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物理学Physics

Gaussian boson sampling with 1,024 squeezed states in 8,176 modes

中国科大研制出1024个量子压缩态输入8176模式的可编程量子计算原型机“九章四号”

▲作者：Hua-Liang Liu, Hao Su, Yu-Hao Deng, Si-Qiu Gong, Yi-Chao Gu, Hao-Yang Tang, Meng-Hao Jia, Qian Wei, Yu-Kun Song, Dong-Zhou Wang, Ming-Yang Zheng, Fa-Xi Chen, Li-Bo Li, Si-Yu Ren, Xue-Zhi Zhu, Mei-Hong Wang, Yao-Jian Chen, Yan-Fei Liu, Long-Sheng Song, Peng-Yu Yang, Jun-Shi Chen, Hong An, Lei Zhang, Lin Gan, Jian-Wei Pan, etc

▲链接：

https://www.nature.com/articles/s41586-026-10523-6

▲摘要：

开发大规模、高保真度的量子处理器是一项基础性的科学挑战，对于探索经典计算的极限以及向容错量子系统迈进至关重要。

高斯玻色采样不仅是展示量子计算优越性的重要模型，还能生成用于容错量子计算的玻色纠错码。然而，其可扩展性一直受到日益庞大和复杂编码电路中显著光子损耗的制约。

中国科学技术大学常务副校长潘建伟院士、陆朝阳教授等展示了一款可编程的光子量子处理器——九章4.0。该处理器将1024个高效率压缩态整合进一个采用混合时空编码的、包含8176个模式的电路中。

通过实现92%的源效率和51%的系统总效率，该处理器生成的样本中单次探测事件的光子数最高可达3050个，比之前的演示成果提升了一个数量级。

该架构实现了连接度的立方级扩展（163=4096），使其能够在一个维度约为102461的希尔伯特空间中进行采样。

实验结果经过了当前所有经典模拟方法的严格验证，特别是针对利用光子损耗的新型矩阵乘积态算法。

在可编程的低损耗量子处理器中操控数千个光子的能力，将实验前沿推向了远超经典计算可及的全新领域，并为实现万亿级-连续变量的三维团簇态以及容错光量子硬件开辟了道路。

▲ Abstract：

The development of large-scale, high-fidelity quantum processors is a fundamental scientific challenge, essential for exploring the boundaries of classical computation and advancing towards fault-tolerant systems. Gaussian boson sampling not only serves as a prominent model for demonstrating quantum computational advantage but can also generate bosonic error-correcting codes for fault-tolerant quantum computing. However, its scalability has been hindered by significant photon loss in increasingly large and complex

encoding circuits. Here we show a programmable photonic quantum processor, Jiuzhang 4.0, which incorporates 1,024 high-efficiency squeezed states into a hybrid spatial – temporal encoded 8,176-mode circuit. By achieving 92% source efficiency and 51% overall system efficiency, the processor produces samples with detection events up to 3,050 photons, representing an order-of-magnitude increase in scale over previous demonstrations. This architecture realizes a cubic scaling of connectivity (163 = 4, 096), enabling sampling within a Hilbert space of dimension approximately 102,461. The experimental results are rigorously validated against all current classical simulation methods, especially the matrix product state algorithms recently designed to exploit photon loss11. The ability to control thousands of photons in programmable low-loss quantum processors pushes the experimental frontier into a regime far beyond classical tractability and opens a pathway to trillion-qumode three-dimensional cluster states and fault-tolerant photonic quantum hardware.

Imaging hidden objects with consumer LiDAR via motion-induced sampling

利用消费级LiDAR通过运动诱导采样对隐藏物体进行成像

▲ 作者：Siddharth Somasundaram, Aaron Young, Akshat Dave, Adithya Pediredla Ramesh Raskar

▲链接：

https://www.nature.com/articles/s41586-026-10502-x

▲摘要：

光探测与测距（LiDAR）技术正越来越多地应用于消费级成像领域，涵盖手持设备、可穿戴设备和机器人应用。这些传感器能以皮秒级的时间分辨率测量光的飞行时间，这使其有可能对视野外的隐藏物体进行成像。

尽管这种非视距（NLOS）成像能力已在研究级LiDAR设备上得到验证，但由于消费级设备激光功率低、空间分辨率低以及物体和相机存在运动，导致信号质量较差，因此在此类设备上实现NLOS成像仍具挑战性。

麻省理工学院的研究者提出了一种多帧融合策略来克服这些挑战，并在消费级LiDAR上成功演示了NLOS成像。

他们引入了运动诱导孔径采样模型，将物体形状、物体运动和相机运动的影响统一在一个测量模型下。

利用该模型，他们在智能手机级别的LiDAR上展示了几种NLOS能力：（1）三维重建；（2）单物体和多物体跟踪；（3）利用隐藏物体进行相机定位。

此前，NLOS成像能力仅限于体积庞大且昂贵的研究级硬件，这些硬件需要复杂的设置和校准。

该成果标志着向即插即用式NLOS成像的转变，任何人都可以使用成本低于100美元的现成硬件，且无需额外设置，即可对隐藏物体进行成像。研究者认为，这种能力的普及将推动NLOS成像在消费领域的应用。

▲ Abstract：

Light-detection and ranging (LiDAR) is being increasingly deployed for consumer imaging across handheld, wearable and robotic applications1,2,3,4. These sensors measure the time-of-flight of light at picosecond resolution, which could enable them to image objects hidden from their field of view. Although such non-line-of-sight (NLOS) imaging capabilities have been shown on research-grade LiDAR devices, they remain challenging to achieve on consumer devices due to poor signal quality resulting from low laser power, low spatial resolution, and object and camera motion. Here we propose a multi-frame fusion strategy to overcome these challenges and demonstrate NLOS imaging on consumer LiDAR. We introduce the motion-induced aperture sampling model to unify the effects of object shape, object motion and camera motion under a single measurement model. Using this model, we demonstrate several NLOS capabilities on a smartphone-grade LiDAR: (1) three-dimensional reconstruction; (2) single- and multi-object tracking; and (3) camera localization using hidden objects. Previously, NLOS imaging capabilities were restricted to bulky and expensive research-grade hardware that requires extensive set-up and calibration. Our results represent a shift towards plug-and-play NLOS imaging, where anyone can image hidden objects with off-the-shelf hardware (for less than US$100) and no additional set-up. We believe democratization of such capabilities will advance consumer applications of NLOS imaging.

Cusp-singularity-enhanced Coriolis effect for sensitive chip-scale gyroscopes

基于尖点奇异性增强科里奥利效应的灵敏芯片级陀螺仪

▲ 作者：Sen Zhang, Dingbang Xiao, Fei Wang, Ran Huang, Lei Yu, Ning Zhou, Kaixuan He, Xuezhong Wu, Franco Nori, Hui Jing Xin Zhou

▲链接：

https://www.nature.com/articles/s41586-026-10565-w

▲摘要：

陀螺仪作为基础性惯性传感器，对于消费电子、汽车和航空航天工业中的旋转测量至关重要，其中使用最广泛的类型依赖于科里奥利效应。

芯片级科里奥利振动陀螺仪（CVG）虽然尺寸、重量和成本都有所降低，但其性能远低于传统的宏观尺度CVG。这是因为微芯片中固有的弱科里奥利因子，在对抗相较于宏观器件本就更为突出的布朗噪声时，从根本上限制了灵敏度的提升。

为了突破这一物理极限，南方科技大学的研究者与国内外合作者提出并实验演示了一种新方法：利用芯片级CVG相位跟踪振荡中位于尖点突变内的三阶奇点，从而实现科里奥利效应诱导频率调制的立方根尺度放大。

利用这一效应，他们将科里奥利因子提升了三个数量级，信噪比提高了253倍，精度提高了297倍。

此外，尖点奇点还实现了一种前所未有的超高灵敏度相位调制亚线性测量，使硅芯片陀螺仪的信

噪比性能达到了创纪录的水平。这些发现不仅通过填补观测和控制奇点增强科里奥利效应的空白，为陀螺仪技术带来了革命性进步，也为其他超高灵敏度传感应用提供了新的思路。

▲ Abstract：

Gyroscopes, as fundamental inertial sensors, are crucial for rotation measurements in the consumer electronics, automotive and aerospace industries, with the most widely used kind relying on the Coriolis effect. The chip-scale Coriolis vibratory gyroscopes (CVGs) show reduced size, weight and cost but have far lower performance than traditional macroscale CVGs, as the weak intrinsic Coriolis factor sets a fundamental limit on scaling the sensitivity against the inherently louder Brownian noise in microchips compared with the macroscale ones. Here, to overcome this physical limit, we propose and experimentally demonstrate the use of third-order singularities lying within cusp catastrophes in the phase-tracked oscillations of an on-chip CVG to facilitate a cubic-root scaling of the Coriolis-effect-induced frequency modulation. Using this effect, we achieve a three-orders-of-magnitude enhancement in the Coriolis factor, yielding a 253-fold improvement in the signal-to-noise ratio and a 297-fold increase in precision. Moreover, the cusp singularity enables a previously unattainable ultrasensitive phase-modulated sublinear measurement, achieving record signal-to-noise ratio performance for silicon-chip gyroscopes. These findings not only provide revolutionary advancements in gyroscope technologies, by filling the gap in observing and controlling the singularity-enhanced Coriolis effect, but also shed new light on other ultrasensitive sensing applications.

Mesoscale atomic engineering in a crystal lattice

晶格中的介观原子工程

▲ 作者：Julian Klein, Kevin M. Roccapriore, Mads Weile, Sergii Grytsiuk, Andrew R. Lupini, Zdenek Sofer, Dimitar Pashov, Mark van Schilfgaarde, Swagata Acharya, Malte R?sner Frances M. Ross

▲链接：

https://www.nature.com/articles/s41586-026-10431-9

▲摘要：

利用激光、离子阱和扫描探针针尖操控单个原子，已经改变了人们对物质的理解，并推动了量子科学的突破。然而，将这种操控能力扩展到三维固体中并达到介观尺度，仍然是一个基础性挑战。

人们已知电子显微镜中的电子辐照可以诱导原子位移，原子操控也已被提出并得到初步演示。但是，可重复且确定性的控制至今仍难以实现。

美国麻省理工学院和橡树岭国家实验室的研究者展示了在三维晶体中的确定性原子工程，能够在150纳米×100纳米×13纳米的体积内，于几分钟内创建超过40000个用户定义缺陷的有序排列。

通过利用精度优于20皮米的电子束，将磁性半导体CrSBr中的单个Cr原子引导至选定的间隙位点，我们制造出了空位-间隙复合体。由此产生的杂质阵列形成了一个嵌入主体晶格内的介观尺度晶体，这是一种新型的人造工程材料，在室温及离开显微镜后依然保持稳定。

通过追踪Cr原子的位移，他们确定了缺陷结构可预测的条件。计算表明，这些缺陷会形成关联杂质态，具备缺陷内的光学跃迁以及缺陷间的动力学与库仑相互作用。

这为在介观尺度乃至潜在宏观尺度上进行原子缺陷工程建立了一个通用平台，为可扩展的量子技术，包括确定性色心布局、多体晶格模型的量子模拟以及原子尺度制造开辟了机遇。

▲ Abstract：

Controlling individual atoms using lasers, ion traps and scanning probe tips has transformed our understanding of matter and enabled breakthroughs in quantum science. Extending this control into three-dimensional (3D) solids and across mesoscopic scales, however, remains a foundational challenge. Electron irradiation in electron microscopes is known to induce atomic displacements7, and atomic manipulation has been proposed8 and demonstrated9,10. Yet repeated and deterministic control has remained elusive. Here we demonstrate deterministic atomic engineering in a 3D crystal, creating ordered arrangements of more than 40,000 user-defined defects within minutes across a 150 nm × 100 nm × 13 nm volume. By steering individual Cr atoms in the magnetic semiconductor CrSBr into selected interstitial sites using an electron beam directed with sub-20-pm-scale accuracy, we create vacancy – interstitial complexes. The resulting impurity array forms a mesoscale crystal embedded within the host lattice, a new form of engineered artificial matter that remains stable at room temperature and outside the microscope. By tracking Cr atom displacements, we identify conditions under which the defect structures are predictable. Our calculations suggest that these defects form correlated impurity states with intra-defect optical transitions and inter-defect kinetic and Coulomb interactions. This establishes a generalizable platform for atomic defect engineering at mesoscopic, and potentially macroscopic, scales, opening opportunities for scalable quantum technologies, including deterministic colour-centre placement, quantum simulation of many-body lattice models and atomic-scale manufacturing.

生理医学physiological medicine

Clinical application of base editing for treating β-thalassaemia

碱基编辑治疗β-地中海贫血的临床应用

▲ 作者：Yongrong Lai, Rongrong Liu, Lijie Wang, Xu-Kai Ma, Yaliang Li, Gaohui Yang, Lingling Shi, Yi-Lin Guo, Zhenbin Wei, Xuemei Zhou, Wenchao Xu, Yaofeng Hou, Annarita Miccio, Bei Yang, Xiaodun Mou, Li Yang Jia Chen

▲链接：

https://www.nature.com/articles/s41586-026-10342-9

▲摘要：

β-地中海贫血是由β-血红蛋白生成减少或缺失引起的。此前，研究者使用变压器碱基编辑器，对β-地中海贫血患者的CD34+造血干细胞和祖细胞进行了实验室规模的电穿孔实验，目标是靶

向HBG1和HBG2启动子中转录抑制因子BCL11A的结合基序，以重新激活胎儿血红蛋白（HbF）的产生。

现在，他们报告了一项1期临床试验的结果，该试验纳入了5名患者，这些患者接受了使用临床级变压器碱基编辑器修饰的自体CD34+细胞（CS-101）。中位随访时间为CS-101输注后23.0个月，中性粒细胞和血小板植入的中位时间分别为16天和25天。此外，所有患者均已停止红细胞输注，CS-101输注后至末次输血的中位时间为18天。输注后第3个月，平均总血红蛋白和HbF浓度分别为12.4±1.0g/dl和11.5±0.9g/dl-1。

在整个随访期间，这些水平维持在此水平或更高，表明造血功能快速重建。CS-101的不良事件总体与白消安清髓性预处理及自体造血干细胞和祖细胞移植相当。未报告死亡或癌症发生。研究发现，CS-101能够快速且持续地提高总血红蛋白和HbF水平，从而使得患者早期实现并持久地脱离输血依赖。

▲ Abstract：

β-Thalassaemia is caused by reduced or absent production of β-haemoglobin. Previously, we performed laboratory-scale electroporation of CD34+ haematopoietic stem and progenitor cells from patients with β-thalassaemia using a transformer base editor. The aim was to target the binding motif of the transcription repressor BCL11A in the HBG1 and HBG2 promoters7 to reactivate fetal haemoglobin (HbF) production. Here we present results of a phase 1 clinical trial (ClinicalTrials.gov identifier: NCT06024876) of five patients who received autologous CD34+ cells modified using a transformer base editor at clinical scale (CS-101). With a median follow-up of 23.0 months after CS-101 infusion, the median times to neutrophil and platelet engraftment were 16 days and 25 days, respectively. Moreover, all patients had stopped red blood cell transfusions, with a median time to the last transfusion of 18 days after CS-101 infusion. The mean total haemoglobin and HbF concentrations were 12.4 ± 1.0 and 11.5 ± 0.9 g dl-1, respectively, at month 3 after infusion. These levels remained at similar or higher levels throughout the follow-up period, which indicated rapid haematopoietic reconstitution. The adverse events of CS-101 were generally consistent with those of busulfan myeloablative conditioning and autologous haematopoietic stem and progenitor cell transplantation. No deaths or cancer occurrences were reported. In summary, CS-101 can lead to rapid and sustained increases in both total haemoglobin and HbF levels, which resulted in early and enduring transfusion independence.

Evolutionary characterization of lung cancer metastasis

肺癌转移的演化特征

▲ 作者：Sonya Hessey, Abigail Bunkum, Ariana Huebner, Kerstin Haase, Kristiana Grigoriadis, Cristina Naceur-Lombardelli, Wing Kin Liu, Caitlin F. Harrigan, Charlotte Grieco, Daniele Marinelli, Boyue Ding, Carlos Martínez-Ruiz, Piotr Pawlik, Mark S. Hill, Olivia Lucas, Corentin Richard, Oriol Pich, Kerstin Thol, Takahiro Karasaki, Sophia Ward, Foteini Athanasopoulou, Monica Sivakumar, Selvaraju Veeriah, Antonia Toncheva, TRACERx Consortium, TRACERx EVO Consortium, PEACE consortium, Mariam Jamal-Hanjani, etc.

▲链接：

https://www.nature.com/articles/s41586-026-10428-4

▲摘要：

伦敦大学学院癌症研究所的研究者利用从TRACERx肺癌研究和PEACE尸检计划中招募的24例非小细胞肺癌（NSCLC）患者的501个纵向收集的原发性和转移性肿瘤样本，推断从诊断到死亡期间的肿瘤演化过程。

基于覆盖了死亡前影像学检测到的70%转移灶的DNA测序数据，并结合配对的多区域采样的原发性肿瘤，他们发现转移灶的基因组与其祖先原发性肿瘤的基因组存在显著差异，表现出在转移播散后发生的额外驱动基因改变和基因组加倍事件。在62.5%的患者中，多个原发性肿瘤亚克隆发生播散，各自形成了不同的转移灶。这些转移灶又成为进一步播散的源头：超过半数的采样转移灶是由其他转移灶播种形成的。

转移灶在原位存在的时间长短影响了其进一步播种转移灶的可能性。大多数转移性迁移起始和终止于同一解剖腔内。少数离开胸腔播种远处转移的亚克隆播散范围广泛，并富集了体细胞拷贝数变异，提示染色体不稳定性可能促进了胸外播散。这项时空演化分析揭示了晚期NSCLC中转移多样性和播种的程度（这一点在单次转移灶活检中往往被低估），并识别出驱动转移进展的基因组和临床介质。

▲ Abstract：

Limited understanding of the biological processes that govern metastatic dissemination hinders its prevention and treatment1. Here, using 501 longitudinally collected primary and metastatic tumour samples from 24 patients with non-small cell lung cancer (NSCLC) enrolled in the TRACERx lung study and PEACE autopsy programme, we infer tumour evolution from diagnosis to death. With DNA-sequencing data encompassing 70% of the metastases that were radiologically detected before death and paired multi-region sampled primary tumours, we show that the genomes of metastases diverge markedly from those of their ancestral primary tumour, with additional driver alterations and genome doubling events occurring after metastatic dissemination. In 62.5% of patients, multiple primary tumour subclones disseminated, each founding a distinct metastasis. These metastases served as sources of onward spread: more than half of the metastases sampled were seeded by other metastases. The duration that metastases existed in situ influenced their likelihood of seeding further metastases. Most metastatic migrations started and ended in the same anatomical cavity. The few subclones that exited the thorax to seed metastases disseminated widely and were enriched for somatic copy-number alterations, suggesting that chromosomal instability may facilitate extrathoracic spread. This spatial and temporal evolutionary analysis sheds light on the extent of metastatic diversity and seeding in advanced NSCLC—which tends to be underestimated in single metastasis biopsies—and identifies genomic and clinical mediators of metastatic progression.

作者： 冯维维 来源：科学网微信公众号