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编者按：2021 年不仅是“十四五”的开局之年，也是两个百年目标交汇与转换之年。为了让我校师生快速了解国内外学术前沿、经典及热点，图书馆学科服务团队特开辟此栏目，利用 WOS/ESI/Incites、Scopus/SciVal 等权威数据库和分析工具筛选研究前沿，或跟踪重要学术网站获取最新学术动态，分专题进行编译报道。因学科专业所限，难免出错，敬请批评指正。同时，我们也面向全校师生征集关注的领域和专题。

本期推荐报道 Nature、Science 期刊上材料科学领域的最新论文。

CONTACT US

联系电话：025-52090336-817

办公地址：李文正图书馆 B401 室

编辑：刘丽娟

审核：陆　美

美国 Science(《科学》)、英国 Nature(《自然》)及美国 Cell(《细胞》)是国际公认的三大享有最高学术声誉的科技期刊，发表在这三大期刊上的论文简称 CNS 论文。本次精选 2021 年 6 月 Science 和 Nature 中的部分物理领域论文，详细情况如下。

物理 6 月 Science 论文

[1]Discovery of a Cooper-pair density wave state in a transition-metal dichalcogenide

过渡金属二硫化物中发现库珀对密度波

出版信息：Science, 25 JUNE 2021, VOL 372, ISSUE 6549

作者：Xiaolong Liu, Yi Xue Chong, Rahul Sharma, J. C. Séamus Davis.

第一作者单位：Laboratory of Atomic and Solid State Physics, Department of Physics, Cornell University, Ithaca, NY 14850, USA.

全文链接：https://science-sciencemag-org-s.vpn.seu.edu.cn:8118/content/372/6549/1447/tab-pdf

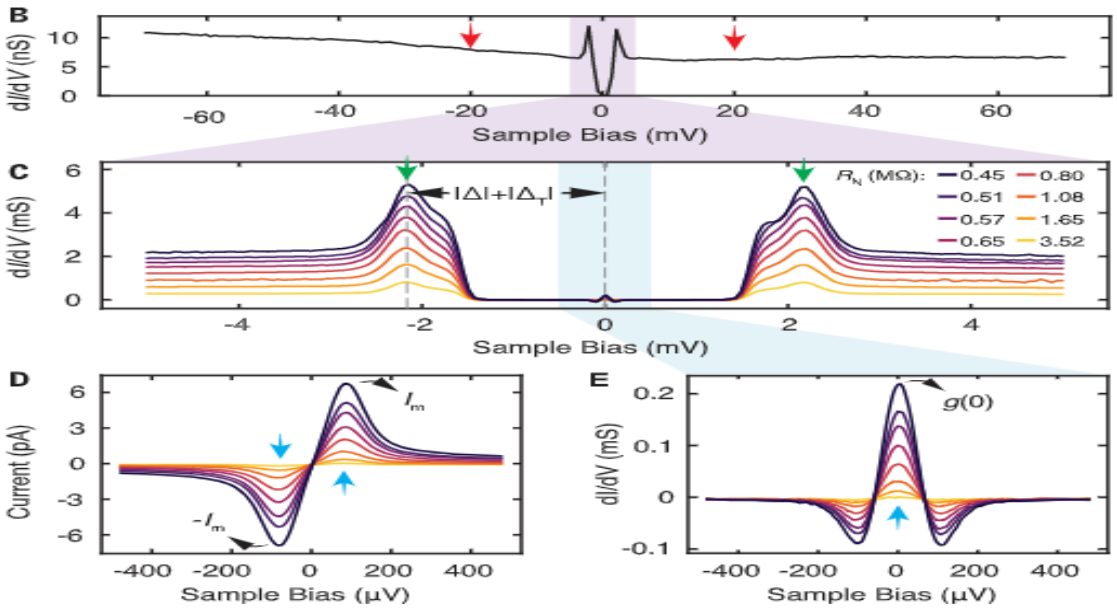
Abstract：Pair density wave (PDW) states are defined by a spatially modulating superconductive order parameter. To search for such states in transition-metal dichalcogenides (TMDs), we used high-speed atomic-resolution scanned Josephson-tunneling microscopy. We detected a PDW state whose electron-pair density and energy gap modulate spatially at the wave vectors of the preexisting charge density wave (CDW) state. The PDW couples linearly to both the s-wave superconductor and the CDW and exhibits commensurate domains with discommensuration phase slips at the boundaries, conforming those of the lattice-locked commensurate CDW. Nevertheless, we found a global $\delta\Phi \cong \pm 2\pi/3$ phase difference between the PDW and CDW states, possibly owing to the Cooper-pair wave function orbital content. Our findings presage pervasive PDW physics in the many other TMDs that sustain both CDW and superconducting states.

摘要翻译：双密度波（PDW）态由空间调制超导序参量定义。为了在过渡金属二硫化物（TMDs）中寻找这种状态，研究组使用了高速原子分辨扫描的约瑟夫森隧道显微镜。

研究组检测到一个 PDW 态，其电子对密度和能隙在预先存在的电荷密度波（CDW）态的波矢上进行空间调制。PDW 与 s 波超导体和 CDW 呈线性耦合，并在边界处呈现出公度错相滑移的相称畴，与晶格锁定的相称 CDW 一致。

然而，研究组发现 PDW 态和 CDW 态之间的整体相位差为 $\delta\Phi \cong \pm 2\pi/3$，这可能与库珀对波函数轨道有关。研究组的发现预示着 PDW 物理学在许多其他维持 CDW 和超导态的 TMDs 中普遍存在。

文中插图：



[2] Imaging orbital ferromagnetism in a moiré Chern insulator

莫尔陈绝缘体中轨道铁磁性成像

出版信息：Science, 18 JUNE 2021, VOL 372, ISSUE 6548

作者：C. L. Tschirhart, M. Serlin, H. Polshyn, A. Shragai, et al.

第一作者单位：Department of Physics, University of California, Santa Barbara, CA 93106, USA.

全文链接：https://science.sciencemag.org/content/372/6548/1323

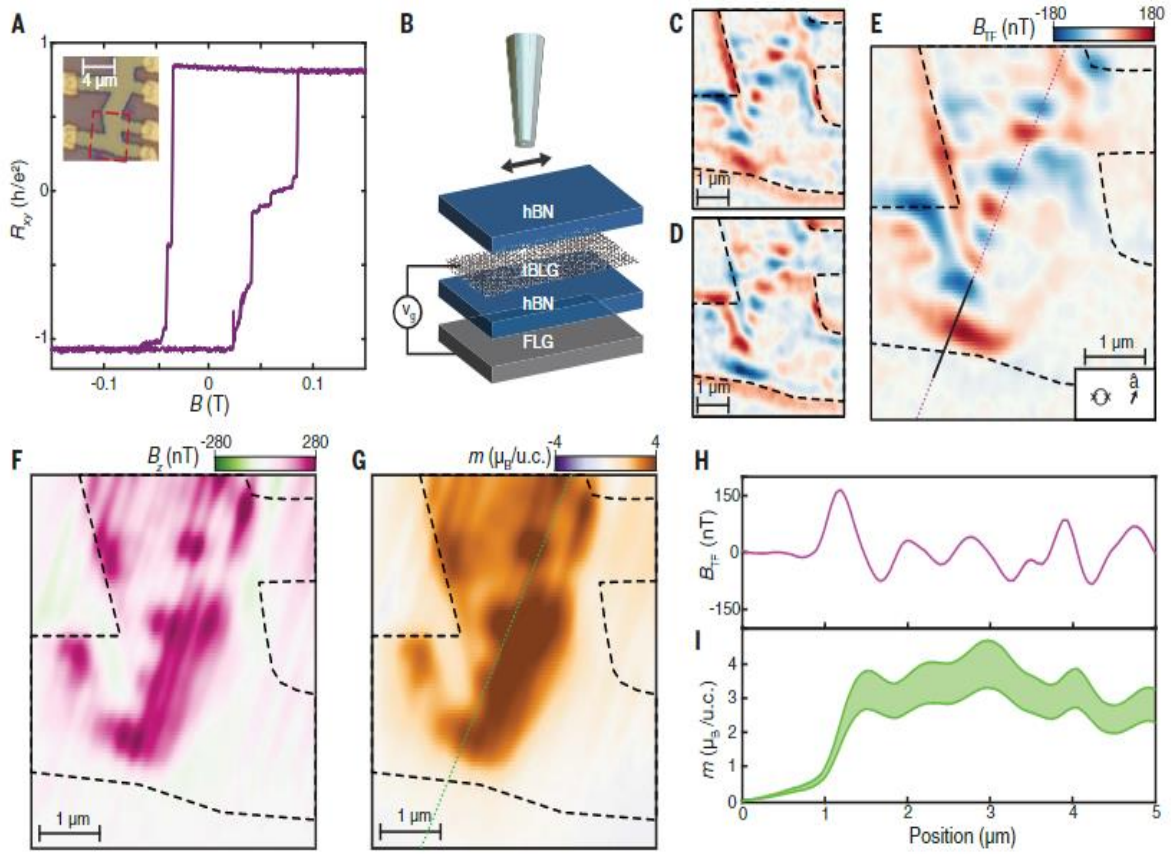
Abstract：Electrons in moiré flat band systems can spontaneously break time-reversal symmetry, giving rise to a quantized anomalous Hall effect. In this study, we use a superconducting quantum interference device to image stray magnetic fields in twisted bilayer graphene aligned to hexagonal boron nitride. We find a magnetization of several Bohr magnetons per charge carrier, demonstrating that the magnetism is primarily orbital in nature. Our measurements reveal a large change in the magnetization as the chemical potential is swept across the quantum anomalous Hall gap, consistent with the expected contribution of chiral edge states to the magnetization of an orbital Chern insulator. Mapping the spatial evolution of field-driven magnetic reversal, we find a series of reproducible micrometer-scale domains pinned to structural disorder.

摘要翻译：莫尔平带系统中的电子可以自发地打破时间反转对称，产生量子化的反常霍尔效应。在这项研究中，我们使用超导量子干涉装置与六方氮化硼对齐的扭曲双层石墨烯中的杂散磁场进行成像。

我们发现每个载流子有几个波尔磁子的磁化，证明了磁性主要是轨道性的。我们的测量显示，当化学势扫过量子反常霍尔隙时，磁化强度有很大的变化，这与手性边缘态对轨道陈绝缘子磁化的预期贡献一致。

通过对场驱动磁反转的空间演化进行映射，我们发现了一系列可重现的微米尺度域，这些域与结构无序有关。

文中插图：



[3] Approaching the motional ground state of a 10-kg object

10 公斤物体被冷却到接近其运动基态

出版信息: Science, 18 JUNE 2021, VOL 372, ISSUE 6548

作者： Chris Whittle, Evan D. Hall, Sheila Dwyer, et al.

第一作者单位： Laser Interferometer Gravitational Wave Observatory (LIGO), Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

全文链接： https://science.sciencemag.org/content/372/6548/1333

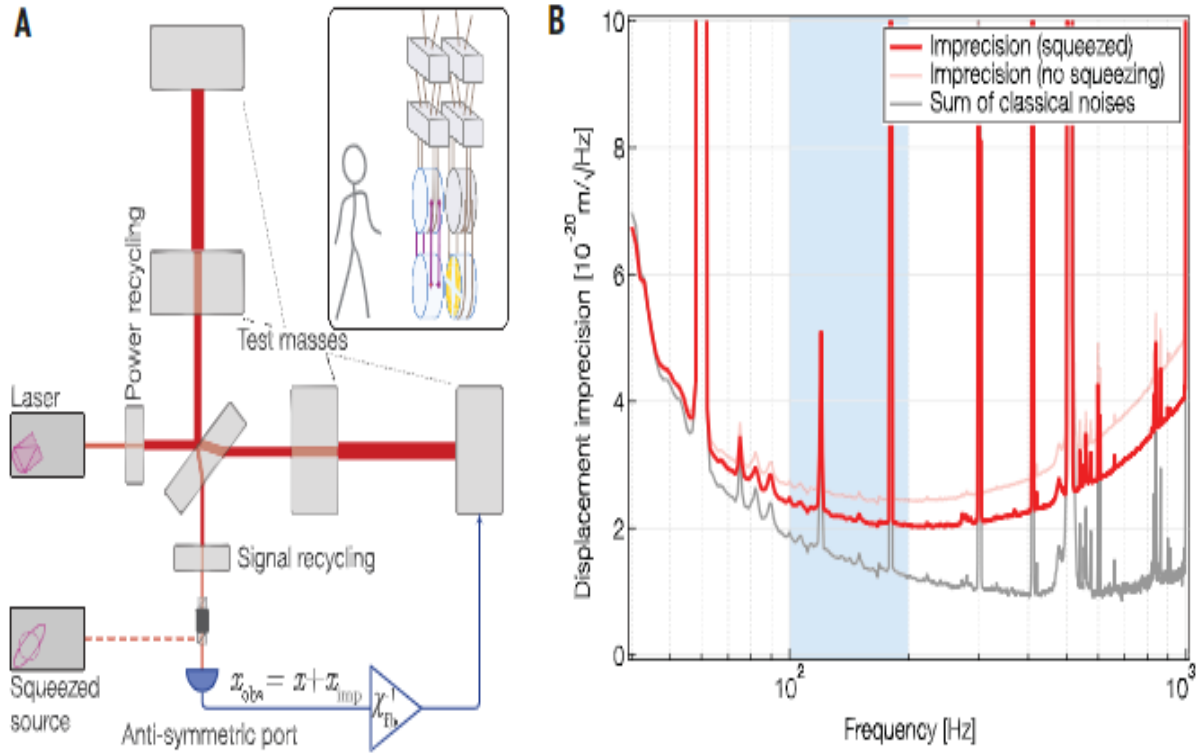
Abstract： The motion of a mechanical object, even a human-sized object, should be governed by the rules of quantum mechanics. Coaxing them into a quantum state is, however, difficult because the thermal environment masks any quantum signature of the object's motion. The thermal environment also masks the effects of proposed modifications of quantum mechanics at large mass scales. We prepared the center-of-mass motion of a 10-kilogram mechanical oscillator in a state with an average phonon occupation of 10.8. The reduction in temperature, from room temperature to 77 nanokelvin, is commensurate with an 11 orders-of-magnitude suppression of quantum back-action by feedback and a 13 orders-of-magnitude increase in the mass of an object prepared close to its motional ground state. Our approach will enable the possibility of probing gravity on massive quantum systems.

摘要翻译： 一个机械物体的运动，即使是一个人体大小的物体，都应该遵循量子力学的规则。

然而，诱使它们进入量子状态是困难的，因为热环境掩盖了物体运动的任何量子特征。热环境也掩盖了在大质量尺度下提出的量子力学修正的影响。我们使了一个 10 公斤机械振荡器在平均声子占 10. 8 的状态下进行质心运动。

温度从室温降低到到 77 纳开尔文，与通过反馈抑制量子反作用的 11 个数量级和在接近其运动基态时制备的物体质量增加的 13 个数量级相当。我们的方法将使在大规模量子系统上探测引力成为可能。

文中插图：



[4] Spatiotemporal imaging of 2D polariton wave packet dynamics using free electrons

二维极化激子波包动力学的时空成像

出版信息：Science, 11 JUNE 2021, VOL 372, ISSUE 6547

作者：Yaniv Kurman, Raphael Dahan, Hanan Herzig Sheinfux, Ido Kaminer, etc.

第一作者单位：Department of Electrical and Computer Engineering, Technion–Israel Institute of Technology, 32000 Haifa, Israel.

全文链接：https://science.sciencemag.org/content/372/6547/1181

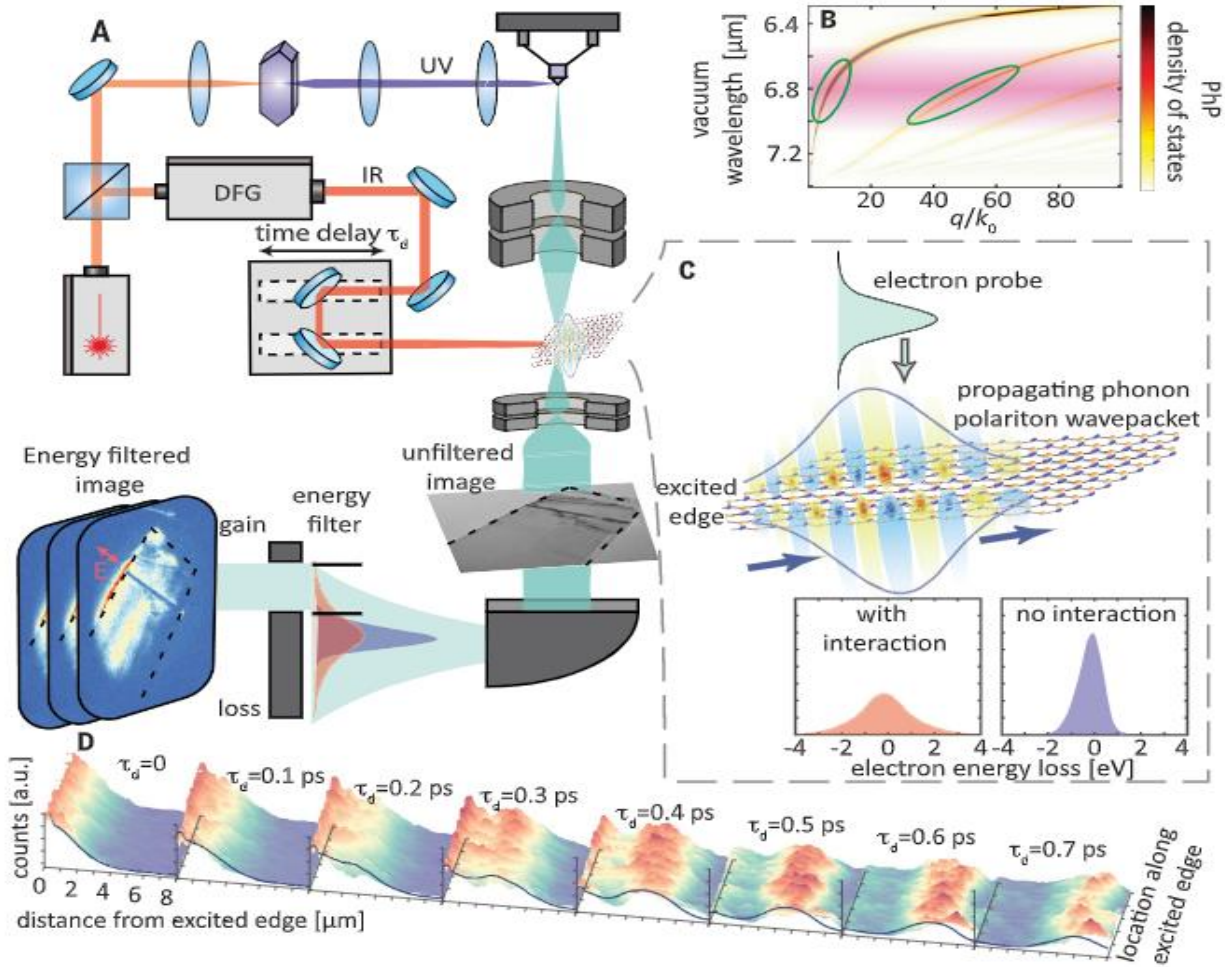
Abstract：Two-dimensional (2D) materials can confine light to volumes much shorter than the wavelength, and, together, the long propagation lengths make them attractive materials for developing nanophotonic platforms. Characterizing the spatiotemporal control of 2D polariton wave packets has been hindered for the same reasons that make their potential applications exciting: They have extremely small wavelengths and are strongly confined inside the material. Kurman et al. developed a new pump-probe technique based on electron emission that provides access to the spatiotemporal dynamics of 2D polaritons. The nanometric spatial resolution and femtosecond temporal resolution will be useful for probing the excitation dynamics of these materials.

摘要翻译：二维材料可将光限制在比波长短得多的体积内，同时，长传播长度使它们成为开发纳米光子平台的有吸引力的材料。

二维极化激子波包的时空控制特性一直受到阻碍，其潜在应用前景令人兴奋的原因是：它们具有极短的波长，并且强烈局限在材料内部。

作者开发了一种新的基于电子发射的泵浦探针技术，该技术提供了获取二维极化子时空动力学的途径。纳米空间分辨率和飞秒时间分辨率将有助于研究这些材料的激发动力学。

文中插图：



[5] Observation of a prethermal discrete time crystal

预热离散时间晶体的观察

出版信息：Science, 11 JUNE 2021, VOL 372, ISSUE 6547

作者：Joint Quantum Institute, Department of Physics, and Joint Center for Quantum Information and Computer Science, University of Maryland, College Park, MD 20742, USA.

第一作者单位：QuTech, Delft University of Technology, 2628 CJ Delft, Netherlands.

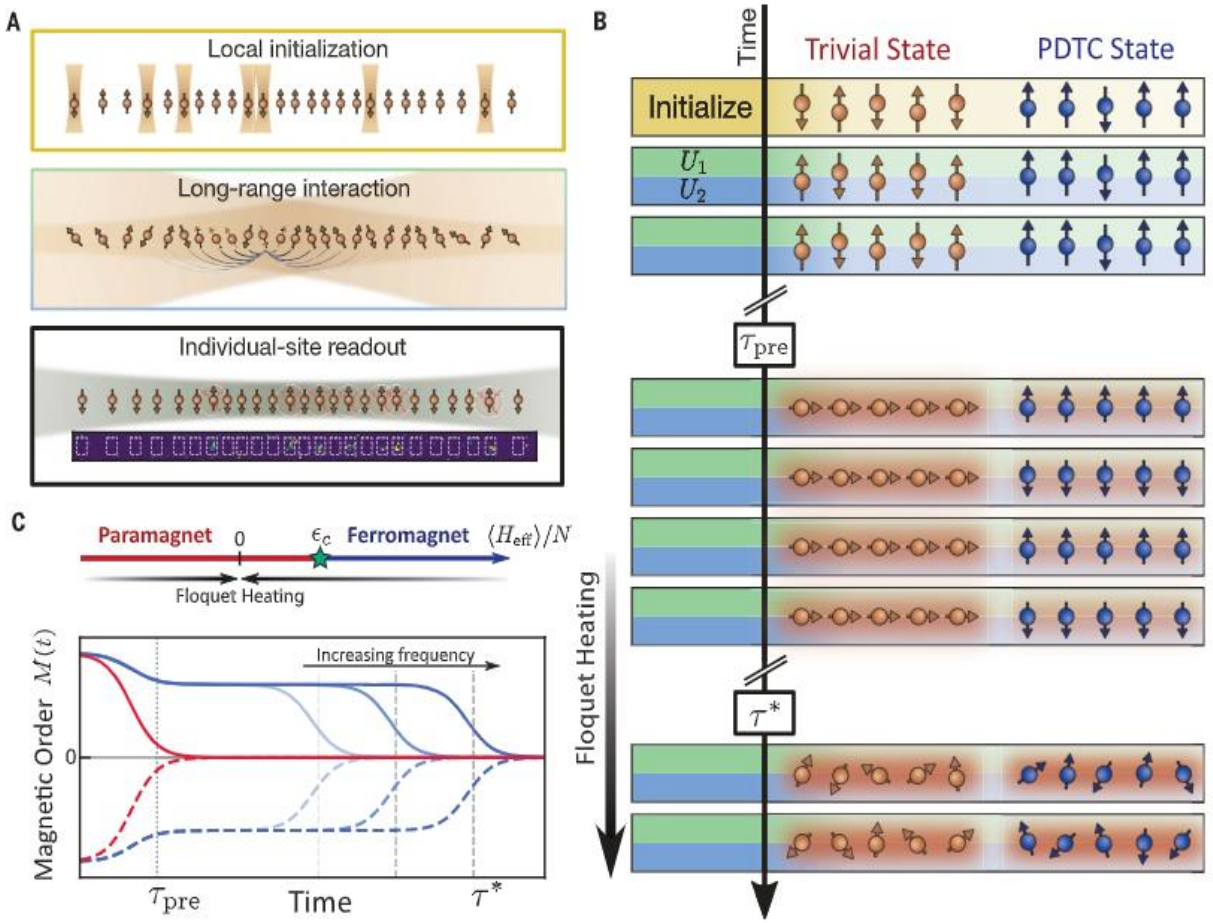
全文链接：https://science.sciencemag.org/content/372/6547/1192

Abstract：Characterizing and understanding different phases of matter in equilibrium is usually associated with the process of thermalization, where the system equilibrates. Recent efforts probing nonequilibrium systems have revealed that periodic driving of the system can suppress the natural tendency for equilibration yet still form new, nonequilibrium phases. Kyprianidis et al. used a quantum simulator composed of 25 trapped ion qubits and spins to observe such a nonequilibrium phase of matter: the disorder-free prethermal discrete time crystal. The flexibility and tunability of their quantum simulator provide a powerful platform with which to study the exotic phases of matter.

摘要翻译：描述和理解处于平衡状态的物质的不同相，通常与系统平衡的热化过程有关。最近对非平衡系统的研究表明，系统的周期性驱动可以抑制平衡的自然趋势，但仍会形成新的非平衡相。

作者使用由 25 个捕获的离子量子位和自旋组成的量子模拟器来观察这种物质的非平衡相：非无序的预热离散时间晶体。量子模拟器的灵活性和可调性为研究物质的奇异相提供了一个强大的平台。

文中插图：



[6] Establishing gold and platinum standards to 1 terapascal using shockless compression

用无冲击压缩法建立 1 太帕金和铂标准

出版信息：Science, 04 JUNE 2021, VOL 372, ISSUE 6546

作者：D. E. Fratanduono, M. Millot, D. G. Braun, S. J. Ali, A. Fernandez-Pañella, C. T. Seagle, et al.

第一作者单位：Lawrence Livermore National Laboratory, Livermore, CA 94550, USA.

全文链接：https://science.sciencemag.org/content/372/6546/1063

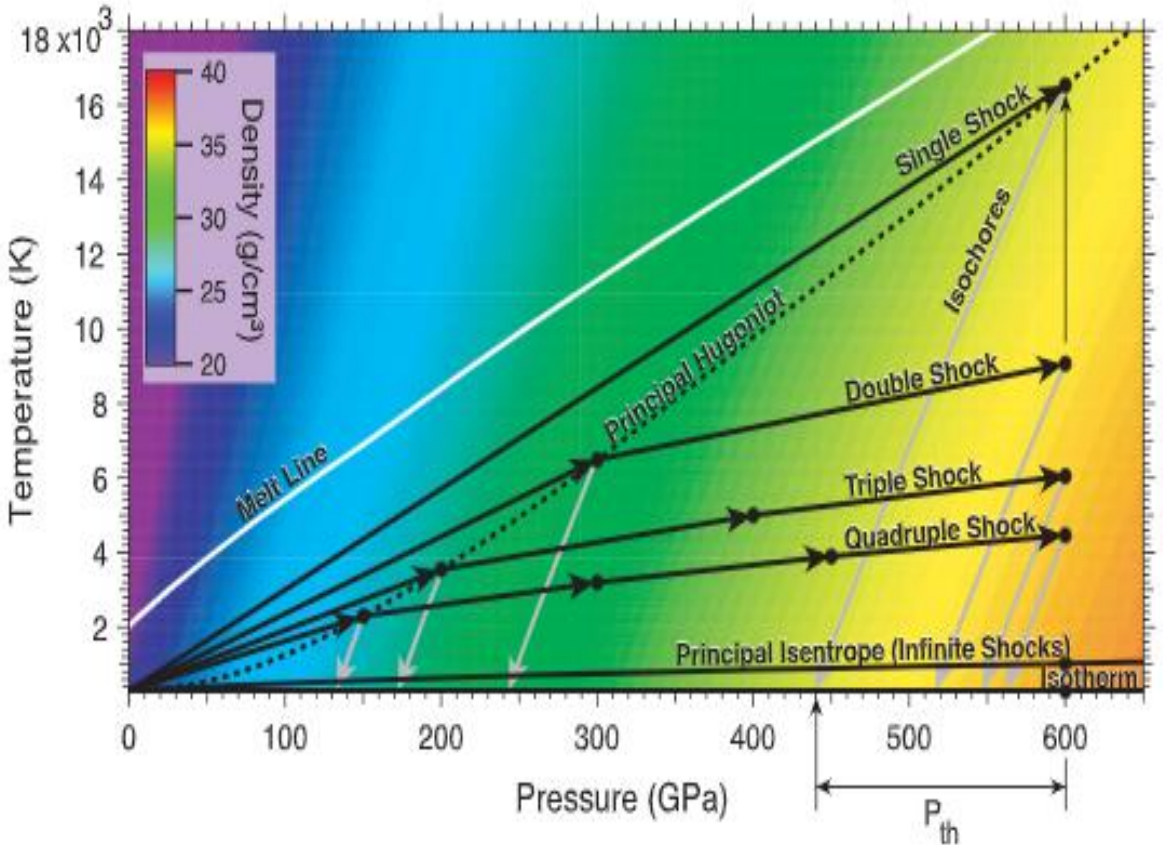
Abstract： New techniques are advancing the frontier of high-pressure physics beyond 1 terapascal, leading to new discoveries and offering stringent tests for condensed-matter theory and advanced numerical methods. However, the ability to absolutely determine the pressure state remains challenging, and well-calibrated pressure-density reference materials are required. We conducted shockless dynamic compression experiments at the National Ignition Facility and the Z machine to obtain quasi-absolute, high-precision, pressure-density equation-of-state data for gold and platinum. We derived two experimentally constrained pressure standards to terapascal conditions. Establishing accurate experimental determinations of extreme pressure will facilitate better connections between experiments and theory, paving the way toward improving our understanding of material response to these extreme conditions.

摘要翻译：新技术突破了 1 太帕以上高压物理学的前沿，导致了新发现，为凝聚态物质理论和先进数值方法提供了严格测试。然而，绝对确定压力状态的能力仍是一个挑战，需要良好校准的压密基准材料。

为了得到了金和铂的准绝对、高精度、压密状态方程，研究组在国家点火装置和 Z 机器上进行了无冲击动态压缩实验，并推导出两个实验约束的太帕条件下的压力标准。

建立极端压力的精确实验测定将有助于更好地将实验与理论联系起来，为提高人们理解这些极端条件下的物质反应而铺路。

文中插图：



[1]Past, present and future stars that can see Earth as a transiting exoplanet

过去，现在和未来看到地球作为过境系外行星的恒星

出版信息：Nature, 24 June 2021 , Volume 594 Issue 7864

作者：L. Kaltenegger & J. K. Faherty

第一作者单位：Carl Sagan Institute, Cornell University, Ithaca, NY, USA

Astronomy Department, Cornell University, Ithaca, NY, USA

全文链接：https://www.nature.com/articles/s41586-021-03596-y

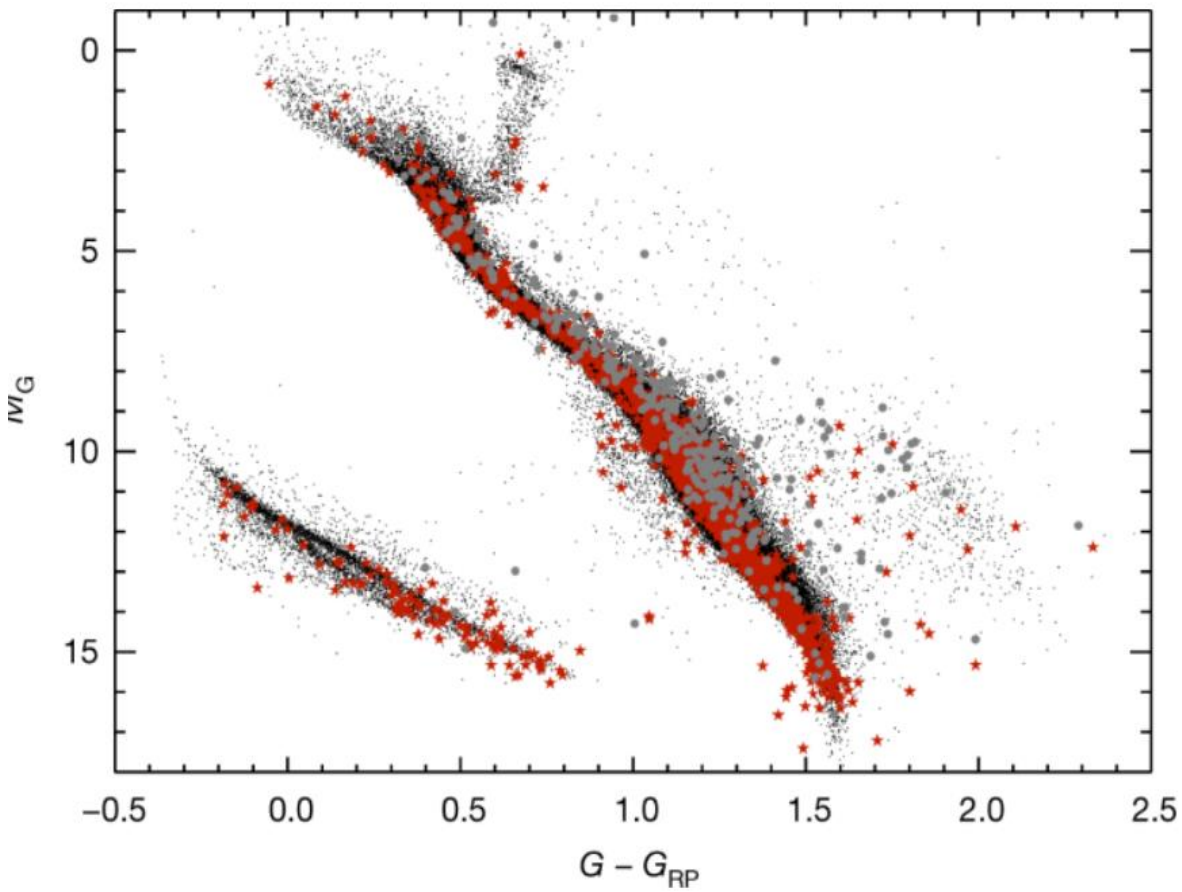
Abstract： In the search for life in the cosmos, transiting exoplanets are currently our best targets. With thousands already detected, our search is entering a new era of discovery with upcoming large telescopes that will look for signs of ‘life’ in the atmospheres of transiting worlds. Here we report that 1,715 stars within 100 parsecs from the Sun are in the right position to have spotted life on a transiting Earth since early human civilization (about 5,000 years ago), with an additional 319 stars entering this special vantage point in the next 5,000 years. Among these stars are seven known exoplanet hosts, including Ross-128, which saw Earth transit the Sun in the past, and Teegarden’s Star and Trappist-1, which will start to see it in 29 and 1,642 years, respectively. We found that human-made radio waves have already swept over 75 of the closest stars on our list.

摘要翻译：在宇宙中寻找生命的过程中，凌日系外行星是目前的最佳目标。随着数千个行星已经被探测到，搜寻工作正进入一个新的发现时代，即将推出的大型望远镜将在过境星球的大气层中寻找“生命”的迹象。

作者报告了自早期人类文明（约 5000 年前）以来，在距离太阳 100 秒差距内的 1715 颗恒星的正确位置，它们可以在过渡地球上发现生命，另外还有 319 颗恒星将在未来 5000 年进入这个特殊的有利位置。

在这些恒星中，有 7 颗已知的系外行星，包括曾观测到地球凌日的罗斯-128，还有蒂加登的恒星和特拉普斯特-1，它们将分别在 29 年和 1642 年后观测到地球。作者发现，人造无线电波已经扫过了榜单上离地球最近的 75 颗恒星。

文中插图：



[2]Accurately computing the electronic properties of a quantum ring

精确计算量子环的电子性质

出版信息：Nature, 24 June 2021 , Volume 594 Issue 7864

作者：C. Neill, T. McCourt, V. Smelyanskiy, etc.

第一作者单位：Google Quantum AI, Mountain View, CA, USA

全文链接：https://www.nature.com/articles/s41586-021-03576-2

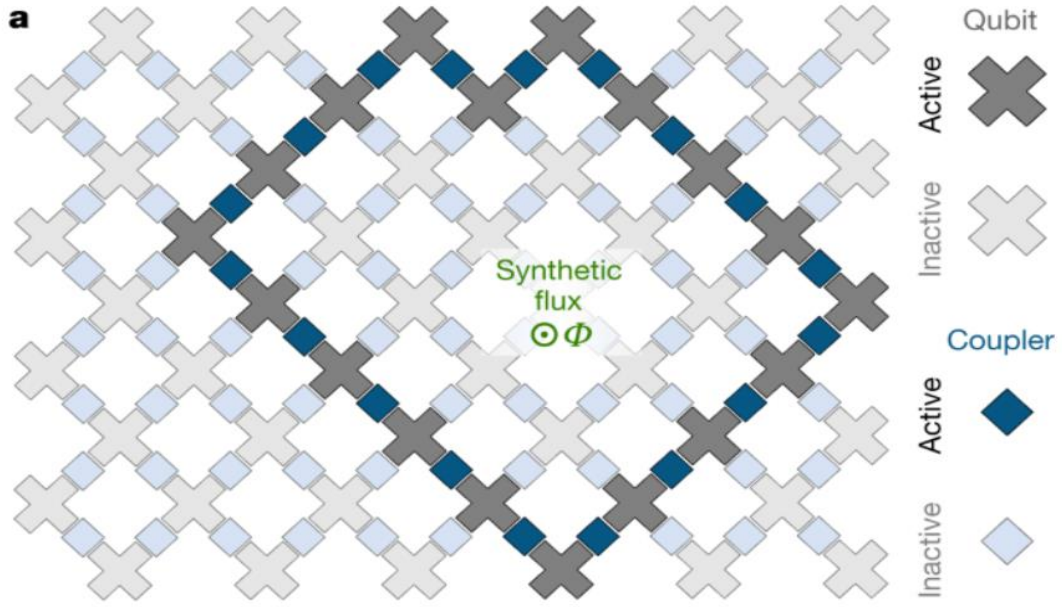
Abstract：A promising approach to study condensed-matter systems is to simulate them on an engineered quantum platform. However, the accuracy needed to outperform classical methods has not been achieved so far. Here, using 18 superconducting qubits, we provide an experimental blueprint for an accurate condensed-matter simulator and demonstrate how to investigate fundamental electronic properties. We benchmark the underlying method by reconstructing the single-particle band structure of a one-dimensional wire. We demonstrate nearly complete mitigation of decoherence and readout errors, and measure the energy eigenvalues of this wire with an error of approximately 0.01 rad, whereas typical energy scales are of the order of 1 rad. Insight into the fidelity of this algorithm is gained by highlighting the robust properties of a Fourier transform, including the ability to resolve eigenenergies with a statistical uncertainty of 10 - 4 rad. We also synthesize magnetic flux and disordered local potentials, which are two key tenets of a condensed-matter system. When sweeping the magnetic flux we observe avoided level crossings in the spectrum, providing a detailed fingerprint of the spatial distribution of local disorder. By combining these methods we reconstruct electronic properties of the eigenstates, observing persistent currents and a strong suppression of conductance with added disorder. Our work describes an accurate method for quantum simulation5,6 and paves the way to study new quantum materials with superconducting qubits.

摘要翻译：研究凝聚态系统的一个很有前途的方法是在一个设计好的量子平台上模拟它们。然而，迄今为止还没有达到优于经典方法所需的精度。作者使用 18 个超导量子位元，为一个精确的凝聚态模拟器提供了一个实验蓝图，并演示了如何研究基本的电子性质。

作者通过重建一维线的单粒子带结构来确定基本方法的基准。他们演示了几乎完全的消相干和读出错误，并测量了导线的能量特征值，误差约为 0.01 rad，而典型的能量尺度为 1 rad。通过强调傅里叶变换的鲁棒性，包括在统计不确定性为 10 - 4 rad 的情况下解析特征能量的能力，可以深入了解该算法的保真度。作者还综合了磁通和无序局域势这两个凝聚态系统的关键原理。当清扫磁通量时，我们观察到频谱中避免的水平交叉，提供了局部无序的空间分布的详细指纹。

通过结合这些方法，作者重建了本征态的电子性质，观察了持续的电流和附加的无序对电导的强抑制。他们表示，这项研究描述了一种精确的量子模拟方法，为研究具有超导量子位的新量子材料铺平了道路。

文中插图：



[3]Correlated charge noise and relaxation errors in superconducting qubits

超导量子比特的相关电荷噪声和弛豫误差

出版信息：Nature, 17 June 2021 , VOL 594 , ISSUE 7863

作者：C. D. Wilen, S. Abdullah, N. A. Kurinsky, C. Stanford, L. Cardani, G. D’ Imperio, et al.

第一作者单位：Department of Physics, University of Wisconsin-Madison, Madison, WI, USA

全文链接：https://www.nature.com/articles/s41586-021-03557-5

Abstract：The central challenge in building a quantum computer is error correction. Unlike classical bits, which are susceptible to only one type of error, quantum bits (qubits) are susceptible to two types of error, corresponding to flips of the qubit state about the X and Z directions. Although the Heisenberg uncertainty principle precludes simultaneous monitoring of X- and Z-flips on a single qubit, it is possible to encode quantum information in large arrays of entangled qubits that enable accurate monitoring of all errors in the system, provided that the error rate is low. Another crucial requirement is that errors cannot be correlated. Here we characterize a superconducting multiqubit circuit and find that charge noise in the chip is highly correlated on a length scale over 600 micrometres; moreover, discrete charge jumps are accompanied by a strong transient reduction of qubit energy relaxation time across the millimetre-scale chip. The resulting correlated errors are explained in terms of the charging event and phonon-mediated quasiparticle generation associated with absorption of γ -rays and cosmic-ray muons in the qubit substrate. Robust quantum error correction will require the development of mitigation strategies to protect multiqubit arrays from correlated errors due to particle impacts.

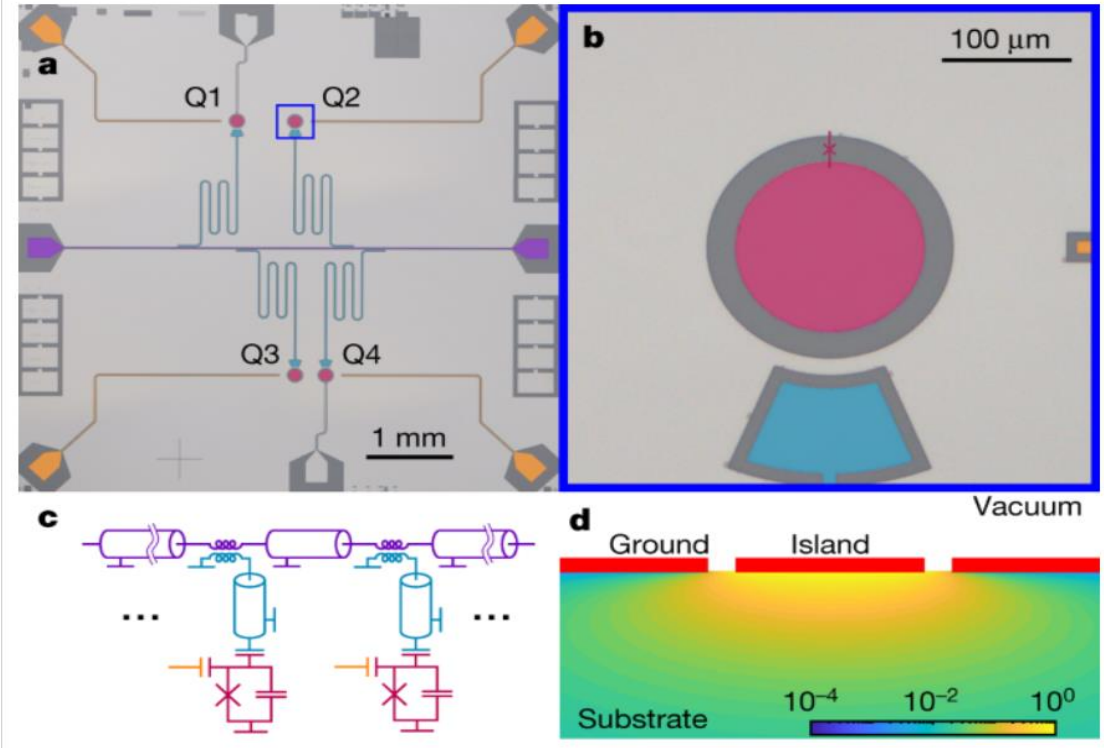
摘要翻译：构建量子计算机的核心挑战是纠错。与只易受一种误差影响的经典比特不同，量子比特易受两种误差的影响，对应于在 X 和 Z 方向上量子比特状态的翻转。

尽管海森堡测不准原理排除了对单个量子比特同时监测 X 和 Z 翻转的可能性，但只要错误率较低，就有可能在纠缠量子比特的大型阵列中对量子信息进行编码，从而准确监测系统中的所有错误。另一个关键要求是错误不能相互关联。

研究组描述了一个超导多量子比特电路，并发现芯片中的电荷噪声在超过 600 微米的长度尺度时高度相关；此外，离散电荷跃迁伴随着毫米级芯片中量子比特能量弛豫时间的强烈瞬态减少。

由此产生的相关误差是因为充电事件和声子介导的准粒子产生，两者与量子比特衬底中 γ -射线和宇宙射线介子的吸收有关。稳健的量子误差校正需要制定缓解策略，以保护多量子比特阵列免受粒子碰撞引起的相关误差的影响。

文中插图：



[4]Symmetry-enforced topological nodal planes at the Fermi surface of a chiral magnet

手性磁铁费米面上对称性保证的拓扑节面

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作者：Michel Fruchart, Ryo Hanai, Peter B. Littlewood & Vincenzo Vitelli

第一作者单位：Centre for QuantumEngineering (ZQE), Technische Universität München, Garching, Germany

全文链接：https://www.nature.com/articles/s41586-021-03543-x

Abstract：Despite recent efforts to advance spintronics devices and quantum information technology using materials with non-trivial topological properties, three key challenges are still unresolved. First, the identification of topological band degeneracies that are generically rather than accidentally located at the Fermi level. Second, the ability to easily control such topological degeneracies. And third, the identification of generic topological degeneracies in large, multisheeted Fermi surfaces. By combining de Haas–van Alphen spectroscopy with density functional theory and band-topology calculations, here we show that the non-symmorphic symmetries in chiral, ferromagnetic manganese silicide (MnSi) generate nodal planes (NPs), which enforce topological protectorates (TPs) with substantial Berry curvatures at the intersection of the NPs with the Fermi surface (FS) regardless of the complexity of the FS. We predict that these TPs will be accompanied by sizeable Fermi arcs subject to the direction of the magnetization. Deriving the symmetry conditions underlying topological NPs, we show that the 1,651 magnetic space groups comprise 7 grey groups and 26 black-and-white groups with topological NPs, including the space group of ferromagnetic MnSi. Thus, the identification of symmetry-enforced TPs, which can be controlled with a magnetic field, on the FS of MnSi suggests the existence of similar properties—amenable for technological exploitation—in a large number of materials.

摘要翻译：尽管最近人们努力利用具有非平凡拓扑性质的材料来推进自旋电子学器件和量子信息技术的发展，但仍有三个关键难题尚未解决。

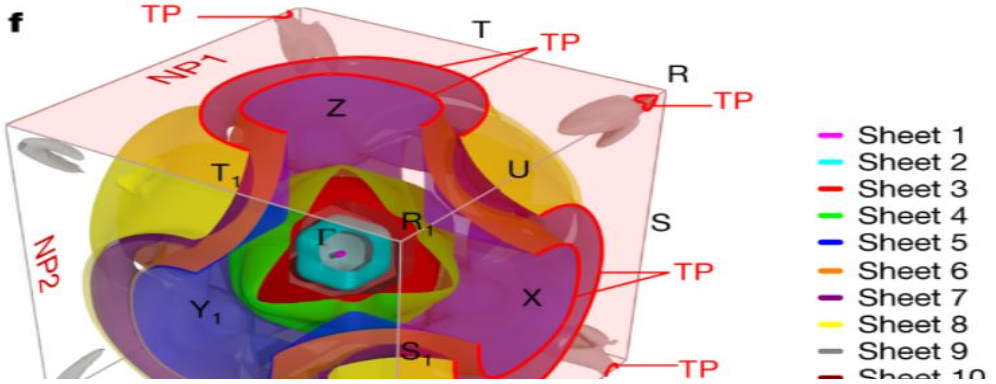
首先，确定通常而非偶然位于费米能级的拓扑带简并；其次，能够较易控制这种拓扑简并；最后，确定大型多片费米面（FS）的拓扑简并。

通过将德哈斯-范阿尔芬光谱学与密度泛函理论和能带拓扑计算相结合，研究组证明手性铁磁性硅化锰（MnSi）中的非点式对称产生了节面（NPs），这使得在 NPs 与 FS 交界处的拓扑保护层（TPs）具有较大的贝里曲率，且与 FS 的复杂性无关。

研究组预测，这些 TPs 将具有相当大的费米弧，这取决于磁化的方向。通过推导拓扑 NPs 的对称性条件，研究组发现 1651 个磁空间群由 7 个灰色群和 26 个具有拓扑 NPs 的黑白群组成，其中包括铁磁性 MnSi 的空间群。

因此，在 MnSi 的 FS 上识别出可由磁场控制的对称性保证的 TPs，这表明在大量材料中存在类似性质，可用于技术开发。

文中插图：



[5]Asymmetric response of interfacial water to applied electric fields

界面水对外加电场的不对称响应

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作者： Angelo Montenegro, Chayan Dutta, Muhammet Mammetkuliev, Haotian Shi, Bingya Hou, Dhritiman Bhattacharyya, Bofan Zhao, Stephen B. Cronin & Alexander V. Benderskii

第一作者单位： Department of Chemistry, University of Southern California, Los Angeles, CA, USA

国内相关报道： http://www.mse.tsinghua.edu.cn/info/1062/1881.htm

全文链接： https://www.nature.com/articles/s41586-021-03504-4

Abstract： Our understanding of the dielectric response of interfacial water, which underlies the solvation properties and reaction rates at aqueous interfaces, relies on the linear response approximation: an external electric field induces a linearly proportional polarization. This implies antisymmetry with respect to the sign of the field. Atomistic simulations have suggested, however, that the polarization of interfacial water may deviate considerably from the linear response. Here we present an experimental study addressing this issue. We measured vibrational sum-frequency generation spectra of heavy water（D2O）near a monolayer graphene electrode, to study its response to an external electric field under controlled electrochemical conditions. The spectra of the OD stretch show a pronounced asymmetry for positive versus negative electrode charge. At negative charge below 5 × 1012 electrons per square centimetre, a peak of the non-hydrogen-bonded OD groups pointing towards the graphene surface is observed at a frequency of 2,700 per centimetre. At neutral or positive electrode potentials, this ‘free-OD’ peak disappears abruptly, and the spectra display broad peaks of hydrogen-bonded OD species （at 2,300–2,650 per centimetre）. Miller’s rule1 connects the vibrational sum-frequency generation response to the dielectric constant. The observed deviation from the linear response for electric fields of about ±3 × 108 volts per metre calls into question the validity of treating interfacial water as a simple dielectric medium.

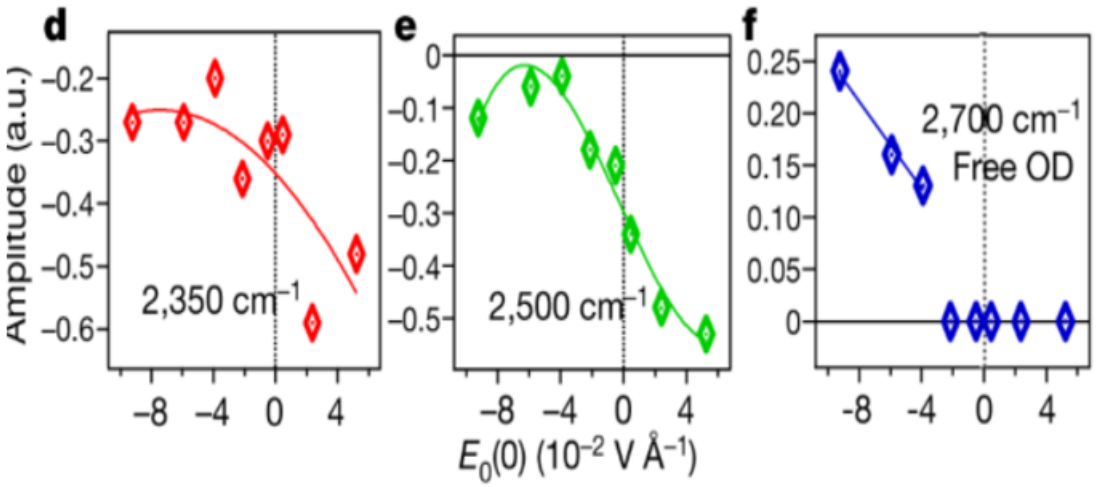
摘要翻译： 人们对界面水的介电响应的理解依赖于线性响应近似：外电场诱导线性比例极化。这意味着对场的符号具有反对称性。然而，原子模拟表明，界面水的极化可能与线性响应有很大的偏差。

作者提出了一项针对这个问题的实验研究。他们测量了单层石墨烯电极附近重水（D2O）的振动和频率产生谱，以研究其在受控电化学条件下对外部电场的响应。OD 拉伸的光谱显示了一个明显的不对称性对正负电极电荷。

当负电荷低于 5 × 1012 电子每平方厘米时，观察到非氢键 OD 基团指向石墨烯表面的峰值频率为每厘米 2700 次。在中性或正极电位下，这种“自由 OD”峰突然消失，而光谱显示氢键 OD 物种的宽峰（在 2300-2650 每厘米）。

米勒定律将振动和频率产生响应与介电常数联系起来。观察到的与每米±3 × 108 伏特电场线性响应的偏差使人们对将界面水作为简单介质处理的有效性提出了质疑。

文中插图：



[6]Signatures of moiré trions in WSe2/MoSe2 heterobilayers

WSe2/MoSe2 异质双层膜中摩尔离子的特征

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作者：Erfu Liu, Elyse Barré, Jeremiah van Baren, Matthew Wilson, Takashi Taniguchi, Kenji Watanabe, Yong-Tao Cui, Nathaniel M. Gabor, Tony F. Heinz, Yia-Chung Chang & Chun Hung Lui

第一作者单位：Department of Physics and Astronomy, University of California, Riverside, CA, USA

国内相关报道：http://www.mse.tsinghua.edu.cn/info/1062/1881.htm

全文链接：https://www.nature.com/articles/s41586-021-03541-z

Abstract：Moiré superlattices formed by van der Waals materials can support a wide range of electronic phases, including Mott insulators, superconductors and generalized Wigner crystals. When excitons are confined by a moiré superlattice, a new class of exciton emerges, which holds promise for realizing artificial excitonic crystals and quantum optical effects. When such moiré excitons are coupled to charge carriers, correlated states may arise. However, no experimental evidence exists for charge-coupled moiré exciton states, nor have their properties been predicted by theory. Here we report the optical signatures of trions coupled to the moiré potential in tungsten diselenide/molybdenum diselenide heterobilayers. The moiré trions show multiple sharp emission lines with a complex charge-density dependence, in stark contrast to the behaviour of conventional trions. We infer distinct contributions to the trion emission from radiative decay in which the remaining carrier resides in different moiré minibands. Variation of the trion features is observed in different devices and sample areas, indicating high sensitivity to sample inhomogeneity and variability. The observation of these trion features motivates further theoretical and experimental studies of higher-order electron correlation effects in moiré superlattices.

摘要翻译：由范德华材料形成的摩尔超晶格可以支持多种电子相，包括 Mott 绝缘体、超导体和广义 Wigner 晶体。当激子被摩尔超晶格限制时，一类新的激子出现了，这为实现人工激子晶体和量子光学效应带来了希望。

当这些摩尔激子与载流子耦合时，可能会产生相关态。然而，对于电荷耦合摩尔激子态，没有实验证据，也没有理论预测它们的性质。

本文报道了二硒化钨/二硒化钼异质薄膜中与摩尔势耦合的离子的光学特征。摩尔三离子态显示了多个尖锐的发射线与复杂的电荷密度依赖关系，这与传统三离子态的行为形成了鲜明的对比。

作者从辐射衰变中推断出对三离子态发射的不同贡献，其中剩余载流子驻留在不同的摩尔微型带中。

在不同的器件和样品区域观察到离子特征的变化，表明对样品的不均匀性和变异性有很高的灵敏度。这些离子特征的观察促进了对摩尔超晶格中高阶电子相关效应的进一步理论和实验研究。

文中插图：