《自然》（20251127出版）一周论文导读

作者：writer 来源：科学网

本文原地址：https://www.iikx.com/news/progress/37083.html

《自然》（20251127出版）一周论文导读。

编译冯维维

Nature,27 November 2025,Volume 647 Issue 8091

《自然》2025年11月27日，第647卷，8091期

物理学Physics

Detection of triboelectric discharges during dust events on Mars

火星沙尘事件期间摩擦放电的探测

▲作者：Baptiste Chide, Ralph D. Lorenz, Franck Montmessin, Sylvestre Maurice, Yann Parot, Ricardo Hueso, German Martinez, Alvaro Vicente-Retortillo, Xavier Jacob, Mark Lemmon, Bruno Dubois, Pierre-Yves Meslin, Claire Newman, Tanguy Bertrand, Gr é goire Deprez, Daniel Toledo, Agustin S á nchez-Lavega, Agn è s Cousin Roger C. Wiens

▲ 链接：

https://www.nature.com/articles/s41586-025-09736-y

▲ 摘要：

闪电是行星大气中能量最强大的电活动表现形式之一，不仅在地球上有记录，在土星和木星上也有观测到。在火星上，长期以来一直怀疑存在电活动，但从未得到直接证实。

研究者报告了通过在“毅力号”火星车上的SuperCam载荷设备捕获的电信号和声学特征识别出的摩擦放电的原位探测。在两个火星年期间，共探测到55次此类事件，这些事件通常与尘卷风和沙尘暴对流前锋有关。这些偶然的观测结果表明，火星电场可以达到火星近地表大气的击穿阈值。

这种电活动可能影响沙尘动力学，并可能加剧反应性电化学环境，从而增强大气的氧化能力，对有机分子的保存产生影响。这一原位证据可能对表面化学、宜居性和人类探索具有深远意义。

▲ Abstract：

Lightning is among the most energetic manifestation of electrical activity in planetary atmospheres, with documented observations not only on Earth but also on Saturn and Jupiter. On Mars, the existence of electrical activity has long been suspected but never directly demonstrated.Here we report in situ detections of triboelectric discharges, identified by their electrical and acoustic signatures captured by the SuperCam microphone aboard the Perseverance rover. Fifty-five events have been detected over two Martian years, usually associated with dust devils and dust storm convective fronts. These serendipitous observations demonstrate that Martian electric fields can reach the breakdown threshold of the near-surface atmosphere of Mars, predicted to be on the order of several tens of kVm?1. Such electrical activity could affect dust dynamics and potentially fuel a reactive electrochemical environment enhancing the oxidizing capacity of the atmosphere, with consequences for the preservation of organic molecules. This in situ evidence may have implications for surface chemistry, habitability and human exploration. Entanglement-enhanced nanoscale single-spin sensing

纠缠增强的纳米级单自旋传感

▲作者：Xu Zhou, Mengqi Wang, Xiangyu Ye, Haoyu Sun, Yuhang Guo, Shuo Han, Zihua Chai, Wentao Ji, Kangwei Xia, Fazhan Shi, Ya Wang Jiangfeng Du

▲ 链接：

https://www.nature.com/articles/s41586-025-09790-6

▲ 摘要：

探测单个自旋——包括稳态与亚稳态——是量子传感领域的一项基础性挑战，在凝聚态物理、量子化学及单分子磁共振成像等领域具有广泛应用。尽管金刚石中的氮空位中心（NV）已成为强大的纳米级传感器，但其单自旋探测性能仍受限于显著的环境噪声和有限的传感体积。

研究者提出并演示了一种纠缠增强传感方案，通过战略性使用纠缠NV对来突破这些限制。在环境条件下，他们的方法相较于单NV中心实现了3.4倍的灵敏度提升和1.6倍的空间分辨率改进。该方案采用精心设计的纠缠态，通过量子干涉放大目标自旋信号，同时抑制环境噪声。

关键的是，他们将此能力拓展至解析亚稳态单自旋动力学，通过识别状态依赖的耦合强度直接观测不同自旋态之间的随机跃迁。这种双重功能使得同时探测静态与动态自旋物种成为可能，为研究复杂量子系统提供了新途径。所实现的性能确立了纠缠增强传感作为实现量子材料与界面原子尺度表征的有效路径。

▲ Abstract：

Detecting individual spins—including stable and metastable states—represents a fundamental challenge in quantum sensing, with broad applications across condensed matter physics, quantum chemistry and single-molecule magnetic resonance imaging. Although nitrogen – vacancy (NV) centres in diamond have emerged as powerful nanoscale sensors, their performance for single-spin detection remains constrained by substantial environmental noise and restricted sensing volume. Here we propose and demonstrate an entanglement-enhanced sensing protocol that overcomes these limitations through the strategic use of entangled NV pairs. Our approach achieves a 3.4-fold enhancement in sensitivity and a 1.6-fold improvement in spatial resolution relative to single NV centres under ambient conditions. The protocol uses carefully engineered entangled states that amplify target spin signals through quantum interference while suppressing environmental noise. Crucially, we extend these capabilities to resolve metastable single-spin dynamics, directly observing stochastic transitions between different spin states by identifying state-dependent coupling strengths. This dual functionality enables simultaneous detection of static and dynamic spin species for studying complex quantum systems. The achieved performance establishes entanglement-enhanced sensing as a viable pathway towards atomic-scale characterization of quantum materials and interfaces.

化学Chemistry

Photocatalytic oxygen-atom transmutation of oxetanes

氧杂环丁烷的光催化氧原子嬗变

▲作者：Ying-Qi Zhang, Shuo-Han Li, Xinglong Zhang Ming Joo Koh

▲ 链接：

https://www.nature.com/articles/s41586-025-09723-3

▲ 摘要：

非芳香杂环和碳环构成了无数生物活性与功能分子的骨架结构。值得注意的是，四元饱和环状分子如氮杂环丁烷、硫杂环丁烷和环丁烷，在药物化学领域日益受到关注。这类分子通常具备与药物研发相关的物理化学特性：高效性、稳定性、代谢稳定性及靶标特异性。通过对易得的氧杂环丁烷进行氧原子替换，将为获取多种环状药效团提供直接途径，然而此类原子置换反应在非芳香分子体系中鲜有报道。

研究者提出了一种通用光催化策略，能够选择性地将氧杂环丁烷中的氧原子替换为含氮、含硫或含碳基团，通过一步操作即可将其转化为多种饱和环状结构单元。该原子置换方法展现出优异的官能团兼容性，适用于后期功能化修饰，可大幅简化药物及复杂药物类似物的合成流程——这些分子原本需要通过多步反应才能制备。机理研究揭示了化学选择性的起源：环内氧原子优先反应生成无环二卤代物中间体，随后在亲核试剂存在下实现高效环重构。

▲ Abstract：

Non-aromatic heterocycles and carbocycles form the skeleton of countless bioactive and functional molecules. Of note, four-membered saturated cyclic molecules such as azetidines, thietanes and cyclobutanes have garnered increasing attention in medicinal chemistry. These molecules often have physicochemical properties relevant to drug discovery: potency, stability, metabolic stability and target specificity. The replacement of oxygen atoms in readily available oxetanes would offer a direct route to a variety of these cyclic pharmacophores, yet such atom swapping has been rarely reported for non-aromatic molecules. Here we report a general photocatalytic strategy that selectively substitutes the oxygen atom of an oxetane with a nitrogen-based, sulfur-based or carbon-based moiety, transforming it into a diverse range of saturated cyclic building blocks in a single operation. This atom-swapping method exhibits high functional group compatibility and is applicable to late-stage functionalization, substantially simplifying the synthesis of pharmaceuticals and complex drug analogues that would otherwise require multistep routes. Mechanistic investigations unveil insights on the origin of chemoselectivity that allows the endocyclic oxygen atom to react preferentially to generate an acyclic dihalide intermediate, which then undergoes efficient ring reconstruction in the presence of a nucleophilic species.

Controlling pyramidal nitrogen chirality by asymmetric organocatalysis

通过不对称有机催化控制锥形氮手性

▲作者：San Wu, Pengquan Chen, Meng Duan, Peng-Ying Jiang, Qingyang Zhou, Shao-Hua Xiang, K. N.

Houk Bin Tan

▲ 链接：

https://www.nature.com/articles/s41586-025-09607-6

▲ 摘要：

手性是生命现象的核心特征，而控制一对镜像分子（对映体）中特定构型的生成更是合成化学的基本准则。尽管对手性碳、硅、磷和硫中心的控制已司空见惯，但胺类物质中的氮手性中心通常难以稳定存在。

目前氮手性对映选择性构建的有限成果主要集中于季铵盐和桥联双环胺类体系——这些结构的锥形构型本身受限。对于非桥联锥形氮手性化合物的不对称合成，长期面临需要超化学计量手性源且立体选择性低下等难题。

研究者提出了一种通过手性布朗斯特酸催化的氯化反应构建无环氮立体中心的催化对映选择性策略。他们设计了具有立体专一性的分子内反应，以克服氮氯化羟胺的结构与构型不稳定性。更重要的是，该策略已成功应用于构建具有构型稳定氮手性中心的N-
氯氮丙啶对映体。控制实验为分子内亲核取代过程的SN2反应路径提供了证据。

▲ Abstract：

Chirality is central to life, and controlling the formation of one of a pair of mirror-image molecules (enantiomers) is a central tenet of synthetic chemistry. Although controlling stereogenic carbon, silicon, phosphorus and sulfur centres is commonplace, nitrogen centres in amines are not typically stable. Limited achievements in the enantioselective construction of nitrogen chirality have primarily been established in quaternary ammonium salts and bridged bicyclic amines, which have a restricted pyramidal configuration. The asymmetric synthesis of non-bridged pyramidal nitrogen-chirogenic compounds suffers from a super-stoichiometric chiral source and exhibits poor stereoselectivity. Here we present a catalytic enantioselective strategy for construction of acyclic nitrogen stereocentres via a chiralBr?nstedacid-catalysed chlorination reaction. We designed a stereospecific intramolecular reaction to overcome the structural and configurational instabilities of nitrogen-chlorinated hydroxylamines. Furthermore, this strategy has been applied successfully to synthesize the enantioselective N-chloroaziridines with a configurationally stable nitrogen stereogenic centre. Control experiments provide evidence for anSN2pathway for the intramolecular nucleophilic substitution event.

生命科学Life Science

Efficient and accurate search in petabase-scale sequence repositories

在拍碱基规模序列库中实现高效精准搜索

▲作者：Mikhail Karasikov, Harun Mustafa, Daniel Danciu, Oleksandr Kulkov, Marc Zimmermann,

Christopher Barber, Gunnar R?tsch Andr é Kahles

▲ 链接：

https://www.nature.com/articles/s41586-025-09603-w

▲ 摘要：

公共数据库中可用的生物测序数据量正在快速增长，已成为生物医学研究的重要资源。然而，如何高效精准地实现这些数据的全文检索仍面临挑战。

研究者基于表征大规模序列集的高效数据结构和算法，提出MetaGraph方法框架，能够利用标注德布鲁因图可扩展地索引大型DNA、RNA或蛋白质序列集。通过整合七个公共数据源，他们实现了对1880万个独特DNA/RNA序列集及2100亿个氨基酸残基的全文检索——涵盖病毒、细菌、真菌、植物、动物和人类等所有生命谱系。

他们还证明了在大型序列库（原始序列达67拍碱基对）中进行经济高效全文检索的可行性：针对不超过1兆碱基对的小型查询，按需成本约100美元；大型查询成本可低至每兆碱基对0.74美元。研究表明，所有公共生物序列的高度压缩表征可容纳于少数消费级硬盘（总成本约2,500美元），使其具备经济实用性并易于传输用于深度分析。

研究者通过多个实践案例探索了挖掘现有档案中有价值关联的可能性，展示了该索引在整合分析中的应用，并证明此类能力有望推动生物医学研究的突破性进展。

▲ Abstract：

The amount of biological sequencing data available in public repositories is growing rapidly, forming a critical resource for biomedicine. However, making these data efficiently and accurately full-text searchable remains challenging. Here we build on efficient data structures and algorithms for representing large sequence sets. We present MetaGraph, a methodological framework that enables us to scalably index large sets of DNA, RNA or protein sequences using annotated de Bruijn graphs. Integrating data from seven public sources, we make 18.8 million unique DNA and RNA sequence sets and 210 billion amino acid residues across all clades of life—including viruses, bacteria, fungi, plants, animals and humans—full-text searchable. We demonstrate the feasibility of a cost-effective full-text search in large sequence repositories (67 petabase pairs (Pbp) of raw sequence) at an on-demand cost of around US$100 for small queries up to 1 megabase pairs (Mbp) and down to US$0.74 per queried Mbp for large queries. We show that the highly compressed representation of all public biological sequences could fit on a few consumer hard drives (total cost of around US$2,500), making it cost-effective to use and readily transportable for further analysis. We explore several practical use cases to mine existing archives for interesting associations, demonstrating the use of our indexes for integrative analyses, and illustrating that such capabilities are poised to catalyse advancements in biomedical research.

Hijacking a bacterial ABC transporter for genetic code expansion

劫持细菌ABC转运体实现遗传密码扩展

▲作者：Tarun Iype, Maximilian Fottner, Paul B?hm, Carlos Piedrafita, Yannis M?ller, Michael Groll Kathrin Lang

▲ 链接：

https://www.nature.com/articles/s41586-025-09576-w

▲ 摘要：

通过位点特异性编码非天然氨基酸（ncAAs），为扩展蛋白质功能库提供了强大工具。然而，当前ncAA掺入策略效率低下，制约了其在基础研究和生物技术领域的广泛应用。研究者揭示了细胞对ncAA摄取不足是高效遗传密码扩展的主要障碍，并通过劫持细菌ATP结合盒（ABC）转运体突破此瓶颈——该工程化转运体可主动摄入易合成的异肽键连接三肽，后者在细胞内被加工释放为ncAAs。

利用该策略，他们成功实现了多种此前难以获得的ncAAs的高效编码，为蛋白质装备了生物正交与交联基团、翻译后修饰以及化学酶促偶联功能基团。他们还进一步开发了高通量定向进化平台，针对历史上难以高效摄取的非天然氨基酸，定制了专属转运系统。表达这些进化转运体的定制大肠杆菌菌株，可实现单位点与多位点ncAA掺入，且效率达到野生型水平。

此外，研究者改造了三肽支架使其能共转运两种不同ncAAs，实现了二者的高效双掺入。本研究整体表明，通过工程化改造摄取系统，是实现化学多样性构建单元程序化导入的有效策略。

▲ Abstract：

The site-specific encoding of non-canonical amino acids (ncAAs) provides a powerful tool for expanding the functional repertoire of proteins. Its widespread use for basic research and biotechnological applications is, however, hampered by the low efficiencies of current ncAA incorporation strategies. Here we reveal poor cellular ncAA uptake as a main obstacle to efficient genetic code expansion and overcome this bottleneck by hijacking a bacterial ATP-binding cassette (ABC) transporter5 to actively import easily synthesizable isopeptide-linked tripeptides that are processed into ncAAs within the cell. Using this approach, we enable efficient encoding of a variety of previously inaccessible ncAAs, decorating proteins with bioorthogonal6 and crosslinker moieties, post-translational modifications and functionalities for chemoenzymatic conjugation. We then devise a high-throughput directed evolution platform to engineer tailored transporter systems for the import of ncAAs that were historically refractory to efficient uptake. Customized Escherichia coli strains expressing these evolved transporters facilitate single and multi-site ncAA incorporation with wild-type efficiencies. Additionally, we adapt the tripeptide scaffolds for the co-transport of two different ncAAs, enabling their efficient dual incorporation. Collectively, our study demonstrates that engineering of uptake systems is a powerful strategy for programmable import of chemically diverse building blocks.

作者：冯维维 来源：科学网微信公众号