing Committee for Physics and Astronomy in the Ministry of Education and Institute of Experimental Physics Teaching in Chinese Colleges and Universities and organized by Qinghai University. The "Multifunctional Raman Optical Microscope" has the following three basic functions.

(1) A complete Raman spectroscopic system can be formed to realize Micro-Raman spectroscopy and Raman spectral mapping if the instrument is combined with a spectrometer.

(2) A comprehensive optoelectronic probe station can be formed to realize field-effect detection and photocurrent imaging of nanomaterials and nanodevices, if the instrument is combined with current and voltage sources and meters.

(3) Synchronous and in situ point by point detection of spectroscopic and optoelectronic properties of nanomaterials can be realized by combining the above two configurations.

These functions not only apply to the teachings in "Modern Physics Experiment", "Comprehensive Physics Experiment", and "Frontier Physics Experiment" but also meet the needs of nanomaterial characterization in scientific research.

## 二、"科研引领实验教学"理念取得重要成果

长期以来，基础物理实验教学中心以"科研引领实验教学"的理念推动队伍和课程建设。鼓励在岗教师积极申请承担科研项目，并且给予配套经费，在基础物理实验教学的过程中插入研究型的实验课程，建设研究型的实验教学平台，培养优秀本科生的科研创新能力，取得了非常好的效果。近两年来，中心教师在研究型实验课程中指导本科生开展科研工作，本科生为第一作者的研究论文发表在Nano Letters、Nanoscale、Applied Physics Letters、Optics Letters 等国际重要学术刊物上，为物理学院的本科生拔尖人才培养做出了突出贡献。在此过程中，中心教师本身也获得了可喜的提升，例如，在物理学院职称晋升的激烈竞争中，青年教师杨景于 2015 年晋升为副教授。

这方面一个典型的例子是表面等离激元方向可控激发的研究。金属表面等离激元可以突破光学衍射极限，被认为是下一代信息技术的可能候选，是纳米光子学领域的研究热点之一。而表面等离激元的高效、方向可控激发是实现各类表面等离激元应用的基础。现有研究主要集中于利用不同表面等离激元激发单元之间的相干相消效应来获得单向激发，需要一定的传播距离来获得相干相消所需要的相位差，因此，表面等离激元单向激发器的尺寸通常比较大。中心青年教师李智、廖慧敏提出利用单个单元的纳米天线结构，借助附加腔在天线内的不同光学模式间进行高效能量转移，并进一步通过不同对称性的光学模式之间的干涉实现表面等离激元的方向可控激发。利用这一新机制，不仅在实验上获得了带宽超过 200 纳米的表面等离激元宽带单向激发，还实现了不同波长下激发方向的反转，而器件的横向尺寸不到一个波长，有效实现了亚波长尺度的表面等离激元方向可控激发，有可能在超高集成度表面等离激元器件中获得广泛应用。研究论文发表在《纳米快报》[Nano Letters 15, 3115–3121 (2015)]，本科生姚文杰、刘尚是论文的共同第一作者，相关研究成果还申请了三项国家发明专利和一项实用新型专利。在此基础上，通过不同亚波长结构单元的级联，实现了高效表面等离激元单向激发器，实验中在横向尺寸 1.1 微米的器件上获得了超过 46% 的表面等离激元单向激发效率，是当时国际上报道的在这么小的尺寸下获得的最大绝对效率，研究论文发表在《纳米尺度》[Nanoscale 8, 6777–6782 (2016)]，本科生宋雪洋、张正兴是论文的共同第一作者。





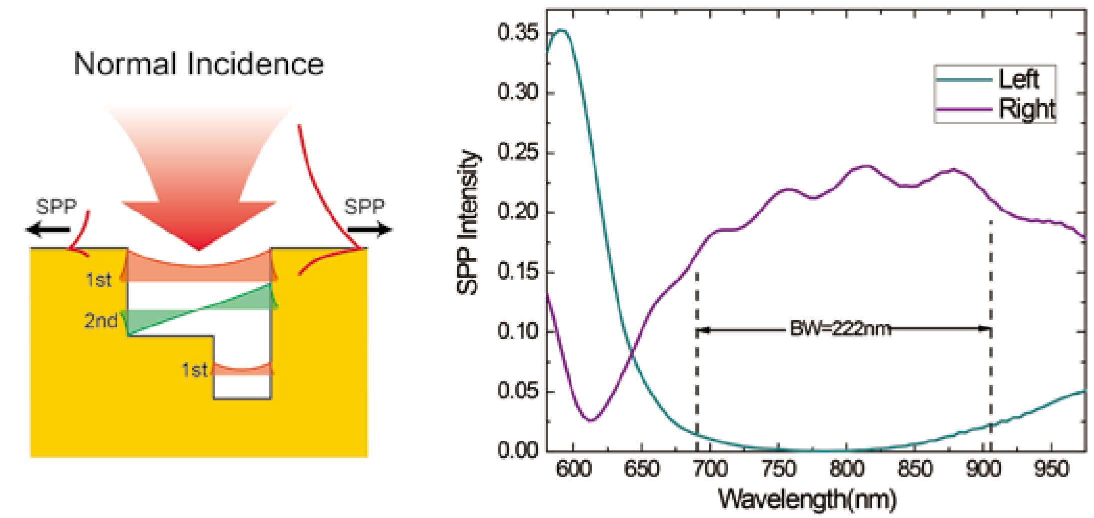



图 3：基于模式转换和模式干涉的表面等离激元方向可控激发

Figure 3: The directional excitation of SPPs based on mode conversion and mode interference.

## II. The idea of "leading experiment teaching by scientific research" achieved important results

The Teaching Center for Experimental Physics has promoted the team building and course construction with the idea of "leading experiment teaching by scientific research" for a long time. We encouraged teachers to apply for research projects, and gave necessary supporting funds. We also encouraged teachers to introduce research progresses to basic physics-experiment teaching and to construct research-based teaching platforms. Thus, we could train excellent undergraduate students to develop the ability of scientific research and innovation. These efforts have achieved very good results. In the past two years, under the direction of our teachers, undergraduates as first authors have published research papers in several important international academic journals, including Nano Letters, Nanoscale, Applied Physics Letters, Optics Letters and so on. Our works made outstanding contributions to the cultivation of scientific research ability of undergraduates. Meanwhile, our teachers also acquired a development. For instance, the young teacher Yang Jing was promoted to associate professor in 2015 in the fierce competition of title promotion.

A typical example of these achievements was the study of the directional excitation of surface plasmon polaritons (SPPs). SPPs can break the optical diffraction limit and are considered as possible candidates for the next generation of information technology. The efficient directional excitation of SPPs is important to exploit various SPP applications. The previous studies mainly focused on utilizing interference effects of different SPP sources to obtain unidirectional SPP excitations. This mechanism requires a certain propagation distance to accumulate sufficient phase differences to realize destructive interference. Therefore, the device size is usually large. Young teachers Li Zhi and Liao Huimin in our center proposed to use ultracompact nanoantenna with a lateral dimension of less than one wavelength to achieve directional SPP excitation. By adding an auxiliary resonant structure to the plasmonic nanoantenna, the highly efficient lowest-order antenna mode was effectively transferred into inactive higher-order modes. On the basis of this mode conversion, scattered optical fields were well manipulated by utilizing the interference between different antenna modes. Both broadband unidirectional excitation of SPPs and inversion of SPP launching direction at different wavelengths were experimentally demonstrated. The proposed strategy based on mode conversion and mode interference provides new opportunities for the design of nanoscale optical devices. The research paper was published in Nano Letters [15, 3115–3121 (2015)]. Undergraduates Yao Wenjie and Liu Shang contributed equally as first authors to the work. They also applied for three invention patents and one utility model patent for the related research. Furthermore, highly efficient unidirectional SPP excitation was successfully demonstrated by cascading identical subwavelength nanoantennas. A high SPP unidirectional excitation efficiency of at least 46% was achieved with a small lateral device size of 1.1 μm. The research paper was published in Nanoscale [8, 6777–6782 (2016)]. Undergraduates Song Xueyang and Zhang Zhengxing contributed equally as first authors to the work.

## 11 电子显微镜专业实验室 Peking University Electron Microscopy Laboratory

北京大学电镜室始建于 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，其中透射电镜 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国际上先进的球差电镜用于材料科学和一台冷冻电镜用于生命科学，实验室仪器总价值已接近 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，实验室主任俞大鹏院士，学术委员会主任叶恒强院士，工程技术系列的老师 8 位。其中，有博士学位的 8 人，高级职称 9 人（含两位教授级高级工程师），平均年龄 44 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。

北京大学电子显微镜实验室的两台球差矫正电镜的配置属于国际领先。其中一台是双球差矫正的 FEI-Themis，空间分辨率高达 60pm，配置很齐全，包括 DPC，球差矫正的 Lorentz 模式，多能谱探头，电子能量损失谱等 。另外一台是美国 Nion 公司的 40-200 kV 的带有单色仪的 HERMES，主要特色是能量分辨率高达 6meV（目前 60kV 的最高纪录），并且空间分辨率在 200kV 也高达 60pm，而且高真空系统无污染，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（Oneview IS, K2 IS），能够高速纪录相变反应，以及对电子束敏感材料成像。

Electron Microscope Laboratory (EML) in Peking University is a user facility center, which was founded in 1964. Now EML is 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 abreactions corrected TEMs for materials science, i.e., High energy resolution spherical aberration correction electron microscope Nion U-HERMES with energy resolution better than 8meV, and FEI Titan Cubed Themis transmission electron microscope with 60 pm in spatial resolution 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 freeze electron microscope and ThermoFisher Helios G4 UX focused ion beam system are also the most advanced electron microscope in the world now. Totally, there are more than 40 large instruments with price more than 400,000 RMB for each. The total value of the instruments is about 150,000,000 RMB. Now there are 11 staffs in the laboratory including 2 academicians of CAS, one 'Youth 1000 Talent Program' fellow. In the staff team, there are 8 with senior professional titles and 9 with a doctor's degree.

Each year, EML provides characterization services for more than 200 research groups in different departments in 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 24 hours in 365 days unless they are under service. Typically, EML serves more than 200 Research Fund Projects every year. In the last a few years, there are hundreds of publications that contain data acquired from EML.

### 一、利用原位透射电镜方法学追踪二维材料中的离子迁移行为

锂离子和钠离子电池具有能量密度高、安全性好、污染小等优点，在新型储能器件领域具有巨大的应用前景。但是锂、钠离子电池也存在容量衰减、循环寿命短、极端温度下工作性能差等缺陷。因此，发展新材料，探究其中离子迁移机制、容量衰减机理是国内外该领域的研究重点。二维材料具有独特的物理化学性质，是离子电池电极的理想材料，其离子迁移行为是决定电池性能的重要因素。然而，从原子尺度上理解电极反应、设计高性能的电极体系仍然是该领域面临的难题。

电子显微镜实验室高鹏研究员课题组在透射电子显微镜中搭建了微观原位测量系统，发展了原子尺度下的原位观察技术，可以实现离子迁移过程及结构演变的实时跟踪。基于这项技术，他们对一系列二维电极材料中的锂离子、钠离子迁移过程进行了原位观察。他们发现对于二维材料 $SnS_2$，锂离子的嵌入会引发快速的两相反应，引起 $SnS_2$ 的体积膨胀并生成有缺陷的 $LiSnS_2$ 相。然而锂离子的脱出过程却是固溶反应，出现了 $Li_{0.5}SnS_2$ 的超结构中间相，且展现出各向异性的成核过程，超结构相的尺寸为 1-4 nm，如图 1 所示。密度泛函理论计算表明，$Li_{0.5}SnS_2$ 的中间相具有良好的动力学性能和结构稳定性。不对称的反应路径解释了宏观电池电化学测试中观察到的大电压回滞和低能量效率，表明碱金属离子在二维材料中嵌入和脱出反应明显地区别于其他的离子键、共价键的电极材料，这是由二维材料中独特的 van der Waals 相互作用决定的。该项研究对揭示层状电极材料中的电化学机理提供了启发性的见解，为理解电极材料中电压迟滞问题的起源提供了新思路。相关结果发表

在 Nano Letters 16, 5582 (2016) 上。

与 Li 相比，Na 成本低廉，然而虽然同为碱金属元素，其离子迁移行为却与锂离子不尽相同。例如商用的锂离子负极材料石墨，就完全不能被 Na 离子嵌入，因此寻找合适的电极材料并揭示其离子迁移机制仍具有很大挑战。二维材料的层间由范德瓦尔斯力作用，有较大的层间距，适合 Na 离子的嵌入与脱出，是理想的电极材料。通过原位电子显微技术，他们发现 MoS2 中 Na 的嵌入反应遵循两相反应机理，即三棱柱结构的 2H-MoS2 相转变为八面体 1T-NaMoS2 相，新形成的 1T-NaMoS2 相含有高密度的缺陷和尺寸为 ~3-5 nm 的超结构微区。两相之间存在约 2 nm 宽的相界，相界面的扩散速度<10 nm/s，这比 Li 离子扩散速度小了 1 个数量级。这是因为 Na 离子更大的质量和直径导致其迁移势垒高，展现出更为迟缓的插层动力学。该项研究结果为寻找合适的钠电极材料和了解二维过渡金属硫族化合物 MoS2 的性质提供了有价值的参考和解读。相关结果发表在 ACS nano 9 (11), 11296 (2015) 上。

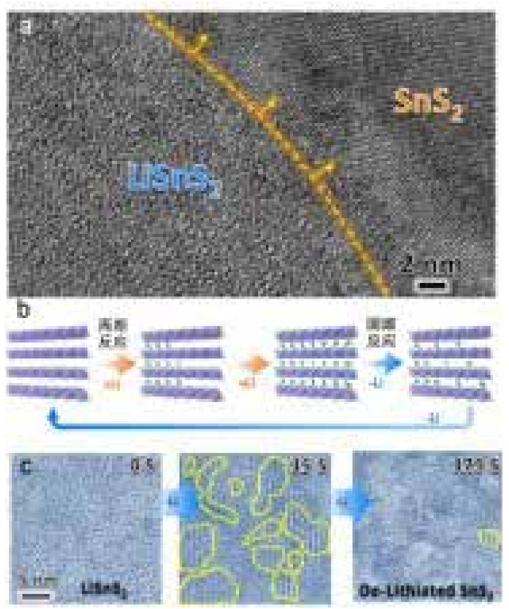



图 1：原子尺度上实时跟踪锂电池电极材料 SnS2 中的离子迁移过程。（a）锂离子嵌入过程中 LiSnS2/SnS2 界面的高分辨 TEM 图像；（b）锂离子嵌入和脱出反应示意图；（c）原位高分辨技术记录了锂离子脱出过程中超结构中间相的生成，及其不均匀的成核过程。

Fig. 1: In-situ Tracking ion migration in electrode material SnS2 of lithium ion battery at atomic resolution. (a) High-resolution TEM images of LiSnS2/SnS2 interface during Li migration; (b) The schematic diagram of lithiation and delithiation reaction; (c) In situ high-resolution technique recorded the formation of intermediate superstructure phase and the heterogeneous nucleation during lithiation.

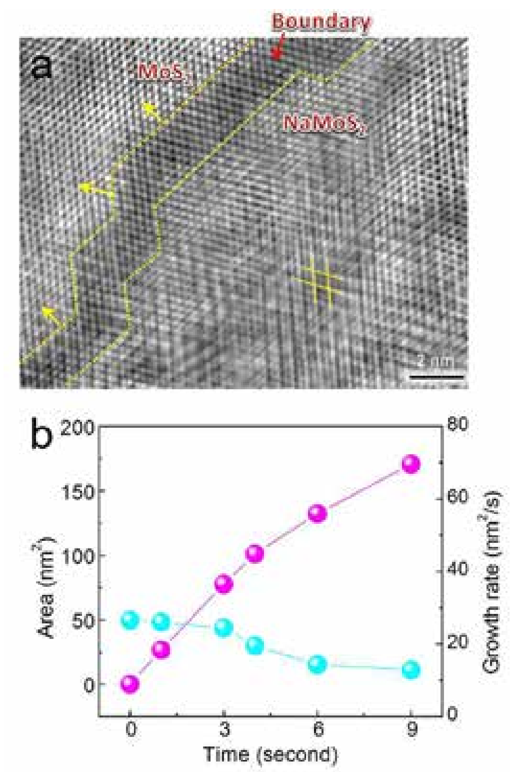



图 2：原子尺度上实时跟踪 MoS2 中的 Na 离子迁移过程。（a） 2H-MoS2 和嵌 Na 后生成的 1T-NaMoS2，其间存在约 2nm 宽的相界。（b）MoS2 中 Na 迁移的面积和扩散速率。

Fig. 2: In-situ Tracking sodium ion migration in MoS2 at atomic resolution. (a) The phase boundary of 2H-MoS2 and 1T-NaMoS2; (b) Area of the sodium-intercalated domain and growth rate (change in domain area with time) are plotted as a function of time.





## I. Tracking ion migration in 2D materials by in situ electron microscopy

Lithium ion batteries and sodium ion batteries have the advantages of high energy density, safety and less pollution, etc., which have great application prospects in the field of new energy storage devices. However, their practical application also involves challenge, such as capacity fade, short cycle life and unsatisfactory performance at extreme temperatures. Therefore, developing new materials, exploring the mechanism of ion migration and the capacity fading are the focus of this field at home and abroad. Two-dimensional materials involve unique physical and chemical properties, which are ideal materials for ion battery electrodes. However, understanding electrode reactions at the atomic scale and designing high-performance electrode systems are still challenges in this field.

A group led by Prof. Peng Gao in Electron Microscope Laboratory has achieved progress in this field recently. By using in-situ TEM technique, they successfully tracked the ion migration and structure transformation in real time at atomic resolution. Based on this advanced technique, they found that in SnS2, the lithium insertion occurs via a fast two-phase reaction to form expanded and defective LiSnS2, while the lithium extraction involves heterogeneous nucleation of intermediate superstructure Li0.5SnS2 domains with a 1-4 nm size. Density functional theory calculations indicate that the Li0.5SnS2 is kinetically favored and structurally stable. Asymmetric reaction path explains the large voltage hysteresis and low energy efficiency observed in macro cell electrochemical test, and indicates that the alkali metal ions reaction in two-dimensional materials is different from other materials with ionic bond and covalent bond, which result from the unique van der Waals interactions in the 2D materials. This study provides an enlightening insight into the electrochemical mechanism of layered electrode materials and also suggest possible alternatives to the accepted explanation of the origins of voltage hysteresis in the intercalation electrode materials. This work has been published in Nano Letters 16, 5582 (2016).

Compared with lithium ion, Na costs less. However, its ion migration behavior is different from lithium ion. For example, graphite, a commercial lithium ion anode material, cannot be inserted by Na ions at all. Hence, it is still a great challenge to find suitable electrode materials and reveal the ion migration mechanism. Due to the action of van der Waals force, the two-dimensional materials have relatively large interlayer spacing, which is suitable for Na ion insertion. Using in-situ TEM, they found that Na intercalation follows the two-phase reaction mechanism, i.e., trigonal prismatic 2H-MoS2 → octahedral 1T-NaMoS2. The newly formed 1T-NaMoS2 contains high density of defects and series superstructure domains with typical sizes of 3-5 nm. The phase boundary is 2 nm thick. The velocity of the phase boundary (<10 nm/s) is 1 order smaller than that of lithium diffusion, suggesting sluggish kinetics for sodium intercalation. These results provide valuable insights into finding suitable Na electrode materials and understanding the properties of transition metal dichalcogenide MoS2. This work has been published in ACS nano 9 (11), 11296 (2015).

系所中心研究亮点 | *Highlights*

## 二、基于球差矫正的定量 ABF 技术在皮米尺度上测量铁电薄膜的表面重构

表界面和缺陷在固体材料的物理性能和化学性能中都起着非常重要的作用，研究他们的结构物性，从而调控、设计表界面和缺陷是现代许多科学技术的核心。在铁电材料的表面，由于极化不连续而产生的束缚电荷会造成自由载流子的重新分布或者表面重构。这种表面层具有和体相不同的性质，对铁电数据存储、传感器、表面化学等应用有很重要的影响。因此，研究铁电材料的表面结构具有非常重要的意义。

虽然关于铁电材料表面结构和性质的理论研究有很多，其中就有研究指出在铁电材料的表明结构取决于表面以下的极化取向，但是关于铁电材料表面的实验报道非常有限。采用体相的表征方法，比如 X 射线技术很难获得样品表明与亚表面的结构信息。另一方面，经常采用的表面探测技术，比如扫描隧道显微镜 (scanning tunneling microscopy) 很难应用到像铁电氧化物材料这样的绝缘体系中，也不能获得表面以下的原子结构。因此，关于铁电材料表面和亚表面层的细节信息，包括极化，应力和氧八面体畸变等仍然不清楚。近些年在球差矫正透射电子显微镜中发展起来的环形明场成像技术 (annular bright-field) 可以同时看到较重的过渡金属阳离子和较轻的氧离子，为准确测量铁电材料表面的原子结构成为提供了可能，并且可以同时观察到材料的表面和亚表面原子结构，可以直接研究表面结构和亚表面结构之间的关系。

北京大学电子显微镜实验室的高鹏研究员团队紧紧围绕铁电表面的结构问题展开研究，并取得了重要的研究进展。他们利用高空间分辨的环形明场成像技术，研究了铁电薄膜 PbZr0.2Ti0.8O3 (PZT) 的表面结构，在皮米尺度上测量了表面上原子键长之间的细微变化，发现 PZT 的表面附近几层的原子结构依赖于表面下的极化取向，在表面薄层中存在“铁电死层”和高能的带电畴壁。通过研究不同铁电畴对应的表面结构，他们发现表面结构受到表面以下极化取向的控制。对于极化向上的表面 (positively poled surfaces)，表面层极化取向和下面一致，不存在结构重建；对于极化向下的表面 (negatively poled surfaces)，有 6 个原子层厚度的极化抑制层和一个带电的 180 度畴壁；对于极化取向平行于表面的情况，有 7 个原子层厚度的极化抑制层和一个带电的 90 度畴壁。他们的实验结果表明实际的铁电薄膜表面结构非常复杂，强烈依赖于表面以下的极化取向。相关研究成果发表在 Nat. Commun. 7, 11318 (2016)。这些发现为铁电薄膜、铁电陶瓷、铁电表面催化等应用提供了非常重要的信息。同时，发展起来的基于环形明场像技术定量测量绝缘氧化物表面结构的方法将极大地提高人们对这些复杂功能氧化物材料物性的认知。

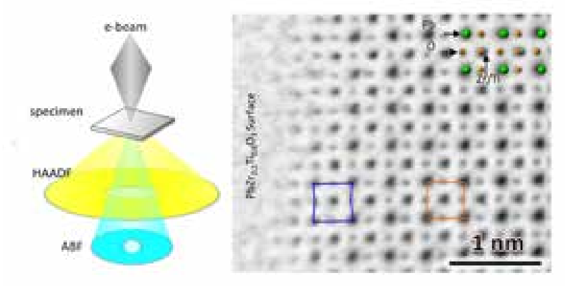



图 1：（a）环形明场成像原理示意图。（b）环形明场像的 PbZr0.2Ti0.8O3 薄膜的表面结构。

Figure 1. (a) Schematic of annular bright-field (ABF) imaging. (b) An atomically resolved ABF image of the PbZr0.2Ti0.8O3 negatively poled surface. The viewing direction is along [010]. Scale bar, 0.5 nm.

## II. Atomic mechanism of polarization-controlled surface reconstruction in ferroelectric thin film

Surfaces and defects have significant effects on the properties of materials and have been the core of many modern science and technology. At the ferroelectric surface, the broken translational symmetry induced bound charge should significantly alter the local atomic configurations. Thus, revealing the surface structure and relation with the subsurface is vital for applications in electronic devices and lies at the heart of the ferroelectric surface chemistry.

Despite a lot of simulation efforts have so far been devoted and various properties of ferroelectric surfaces have been predicted, only few experimental studies can be found. By using those bulk-based techniques such as the X-ray characterization, it is extremely difficult to extract the information of surface structures or determine the relation with subsurface structures because of the strong spatial variety between nano-sized domains and ultrathin thickness of surface reconstruction layers. On the other hand, the commonly used surface probe technique scanning tunneling microscopy (STM) is usually not suitable to study these insulator-like ferroelectric oxides and unable to obtain the information underneath the surface. The details of a ferroelectric surface layer (including both the topmost surface skin and nearby subsurface structure) such as the polarization, strain and octahedral tilt, therefore, remain exclusive. Recently, the advancements of the annular bright-field (ABF) imaging in an aberration corrected scanning transmission electron microscope have made it possible to simultaneously determine both the heavier cation and lighter oxygen positions in oxides, allowing us to precisely measure the structural parameters at both the surface and subsurface of functional materials irrespective to their conductivities.

Peng Gao group in Peking University has achieved progress in this field. By using the ABF, they find that under negatively poled surfaces, there are six atomic layers with suppressed polarization and a charged 180 degree domain wall, while no reconstruction exists at positively poled surfaces. And there are seven atomic layers with suppressed polarization and a charged 90 degree domain wall exist under nominally neutral surfaces in ferroelastic domains. The results have been published in Nat. Commun. 7, 11318 (2016). These results provide critical insights into engineering ferroelectric thin films, fine grain ceramics and surface chemistry devices. The state-of-the-art methodology demonstrated here can greatly advance our understanding of surface science for oxides.

# 12 量子材料科学中心 International Center for Quantum Materials

北京大学量子材料科学中心成立于 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，量子材料科学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 2016 年 12 月，中心已有全职到岗教师 25 人，

其中特聘讲席教授 1 人，讲席教授 4 人，教授 3 人，长聘副教授 5 人，预聘副教授 / 助理教授 12 人。每名教师建有独立的研究小组，实行项目负责人制。成员中 1 人获诺贝尔物理学奖，2 人当选中国科学院院士，2 人入选中组部“海外高端人才计划”，3 人当选中国教育部“长江学者特聘教授”，7 人曾获国家杰出青年科学基金，5 人入选基金委优秀青年基金项目，15 人入选中组部“海外高端人才计划（青年）”，1 人入选中组部“青年拔尖人才支持计划 ”。

量子材料科学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，目前中心有博士后 14 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 142 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。

量子材料科学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、凝聚态物理计算五个研究部分。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（包含正在建设中的 3 个实验室）15 个独立实验室及 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 ( 北京大学液氦车间 )。

量子材料科学中心自成立以来，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 2016 年 12 月，中心共发表 SCI 论文 480 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 30 余项，科研经费总计约 1.8 亿元人民币，其中包括科技部“973 计划”5 项、国家自然科学基金重大专项 1 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、陈嘉庚科学奖、华人物理学会亚洲成就奖、求是杰出青年学者奖、马丁伍德爵士中国物理科学奖、国际纯粹与应用物理学联合会青年科学家奖、教育部“创新团队”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 founding of International Center for Quantum Materials (ICQM) in 2010 marked a major initiative taken by Peking University, aiming to create a platform of world-class excellence for physics research and education. ICQM has since been committed to building interdisciplinary research programs that span a wide spectrum of topics in condensed-matter and materials physics, to be based concretely on an intellectual environment that attracts scholars of the highest-caliber, and on a flexible and supportive infrastructure that promotes creativity, collaboration and exploration at the leading edges.

ICQM is dedicated to bringing in both internationally-renowned scientists and excellent young researchers and enabling them to work together productively in a dynamical culture. Located in Beijing and amid the fast



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socioeconomical transformation of China, ICQM endeavors to implement new academic systems that include two major components: independent research groups lead by principle investigators and tenure appraisal system. As of December 2016, ICQM has on its faculty 4 Chair Professors, 3 tenured Professors, 5 tenured Associated Professor, 12 tenure-track faculty members. Among the senior researchers are 1 Nobel Laureate, 2 Member of Chinese Academy of Sciences and 4 Fellows of American Physical Society. At full strength, ICQM will have research personnel consisting of 40 permanent members and over 200 Ph.D. students and postdoctoral fellows.

ICQM also provides first-rate research opportunities and solid training to younger scientist, including postdoctoral researchers and graduate students from both domestic and foreign institutions. In the past few years, ICQM has hosted 14 postdocs, several of whom have made important progresses in their research. The graduate students of ICQM are typically graduates from top Chinese universities, with exceptional academic performances. In addition to research, young researchers at ICQM are also profusely exposed to a wide-range of frontier topics research through a rich array of academic activities, such as seminars, lectures and summer schools.

Based on field of expertise, the research at ICQM is organized into 6 divisions, namely

- ● Low temperature and quantum transport experiments;
- ● Spintronics and low-dimensional magnetism experiments;
- ● Spectroscopy and high-resolution detection experiments;
- ● AMO experiment and precision measurement;
- ● Theoretical condensed matter physics;
- ● Computational physics.

Topics and systems of current interest include quantum transport, strongly-correlated electron systems, low-dimensional quantal 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, soft matters materials, and lots beyond. ICQM has 12 fully operational experimental laboratories with 3 more under construction, supported by a shared nanofab facility and a helium center. The PKU Daniel Chee Tsui laboratory is affiliated to ICQM, which will focus on extremely low temperature physics.

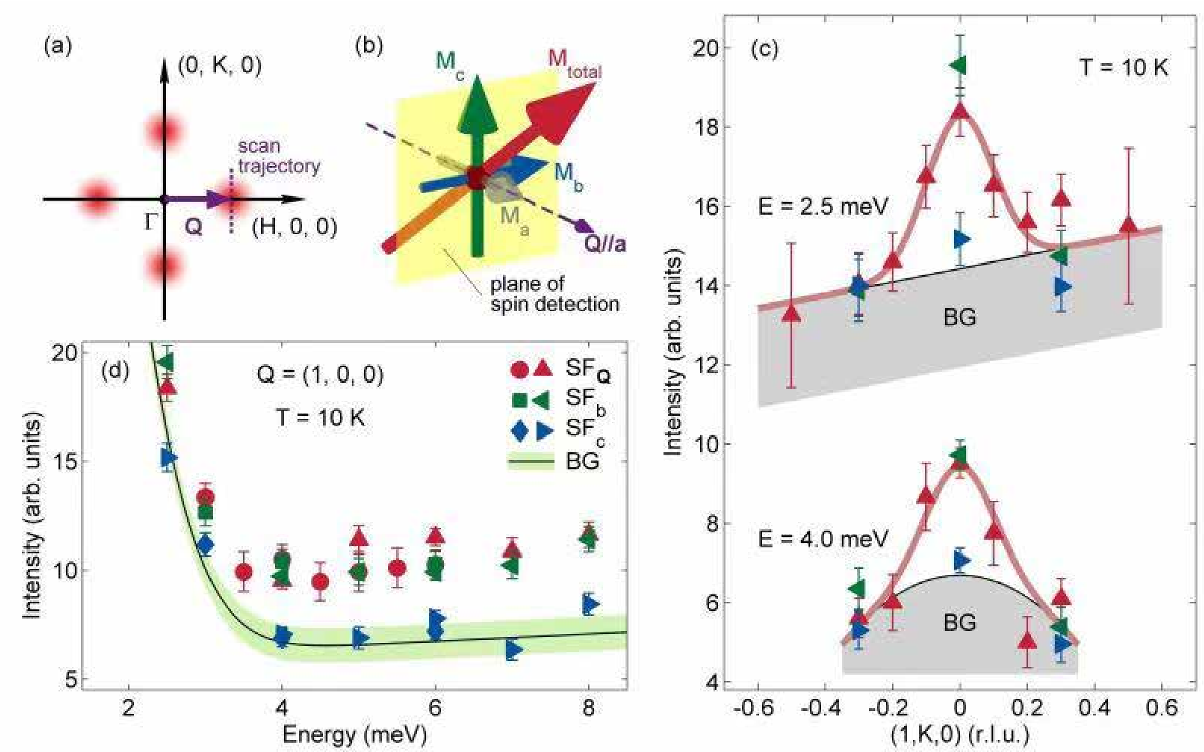
Up to December 2016, ICQM has 480 SCI publications, many of which were published in the most influential scientific journals in the world, such as Science, Nature series journals, Physical Review Letters, etc. The research funding received by ICQM faculty members from Chinese research funding agencies has almost reached 180 million RMB. ICQM members have garnered many national and international awards, such as ACCMS Award, Ho Leung Ho Lee prize, OCPA AAA-Poe Prize, State Natural Science Award.

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

系所中心研究亮点 | *Highlights*

## 一、铁基超导材料中的向列序和自旋 - 轨道相互作用

在铁基高温超导材料中有两种主要的电子自组织行为，其一为超导电子配对，其二为电子对晶格四重旋转对称性的破缺，形成所谓的向列序。由于两种行为为密切相关，向列序的形成机理成为了领域中的重要问题，主要争论之一是究竟是电子的自旋还是轨道自由度驱动了向列序的形成。FeSe（块体）超导材料由于不具有长程磁有序，被视为解决这一问题的重要突破口。本系列工作中，我们从两个角度，澄清了电子自旋和轨道自由度对向列序的影响，同时发现了两种自由度之间的协同关系。通过高分辨的拉曼光谱实验，我们对比了 FeSe 和 BaFe2As2 体系中的晶格振动在向列序中出现的能级劈裂，发现电子的自旋相互作用虽然在 FeSe 中没有最终导致磁有序，但仍是能级劈裂的主要驱动力 [1]。而通过自旋极化的中子散射实验，我们测定了 FeSe 中的低能自旋激发，发现自旋只能沿晶格的 c 轴方向振动；这种自旋空间的各向异性表明向列序中的自旋 - 轨道耦合给 FeSe 中的磁性带来了显著的影响 [2]。




图：通过比对沿不同方向的自旋翻转（spin-flip, SF）通道中的非弹性中子散射信号，我们发现 FeSe 中能量在 8 meV 以下的自旋激发只含有沿晶体 c 轴方向的分量。

Figure: By comparing spin-flip (SF) inelastic scattering signals measured with incoming neutron spin along different directions, we discovered that all spin excitations in FeSe below 8 meV are polarized along the crystallographic c direction.

## I. Nematic order and spin-orbit interactions in Fe-based superconductors

In Fe-based superconductors, there are two important types of self-organization of electrons, namely, the superconducting Cooper pairing, and the spontaneous breaking of four-fold lattice rotational symmetry by the so-called nematic order. As the two types of ordering may be driven by a common mechanism, the origin of the nematic order is focus of major research effort, a central question being whether it is the spin or orbital degree of freedom that drives the nematic order. The FeSe (bulk) superconductor is regarded as an important system to resolve this issue because it possesses nematic order but no long-range magnetic order. In our laboratory, we elucidated the microscopic origin of the nematic order and the importance of spin-orbit interactions in FeSe by performing scattering spectroscopic measurements. Using Raman spectroscopy, we quantitatively compared lattice vibrational modes in FeSe and BaFe2As2 that undergo an energy splitting upon the formation of the nematic order. We show that, despite the fact that electronic spin interactions in FeSe do not lead to long-range magnetic order, they do exert a strong influence on the lattice dynamics and is primarily responsible for the splitting [1]. Then, using spin-polarized inelastic neutron scattering, we determined the nature of low-energy spin excitations in FeSe, and found that they are primarily along the crystallographic c direction. The distinct spin-space anisotropy highlights the prominent role of spin-orbit interactions in defining magnetism in the nematic phase of FeSe [2].

Related publication and preprint:

[1] Y. Hu et al., Phys. Rev. B 93, 060504(R) (2016).
[2] M. Ma et al., Phys. Rev. X 7, 021025 (2017).

## 二、二维人工自旋轨道耦合的实现和新发展

自旋轨道耦合是量子物理学的基本物理效应。过去十几年来对自旋轨道耦合的相关研究产生了自旋电子学，拓扑绝缘体，拓扑超导体等重大前沿领域。但因普遍存在难控制的复杂环境，很多新奇物理难在固体中精确研究，这带来挑战。这些挑战可能通过超冷原子量子模拟解决。这使得在超冷原子中实现人工自旋轨道耦合，研究新型量子物态成为重要课题。超冷原子中一维自旋轨道耦合的实验（2011Nature）是基于我们 2009 年初 PRL 工作所指出的方案。然而，在过去数年里实验仅做出一维人工自旋轨道耦合（对应 Abelian 规范势），而探索广泛的新奇拓扑量子物态须获得二维及以上自旋轨道耦合（对应 non-Abelian 规范势）。因而过去数年里，实现超冷原子高维自旋轨道耦合成为该领域公认的关键重要课题，同时也存在很大挑战。为克服根本困难，北大刘雄军带领的小组提出了称作为拉曼光晶格（optical Raman lattice）的量子系统，并发现基于该系统，不仅可完好实现二维人工自旋轨道耦合，并能自然地得到如量子反常霍尔效应和拓扑超流等一系列基本物理效应。刘雄军组进一步针对 87Rb 玻色子设计了具体的实验实现方案和测量方案，基于这些与中国科大潘建伟及陈帅组合作开展实验，成功在光晶格中实现二维人工自旋轨道耦合和拓扑能带。这是超冷原子量子模拟领域的一项突破，使得超冷原子量子模拟从阿贝尔规范场进入非阿贝尔规范场量子模拟

新阶段。文章于 2016 年 10 月被 Science 以研究长文（Research Article）形式发表，同时《科学》杂志在同期的观点栏目（Perspective）专门配发了题为”Cold atoms twisting spin and momentum”的评论文章。文章发表后已引起广泛影响和兴趣，2 年多 SCI 引用超 220 次，加上待发表的文章引用近 300 次。进一步，最近两年里，刘雄军组在高维自旋轨道耦合量子气体的理论和推动实验研究方面连续获得诸多新突破。这些将全面推动在超冷原子中基于自旋轨道耦合量子模拟的有关研究。

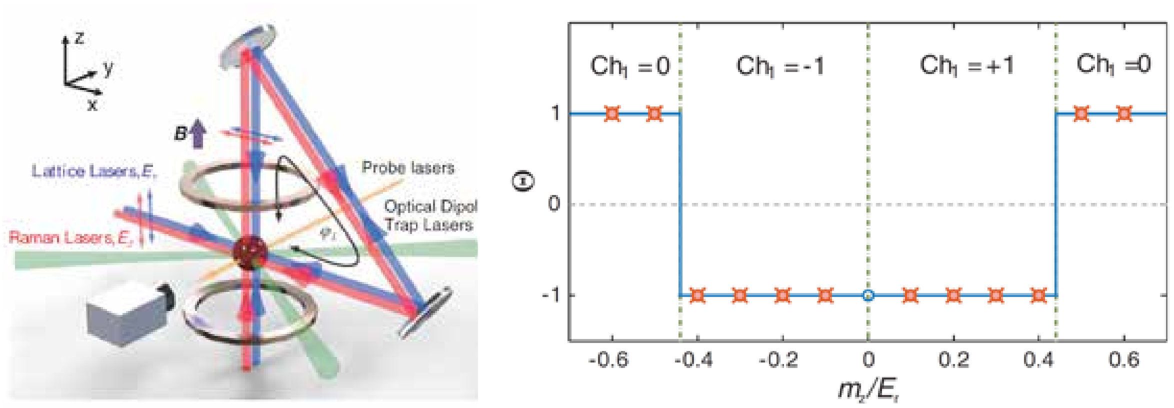



图 1：二维自旋轨道耦合和拓扑能带实现示意图和陈省身数测量。

Fig. 1 Sketch of realizing 2D spin-orbit coupling and topological band, and the measurement of Chern numbers.

## II. Realization of 2D spin-obit coupling for ultracold atoms and new progresses

The spin-orbit (SO) interaction plays an essential role in many prominent effects, with their studies having led to several important research fields, including spintronics, topological insulators, and topological superconductors. There has been also considerable interest in emulating SO effects and topological phases with cold atoms, driven by the fact that cold atoms can offer extremely clean platforms with full controllability to explore such exotic physics. Nevertheless, in the past five years (from 2011 to 2015/2016), only the 1D SO interaction, which corresponds to an Abelian gauge potential, has been realized for ultracold atoms. Realizing higher dimensional SO couplings, which correspond to non-Abelian gauge potentials, is however much more important, and indeed necessary for the study of broader range of nontrivial topological quantum physics. As a result, to realize a 2D SO interaction became a foremost outstanding goal in the field of ultracold atoms.

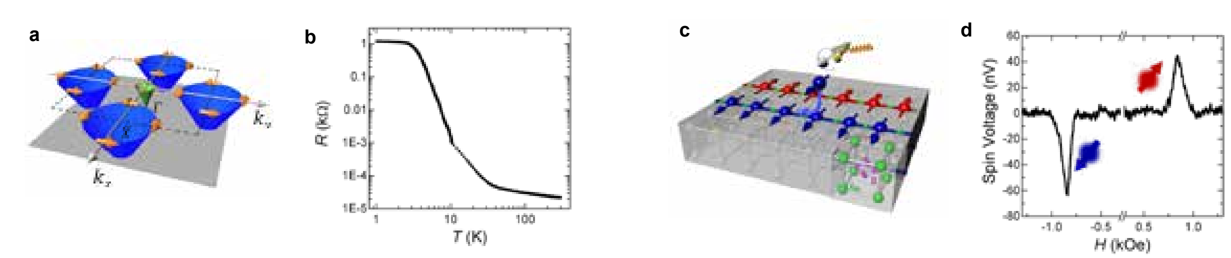
The Xiong-Jun Liu group at PKU proposed a new minimal scheme to realize 2D SO coupling and topological quantum physics in optical lattice, and designed both the concrete experimental realization and detection schemes based on rubidium-87 atoms. Based on this proposal, the applicant collaborated with an experimental group led by Jian-Wei Pan and Shuai Chen at USTC and successfully realized the 2D SO coupling for 87Rb atoms trapped in a square lattice, without phase-locking or fine-tuning of optical potentials. The controllable SO effects and nontrivial band topology are observed by measuring the atomic cloud distribution and spin texture in momentum space. Interestingly, the Hamiltonian realized here describes a minimal spin-1/2 quantum anomalous Hall model driven by SO interaction, which cannot be exactly realized in solid state matter but has been achieved in our ultracold atom experiment. The realization of 2D SO coupling signifies a milestone progress for the topic of quantum simulation with synthetic gauge fields, and can open a broad avenue in cold atoms to study exotic quantum phases, including nonequilibrium physics and interacting physics with novel topology. The paper was published with the title “Realization of 2D spin-orbit coupling for Bose-Einstein condensate” in Science as a Research Article: Science 354, 83-88 (Oct. 2016), and soon attracted broad attention and interests. So far it has been cited over 220 times in web of science, and nearly 300 times in Google Scholar.





## 三、利用自旋注入实现拓扑表面态中的逆 Edelstein 效应

自旋电子学一直致力于利用自旋自由度来研发新型的信息存储和信息技术。近期研究发现 SmB6 是一种新型的近藤拓扑绝缘体。在其表面态上狄拉克费米子的自旋方向和动量方向是锁定的，如图 (a) 所示。这种自旋轨道锁定会引起 Edelstein 效应和逆 Edelstein 效应。而如图 (b) 所示，当温度低于 ~3K 时，SmB6 的体态完全绝缘，只有表面态导电。因此，相较于基于 Bi2Se3 的拓扑绝缘体，近藤拓扑绝缘体是一种更为理想的研究拓扑表面态性质的载体。如图 (c) 和图 (d) 所示，在陈仙辉课题组提供的 SmB6 样品和张弛课题组提供的微波氦 3 低温环境的帮助下，韩伟课题组使用自旋泵浦技术从坡莫合金（Py）向 SmB6 注入自旋流，并进行逆 Edelstein 效应的测量。工作系统地测量了逆 Edelstein 效应随频率、功率、温度和磁场角度的变化关系，从各个方面证实了所观察到的信号。在新型近藤拓扑绝缘体 SmB6 的表面态中对逆 Edelstein 效应的发现，将会进一步推动关于近藤拓扑绝缘体中的强关联物理的研究，并进一步推进人们在拓扑绝缘体表面态中探索如何更高效率地产生自旋流的步伐。成果发表在 Nature Communications, 7, 13485 (2016)。




图：SmB6 表面态中的自旋注入和逆 Edelstein 效应。（a）SmB6 表面态自旋动量锁定关系；（b）SmB6 电阻随温度的关系；（c）自旋泵浦注入到 SmB6 表面态；（d）测量到的电压随磁场关系。

Figure: Spin injection and IEE in surface state of SmB6 (a) spin-momentum locking of surface state; (b) R-T curve; (c) mechanism of spin injection and IEE; (d) detected voltage signal dependent of magnetic field.

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### III. Spin injection and inverse Edelstein effect in the surface states of topological Kondo insulator $SmB_6$

Spintronics aims to use the spin degrees of freedom for information storage and computing technologies. Recently, SmB6, a Kondo insulator, has been found to be a new type of TI with special gapless surface states where the spin polarization of the Dirac fermions is locked to the momentum direction as illustrated in the figure (a). This spin-momentum locking property gives rise to the Edelstein and inverse Edelstein effects. At temperatures below 3K, the bulk states are insulating, and only surface carriers contribute to the conduction, as demonstrated in figure (b) and the previous surface Hall measurements from other groups. So compared to these Bi2Se3-based three-dimensional TI, SmB6 would be a better ideal candidate for exploring the property of surface state. We use the spin pumping technique to inject the spin current from Py to SmB6 and measured the inverse Edelstein effect as illustrated in the figure (c) and (d). Systematical measurements, including frequency, power, temperature and the magnetic field angle dependences of the spin signal strongly support the observation. This observation could lead to future studies of the role of strong correlation in TKIs for spintronics and highly efficient spin current generation in the surface states of TIs via the materials design and engineering. This work was published in Nature Communications, 7, 13485 (2016).

## 13 北京大学科维理天文与天体物理研究所 Kavli Institute for Astronomy and Astrophysics

科维理天文与天体物理研究所是北京大学和美国 Kavli 基金会合作于 2006 年 6 月成立的，并于 2007 年开始正式运行。研究所致力于建设一个国际一流的天文与天体物理研究中心，在活跃的学术氛围下，开展前沿天体物理领域的基础科学研究。工作语言为英语。研究所积极参加理论和观测天体物理研究项目，开发和利用观测设备，培养本科生、研究生和博士后。定期举办专题研讨会和学术会议，并开展一系列旨在推动与国内外天文界合作与交流的学术活动。研究所与其它 Kavli 研究所以及世界上很多大学和研究机构建立了各种交流与访问计划。

研究所的主要研究领域包括：1) 观测宇宙学，星系的形成与演化；2) 恒星形成，恒星与行星系统 ; 3) 引力物理和高能现象；4) 计算天体物理。

研究所现任所长何子山，副所长吴学兵，协调人陈建生。由国际科学顾问委员会 (SAC) 在学术活动、重大计划、研究方向和教师聘用等方面提供指导。刚刚成立的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。研究所与天文学系合作密切，人员共聘，资源共享，联合开展科学研究和人才培养。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 30 名博士后和多名访问学者。

更多信息请访问科维理天文与天体物理研究所网站：http://kiaa.pku.edu.cn/

The Kavli Institute for Astronomy and Astrophysics (KIAA) is jointly supported by Peking University and an endowment made possible by a generous gift from the Kavli Foundation, USA. KIAA was established in June, 2006 and started operation in 2007. KIAA's mission is to establish an international center of excellence in astronomy and astrophysics that promotes the development of basic astrophysical research. Its primary goal is to foster frontier research in a vibrant intellectual environment. With English as its working language, KIAA is engaged in theoretical and observational initiatives, development and utilization of astronomical facilities, and training of undergraduate and graduate students and postdoctoral fellows. KIAA regularly sponsors thematic workshops, conferences, and a range of other academic activities to facilitate scientific exchange with the domestic and international astronomy community. It is establishing exchange and visiting programs with other Kavli institutes and a network of universities and astronomy centers worldwide.

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 physics and high-energy phenomena; and 4) computational astrophysics.

The Institute is under the leadership of its Director Luis C. Ho, Associate Director X.-B. Wu, and coordinator J. S. 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, has been established to oversee the management and operations of the Institute. 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 30 postdoctoral fellows, a number of visiting scholars, and five administrative staff members.

For more information, please refer to KIAA homepage: http://kiaa.pku.edu.cn/

### 一、发现有史以来最强的超新星爆发

超新星是某些恒星在生命终点的剧烈爆发现象。近两千年前，中国天文学家就在《后汉书》中记载了人类史上最早观测到的一次超新星爆发。（这颗现称为 SN 185 的超新星被天文学家划归为 Ia 型）至今，人类记录了上万颗超新星爆发，其中最常见的类别就是 Ia 型。而 2015 年夏天发现的一颗超新星震惊了天文学界——其爆发强度超过了 Ia 型超新星约两百倍，是“前记录保持者”的两倍以上。

这颗名为 ASASSN-15lh 的极亮超新星是由北京大学科维理天文与天体物理研究所研究员东苏勃领导一支国际团队发现的。这一最新研究成果以东苏勃为第一作者、通讯作者身份发表在 2016 年 1 月 15 日出版的《科学》（Science）杂志上。据《科学》文章报道，ASASSN-15lh 距离地球 38 亿光年，属于罕见的“极亮型超新星”家族中的一员。它的发现有望为天文学家揭开极亮型超新星的爆发之谜提供重要线索。

ASASSN-15lh 达到的最高光度比太阳要强 5700 亿倍，是整个银河系千亿颗恒星总光度的 20 倍左右。东苏勃称：“ASASSN-15lh 是迄今为止人类记录到的最强的超新星爆发。由于它辐射的能量太高，目前的超新星理论难以对它的爆发机制和能量来源给予令人满意的解释。”

ASASSN-15lh 是 2015 年 6 月由位于智利安第斯山脉托洛洛山顶的两架 14 厘米口径“全天自

动超新星搜索项目”望远镜发现的。

在 ASASSN-15lh 发现当天，东苏勃和其合作者立即将有关讯息公开给全球的超新星研究者，以便人们能够更快、更好地进行观测。ASASSN-15lh 引起了天文学家们的强烈兴趣，世界上诸多大型望远镜和美国 NASA 的“雨燕”太空望远镜马上投入到了后续观测之中。时至今日，研究者们还在从光学、X 射线、射电等诸多波段对这颗超新星进行持续观测。

2015 年 6 月 21 日，东苏勃在美国卡内基天文台的合作者利用位于智利的 2.5 米杜邦望远镜拍摄到了 ASASSN-15lh 的第一条谱线。天文学家们用谱线来认证超新星抛射物中的化学组分和物理状态，为超新星归类并研究其爆发的物理过程。然而，ASASSN-15lh 的谱线远异于“全天自动超新星搜索项目”已发现的 200 多颗超新星，这使天文学家们起初感到非常困惑。

在与同事智利迪亚哥伯达里斯大学教授何塞·普利艾特和斯坦尼克讨论后，东苏勃突然意识到 ASASSN-15lh 可能属于极亮型超新星。根据他的推测，若 ASASSN-15lh 距离我们 38 亿光年远，那么它最突出的谱线特征与 2010 年发现的一颗极亮超新星的光谱极为匹配。如果这个推断是正确的，就应该可以在特定波长上看到超新星光线穿过宿主星系中气体产生的吸收谱线。而预期中的特征吸收谱线波长较短，需要利用覆盖足够蓝端光谱的仪器才能观测到。在接下来的几天，东苏勃和同事们联系到了三架可拍摄蓝端光谱的望远镜，可惜数次观测都由于天气原因和仪器故障功亏一篑。十天之后，10 米口径的“南非巨型望远镜”（SALT）终于成功拍摄到了所需光谱，东苏勃的推断被证实了！

2015 年 7 月 1 日北京时间凌晨两点，东苏勃收到了南非望远镜的观测信息。他说：“当看到南非望远镜拍摄的光谱并意识到我们发现了史上最强的超新星爆发时，我兴奋得彻夜难眠。”

后续的观测进一步印证了 ASASSN-15lh 的特性与以往发现的所谓的贫氢极亮型超新星（也称“I 型极亮超新星”）有诸多关键的共同之处。这些剧烈爆发产生的抛射物中探测不到宇宙中最为丰富的氢元素的迹象。然而，除了其爆发强度鹤立鸡群之外，ASASSN-15lh 的温度也远高于其它 I 型极亮超新星。另外，以往发现的 I 型极亮超新星多在黯淡的矮星系中，但 ASASSN-15lh 的宿主星系比银河系还要亮数倍。随着超新星逐渐变暗，后续观测将可以更好的研究宿主星系，这对理解贫氢极亮型超新星的爆发环境具有重要意义。包括北京大学物理学院天文学系博士研究生陈平在内的东苏勃团队将利用哈勃空间望远镜等强大的天文仪器对该超新星和其宿主星系做进一步地纵深分析和研究。

解释极亮超新星能源机制最为流行的理论之一是磁中子星模型。在这个模型中，恒星爆发后会在中心遗留一颗有着极强磁场并飞速自转的中子星，这颗磁中子星的剧烈磁化星风可将爆炸抛射物加热到高温从而产生辐射。然而，自发现后的仅四个月时间里，ASASSN-15lh 辐射的总能量就相当于太阳以现在的强度照耀 900 亿年。如此之高的能量刚好超过了磁中子星理论模型所允许的上限。另一种可能解释是，ASASSN-15lh 的辐射是由极高质量恒星爆发产生的数十倍太阳质量的放射性元素衰变导致的。

东苏勃说：“ASASSN-15lh 的发现对超新星爆发理论提出了一个全新挑战。它可能会引发对极亮超新星整体的理论创新和更多的观测。我们将拭目以待。”





图：史上最强超新星爆发 ASASSN-15lh 的想像图。该图示意了从超新星宿主星系中一颗距离 ASASSN-15lh 约 1 万光年的行星上观看 ASASSN-15lh 爆发的情景。（图片制作：北京天文馆马劲）

Figure: An artist's impression of the record-breakingly powerful, superluminous supernova ASASSN-15lh as it would appear from an exoplanet located about 10,000 light years away in the host galaxy of the supernova. (Credit: Beijing Planetarium / Jin Ma)

## I. Record-breakingly superluminous supernova ASASSN-15lh

Stunned astronomers have witnessed a cosmic explosion about 200 times more powerful than a typical supernova—events which already rank amongst the mightiest outbursts in the universe—and more than twice as luminous as the previous record-holding supernova.

At its peak intensity, the explosion—called ASASSN-15lh—shone with 570 billion times the luminosity of the Sun. If that statistic does not impress, consider that this luminosity level is approximately 20 times the entire output of the 100 billion stars comprising our Milky Way galaxy.

The record-breaking blast is thought to be an outstanding example of a "superluminous supernova," a recently discovered, supremely rare variety of explosion unleashed by certain stars when they die. Scientists are frankly at a loss, though, regarding what sorts of stars and stellar scenarios might be responsible for these extreme supernovae.

As described in a new study published today in Science, ASASSN-15lh is amongst the closest superluminous supernovae ever beheld, at around 3.8 billion light years away. Given its uncanny brightness and closeness, ASASSN-15lh might offer key clues in unlocking the secrets of this baffling class of celestial detonations.

"ASASSN-15lh is the most powerful supernova discovered in human history," said study lead author Subo Dong, an astronomer and a Youth Qianren Research Professor at the Kavli Institute for Astronomy and Astrophysics (KIAA) at Peking University. "The explosion's mechanism and power source remain shrouded in mystery because all known theories meet serious challenges in explaining the immense amount of energy ASASSN-15lh has radiated."

ASASSN-15lh was first glimpsed in June 2015 by twin, telescopes with 14-centimeter diameter lenses in Cerro Tololo, Chile conducting the All Sky Automated Survey for SuperNovae (ASAS-SN), an international collaboration headquartered at The Ohio State University. (Hence ASASSN-15lh's somewhat menacing moniker.) These two tiny telescopes sweep the skies to detect suddenly appearing objects like ASASSN-15lh that are intrinsically very bright, but are too far away for human observers to notice.

"ASAS-SN is the first astronomical project in history to frequently scan the entire optical sky for optical transients," said Krzysztof Stanek, professor of astronomy at the Ohio State University and the co-Principal Investigator of ASAS-SN. "Every time in science we open up a new discovery space, exciting findings should follow. The trick is not to miss them."

Dong and colleagues immediately put out word about the sighting of ASASSN-15lh in order for as much data as possible to be gathered. Multiple, far larger ground-based telescopes across the globe, as well as NASA's Swift satellite, have since taken part in an intense observing campaign that continues to this day.

In just the first four months after it went kablooie, so much energy beamed out of ASASSN-15lh that it would take our Sun in its current state more than 90 billion years to equal its emissions. By examining this bright, slowly fading afterglow, astronomers have gleaned a few basic clues about the origin of ASASSN-15lh.

Using the 2.5 meter du Pont telescope in Chile, Dong's colleagues Ben Shappee and Nidia Morrell at the Carnegie Observatories in the United States took the first spectrum of ASASSN-15lh to identify the signatures of chemical elements scattered by the explosion. This spectrum puzzled the ASAS-SN team members, for it did not resemble any of spectra from the 200 or so supernovae the project had discovered to date.

Inspired by suggestions from Jose Prieto at Universidad Diego Portales in Chile and Stanek, Dong realized that ASASSN-15lh might in fact be a superluminous supernova. Dong found a close spectral match for ASASSN-15lh in a 2010 superluminous supernova, and if they were indeed of a kind, then ASASSN-15lh's distance would be confirmable with additional observations. Nearly 10 days passed as three other telescopes, stymied by bad weather and instrument mishaps, attempted to gather these necessary spectra. Finally, Dong' s colleague Saurabh Jha at Rutgers University (USA) was able to use the 10 meter Southern African Large Telescope (SALT) to secure the observations of elemental signatures verifying ASASSN-15lh's distance and extreme potency.

"Upon seeing the spectral signatures from SALT and realizing that we had discovered the most powerful supernova yet, I was too excited to sleep the rest of the night," said Dong, who had received word of the SALT results at 2 AM in Beijing on July 1, 2015.

The ongoing observations have further revealed that ASASSN-15lh bears certain features consistent with "hydrogen-poor" (Type I) superluminous supernovae, which are one of the two main types of these epic explosions so named for lacking signatures of the chemical element hydrogen in their spectra. ASASSN-15lh has likewise shown a rate of temperature decrease and radius expansion similar to some previously discovered Type I superluminous supernova.

Yet in other ways, besides its brute power, ASASSN-15lh stands apart. It is way hotter, and not just brighter, than its apparently nearest of supernova kin. The galaxy it calls home is also without precedent. Type I superluminous supernova seen to date have all burst forth in dim galaxies both smaller in size and that churn out stars much faster than the Milky Way.

Noticing the pattern, astronomers hoped this specific sort of galactic environment had something to do with superluminous supernovae, either in the creation of the exotic stars that spawn them or in setting these stars off. Exceptionally, however, ASASSN-15lh's galaxy appears even bigger and brighter than the Milky Way. On the other hand, ASASSN-15lh might in fact reside in an as-yet-unseen, small, faint neighboring galaxy of its presumed, large galactic home.

To clear up where exactly ASASSN-15lh is located, as well as numerous other mysteries regarding it and its hyper-kinetic ilk, the research team has been granted valuable time this year on the Hubble Space Telescope. With Hubble, Dong and colleagues will obtain the most detailed views yet of the aftermath of ASASSN-15lh's stunning explosion. Important insights into the true wellspring of its power should then come to light.

One of the best hypotheses is that superluminous supernovae's stupendous energy comes from highly magnetized, rapidly spinning neutron stars called magnetars, which are the leftover, hyper-compressed cores of massive, exploded stars. But ASASSN-15lh is so potent that this compelling magnetar scenario just falls short of the required energies. Instead, ASASSN-15lh-esque supernovae might be triggered by the demise of incredibly massive stars that go beyond the top tier of masses most astronomers would speculate are even attainable.

"The honest answer is at this point that we do not know what could be the power source for ASASSN-15lh," said Dong. "ASASSN-15lh may lead to new thinking and new observations of the whole class of superluminous supernova, and we look forward to plenty more of both in the years ahead."

## 二、国家重点研发计划“大质量黑洞与星系的协同演化及其宇宙学效应”启动

“大质量黑洞与星系的协同演化及其宇宙学效应”为国家科技部支持的国家重点研发计划的大科学装置前沿研究项目，首席科学家为 KIAA 所长何子山教授，参与项目的 17 个核心成员分别来自中科院国家天文台、北京大学、中科院高能物理研究所、中科院上海天文台、南京大学和中国科技大学。有关该项目的更多信息，请访问 http://kiaa.pku.edu.cn/bhole

本项目依托国家天文台，将使用我国三大天文设备，同时结合国际设备进行观测，获得大量观测数据。利用 LAMOST 光谱和 FAST 射电观测，预期可以取得：1）建立参数范围更宽且均匀的完备大样本，建立高精度测量黑洞质量方法，完成数百个黑洞质量的测量，发现新的经验关系，探索黑洞形成和演化规律；建立大质量双黑洞候选体判据，预期发现若干引力波源候选体；结合 X 射线观测，测量大样本黑洞辐射的能谱，以及可能的吸积演化序列。2）我们将获得星系气体质量，光学红外观测研究恒星星族并获得恒星质量，检验恒星形成和黑洞活动以及反馈效应，分类探讨协同演化关系，建立星系组装过程中的恒星形成规律和黑洞活动触发机制；3）结合红外观测，发现若干个高红移

类星体，特别是具有极端性质的类星体，例如质量大、吸积率高、红移高等，研究黑洞形成和早期演化规律； 4）在理论和数值模拟方面，揭示经验关系和协同演化规律背后的物理过程。

自 2016 年正式实施以来，项目取得了一系列瞩目的研究成果：按计划开展了一系列多波段观测活动；落实了与国际研究机构协商长期合作和使用望远镜的计划；与澳大利亚开展澳大利亚平方公里阵列探路者（ASKAP）项目的中性氢（HI）巡天工作，研发了一系列数据处理和分析软件；招聘了 20 名博士后，培养了 66 名研究生和 20 名本科生；组织多次科研研讨会；发表文章 100 余篇，其中《自然》1 篇，《自然天文》1 篇，美国天文学会刊物亮点推荐文章 2 篇，并投稿《科学》1 篇，超额完成项目计划。部分重要亮点工作包括：

提出活动星系核宽线区起源于尘埃环的理论，借由分解维里化成份，黑洞测量精度有望大幅提高到 20%；

通过研究 Swift/BAT X 射线活动星系核样本，揭示了活动星系核内区的气体和尘埃分布的几何结构，发现 I 型和 II 型活动星系核在中心黑洞物质吸积和能量释放率上有很大不同，颠覆了当前天文学家认为这两种活动星系核具有相同的基本结构和能量分布的认识；

发现红移 7（宇宙年龄为现在的 7%）的早期宇宙巨型原初星系团；

使用阿塔卡玛大型毫米波 / 亚毫米波阵列（ALMA）获得了红移为 6.13 的高红移类星体宿主星系的气体分布和动力学；

数值模拟和分析发现黑洞冕区热气体无法逃逸，无法形成风，从而对当前黑洞标准薄盘模型提出挑战等。

本专项已成为一个出色的科研、交流，以及更重要的对下一代天文学家进行培养的平台。


图：“大质量黑洞与星系的协同演化及其宇宙学效应”项目成员合影

Figure: Group Photo of the BHOLE Project Members





## II. Inception of Black hole - Host Lifecycle Evolution (BHOLE) Project

The Black hole - Host Lifecycle Evolution (BHOLE) Project is supported by the Ministry of Science and Technology of China (MOST). The principal investigator is Professor Luis C. Ho, Director of KIAA. It is a collaboration of 17 core investigators from six institutions in China (KIAA, Institute of High-energy Physics, National Astronomical Observatory of China, Shanghai Astronomical Observatory, Nanjing University, and University of Science and Technology of China). More information about the project can be found at http://kiaa.pku.edu.cn/bhole

We put forward the following research program, which is based on China's LAMOST (Large Sky Area Multi-Object Fibre Spectroscopic Telescope) and FAST (Five-hundred-meter Aperture Spherical Telescope), and try to combine HXMT (Hard X-ray Modulation Telescope), to study the coevolution of supermassive black holes and their host galaxies by the means of multi-wavelength observation, in order to establish a complete image and reveal its cosmological effects

Since its inception in July 2016, the project has made remarkable achievements in research, having completed over 100 papers in top international SCI journals, including two papers in Nature, one submitted to Science, and two listed as AAS Highlights in ApJ. The project has recruited seven new postdocs, organized five domestic workshops and three international conferences. Research highlights include

“Tidally disrupted dusty clumps as the origin of broad emission lines in active galactic nuclei” (J.-M. Wang et al. 2017, Nature Astronomy)

“The close environments of accreting massive black holes as shaped by radiative feedback” (Ricci et al. 2017, Nature)

A giant protocluster of galaxies at redshift 5.70” (L. Jiang et al. 2017, Science, submitted)

“Discovery of 16 new z ~ 5.5 quasars: filling in the redshift gap of quasar color selection”, (Yang, Fan, X.-B. Wu, et al. 2017, ApJ, AAS Highlight)

Gas dynamics of the luminous z = 6.13 quasar ULAS J1319+0950 revealed by ALMA high-resolution” (Shao, R. Wang, et al. 2017, ApJ, AAS Highlight).

The project has become an outstanding platform for scientific research and exchange, and for next-generation astronomers training.

## 三、球状星团年轻星族研究中的突破

球状星团是宇宙中最为简单且十分耀眼的恒星集合体，它包含着成千上万颗恒星。天文学家们一直认为球状星团中的恒星是同时形成的，它们的年龄十分相近，犹如“同班同学”。然而后来科学家们在球状星团中发现了数量众多且相对大部分成员显得更年轻的恒星成分，使得这一看法遭到了挑战。到底球状星团中那些年轻的恒星是如何形成的？由北京大学科维理天文与天体物理研究所和中国科学院国家天文台领衔的科研团队，与美国西北大学和阿德勒天文馆的天文学家合作，对这一长久以来的疑难作出了解释。利用哈勃太空望远镜的观测数据，该团队首次发现了中等年龄球状星团可以靠自身引力俘获外部气体来成批形成年轻恒星。这一发现突破了球状星团仅依赖内部气体循环来形成下一代恒星的理论。这一突破性成果于 1 月 28 日发表于 Nature 杂志。

“这一研究为星团中多成分的恒星该如何形成提供了新的观点”，领导这一工作的李程远在北京大学科维理研究所和中国科学院国家天文台学习并获得北京大学理学博士学位，现就任中国科学院紫金山天文台研究员。他说：“我们的研究表明，形成这些年轻恒星的气体来源于星团外部。形象地说，这些相对年轻的恒星似乎是由星团后来俘获的气体生成并寄生在球状星团中，而非星团自身孕育”。

“把年轻恒星来源归结为星团的外部环境的理论解释，是取代传统认知的最好的方案”， 来自北京大学教授 Richard de Grijs（李程远博士的导师）这样告诉我们：“这使得球状星团的演化行为变得比预料的更加复杂”。银河系的球状星团都十分年老。为了研究更为年轻的样本，该研究团队对银河系外的两个卫星星系，即大、小麦哲伦星云中的中等年龄星团进行了筛查。团队在研究工作中关注的是大麦哲伦星云中编号为 NGC1783、NGC1696，小麦哲伦星云中编号为 NGC411 的三个特征突出的星团。通过精确测量和仔细分析这些星团中恒星的亮度和颜色，他们得到了可靠的结论。以星团 NGC1783 为例，其大部分的恒星年龄都在约 14 亿年左右，而新形成的两批恒星年龄分别约为 4 亿 5000 万年和 8 亿 9000 万年。

“为什么会存在这些年轻的恒星呢？传统的解释是，这些星团一开始就留有足够的气体，在形成了第一批恒星之后又继续形成了下两批恒星。但存在的疑问是，第一批恒星中的大质量成员会快速演化产生强烈的星风，最后爆发成超新星，这些过程会将剩余的原初气体迅速吹走，使得星团中的恒星形成过程不会超过 1000 万年。”国家天文台的邓李才研究员（李程远博士另一位导师）详细地解释了星团形成的原理。

在早期的研究中，人们猜想这些星团实际上是在围绕星系旋转的过程中，靠其引力势阱俘获了一些超大质量的气体云，从而形成了新的恒星。关于星团可以从外部俘获星际介质的理论可以追述到 1952 年，直到逾半个世纪后的今天，这一推测才获得了观测证实。Richard 说：“我们的计算表明这一俘获外部气体的模型是可行的，而且看起来除了我们研究的三个星团之外，其它星团也有类似的特征。我们正在进行的工作将进一步加深和细化这个认识。”

来自北京大学科维理天文与天体物理研究所的李程远博士、Richard de Grijs 教授以及来自中国科学院国家天文台的邓李才研究员是这项工作的主要作者，参与此项研究工的还有中国科学院国家天文台的新宇博士和胡义博士，以及来自美国西北大学 Center for Interdisciplinary Exploration and Research in Astrophysics（CIERA）和物理与天文学系的 Claude-André Faucher-Giguère 博士、Aaron Geller 博士后研究员。

### III. Formation of new stellar populations from gas accreted by massive young star clusters

Among the most striking objects in the universe are glittering, dense swarms of stars known as globular clusters. Astronomers had long thought globular clusters formed their millions of stars in bulk at around the same time, with each cluster's stars having very similar ages, much like twin brothers and sisters. Yet recent discoveries of young stars in old globular clusters have scrambled this tidy picture.

Instead of having all their stellar progeny at once, globular clusters can somehow bear second or even third sets of thousands of sibling stars. Now a new study led by Chengyuan Li and Richard de Grijs at the Kavli Institute for Astronomy and Astrophysics (KIAA) at Peking University might explain these puzzling, successive stellar generations. Using observations by the Hubble Space Telescope, the research team has for the first time found young populations of stars within globular clusters that have apparently developed courtesy of star-forming gas flowing in from outside of the clusters themselves. This method stands in contrast to the conventional idea of the clusters' initial stars shedding gas as they age in order to spark future rounds of star birth.

The KIAA-led research team proposes that globular clusters can sweep up stray gas and dust they encounter while moving about their respective host galaxies. The theory of newborn stars arising in clusters as they "adopt" interstellar gases actually dates back to a 1952 paper. More than a half-century later, this once speculative idea suddenly has key evidence to support it.

Published paper: Li, de Grijs, et al., 2016, Nature, 529, 502–504. "Formation of new stellar populations from gas accreted by massive young star clusters"

哈勃太空望远镜拍摄的大麦哲伦星云中 NGC1783 星团的照片：这一致密星团距离我们约 16 万光年，包含约 17 万倍太阳质量的恒星。由北京大学科维理天文与天体物理研究所、中国科学院国家天文台、美国西北大学、美国阿德勒天文馆组成的联合团队研究表明，这一星团从外部环境获得了额外的气体形成了新的恒星（版权：ESA/Hubble & NASA）致谢 Judy Schmidt（Geckzilla.com）

A portrait of the massive globular cluster NGC 1783 in the Large Magellanic Cloud. A new study suggests the globular cluster swept up stray gas and dust from outside the cluster to give birth to three different generations of stars. (Credit: ESA/Hubble & NASA. Acknowledgement: Judy Schmidt (geckzilla.com))

## 14 人工微结构和介观物理国家重点实验室 State Key Laboratory for Artificial Microstructure and Mesoscopic Physics

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。注意学科交叉，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”。


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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，长江特聘教授 7 人，国家杰出青年基金获得者 12 人，万人计划 7 人，教育部新世纪 / 跨世纪人才 11 人，国家优秀青年基金获得者 11 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，以及何梁何利科学与进步奖、教育部一等奖等奖励十多项。获国家技术发明奖二等奖 1 项，中国高等学校十大科技进展 2 项。近 5 年来，承担经费超过 5 亿元，发表 SCI 论文 800 余篇，其中，有 8 篇刊登于 Nature（2 篇）和 Science（6 篇）；授权专利 50 余件。

State key Laboratory for Artificial Microstructure and Mesoscopic Physics was built in the year 1990, and was supported by the State Planning Commission. In 1992, our Laboratory passed the evaluation of the State Education Commission and started to run. The guideline for our Laboratory is to investigate the new phenomena and new laws of mesoscopic physics when the matters changes spatially and temporally, and we aim to strengthen the development of theoretical methods and the measurement of physical processes in ultrasmall space and ultrashort time scale. Paying attention to the intersection of disciplines, we develop the research methods and built the concepts to promote the artificial microstructure and mesoscopic physics in life sciences, energy, and various applied disciplines. Our Lab aims to facing 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 optics and condensed matter, 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, 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 now, including: 5 academicians of the Chinese Academy of Sciences, 7 special professors of the Yangtze River, 12 winners from the China National Funds for Distinguished Young Scientists, 7 winners from the National special support program for high-level personnel recruitment, 11 winners from the New Century Excellent Talents in University,4 Young Yangtze Scholar and 11 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, as well as more than 10 awards such as He Liang He Li Science and Progress Award and the first prize of the Ministry of Education, the second prize of the National Technology Invention Award in 2018，two awards on the top-ten-scientific and technological advances in Chinese university of science and technology. In the past five years, the laboratory has funded more than 500 million yuan and published more than 800 SCI papers. Among them, 8 articles were published in the leading journals, i.e., Nature (2 articles) and Science (6 articles); more than 50 patents were granted.



系所中心研究亮点 | *Highlights*

## 一、强激光场下分子隧道电离

强激光场下原子分子隧道电离是强场物理的基本问题，对光场调控原子分子动力学有着重要影响，比如电子关联和高次谐波产生等。理论上精确描述在强激光场作用下分子隧道电离是非常困难的，人们对从分子隧道电离电子波包的特征缺少深入认识，通常近似地认为分子隧道电离的电子波包为平面波。

北京大学物理学院人工微结构和介观物理国家重点实验室“极端光学创新研究团队“刘运全教授和龚旗煌院士等在《物理评论快报》发表了标题为“Phase Structure of Strong-Field Tunneling Wave Packets from Molecules”的研究论文 [Physical Review Letters 116, 163004(2016)]。团队成员创新性提出了分子隧道电离的量子轨迹蒙特卡洛理论 (Molecular-Quantum-Trajectory Monte Carlo theory), 解析地给出了分子坐标系下隧道电离率，揭示取向分子隧道电离的电子波包存在初始相位，进一步通过他们发展的蒙特卡洛模拟和费曼路径积分的方法 [M. Li et al., Phys. Rev. Lett.112, 113002(2014)]，计算得到分子坐标系下的光电子角分布。解释了实验上观测到取向氮气分子的不对称的归一化动量角分布以及预测了取向 O2 分子的光电子角分布。

结果表明，分子坐标系下的光电子角分布依赖分子外层轨道的电子云分布 ( 氮气分子的外层轨道为σ g, 氧气分子的外层轨道为 π g), 隧道电离电子波包的初始相位以及分子轴相对与激光偏振轴的取向角度，并可以广泛应用于多原子分子的隧道电离问题。该研究成果揭示了分子隧道电离的电子波包相位，对光电子全息成像、高次谐波成像、以及超快量子调控方面等方面具有重要应用。

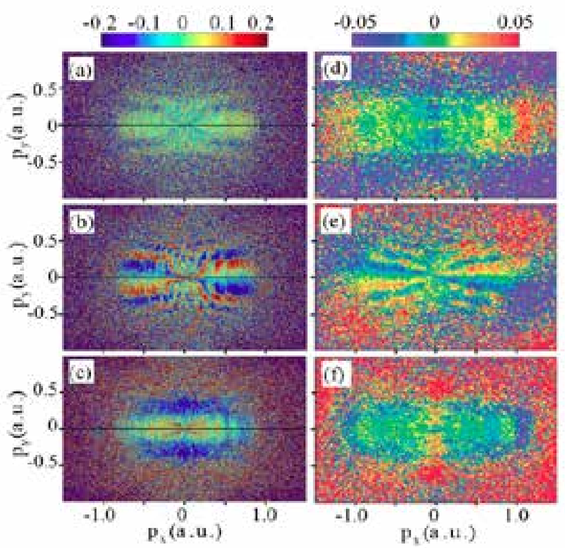



图 1 ( 左 ) 理论上计算得到 N2 分子在分子轴与激光偏振轴夹角为 0 度，45 度和 90 度下的归一化动量角分布。（右）图为实验结果。

Fig. 1(left) the simulated normalized momentum difference plots at the alignment angle of 0°, 45°, and 90° for N2 molecules. (right) the measured spectrum.

## I. Strong-field tunneling ionization of molecules

Strong-field tunneling ionization is one of key processes in ultrafast laser atom interaction, which is important to understand the above threshold ionization, high harmonic generation etc. It is very hard to deal with the wave structure of tunneling wavepackts from molecules. The colleagues from State Key Laboratory for Mesoscopic Physics have studied the phase structure of the tunneling wave packets from strong-field ionization of molecules and present a molecular quantum-trajectory Monte Carlo (MO-QTMC) model to describe the laser-driven dynamics of electron process in molecules. Using our model, They can reproduce and explain the alignment-dependent molecular frame photoelectron spectra of strong-field tunneling ionization of N2 reported by M. Meckel et al. [Nat. Phys. 10, 594(2014)], as seen in Fig. 1. Besides modelling the low-energy photoelectron angular distributions quantitatively, we extract the phase structure of strong-field molecular tunneling wave packets, shedding light on its physical origin. The initial phase of the tunneling wave packets at the tunnel exit depends on both, the initial transverse momentum distribution and the molecular internuclear distance. We further show that the ionizing molecular orbital has a critical effect on the initial phase of the tunneling wave packets. The phase structure of photoelectron wavepacket is a key ingredient for modelling strong-field molecular photoelectron holography, high-harmonic generation and molecular orbital imaging. This work has been published on Physical Review Letters. [Ming-Ming Liu, Min Li, Chengyin Wu, Qihuang Gong, André Staudte, and Yunquan Liu,"Phase Structure of Strong-Field Tunneling Wave Packets from Molecules," Phys. Rev. Lett. 116, 163004 (2016).]

## 15 核物理与核技术国家重点实验室 State Key Laboratory of Nuclear Physics and Technology

核物理与核技术国家重点实验室成立于 2007 年，是我国核科技领域第一个国家重点实验室。实验室有约 80 位骨干研究人员，包括近 5 年来新引进的青年人才 25 位。实验室每年招收研究生 50 人以上，博士后 10 以上。实验室的主要科研方向包括：放射性核束物理；强子物理；先进粒子加速器技术；核技术应用。实验室承担科研项目约 120 项，年均外来竞争性科研经费约 6000 万元。实验室拥有大型加速器设备 4 台，提供粒子束流支撑多学科用户的研究和应用。实验室开展广泛的国际国内合作，典型的如与日本理化所合办的仁科学校（2008- ）；由美国能源部和中国自然科学基金委支持的中美奇特核理论研究所；得到国家留学基金委专项资助的 FRIB 博士后学者计划；在欧洲 LHC、日本 RIKEN、美国 ANL 等实施实验研究计划等。2015-2016 年代表性的科研工作如：新强子态的研究；轻丰中子核奇特结构研究；超小型激光加速器研制；抗辐照材料研究；等等。实验室近几年聚焦的一项涉及实验室整体的工作，是推动北京 ISOL 大科学装置的立项。该装置由中国原子能科学研究院与北京大学共同提出，2016 年经过国家发改委组织的多轮评审，纳入到《国家重大科技基础设施建设“十三五”规划》筹备论证后备项目。





The State Key Laboratory of Nuclear Physics and Technology at Peking University was established in 2007. The lab is composed of about 80 key researchers, including 25 young talents recruited in the past five years. Each year the laboratory enrolls more than 50 PhD candidate students and 10 postdocs. The main research fields of the laboratory include the rare isotope beam physics, hadron physics, advanced accelerator technology and application of nuclear techniques. About 120 research projects are undertaken by this lab, with an annual budget of about 60 million yuan from the outside funding sources. The lab is equipped by four large scale accelerator devices which provide beams for users from multidisciplinary research fields. 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), FRIB fellow program supported by CSC (since 2015), many experimental programs at user facilities in world wide. In the years 2015-2016, new research achievements were realized, such as the exotic multi-quark states in hadrons; cluster and intruder states in light neutron-rich nuclei; production of ion beams from an extra-intense laser driver; radiation hardening material investigation; and so on. One of the major focus of this lab for the past few years is to design and promote the large-scale science facility “Beijing Isotop-Separation On Line neutron rich beam facility (BISOL)”. This facility was proposed to the national 13th “five-year plan” by CIAE and PKU. During 2016, it was evaluated by the central government and has been successfully included into the preparation list of the national plan.

### 一、核物理第一性原理计算

原子核的第一性原理计算（又称从头计算）是当前理论核物理的前沿问题。这种计算从现实核力出发（而不是唯象核力），用较严格的量子多体计算方法求解原子核结构或核反应问题。计算过程不涉及任何新参数，不需要拟合核结构实验数据。这样的计算能给出更基本的物理内容，能探究核力和核子关联更本质的东西。核物理的第一性原理计算很具挑战性，涉及复杂的数学与物理，对计算机资源的要求也很高。仅仅在最近 10 余年，核物理第一性原理计算才得到较大发展。

核物理与核技术国家重点实验室许甫荣教授与他的团队，10 余年致力于核物理的第一性原理计算，在手征有效场论、核力重整化和 ab initio 量子多体计算方面取得突破性进展。他们的工作有自己的特色，特别是把第一性原理计算推广到复动量空间，从而使得计算包含连续谱影响，这对弱束缚或不束缚的滴线区原子核描述很重要。他们发展的 Gamow 第一性原理计算可以很好描述滴线区核的共振性质，预言共振宽度。三体核力是当前核物理研究的又一个热点前沿问题。三体力在描述滴线区原子核中往往起关键作用。他们发展了手征有效场论 N2LO 三体力，并进一步扩展到复动量 Berggren 空间。

他们利用 Hartree-Fock 基，发展了角动量耦合多体微扰计算方法。Hartree-Fock 基下的角动量耦合多体微扰方法可以大大提高核结构第一性原理计算的收敛性。而通常的多体微扰都是在谐振子基矢的 m 表象进行，尽管计算过程简单些，但收敛性相对较差。许甫荣教授课题组从手征有效场论出发，用相似重整化群（SRG）软化核力，对氦和氧同位素开展了第一性原理的多体微扰计算。在 Hartree-Fock 基矢空间的角动量耦合表象里，多体微扰计算到三阶微扰就可以给出收敛的能量，

二阶计算就可以给出收敛的核半径计算，这大大提升了第一性原理的计算能力，可以计算较重的原子核，相关文章发表在 Phys. Rev. C 94, 014303 (2016)。图 1 和图 2 分别给出了基于手征有效场论核力 N3LO，用多体微扰方法计算的 16O 基态能量和半径。

相关论文：

1.B. S. Hu ( 胡柏山 ), F. R. Xu ( 许甫荣 )*, Z. H. Sun ( 孙中浩 ), J. P. Vary, and T. Li ( 李通 ), Phys. Rev. C 94, 014303 (2016): Ab initio nuclear many-body perturbation calculations in the Hartree-Fock basis.

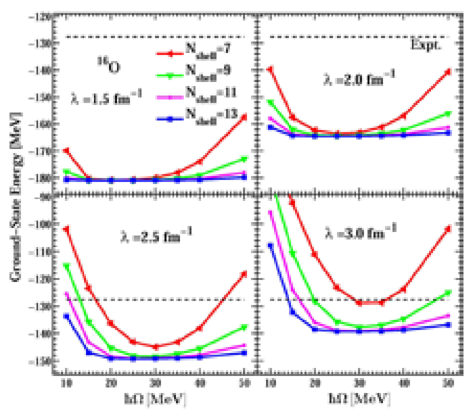


图 1. 手征有效场论 N3LO 多体微扰第一 性原理计算的 $^{16}$O 基态能量

Fig.1. ab initio N3LO MBPT calculations of $^{16}$O ground-state energy as a function of harmonic oscillator parameter Ω .

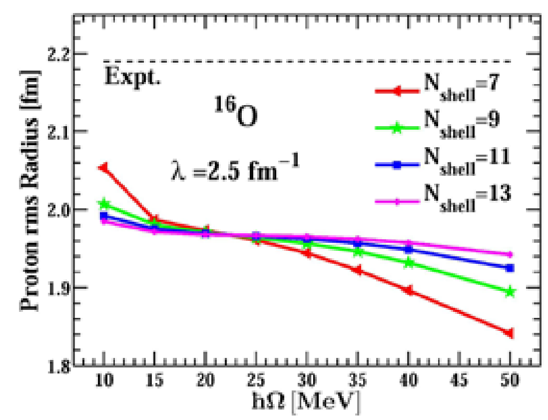



图 2. 手征有效场论 N3LO 多体微扰第一性原理计算的 $^{16}$O 基态半径 .

Fig.2. ab initio N3LO MBPT calculations of $^{16}$O ground-state radius as a function of harmonic oscillator parameter Ω .

## I. First-principles (ab initio) calculations of atomic nuclei

Nuclear first-principles calculation (also known as ab initio calculation) is a frontier issue of current theoretical nuclear physics. This kind of calculation starts from realistic nuclear forces (rather than phenomenological forces) and solves nuclear structure or reaction problems with rigorous quantum many-body methods. The calculation does not involve any new parameters and does not need to fit nuclear structure experimental data. Such calculations can provide more basic physics associated with nucleon-nucleon interactions and correlations. The first-principles calculation of nuclear physics is challenging, involving complicated mathematics and physics, and demanding huge computer resources. Only in the past decade, the first-principles calculation of nuclear physics has been developed significantly.

Professor Furong Xu and his team, at the State Key Laboratory of Nuclear Physics and Technology, have been working on the first-principles calculation of nuclear physics for more than 10 years. They made





breakthrough progresses in nuclear chiral effective field theory, nuclear force renormalizations and ab initio quantum many-body methods. In particular, they extended the first-principles calculations to a complex-momentum space, so that the calculations can include effects from the continuum which is important for the descriptions of weakly bound or unbound nuclei in dripline regions. Their developments of the Gamow first-principles calculations can well describe the resonance properties of weakly bound and unbound nuclei, and predict their resonance widths. Three-body nuclear force is another hot topic at the current nuclear physics research. Three-body forces often play a key role in describing nuclei in dripline regions. They have developed the three-body force N2LO of the chiral effective field theory (chiral EFT) and further extended to the complex-momentum Berggren space.

Within the Hartree-Fock basis, they have developed an angular-momentum coupled many-body perturbation method. The Hartree-Fock angular-momentum coupled many-body perturbation theory (MBPT) can remarkably improve the convergences of the first-principles calculations of nuclear structures. The usual many-body perturbation calculation is performed in the m-scheme within the harmonic basis. Although the m-scheme calculation is simpler, the convergence is relatively poor. Starting from the chiral effective field theory and using the similarity renormalization group (SRG) to soften the nuclear force, Professor Furong Xu' s group carried out the first-principles many-body perturbation calculations for helium and oxygen isotopes. In the angular-momentum coupling representation within the Hartree-Fock basis, the many-body perturbation calculations up to the third-order correction can lead to the converged energies of nuclei, and calculations up to the second-order correction can give the converged radii of nuclei. This promotes significantly the computational power of nuclear first-principles calculations, towards heavier nuclei. This work has been published in Phys. Rev. C 94, 014303 (2016). Figures 1 and 2 show the 16O ground-state energy and radius calculated by the ab initio many-body perturbation theory based on the chiral EFT N3LO force, respectively.

Selected publication：

1.B. S. Hu, F. R. Xu *, Z. H. Sun, J. P. Vary, and T. Li, Phys. Rev. C 94, 014303 (2016): Ab initio nuclear many-body perturbation calculations in the Hartree-Fock basis.

## 二、离子辐照增强二维纳米材料催化性能机理研究

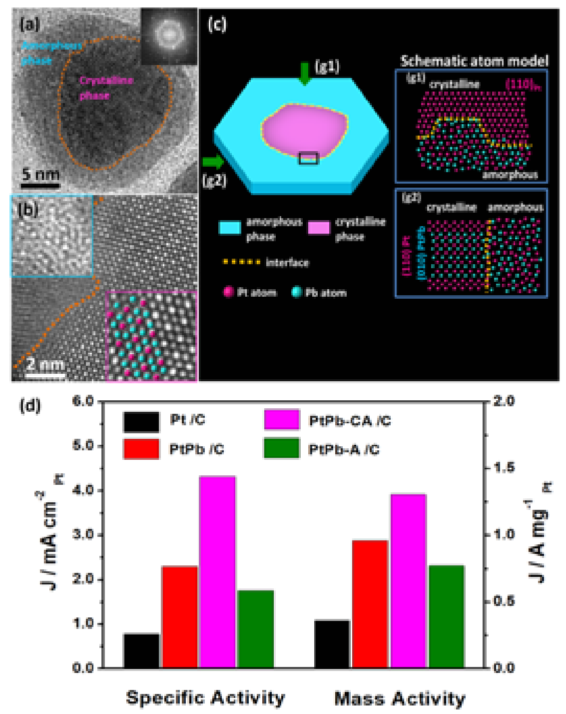
在可持续发展和环境友好的能源中，燃料电池是一种具有发电效率高、环境污染小、比能量高等诸多优点的新能源。在燃料电池能量转化过程中，催化剂活性是影响电池质量及其发展应用的关键，已成为国际前沿领域的研究热点。近年来，许多研究者主要是通过化学合成的方法调控催化剂的形貌、尺寸和微观结构，来提高催化剂电化学催化活性。然而，传统化学合成的方法仅对某些催化剂体系有效，并且很难在原子尺度上构造大量缺陷或引起其它结构改变，其诱导催化性能提高的机制也不甚明晰。针对以上问题，核物理与核技术国家重点实验室付恩刚课题组首次将离子束辐照技术应用于电化学催化领域，充分利用离子束辐照技术的可控、精准、适用材料广泛等优点，实现了精准调控

和修饰纳米催化材料的结构，极大地提高了催化性能，并揭示了辐照诱导结构变化对催化性能影响的内在机理。

本研究首次采用核技术方法，利用高能离子束辐照，通过对具有核壳结构的铂铅（PtPb）二维纳米片进行了原子尺度结构调控和修饰，极大地提高了其催化性能，获得了在甲醇氧化反应、乙醇氧化反应及氧还原反应等多体系下的高效催化剂。通过研究不同辐照剂量对材料结构的影响，揭示了 PtPb 纳米片在辐照条件下的结构演变过程，精确、有效地控制缺陷产生的类型、数量及其演化过程，得到具有不同催化活性的 PtPb 二维纳米片材料。同时，结合催化性能研究，揭示了入射高能离子与纳米片中的原子相互作用，利用键长变化和电子轨道杂化等机制来修饰表面原子的电子结构，从而增加催化反应活性位点，增强催化性能。在此基础上，进一步提出利用不同种类入射离子对二维纳米片进行辐照实验，制备得到了一种新型晶体 / 非晶环状结构，并结合实验和模拟，系统性地研究了新结构中晶体 / 非晶界面对于影响催化性能的关键因素及内在机理。

通过将离子束辐照应用于电化学催化领域，利用离子辐照的独有优势，开创性地提出了一种新的增强催化活性的方法，有望进一步提高现有的纳米催化剂的催化活性，为先进材料的设计以及对纳米催化材料的结构调控提供了指导和思路，对燃料电池的应用和催化领域发展有着重要的作用。相关研究工作发表在 Small 及 Nanoscale 等学术期刊上。

这项工作得到了国家自然科学基金，国家磁约束核聚变能研究专项，海外高层次人才项目和北京大学核物理与核技术国家重点实验室等的支持。




图：离子辐照诱导 PtPb 纳米片产生新结构，提升电化学催化性能。

Figure: The novel structure induced by ion irradiation enhances the electrocatalytic performance in PtPb nanoplates.

## II. Mechanisms of high electrocatalytic performance enhanced by ion irradiation in two-dimensional nanomaterials

Fuel cells are considered as one of the cleanest and the most efficient devices with many advantages, such as high power generation efficiency, low environmental pollution and high specific energy. In the process of energy conversion in a fuel cell, catalyst activity is the key factor to affect the quality of fuel cell, becoming a research hotspot in the international frontier field. In recent years, many researchers revealed that the catalytic behaviors of metallic nanocrystals could be improved by controlling their morphology, grain size and microstructure by using chemical synthesis. However, there are some limitations in systematically studying the role of crystal detects in nanocrystals toward the catalytic activity. The common method for producing defects is only efficient for a few catalytic systems. The used catalysts are generally at nanoscale, which are difficult to induce the controllable defects via traditional chemistry strategies. Moreover, it is not clear whether the induced defects and the defect-related interfaces are the main factors in catalytic activity enhancement or not. To this end, a group led by Prof. Engang Fu from State Key Laboratory of Nuclear Physics and Technology at Peking University reported an effective strategy for tuning/optimizing the defects and interfaces in two-dimensional nanomaterials by ion irradiation to achieve more efficient fuel cell catalysis for the first time. Ion irradiation is a powerful approach in material modification with many features such as energy-, dose-controllable and precision-modification, and it can modify the materials at the atomic level. The new findings also revealed the mechanisms of high electrocatalytic performance enhanced by ion irradiation in two-dimensional nanomaterials.

They reported the first example on tuning/optimizing the defects and defects-related interfaces on PtPb nanoplates by ion irradiation to achieve more efficient catalysis for methanol oxidation reaction (MOR), ethanol oxidation reaction (EOR) and oxygen reduction reaction (ORR). By studying the effects of irradiation doses on the structure of PtPb nanoplates, the structural evolution process of PtPb nanosheets under irradiation conditions was revealed. The density and evolution of defects could be accurately and effectively controlled and two-dimensional PtPb nanoplates with different catalytic activities were obtained. At the same time, the interaction between incident high energy ions and target atoms in nanoplates was revealed. The electronic structure of surface atoms was modified by the mechanism of bond length change and electron orbital hybridization, so as to increase the active sites of catalytic reaction and enhance the catalytic performance. Furthermore, a novel crystalline/amorphous structure was designed for the first time in PtPb nanoplates by using ion irradiation, and the PtPb with this structure has an excellent catalytic activity. Combining with the results of density function theory calculations, the mechanism of crystalline/amorphous interface enhancing the electrocatalytic property was revealed.

The current work presents an advanced defect-engineering approach to maximize the catalytic activity of Pt-based catalysis by ion irradiation, and may provide a new guidance for the rational design of highly efficient defect catalysts for future practical fuel-cells applications. The relevant research works were published in journals of Small and Nanoscale.

The works were supported by the National Natural Science Foundation of China, the National Magnetic Confinement Fusion Energy Research Project, and the State Key Laboratory of Nuclear Physics and Technology of Peking University.

# 16 北京大学高能物理中心 Center for High Energy Physics

北京大学高能物理中心由李政道先生担任主任。目前有8位海外资深学者，31位国内特聘兼职研究员，6位青年学者，7位博士后研究人员。研究的领域包括：宇宙学、量子场论、粒子物理唯象学、强子物理等。

With Prof. T. D. Lee as the director, the Center for High Energy Physics at Peking University now has 8 senior fellows from abroad, 8 research associates, 31 junior fellows and 6 postdocs. The research interests include: cosmology, quantum field theory, particle physics phenomenology and hadronic physics.

## 一、使用希格斯对产生过程判别单希格斯产生过程中的新物理参数简并问题

历经近半世纪的苦苦寻觅，2012 年人们终于在欧洲核子中心的大型强子对撞机上发现了所谓的“上帝粒子”——希格斯粒子。按照粒子物理的标准模型，已知粒子的质量都是起源于和希格斯粒子的相互作用，此相互作用在电弱对称性自发破缺后赋予粒子质量。但非常遗憾地是，人们对于对称性自发破缺机制（又名为希格斯机制）的起源还一无所知。对于希格斯粒子属性的精确测量有望帮助我们理解希格斯机制背后的更深层次的物理。

在大型强子对撞机上，希格斯粒子主要产生过程是双胶子聚合成单个希格斯粒子的过程，即 gg → H。此过程中新物理的贡献可以用两个模型无关的高量纲算符 $c_g$ 和 $c_t$ 来描述，但已知的精确实验测量结果仅仅给出两个算符之间的关联，特别是得到了两个简并的新物理参数空间，如下图所示。其中红色阴影区间表明包含了标准模型（红色方块）的参数空间，而蓝色阴影区间则表示完全独立于标准模型的参数空间。虽然基于蓝色阴影参数空间很难构造自洽的新物理模型，但进一步提高 gg → H 过程的测量精度也无助于我们排除它，因为两个新物理算符之间存在着强烈的偶然相互消除效应。

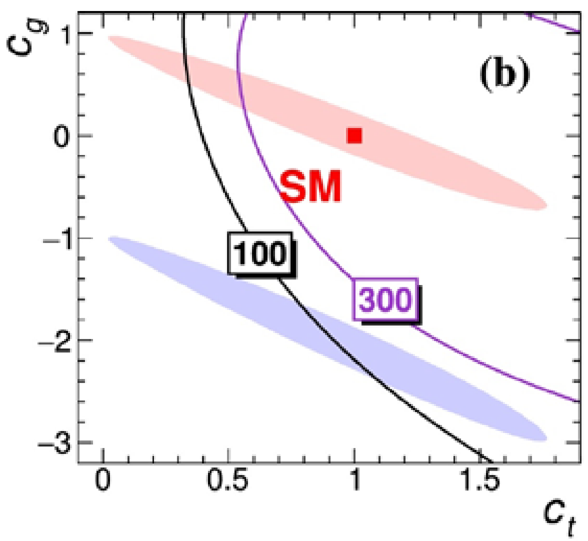
希格斯粒子成对产生过程（gg → HH）可以帮助我们判别那个参数空间才是物理上允许的。值得指出，在不包含标准模型的蓝色阴影区间，过程的产生截面会被极大增加，从而易于实验检验。细致的蒙特卡洛模拟指出，只要在大型强子对撞机上积累 $300fb^{-1}$ 的数据量，那么就可以彻底排除掉蓝色阴影参数空间。下图中的红色实线表示积分亮度为 $300fb^{-1}$ 时，如果在 gg → HH 过程中没有观测到新物理超出信号，那么就可以把红色曲线下方的参数空间完全排除。

## I. Resolving the degeneracy in single Higgs production with Higgs pair production

The Higgs boson, the so-called 'God particle', was eventually discovered at the Large Hadron Collider in 2012. The Higgs boson is very unique in the Standard Model of particle physics as it is the origin of the mass of all the massive particles. After the spontaneous symmetry breaking all the massive particles achieve their masses from the interaction with the Higgs boson. Unfortunately, four years passed and we still did not know the mechanism behind the spontaneous symmetry breaking. However, it is commonly believed that the precise knowledge of the Higgs boson might shed lights on the new physics beyond the Standard Model.

At the Large Hadron Collider, the Higgs boson is predominantly produced singly through the gluon fusion channel, i.e. the single Higgs channel gg → H. One can describe the unknown new physics effects with the model independent high dimension operators. The single Higgs channel is affected by two new physics operators, $c_g$ and $c_t$ . However, the two operators correlate with each other and the precison measurment of single Higgs channel cannot tell them apart. As a matter of fact, the current best knowledge yields two degenerate parameter space of the two operators. As shown in the Figure, the red shaded region represents the new physics parameter space consisting of the Standard Model while the blue shaded region denotes the new physics region that does not have the decouple limit of the Standard Model. That means that, if the new physics particles are very heavy, then the blue region cannot reproduce the well-established Standard Model. Obviously, even still allowed by the single Higgs measurement, the blue region is very unnatural. Even worse, owing to the strong cancellation between the two new physics operators in the gg → HH channel, one cannot exclude the blue region at all using the single Higgs channel alone.

We pointed out that the two new physics operators also contribute to the Higgs boson pair production (gg → HH) and their interaction is constructive. In the blue region the production is dramatically enhanced and could be observed at the Large Hadron Collider. The Monte Carlo simulation indicates that, when reaching an integrated luminosity of $300fb^{-1}$, one can rule out the entire blue parameter space if no excess is observed in the gg → HH channel. That can be tested in the future operation of the Large Hadron Collider.




图：新物理参数 $c_g$ 和 $c_t$ 的关联：1）红色和蓝色阴影区间为单希格斯产生过程所允许的新物理参数空间；2）红色方块表示已知的标准模型；3）黑色和红色曲线则代表未来的高亮度大型强子对撞机上希格斯对产生过程能够排除的参数空间（曲线下方为不允许参数空间），其中黑线和红线对应于大型强子对撞机收集 $100fb^{-1}$ 和 $300fb^{-1}$ 积分亮度时的情况。

Figure: Correlation between the new physics operator $c_g$ and $c_t$: 1) the red and blue shaded region represents the allowed parameter space by the single Higgs channel (gg → H); 2) the red box denotes the Standard Model; 3) the region below the black curve ($100fb^{-1}$) and red curve ($300fb^{-1}$) are expected to be excluded by the Higgs boson pair production (gg → HH) at the high luminosity Large Hadron Collider.


系所中心研究亮点 | *Highlights*

# 学生活动
# *Students*

物理学院鼓励本科生参与科研。2016 年 5 月，物理学院举行第五届本科生小型科研项目训练比赛。

The junior undergraduates are encouraged to participate in academic research. In May 2016, the school held the fifth session of research program training contest for undergraduate students.

2016 年 8 月，物理学院 2015 级本科生参加军训。

The undergraduate students of 2015 class took part in physical training in August 2016.



学生活动 | *Students*

2016 年 9 月 17 日，物理学院研究生举行秋游活动，来自各专业的研究生同学通过秋游加深了了解，丰富了研究生课余生活。10 月 23 日，物理学院在校园内举行学生定向越野比赛。

The graduate students had a school outing in September and attended in orienteering on campus in October of 2016.


为加强在校学生的社会实践锻炼，学院每学期组织数次学生到校友企业参访活动。图为 2016 年 10 月 28 学院师生到贝塔创客工场参访。

The students have opportunities to visit alumni enterprises and learn from their seniors. On October 28, 2016, the students went to Beta Makeblock for social practice.

2016 年 12 月 9 日，物理学院新生代表在北京大学 2016 年新生“爱乐传习”项目暨纪念“一二·九”运动 81 周年师生歌会上演唱《星河》，获得了在场观众的热烈掌声。物理学院学生每年自发组织迎新晚会和元旦晚会，以丰富的节目欢迎新生及庆祝新年。

On December 9, 2016, the school' s freshmen performed “The Galaxy” at the 12.9 Memorial Concert at PKU. The students held evening parties every year to welcome new students and celebrate the New Year.


为让更多的同学走出课堂、走向户外，提升学院凝聚力和团队协作能力，学生会和研会积极举办户外素质拓展活动和定向越野比赛，得到同学们的一致欢迎。

In 2016, the school held outdoor quality development activities and orienteering competitions to promote the students' cohesion and team spirit.



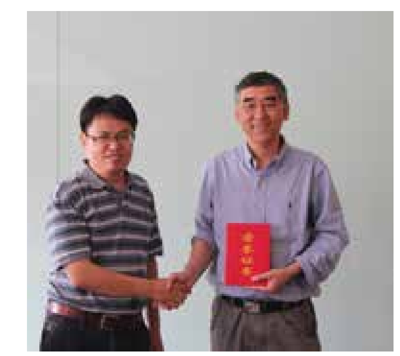


第十三、十四届“北京大学钟盛标物理教育基金”研究生学术论坛成功举办，基金捐赠人钟赐贤先生及夫人夏晓峦女士来校参加颁奖典礼。两年来，平均每年参加论坛学生百余人，报名专业涵盖物理学院全部九个学科。

The 13th and 14th sessions of graduate students academic forums were supported by the Paul Shin-Piaw Choong Educational Fund for Physics. Over 100 students across nine disciplines attended the forum each year.

第二、三届兴诚本科生学术论坛接连举办。兴诚奖学金由校友出资设立，用于奖励在本科生科研中表现优秀的学生。每年十几位本科生同学参加，采取学生作现场报告和墙报展示两种方式进行。

The school held the 2nd and 3rd undergraduate academic forums supported by the Xingcheng Fund. This fund was developed by physics alumni to reward the excellent undergraduate students in research programs. Each year, students participate in the forum with their oral reports and poster reports.



物理学院在学校春季运动会取得了甲组第四名的好成绩，在秋季运动会及新生趣味运动会中取得了甲组第三名的佳绩。在中国大学生马拉松联赛北京大学站暨第 23 届北京大学冬季越野跑赛中，物理学院荣获团体第一名。

The students performed well at the university' s spring and autumn sports meetings. The school scored best at the National College Students Marathon and the 23rd PKU Winter Trail running race.

物理学院 2015 年毕业典礼在英杰交流中心阳光大厅隆重举行。北大物理系 80 级校友、中国国际金融有限公司（CICC）首席风险官、董事总经理黄康林先生作为校友代表发言。物理学院 2016 届毕业典礼在北京大学英杰交流中心阳光大厅举行。物理系 1987 级校友陈恂先生作为校友代表参加仪式并致辞。

In 2015, the school' s graduation ceremony took place at the Yingjie Exchange Center at PKU. The alumni representative Kanglin Huang from the 1980 physics class, who is Managing Director and Chief Risk Officer of CCIC, was invited to give a speech. In 2016, the school' s graduation ceremony invited the 1987 physics alumnus Xun Chen for a speech to the graduates.






# 校友与基金
# *Alumni and Funds*

2015 年 1 月 10 日，北京大学物理学院 2015 年校友新年论坛在物理大楼成功举行。跨越 50 多个年级、涵盖物理、技物、天文、大气、气象等专业的近百位校友齐聚一堂，欢度元旦佳节，分享人生体悟，建言学院发展。

In January 2015, the school held its New Year Forum, which was attended by nearly a hundred alumni from more than 50 grades and different specialized subjects.

2016 年 2 月 28 日， 北京大学物理系 95 级校友、LIGO 团队核心成员、加州理工学院物理学教授、美国物理学会会士陈雁北教授于英杰交流中心阳光厅作了题为《引力波探测：历史、现状和未来》的报告。

Yanbei Chen from the 1995 physics class, who was a physics professor at the California Institute of Technology and a core member of LIGO, was invited to give a lecture on gravity wave detection at PKU.

2016 年 5 月 11 日，北京大学物理系 52 级校友毕业六十周年聚会在物理西楼 202 报告厅顺利举行。耄耋之年的老校友们从全国各地甚至世界各地赶来相聚，赴这场阔别六十载的聚会。

The school held the 60th anniversary of graduation for the 1952 physics class on May 11, 2015. Nearly 50 alumni from all over the world came back for the big gathering.

2016 年 5 月 4 日上午，北京大学物理系 60 级校友毕业五十周年聚会顺利举行。

The 1960 physics class held its 50th anniversary of graduation on May 4, 2016.

2016年5月21日，北京大学物理系56级校友180余人齐聚物理学院西楼202，共同庆祝入学六十周年。

On May 21, 2016, over 180 alumni from the 1956 physics class gathered at the school to celebrate their 60th anniversary of admission.



校友与基金 | *Alumni and Funds*

2016 年 12 月 18 日，物理学院举办主题为《网罗世界，物理人生——互联网浪潮中的物理人》的 2017 年校友新年论坛。论坛邀请陈超、陈昌明、于冬琪三位校友与同学们分享大数据产业、互联网产品和互联网金融等领域有丰富经验和丰硕成果。

The school held its 2017 New Year Forum on Internet Development on September 18, 2016. The Forum invited alumni Chao Chen, Changming Chen and Dongqi Yu to share with students their experience in big data industry, internet products and finance.

12 月 26 日，北京大学物理学院 2017 年校友新年论坛第二场在物理西楼 213 会议室成功举办。此次论坛也是 2000 级校友的年级聚会报告。

The second session of the 2017 New Year Forum was held on September 26, which was also the gathering party for the 2000 physics class.



**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 Qisun Ye Experimental Physics Fund | 叶企孙（补发工资），叶先生的友人和学生 Mr. Qisun Ye, his friends and students |
| 1996 | 谢义炳基金 Yibing Xie Fund | 谢义炳先生，谢先生的学生（毛节泰等）Mr. Yibing Xie, his students (Mr. Jietai Mao et al.) |
| 2002 | 77 物理班级基金（助）'77 Physics Class Fund | 北大物理 77 级校友 The '77 physics class |
| 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 | 80 物理兰怡女子助学金（助）'80 Ellen Yi Lan Woman Physicist Scholarship | 北大物理 80 级校友、兰怡女士的家人和朋友 The '80 physics class, Ms. Yi Lan's family and friends |
| 2005 | 86 物理班级基金 '86 Physics Class Fund | 北大物理 86 级校友 The '86 physics class |
| 2006 | 88 物理班级基金（助）'88 Physics Class Fund | 北大物理 88 级校友 The '88 physics class |
| 2008 | 陈互雄物理教育基金 Huxiong Chen Educational Fund for Physics | 陈敬熊院士与夫人常菊芳女士 Mr. Jingxiong Chen and Ms. Jufang Chang |
| 2008 | 胡宁奖学金 Ning Hu Scholarship | 胡宁家属，秦旦华、苏肇冰夫妇，赵光达等 Mr. Ning Hu's family, Ms. Danhua Qin, the Zhaobing Su couple, and Mr. Guangda Zhao et al. |
| 2010 | 赵凯华物理教育基金 Kaihua Zhao Educational Fund for Physics | 北大校友、师生及相关单位 PKU alumni and concerned departments |
| 2011 | 求索奖学金 Truth-seeking Scholarship | 北大物理 80 级校友汤漪先生与夫人杨洪女士 Mr. Yi Tang and Ms. Hong Yang |
| 2011 | 张文新教育基金 Wenxin Zhang Educational Fund for Physics | 北大物理 49 级校友张文新先生 Mr. Wenxin Zhang |
| 2011 | 海鸥奖学金 Ou Hai Scholarship | 北大物理 78 级校友张兴云先生、樊培女士 Mr. Xingyun Zhang and Ms. Pei Fan |
| 2011 | 北大物理 91 基金（助）'91 Physics Class Fund | 北大物理 91 级校友 The '91 physics class |
| 2011 | 物理学院学生发展基金 PKU Physics Students Development Fund | 北大物理 00 级校友李川、夏英姿、天美等 Mr. Chuan Li, Yingzi Xia, the Tianmei company and et al. |
| 2011 | 沈克琦物理教育基金 Keqi Shen Educational Fund for Physics | 北大物理 88 级校友王多祥先生 Mr. Duoxiang Wang |
| 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 |
| 2012 | 北大物理 85 念恩奖学金 '85 Physics Class Fund | 北大物理 85 级校友（方晶、雷弈安等）The '85 phyics class (Ms. Jing Fang, Mr. Yi'an Lei and et al.) |
| 2013 | 北大物理紧急救助基金 Emergency Aid for Physics at PKU | 北大物理校友、社会各界 PKU physics alumni and community |

| | | |
|---|---|---|
| 2013 | 北大物理新楼报告厅座椅认捐基金 PKU Physics Lecture Hall Chair Donation Fund | 北大物理校友、社会各界 PKU physics alumni and community |
| 2013 | 北大物理 79 级捐赠园林基金 '79 Physics Class Fund for Garden Donation | 北大物理 79 级校友 The '79 physics class |
| 2013 | 北大物理新楼视频会议室基金 PKU Physics Video Meeting Room Fund | 北大物理 77 级校友夏廷康 Mr. Tingkang Xia |
| 2013 | 北大物理新楼楼前花园捐赠基金 Physics Building Front-garden Fund | 北大物理 78 级校友胡铭 Mr. Ming Hu |
| 2013 | 北大物理新楼 7802 会议室基金 PKU Physics 7802 Meeting Room Fund | 北大物理 78 级校友 The '78 physcs class |
| 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 '12 physics graduates Ji Li, Hua Zong, and Jianbo Fu |
| 2013 | 北大 78 级核物理校友奖励基金 '78 Nuclear Physics Class Fund | 北大原子核物理 78 级校友（纪力强等）The '78 nuclear physics class (Liqiang Ji et al.) |
| 2013 | 北大物理兴诚本科生科研基金 PKU Xingcheng Fund | 北大技物系 79 级校友 A '79 technical physics alumnus |
| 2014 | 北大物理 80 校友捐赠基金 '80 Physics Class Fund | 北大物理 80 级校友 The '80 physics class |
| 2014 | 北大物理新楼图书馆新馆阅览室基金 PKU Physics New Liabrary Reading Room Fund | 北大物理校友、社会各界 PKU physics alumni and community |
| 2015 | 北大物理中 212 会议室座椅认捐基金 PKU Physics Buidling 212 Middle Room Chair Donation Fund | 北大物理校友、社会各界 PKU physics alumni and community |
| 2015 | 北大物理津徽学生发展基金 PKU Physics Jinhui Students Development Fund | 北大物理 97 级校友王晨扬与夫人程雅女士 Mr. Chenyang Wang and Ms. Ya Cheng |



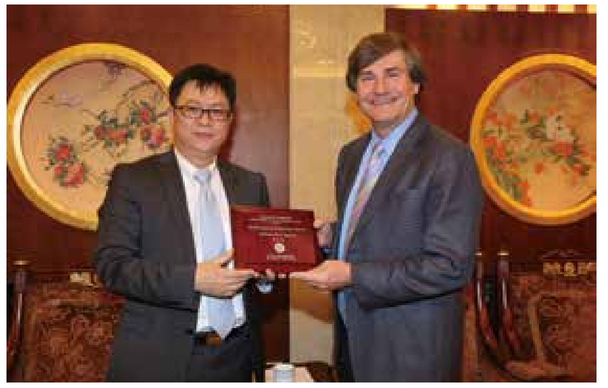


# 合作与交流
# *Exchange & Cooperation*

## 一、格物明理，接轨国际 The Centennial Physics Lectures

2015 年度成功举办“北京大学百年物理讲坛”第十三、十四讲。第十三讲邀请到美国加利福尼亚大学伯克利分校天文系教授 Alex Filippenko 来校报告并与师生交流。

In 2015, the school held the 13th and 14th sessions of The Centennial Physics Lectures. The 13th Lecture was given by Prof. Alex Filippenko from the Department of Astronomy, University of California, Berkeley.



北京大学“大学堂”顶尖学者计划暨“北京大学百年物理讲坛”第十四讲邀请到 2014 年度诺贝尔物理学奖获得者 Hiroshi Amano（天野浩）教授和 Shuji Nakamura（中村修二）教授来校报告访问。

The 14th lecture was included into the PKU Global Fellowship program. We invited the Nobel laureates in physics Profs. Hiroshi Amano and Shuji Nakamura for lectures and workshops.


2016 年度成功举办“北京大学百年物理讲坛”第十五、十六讲。第十五将邀请到国际著名物理学家、法国南巴黎大学固体物理实验室荣誉教授、2007 年诺贝尔物理学讲获得者 Albert Fert 教授来校报告并与北大师生交流。

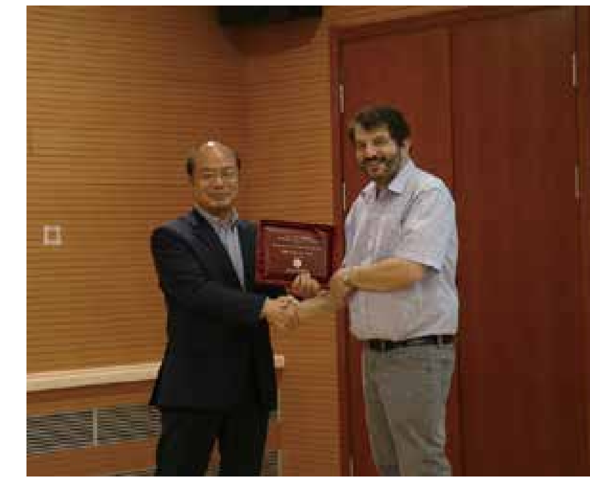
We held the 15th and 16th lectures in 2016. The 15th lecture was given by the 2007 Nobel laureate in physics Albert Fert, an emeritus professor at Université Paris-Sud in Orsay and scientific director of a joint laboratory.





第十六讲邀请到美国科学院院士、哈佛大学 David A. Weitz 教授来校报告访问。

The 16th lecture was given by Prof. David A. Weitz, Academician of the American Academy of Sciences from Harvard University.



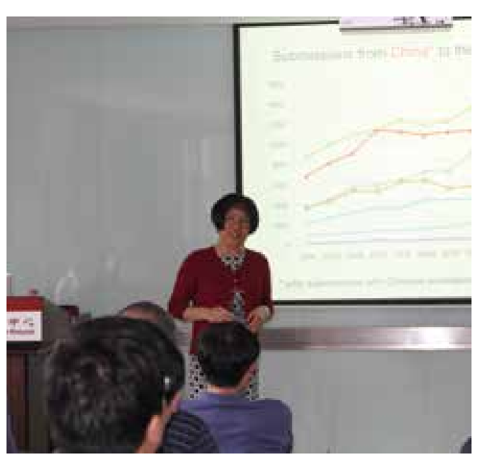
## 二、邀请报告与合作交流 Invited Talks and Exchange Activities

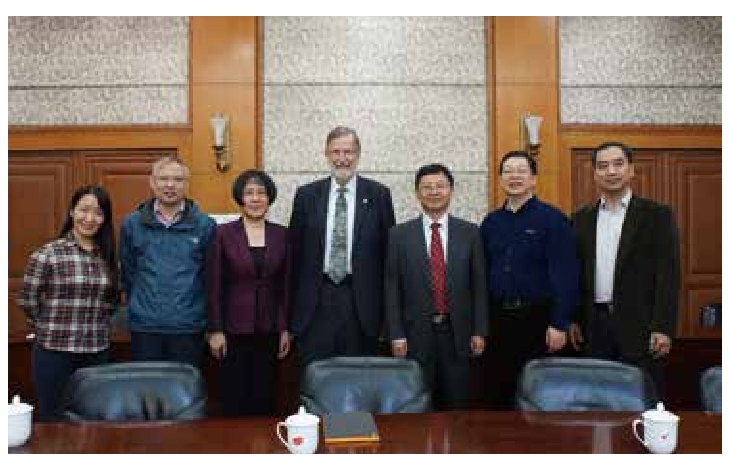
2015 年承办“大学堂”顶尖学者计划，邀请到美国科学院院士、全球最具影响力气候学家 James Hansen 教授来校报告并与师生交流。

In 2015, the school invited Prof. James Hansen a world-renowned climatologist, Academician of the American Academy of Sciences, Professor of Columbia University and Former Director of NASA Goddard Institute for Space Studies, to give the PKU Global Fellowship speech. Prof. Hansen had a group discussion with students and faculty in the Department of Atmospheric and Oceanic Sciences.

4 月，美国物理学会（APS）主编 Gene Sprouse 教授、PRX 执行主编 Ling Miao 博士、PRL 副主编王牧教授一行来访，Gene Sprouse 教授、Ling Miao 博士作了题为“The Physical Review Journals”的特邀报告。北京大学高松副校长在校办会见了代表团。物理学院院长谢心澄教授、副院长龚旗煌教授接待了代表团。

In April, the American Physical Society (APS) Chief Editor Prof. Gene Sprouse, Executive Editor of PRX Dr. Ling Miao, and Associate Editor of PRL Prof. Mu Wang visited the school. Prof. Gene Sprouse and Dr. Ling Miao were invited to give lectures on “The Physical Review Journals.” Vice President of PKU Song Gao met with the delegation. School Dean Xincheng Xie and Vice Dean Qihuang Gong had a discussion with the delegation.







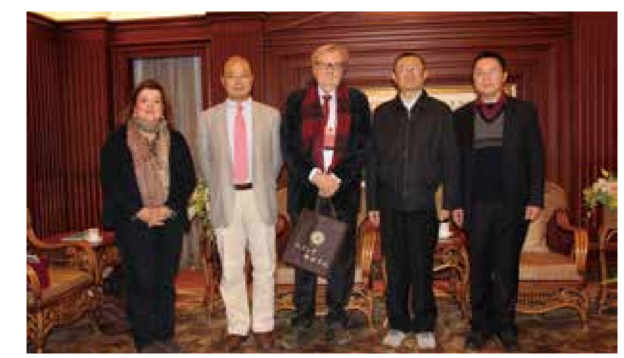


5 月，诺贝尔奖获得者、德国马普学会固体物理研究所所长 Klaus von Klitzing 教授应北京大学物理学院院长谢心澄教授和量子材料科学中心主任杜瑞瑞教授的邀请，到量子材料科学中心进行访问并与物理学院五十余名本科生举行了名为”Meeting the Nobel Laureate”的座谈会。

In May, the Nobel laureate and Director of Max Planck Institute for Solid State Physics, Klaus von Klitzing, was invited by Dean Xincheng Xie and Director of the International Center for Quantum Materials Ruirui Du to visit the school and have a discussion with over 50 undergraduate students.

11 月，1984 年度诺贝尔物理学奖获得者 Carlo Rubbia 教授来访并做了题为“能源的未来”的主题报告。北京大学副校长王杰、物理学院副院长胡永云教授和技术物理系主任冒亚军教授在报告会前亲切会见了 Carlo Rubbia 教授。

In November, the 1984 Nobel Laureate in physics Carlo Rubbia visited the school and gave a theme lecture on “The Future of Energy.” PKU Vice President Jie Wang, School Vice Dean Yongyun Hu, Director of the Department of Technical Physics Yajun Mao met with Prof. Rubbia before the lecture.

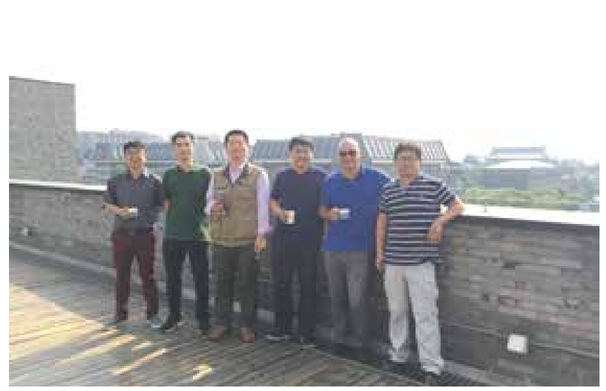


2016 年 2 月，美国物理联合会（American Institute of Physics）首席执行官 Robert G. W. Brown 博士、首席运营官 Catherine O’ Riordan 博士和中国办公室经理张铮铮博士访问我院。物理学院院长谢心澄院士、党委书记陈晓林教授、副院长刘玉鑫、王宇钢、胡永云教授、院长助理朱守华教授在物理楼与外宾座谈。

In February 2016, an American Institute of Physics (AIP) delegation, led by its CEO, Dr. Robert G. W. Brown, visited the school. Dean Xincheng Xie, Committee Secretary Xiaolin Chen, Vice Deans Yuxin Liu, Yugang Wang, Yongyun Hu, and Assistant Dean Shouhua Zhu had an informal discussion with the AIP delegation.

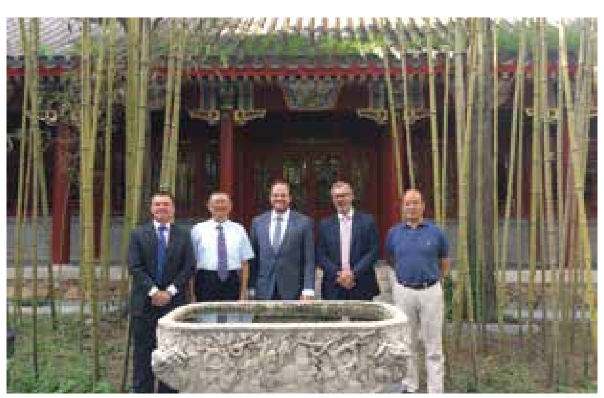
5 月，香港中文大学物理系主任 Dickon H. L. Ng 教授一行 16 人访问我院，物理学院院长助理王新强教授会见了代表团。代表团与凝聚态物理和量子物理、材料科学、生物物理和软物质、高能物理和天文领域的研究人员进行了分组研讨。

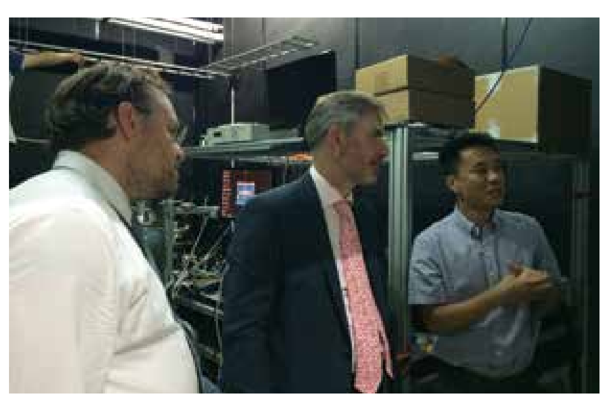
In May, a Chinese University of Hong Kong delegation, led by head of Department of Physics, Prof. Dickon H. L. Ng, visited the school. Assistant Dean Xinqiang Wang met with the CUHK delegation. Three parallel seminars were held on high energy/astronom, condensed mater physics and quantum physics, material sciences, bio physics, and soft matters.



8 月，英国物理学会（UK Institute of Physics, IOP）首席执行官 Paul Hardaker 教授率领代表团一行五人访问北京大学。北京大学副校长王杰在临湖轩接见了英国物理学会代表团，国际合作部副部长郑如青、物理学院副院长胡永云等参加了会见，并与代表团座谈。代表团一行参观了物理学院实验室并与相关人员深入交流。

In August, a UK Institute of Physics (IOP) delegation led by its CEO Prof. Paul Hardaker visited PKU. PKU Vice President Jie Wang met with the delegation, accompanied by Vice Director of International Relations Office Ruqing Zheng, Vice Dean of School of Physics Yongyun Hu. The delegation visited the school' s laboratories and discussed with faculties.



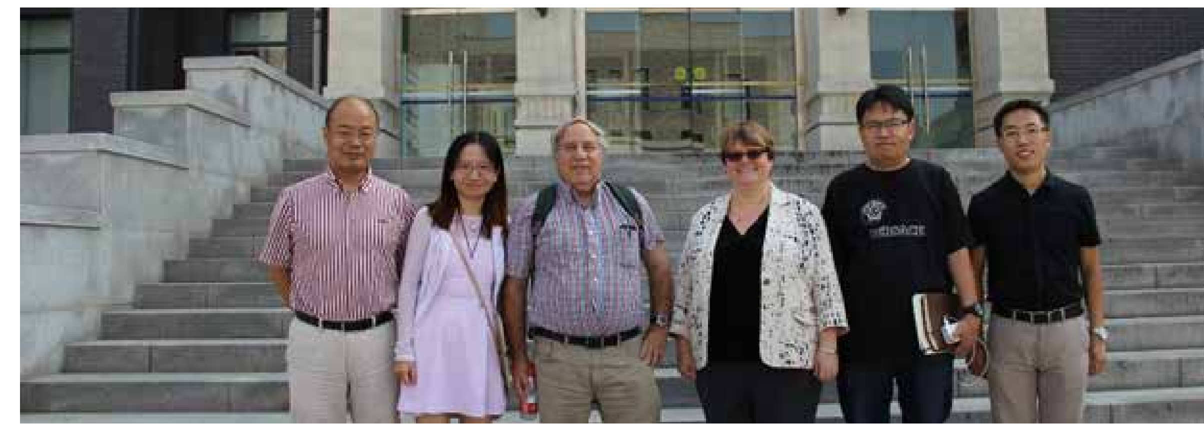




合作与交流 | *Cooperation*

9 月，美国物理教师协会（AAPT）会长 Janelle Bailey 教授、AAPT 前会长 David Sokoloff 教授以及美国物理联合会（AIP）张铮铮博士一行 3 人到物理学院访问并举行座谈。物理学院副院长胡永云、朱守华等参加座谈。

In September, President of The American Association of Physics Teachers (AAPT) Prof. Janelle Bailey, Former President Prof. David Sokoloff visited the school. Vice Deans Yongyun Hu and Shouhua Zhu held a discussion with our guests.

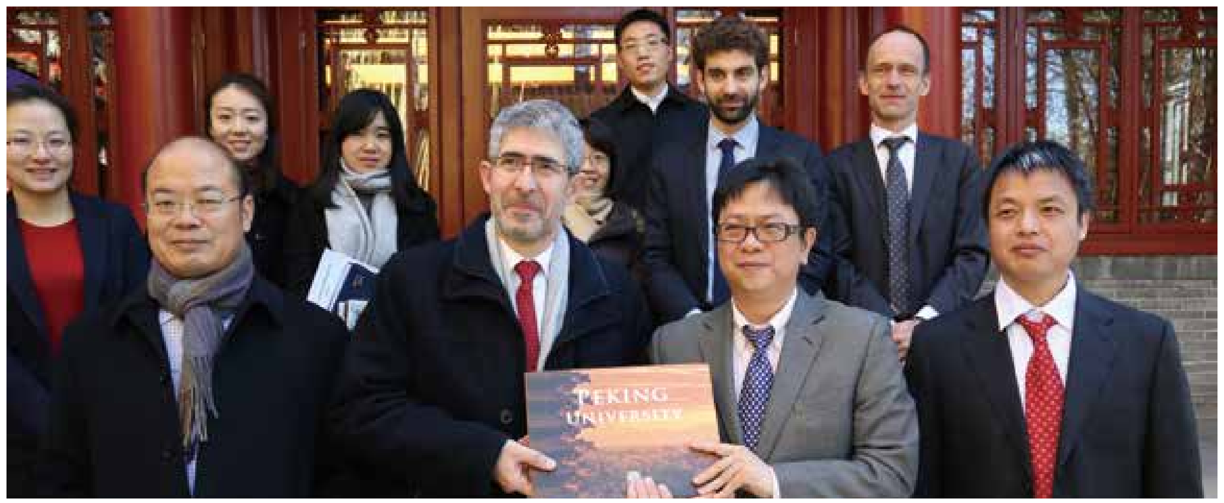


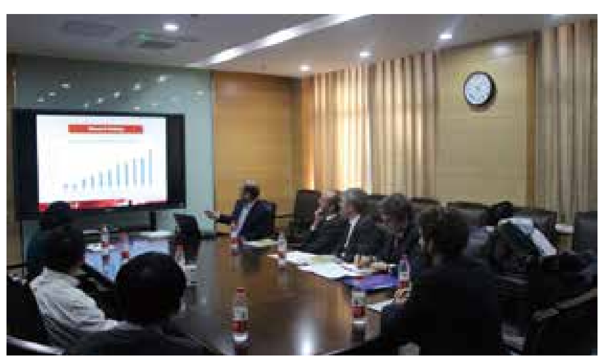
12 月，美国物理学会（APS）总编 Pierre Meystre 教授、Physical Review Letters 副主编王牧教授一行到访北京大学物理学院。Pierre Meystre 教授作了题为“有关美国物理学会杂志的思考”的报告。物理学院院长谢心澄院士与学院师生代表进行座谈。

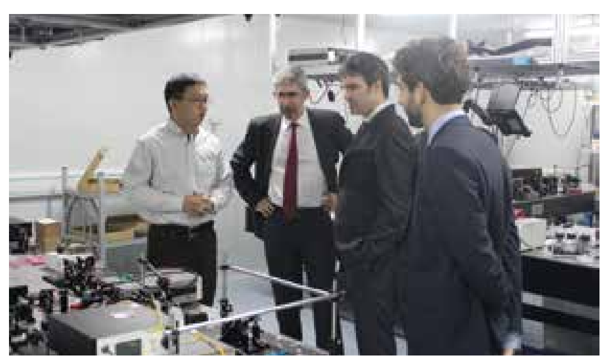
In December, Chief Editor of American Physics Society (APS) Prof. Pierre Meystre and Associate Editor of Physical Review Letters Prof. Mu Wang visited the school. Prof. Meystre gave a report on the “Thoughts on the American Physical Society journals.” Dean Xincheng Xie and faculty representatives held a discussion with our guests.

法国巴黎萨克莱大学（University Paris-Saclay）校长 Gilles Bloch 一行 5 人访问北京大学并到物理学院座谈。北京大学副校长李岩松在临湖轩会见了来宾，物理学院副院长胡永云参加学校会见及学院座谈。访问团参观访问物理学院光学实验室。

A University Paris-Saclay delegation led by its President Gilles Bloch visited PKU. PKU Vice President Yansong Li met with the delegation. School Vice Dean Yongyun Hu discussed with the delegation. The delegation also visited the Laboratories of Institute of Modern Optics at the school.





### 三、国际 / 港澳台会议 International/Hong Kong/Macao/Taiwan Conferences

2015 年 7 月 7-9 日，由北京大学物理学院主办的第十届全国硅基光电子材料及器件研讨会在贵阳市召开。来自美、英、德、中的近百位专家和研究生参加了本次会议。

The 10th National Symposium on silicon-based optoelectronic materials and devices was held by the School of Physics, PKU on July 7-9, 2015. Nearly a hundred scholars and graduate students from China, US, UK and Germany attended this symposium.






2015 年 8 月 30 日至 9 月 4 日，由北京大学物理学院宽禁带半导体研究中心主办的第十一届国际氮化物半导体会议（ICNS-11）顺利在北京国际会议中心召开。来自 33 个国家和地区 800 余人参加了本次会议。

The 11th International Conference on Nitride Semiconductors (ICNS-11) was held at Beijing International Convention Center on August 30 to September 4, 2015. The conference was very well attended with 821 attendees from 33 countries and areas.

第八届国际中子照相专题研讨会（ITMNR-8）于 2016 年 9 月 4-8 日在北京大学召开。本次会议由北京大学核物理与核技术国家重点实验室主办，中国原子能科学研究院、中国工程物理研究院二所、清华大学协办，并得到中国高等科学技术中心和一些企业的资助。北出席此次会议的有来自 18 个国家的 106 位代表，其中国内代表 38 人。

The 8th International Topical Meeting on Neutron Radiography (ITMNR-8) was held at Peking University, Beijing, China on September 4-8, 2016. The conference was held by the State Key Laboratory of Nuclear Physics and Technology at PKU and attended by 106 participants from 18 countries.

2016 年 10 月 10-14 日，“国际天文学联合会第 323 次学术会议（IAUS323）——行星状星云：恒星和星系演化的多波段探针”在北京大学举行，包括国际天文学联合会主席 Silvia Torres Peimbert 在内的国内外 100 余名该领域的专家学者以及研究生参加了会议。本次会议由北京大学物理学院承办，并得到国家自然科学基金委和中国科学院国家天文台的支持。

On October 10-14, 2016, the international conference on “The Planetary nebulae: Multiwavelength probes of stellar and galactic evolution” was held at PKU. More than a hundred scholars, including Silvia Torres Peimbert, President of the International Astronomical Union, and graduate students attended the conference. This conference was held by the school and supported by the National Natural Science Foundation and National Astronomical Observatory, Chinese Academy of Sciences.







# 奖励与荣誉
# *Awards & Honors*

**2015 年度：**
**In 2015,**

- 谢心澄、俞大鹏当选为中国科学院院士。
  Xincheng Xie and Dapeng Yu were elected Academicians of the Chinese Academy of Sciences.
- 吴学兵科研团队的“发现宇宙早期发光最亮、中心黑洞质量最大的天体”入选 2015 年度“中国高等学校十大科技进展”。
  Xuebing Wu' s team won the Ten Major Scientific Progress of Higher Education in China.
- 叶沿林教授获 2015 年度第十届周培源物理奖。
  Yanlin Ye was awarded “The Peiyuan Zhou Medal.”
- 叶沿林教授获何梁何利基金 2015 年度科学与技术进步奖。
  Yanlin Ye won the Scientific and Technological Progress Medal awarded by the Ho Leung Ho Lee Foundation.
- 孙庆丰教授获 2015 全球华人物理与天文学会亚洲成就奖。
  Qingfeng Sun won the Global Chinese Physics and Astronomy Society Asia Achievement Award.
- 龚旗煌获国家自然科学基金委国家重大科研仪器研制项目。
  Qihuang Gong was awarded the major scientific research instrument development projects approved by the National Natural Science Foundation of China.
- 沈波获创新研究群体科学基金项目。
  Bo Shen won the innovative research group science fund.
- 古英、徐莉梅获杰出青年基金。
  Ying Gu and Limei Xu were awarded the National Funds for Distinguished Young Scientists.
- 李源、裴俊琛、刘开辉、唐宁获批优秀青年科学基金资助。
  Yuan Li, Junchen Pei, Kaihui Liu, and Ning Tang were awarded the National Funds for Excellent Young Scientists.

- 肖立新等获 2015 年度高等学校科学研究优秀成果奖（科学技术）自然科学奖一等奖。
  Lixin Xiao' s group was awarded the first prize of Natural Science Award of Higher Education Science Research Excellent Achievements.

- 胡永云获 2015 年度高等学校科学研究优秀成果（科学技术）自然科学奖二等奖。
  Yongyun Hu was awarded the second prize of Natural Science Award of Higher Education Science Research Excellent Achievement.

- 林金泰获美国科学院院刊 Cozzarelli 奖。
  Jintai Lin won the Cozzarelli Prize by the American Academy of Sciences.

- 林金泰获中国气象学会涂长望青年科技奖一等奖。
  Jintai Lin won the first prize of Tu Changwang Youth Science and Technology Award by China Meteorological Society.

**2016 年度：**
**In 2016,**

- 王恩哥和江颖团队首次揭示水的核量子效应，其成果入选 2016 年中国十大科技进展新闻。
  Enge Wang and Ying Jiang' s group won the Top Ten Science and Technology Progress in China.

- 孟杰科研团队“发现原子核手征对称性和空间反射对称性的联立自发破缺”入选 2016 年度“中国高等学校十大科技进展”。
  Jie Meng' s group won the Ten Major Scientific Progress of Higher Education in China.

- 龚旗煌获 2016 年度“何梁何利基金科学与技术进步奖”电子信息技术奖。
  Qihuang Gong won the Scientific and Technological Progress Medal in Electronics and Information Technology awarded by the Ho Leung Ho Lee Foundation.

- 张树霖被授予“拉曼终身成就奖（Raman Lifetime Award）”。
  Shulin Zhang was awarded the Raman Lifetime Award.

- 王恩哥、俞大鹏、王新强、赵春生获国家重点研发计划项目首席。
  Enge Wang, Dapeng Yu, Xinqiang Wang and Chunsheng Zhao were elected Chief of the National key R & D project.

- 吴成印获杰出青年基金。
  Chengyin Wu was awarded the National Funds for Distinguished Young Scientists.





- 何琼毅、赵清获批优秀青年科学基金资助。
  Qiongyi He and Qing Zhao were awarded the National Funds for Excellent Young Scientists.

- 何琼毅、廖志敏、江颖入选青年长江。
  Qiongyi He, Zhimin Liao and Ying Jiang were appointed the Young Yangtze River Scholar.

- 刘富坤获政府特殊津贴。
  Fukun Liu was awarded Special government allowance.

- 刘运全获北京市青年拔尖团队项目。
  Yunquan Liu was appointed the Beijing Youth Top-notch Team Project.

- 颜学庆等获 2016 年度高等学校科学研究优秀成果奖（科学技术）自然科学奖二等奖。
  Xueqing Yan was awarded the second prize of Natural Science Award of Higher Education Science Research Excellent Achievement.

- 赵凯华教授获得国际物理教育奖章 (ICPE-Medal)，为亚洲学者个人首次获得此项奖励。
  Kaihua Zhao won the International Committee on Physics Education Medal (ICPE-Medal), and became the first individual in Asia to win this award.