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BREAKTHROUGH
OF THE YEAR



Sun-like stars produce superflares roughly once per century

类日恒星大约每世纪产生一次超级耀斑

▲ 作者：VALERIY VASILYEV, TIMO REINHOLD, ALEXANDER I. SHAPIRO, ILYA USOSKIN, NATALIE A. KRIVOVA, HIROYUKI MAEHARA, ET AL.

▲ 链接：<https://www.science.org/doi/10.1126/science.adl5441>

▲ 摘要：

恒星超级耀斑是电磁辐射的高能爆发，类似于太阳耀斑，但释放的能量更多，在主序星上可达10³⁶尔格。目前尚不清楚太阳是否会产生超级耀斑，以及如果会的话，其发生频率是多少。

研究组使用开普勒太空天文台的光度测量技术来研究具有类日基本参数的其他恒星上的超级耀斑。在观测到的56450颗类日恒星中，其中2527颗上发现了2889次超级耀斑。

这一探测率表明，能量超过10³⁴尔格的超级耀斑大约每世纪在具有类似太阳温度和可变性的恒星上发生一次。由此产生的恒星超级耀斑的频率-能量分布与太阳耀斑向更高能量分布的外推一致，因此研究组认为两者由相同的物理机制产生。

▲ Abstract：Stellar superflares are energetic outbursts of electromagnetic radiation that are similar to solar flares but release more energy, up to 10³⁶ erg on main-sequence stars. It is unknown whether the Sun can generate superflares and, if so, how often they might occur. We used photometry from the Kepler space observatory to investigate superflares on other stars with Sun-like fundamental parameters. We identified 2889 superflares on 2527 Sun-like stars, out of 56,450 observed. This detection rate indicates that superflares with energies >10³⁴ erg occur roughly once per century on stars with Sun-like temperature and variability. The resulting stellar superflare frequency-energy distribution is consistent with an extrapolation of the Sun's flare distribution to higher energies, so we suggest that both are generated by the same physical mechanism.

材料科学Materials Science

Addressing interconnect challenges for enhanced computing performance

解决互连难题以提升计算性能

▲ 作者：JOON-SEOK KIM, JOONYUN KIM, DAE-JIN YANG, JAEWOO SHIM, LUHING HU, CHANG - SEOK LEE, ET AL.

▲ 链接：<https://www.science.org/doi/10.1126/science.adk6189>

▲ 摘要：通过在单个芯片上集成更多器件，半导体技术的进步已达到瓶颈，即仅靠器件缩放不再能有效提高器件性能。

其中一个问题在于连接晶体管的互连，当金属的尺寸缩小到与晶体管的尺寸相匹配时，金属的电阻率会呈指数级增长。因此，总信号处理延迟主要由互连的电阻-电容（RC）延迟而不是由晶体管开关速度的延迟来决定。

这一瓶颈促使学术界和工业界努力探索替代材料和颠覆性器件结构。因此，研究组提出了从材料和器件两个方面克服互连RC延迟的策略。

▲ Abstract : The advancement in semiconductor technology through the integration of more devices on a chip has reached a point where device scaling alone is no longer an efficient way to improve the device performance. One issue lies in the interconnects connecting the transistors, in which the resistivity of metals increases exponentially as their dimensions are scaled down to match those of the transistors. As a result, the total signal processing delay is dominated by the resistance-capacitance (RC) delay from the interconnects rather than the delay from the transistors' switching speed. This bottleneck has spurred efforts both in academia and industry to explore alternative materials and disruptive device structures. Therefore, we suggest strategies to overcome the RC delay of the interconnects in both material and device aspects.

Inverse design workflow discovers hole-transport materials tailored for perovskite solar cells

逆向设计工作流程发现适合钙钛矿太阳能电池的空穴传输材料

▲ 作者：JIANCHANG WU, LUCA TORRESI, MANMAN HU, PATRICK REISER, JIYUN ZHANG, JUAN S. ROCHA-ORTIZ, ET AL.

▲ 链接：<https://www.science.org/doi/10.1126/science.ads0901>

▲ 摘要：为高度复杂的特定光电器件定制有机分子的逆向设计具有巨大潜力，但尚未实现。当前模型依赖于通常不存在于专业研究领域的大型数据集。

研究组展示了一个闭环工作流程，将有机半导体高通量合成来创建大型数据集与贝叶斯优化相结合，以发现契合太阳能电池应用特性的新型空穴传输材料。预测模型基于分子描述符，使人们能够将这些材料的结构与其性能联系起来。

研究组从最少的建议中确定了一系列高性能分子，并在钙钛矿太阳能电池中实现了高达26.2%（经认证为25.9%）的功率转换效率。

▲ Abstract : The inverse design of tailored organic molecules for specific optoelectronic devices of high complexity holds an enormous potential but has not yet been realized. Current models rely on large data sets that generally do not exist for specialized research fields. We demonstrate a closed-loop workflow that combines high-throughput synthesis of organic semiconductors to create large datasets and Bayesian optimization to discover new hole-transporting materials with tailored properties for solar cell applications. The predictive models were based on molecular descriptors that allowed us to link the structure of these materials to their performance. A series of high-performance molecules were identified from minimal suggestions and achieved up to 26.2% (certified 25.9%) power conversion efficiency in perovskite solar cells.

Nanobinders advance screen-printed flexible thermoelectrics

纳米粘合剂助力丝网印刷柔性热电材料

▲ 作者：WENYI CHEN, XIAO-LEI SHI, MENG LI, TING LIU, YUANQING MAO, QINGYI LIU, ET AL.

▲ 链接：<https://www.science.org/doi/10.1126/science.ads5868>

▲ 摘要：柔性度有限、制造工艺复杂、高成本和性能不足是限制柔性无机热电材料（用于可穿戴电子产品和其他高端冷却应用）的可扩展性和商业化的主要因素。

研究组开发了一种创新且具有成本效益的技术，其集成了溶剂热、丝网印刷和烧结技术来制备无机柔性热电薄膜。该可印刷薄膜以Bi₂Te₃基纳米板作为高度取向晶粒，以纳米棒作为纳米粘合剂，具有优异的可印刷薄膜热电性能、良好的柔韧性、可大规模制造性和低成本。

研究组构建了由可印刷的n型Bi₂Te₃基薄膜和p型Bi_{0.4}Sb_{1.6}Te₃薄膜组装而成的柔性热电器件，其归一化功率密度超过3 μW cm⁻² K⁻²，在丝网印刷器件中表现优异。此外，该技术可扩展至其他无机热电薄膜体系，如Ag₂Se，显示出广泛的适用性。

▲ Abstract：Limited flexibility, complex manufacturing processes, high costs, and insufficient performance are major factors restricting the scalability and commercialization of flexible inorganic thermoelectrics for wearable electronics and other high-end cooling applications. We developed an innovative, cost-effective technology that integrates solvothermal, screen-printing, and sintering techniques to produce an inorganic flexible thermoelectric film. Our printable film, comprising Bi₂Te₃-based nanoplates as highly orientated grains and Te nanorods as nanobinders, shows excellent thermoelectric performance for printable films, good flexibility, large-scale manufacturability, and low cost. We constructed a flexible thermoelectric device assembled by printable n-type Bi₂Te₃-based and p-type Bi_{0.4}Sb_{1.6}Te₃ films, which achieved a normalized power density of >3 μW cm⁻² K⁻², ranking among the highest in screen-printed devices. Moreover, this technology can be extended to other inorganic thermoelectric film systems, such as Ag₂Se, showing broad applicability.

地球科学Earth Science

Abyssal marine tectonics from the SWOT missionSWOT

任务助力测绘深海海洋构造

▲ 作者：YAO YU, DAVID T. SANDWELL AND GERALD DIBARBOURE

▲ 链接：<https://www.science.org/doi/10.1126/science.ads4472>

▲ 摘要：海洋覆盖了地球表面的71%，但与陆地、月球、火星和金星相比，海底的地图绘制差强人意。传统的海洋测绘使用船舶测深和最低点卫星雷达测高，前者在空间覆盖范围上有限，后者在空间分辨率上有限。

NASA-CNES（美国航空航天局-法国空间研究中心）的地表水和海洋地形（SWOT）联合任务使用相位相干、宽测绘带雷达测高法以高精度测量海洋表面高度。研究组表明，1年的SWOT数据与30年的海洋重力卫星最低点测高数据相比提供了更详细的信息，能够以8千米的空间分辨率探测复杂的海底结构。

由于任务仍在进行中，SWOT有望为测深图、构造板块重建、水下导航和深海混合提供重要见解。

▲ Abstract : The global ocean covers 71% of Earth ' s surface, yet the seafloor is poorly charted compared with land, the Moon, Mars, and Venus. Traditional ocean mapping uses ship-based soundings and nadir satellite radar altimetry—one limited in spatial coverage and the other in spatial resolution. The joint NASA – CNES (Centre National d ' Etudes Spatiales) Surface Water and Ocean Topography (SWOT) mission uses phase-coherent, wide-swath radar altimetry to measure ocean surface heights at high precision. We show that 1 year of SWOT data offers more detailed information than 30 years of satellite nadir altimetry in marine gravity, enabling the detection of intricate seafloor structures at 8-kilometer spatial resolution. With the mission still ongoing, SWOT promises critical insights for bathymetric charting, tectonic plate reconstruction, underwater navigation, and deep ocean mixing.

More flow upstream and less flow downstream: The changing form and function of global rivers
上游流量增加，下游流量减少：全球河流形态与功能的变化

▲ 作者：DONGMEI FENG AND COLIN J. GLEASON

▲ 链接：<https://www.science.org/doi/10.1126/science.adl5728>

▲ 摘要：研究组绘制了1984年至2018年约290万条河流的日流量图，以评估全球河流系统的近期变化。结果发现，河流下游以流量显著减少为主，而河流源头流量显著增加的可能性是流量显著减少的1.7倍。这些变化导致大约29%的全球陆地表面经历了显著的上游径流变化。

该研究发现最小的溪流变化最大：侵蚀潜力增加（溪流功率增加约5%），洪水频率增加（百年一遇洪水增加约42%），以及可能的营养动态（季节性流态变化）。研究组通过绘制数百万条单独河流的地图，用尺度细节揭示了这些变化。广泛采用这种方法有望揭示水圈的其他变化。

▲ Abstract : We mapped daily streamflow from 1984 to 2018 in approximately 2.9 million rivers to assess recent changes to global river systems. We found that river outlets were dominated by significant decreases in flow, whereas headwaters were 1.7 times more likely to have significantly increased flow than decreased. These changes result in a significant upstream shift in streamflow experienced by about 29% of the global land surface. We found the most changes in the smallest streams in our study: increases in erosion potential (approximately 5% increase in stream power), flood frequency (approximately 42% increase in 100-year floods), and likely nutrient dynamics (altered seasonal flow regimes). We revealed these changes using detail at scale by mapping millions of individual rivers. Widely adopting this approach could reveal other changes to the hydrosphere.

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