《自然》（20260730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/41282.html

《自然》（20260730出版）一周论文导读。 编译未玖

Nature, 30 July 2026, Volume 655, Issue 8125

《自然》2026年7月30日，第655卷，8125期

物理学Physics

Regression to the mean can explain saturation of geomagnetic storms

均值回归可解释地磁暴的饱和现象

▲ 作者：Nithin Sivadas, David Sibeck, Varsha Subramanyan, Maria-Theresia Walach, Dogacan Su Ozturk, Banafsheh Ferdousi, et al.

▲ 链接：https://www.nature.com/articles/s41586-026-10757-4

▲摘要：

地球上的极端空间天气事件发生在强烈太阳风驱动的间隔期。太阳风驱动了近地空间环境中的等

离子体对流和电流。在驱动参数较低时，地球的响应是线性的，可通过基于地面磁强计活动的极盖指数等参数来估算。

令人费解的是，在极端太阳风驱动下，地球的响应似乎不会超过某个饱和极限。理论学家已对此饱和效应提出了多种解释，但尚未达成共识。

研究组证明，这种饱和现象是太阳风测量时间与幅度的随机不确定性所导致均值回归的表现。该研究结果表明，支撑饱和理论的数据分析存在非线性偏差，从而质疑了这些理论的有效性。

校正这些不确定性后，地球对太阳风驱动的响应始终是线性的，且极端地磁暴的影响可能比先前认为的严重一倍。

研究组进一步表明，均值回归是测量值与真实值之间关系的基本属性，即测量所对应的真实值更接近均值。这种效应在极值的不确定测量中尤为显著，并可能会在从极端气候研究到慢性医学疼痛的多个领域中出现。

▲ Abstract：

Extreme space weather events on Earth occur during intervals of strong solar wind driving. The solar wind drives plasma convection and currents in the near-Earth space environment. For low values of the driver, the Earth’s response is linear, estimated by parameters such as the polar cap index based on ground magnetometer activity. Curiously, for extreme solar wind driving, the Earth’s response appears not to increase beyond a saturation limit. Theorists have advanced a host of explanations for this saturation effect, but there is no consensus. Here we demonstrate that this saturation is a manifestation of the regression to the mean effect arising from random uncertainty in the timing and magnitude of solar wind measurements. Our results reveal that data analysis underpinning the saturation theories is nonlinearly biased, thereby challenging the validity of the theories. Correcting for the uncertainties reveals that the Earth’s response to solar wind driving is linear throughout, and that the impact of extreme geomagnetic storms can be twice as large as previously thought. We show that regression to the mean is a fundamental property of the relationship between measurement and the truth, where the truth corresponding to the measurement is closer to the mean. This effect is particularly pronounced for uncertain measurements of extreme values and is likely to manifest across various fields, from extreme climate studies to chronic medical pain.

A digitally controlled silicon quantum processing unit

一种数控硅量子处理单元

▲ 作者：Members of the HRL Quantum Team and Collaborators

▲链接：

https://www.nature.com/articles/s41586-026-10754-7

▲摘要：

商业相关的量子计算机需要可规模化制造、集成和控制的大量高性能量子比特。硅基纯交换型量

子比特因其控制信号简单且与先进半导体制造工艺兼容，是一种颇具潜力的候选方案，但在实现足够低的噪声以及可扩展的控制与布线方案方面仍存在诸多问题。

研究组介绍了一种量子处理单元，它由定制设计的低温互补金属氧化物半导体（CMOS）控制器、高密度超导带状电缆和低噪声纯交换型量子比特器件组成。

该量子芯片包含一个由54个交换耦合量子点构成的3轨阵列，经配置可容纳多达18个纯交换型量子比特。

研究组集成并使用这些组件来展示单量子比特和纠缠操作下的量子比特性能，将纯交换型方案的技术水平提升了一个数量级。还进一步通过实现距离-5重复码和距离-2量子错误探测码对该系统进行了验证，并与模型模拟进行了详细比较。

该工作可助力开发未来实用规模量子计算机，确保其运营与资本需求可控。

▲ Abstract：

Commercially relevant quantum computers will require large numbers of high-performing qubits that can be manufactured, integrated and controlled at scale. Silicon exchange-only qubits are a strong candidate modality owing to their control-signal simplicity and compatibility with advanced semiconductor manufacturing, but questions remain around the achievability of sufficiently low noise and a scalable control and wiring solution. Here we introduce a quantum processing unit composed of a custom-designed cryogenic complementary metal – oxide – semiconductor (CMOS) controller, a high-density superconducting ribbon cable and a low-noise exchange-only qubit device. The quantum chip features a 3-rail array of 54 exchange-coupled quantum dots, configurable to host up to 18 exchange-only qubits. We integrate and use these components to demonstrate qubit performance for both single-qubit and entangling operations that advances the exchange-only state of the art by an order of magnitude. We further validate this system by implementing a distance-5 repetition code and a distance-2 quantum error-detecting code and then make detailed comparisons with simulations. Our work facilitates the development of future utility-scale quantum computers with manageable operational and capital requirements.

材料科学Materials Science

Programming fracture resistance in metamaterials via elastic instabilities

通过弹性不稳定性编程超材料的抗断裂性能

▲ 作者：Yujia Wang, Yangchengyi Liu, Kunlin Wu, Xuan Zhang, Hanzheng Xing, Songyan Zhang, et al.

▲链接：

https://www.nature.com/articles/s41586-026-10804-0

▲摘要：

长期以来，抗断裂材料的设计一直受到多种长度尺度上增韧机制复杂性的制约。机械超材料为应对这一挑战提供了一个颇有前景的平台，但现有研究主要集中于被动表征传统晶格架构中的断裂行为。

近期研究已展示弹性不稳定性在提升建筑材料功能方面的潜力，但其与抗断裂性能之间的关联尚不清楚。

研究组证明了机械超材料中的断裂行为可通过利用弹性不稳定性进行主动编程，从而将这两种传统上互不关联的失效模式联系起来。

通过实验与模拟相结合，研究组表明，对假塑性超材料中非弹性区尺寸的受控调控能够实现从内在断裂行为到外在断裂行为的转变，同时断裂能提升高达一个数量级。

这项工作标志着断裂力学从被动观察转向主动控制，为设计具有定制抗断裂性能的超材料建立了新框架。该发现不仅增进了对超材料中不稳定性-
断裂相互作用的基础理解，也提出了一条通过不稳定性设计来编程断裂行为的普适性路径。

▲ Abstract：

The design of fracture-resistant materials has long been hindered by the complexity of toughening mechanisms across multiple length scales. Mechanical metamaterials offer a promising platform to address this challenge, yet existing research has largely focused on passively characterizing fracture in conventional lattice architectures. Recent studies have demonstrated the potential of elastic instabilities to enhance functionalities in architected materials; however, their connection to fracture resistance remains unexplored. Here we demonstrate that fracture behaviours in mechanical metamaterials can be actively programmed by exploiting elastic instabilities, thereby bridging the two traditionally disconnected failure modes. Through a combination of experiments and simulations, we show that controlled manipulation of the inelastic zone size in pseudoplastic metamaterials enables a transition from intrinsic to extrinsic fracture behaviour, accompanied by up to a one-order-of-magnitude increase in fracture energy. This work represents a shift from passive observation to active control of fracture mechanics, establishing a new framework for designing metamaterials with tailored fracture resistance. Our findings not only advance the fundamental understanding of instability – fracture interactions in metamaterials but also suggest a broadly applicable route for programming fracture behaviours through instability design.

化学Chemistry

Stereoretentive decarbonylative C(sp3) – C(sp3) cross-coupling

立体保持性脱羰C(sp3) – C(sp3)交叉偶联反应

▲ 作者：Zhidao Huang, Tianrui Wu, Zehao Yuan, Chuxiong Meng, Leah C. Garman, Ilia A. Guzei, et al.

▲链接：

https://www.nature.com/articles/s41586-026-10800-4

▲摘要：

C(sp3) – C(sp3)键形成的交叉偶联方法虽已十分普遍，但立体控制的成键反应仍是一大难题，而这一难题的攻克对药物发现至关重要，特别是当下对更高sp3特征分子的需求正不断上升。

对映特异性交叉偶联方法虽可作为对映选择性偶联的补充，但因更丰富的手性烷基亲电试剂尚无法实现立体特异性氧化加成，其应用此前仅限于可获得性较低的特殊底物。

受经典的立体保持Curtius重排的启发，研究组报道了一种催化策略，通过类似的立体保持脱羰步骤，从易得的手性氨基酸和α-羟基酸衍生物出发，生成一种多功能的手性烷基镍中间体。

该手性烷基镍中间体可在数分钟内发生分解和/或外消旋，但其稳定性足以在相对较低的温度（22-40°C）下与烷基自由基（衍生自烷基碘化物）进行立体保持的交叉亲电偶联。

该机理策略为立体控制的C(sp3) – C(sp3)键形成提供了一种直接的途径，包括那些通过立体选择性自由基机制无法获得的非对映异构体。该研究所描述的金属-Curtius策略为开发多种立体特异性交叉偶联反应奠定了机理基础。

▲ Abstract：

Although C(sp3) – C(sp3) bond-forming cross-coupling methods have become more common, stereocontrolled bond formation remains a challenge, despite its importance for drug discovery, where there is a emerging demand for molecules with increased sp3 character. Enantiospecific cross-coupling approaches would complement advances in enantioselective coupling, but have been limited to specialized substrates with lower availability because stereospecific oxidative addition of more abundant chiral alkyl electrophiles is unknown. Inspired by the classic, stereoretentive Curtius rearrangement, here we disclose a catalytic strategy that proceeds by an analogous stereoretentive decarbonylation step to form a versatile chiral alkylnickel intermediate from easily available chiral amino acid and α-hydroxy-acid derivatives. The chiral alkylnickel intermediates decompose and/or racemize on the order of minutes, but are sufficiently stable to enable stereoretentive cross-electrophile coupling with alkyl radicals (derived from alkyl iodides) at relatively low temperature (22 – 40? ° C). This mechanistic strategy provides a straightforward approach to stereocontrolled C(sp3) – C(sp3) bond formation, including diastereomers that are inaccessible by stereoselective radical mechanisms. The ‘ metallo-Curtius ’ strategy described in this study lays a mechanistic foundation for the development of many stereospecific cross-coupling reactions.

C-glycoside synthesis through radical cross-coupling of glycohydrazides

糖酰肼自由基交叉偶联合成C-糖苷

▲ 作者：Yinliang Guo, Yiheng Li, Benedikt Buchberger, Yixin Liu, Carla Capone, Tapas Adak, et al.

▲链接：

https://www.nature.com/articles/s41586-026-10807-x

▲摘要：

碳水化合物是自然界中含量最丰富、结构最多样的生物分子之一，在能量储存、分子识别和细胞信号传导中发挥着核心作用。

在这一领域中，C-糖苷（即O-糖苷中糖苷键的氧原子被碳原子取代的化合物）因其可抵抗酶促水解，已成为药物化学中的重要结构单元。

其中尤为重要的是C-芳基糖苷，例如SGLT2抑制剂达格列净、卡格列净和恩格列净，它们是治疗2型糖尿病的一线药物。

然而，C-芳基糖苷的可扩展合成传统上依赖受保护的糖衍生物、冗长的合成路线或常规交叉偶联反应，这些方法往往存在选择性差、底物范围有限以及需要大量保护基操作等问题。

研究组报道了一种使用糖基磺酰肼作为氧化还原中性自由基前体进行交叉偶联以制备C-芳基糖苷的实用方法。这些试剂可直接从未保护的天然糖制备，在温和条件下生成糖基自由基，并能高效合成多种C-芳基糖苷，包括所有已获批的SGLT2抑制剂、天然产物如沙莫螯素和新石蜡素，以及医学相关探针。

该平台不仅实现了端基官能团化，还可在糖骨架多个位点构建C-C键，并兼容立体保持的自由基偶联，从而有效规避固有立体化学偏好，拓展了糖基治疗药物与化学探针的获取路径。

▲ Abstract：

Carbohydrates are among the most abundant and structurally diverse biomolecules in nature, playing central roles in energy storage, molecular recognition and cell signalling. Within this domain, C-glycosides, in which the oxygen atom of the glycosidic bond in O-glycosides is replaced by carbon, have emerged as valuable motifs in medicinal chemistry due to their resistance to enzymatic hydrolysis. Of particular importance are C-aryl glycosides, exemplified by the SGLT2 inhibitors dapagliflozin, canagliflozin and empagliflozin, which are frontline therapies for type?2 diabetes. However, scalable syntheses of C-aryl glycosides have relied traditionally on protected sugar derivatives, lengthy sequences or conventional cross-couplings that often suffer from poor selectivity, limited scope and extensive protecting-group manipulation6. Herein, we report a practical approach to C-aryl glycosides using glycosyl sulfonyl hydrazides as redox-neutral radical precursors for cross-coupling. Prepared directly from unprotected native sugars, these reagents generate glycosyl radicals under mild conditions and enable efficient access to diverse C-aryl glycosides, including all approved SGLT2 inhibitors, natural products such as salmochelins and neopetrosins, and medicinally relevant probes. Beyond anomeric functionalization, this platform enables C – C bond formation at several positions on carbohydrate scaffolds and supports stereoretentive radical coupling that can override inherent stereochemical biases, expanding practical access to carbohydrate-derived therapeutics and chemical tools.

地球科学Earth Science

Role of methanesulfonic acid in atmospheric particle nucleation and growth

甲磺酸在大气粒子成核与生长中的作用

▲ 作者：Rima Baalbaki (???? ??????), Jiali Shen (沈佳莉), Mario Simon, Hannah Klebach, Samuel Ruhl, Jenna DeVivo, et al.

▲链接：

https://www.nature.com/articles/s41586-026-10810-2

▲摘要：

海洋浮游植物产生的二甲硫醚（DMS；CH3SCH3）是大气硫的一个重要来源。其氧化产物包括硫酸（SA；H2SO4）和甲磺酸（MSA；CH3SO3H），MSA在低于10°C时的产率高于SA。

尽管已知SA可驱动新粒子形成，这些粒子随后可能生长并充当云凝结核（CCN），但MSA的作用尚不清楚。

研究组在CERN CLOUD（宇宙射线室外液滴形成）反应舱大气条件下进行的实验表明，在?10?°C以下，MSA与氨（NH3）共同成核，其成核速率与SA-NH3相当。

此外，在?10?°C以下，MSA和SA协同成核，与NH3形成多酸分子簇。即使在超低NH3水平下，在低于9?°C且相对湿度（RH）高于40%的条件下，MSA也能在接近或达到动力学极限的速率下驱动粒子生长。

由于在寒冷海洋区域，MSA和SA通常以相似浓度共存，这导致与仅SA-NH3比，成核速率可加快10倍，生长速率可加快2倍。研究组的全球模型模拟表明，MSA可提高CCN浓度，尤其在极地地区。

研究组提出，MSA可能是当今和工业化前大气中寒冷、原始海洋区域生物源颗粒的重要驱动因素，但在全球气候模型中尚未明确。

▲ Abstract：

Dimethyl sulfide (DMS; CH3SCH3) from marine phytoplankton is a notable source of atmospheric sulfur. Its oxidation products include sulfuric acid (SA; H2SO4) and methanesulfonic acid (MSA; CH3SO3H), which has a higher yield than SA below 10? ° C. Although SA is known to drive the formation of new particles, which may subsequently grow and act as cloud condensation nuclei (CCN), the role of MSA remains unclear. Here, in experiments performed under atmospheric conditions at the CERN CLOUD (Cosmics Leaving OUtdoor Droplets) chamber, we show that MSA nucleates together with ammonia (NH3) below ?10? ° C, at rates comparable with SA-NH3. Moreover, MSA and SA nucleate synergistically below ?10? ° C, forming multi-acid molecular clusters with NH3. Even at ultralow NH3 levels, MSA drives particle growth at or near the kinetic limit below 9? ° C and above 40% relative humidity (RH). Because MSA and SA generally coexist at similar concentrations in cool marine regions, our findings indicate that nucleation rates may be accelerated up to tenfold and growth rates up to twofold compared with SA-NH3 alone. Our global model simulations indicate that MSA can enhance CCN concentrations, especially in polar regions. We propose that MSA might be an important driver of biogenic particles in cool, pristine marine

regions of both the present-day and pre-industrial atmospheres and yet is unaccounted for in global climate models.

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