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Superfast superconducting vortices

Nanoscale images capture vortices exhibiting extreme, previously unexplored dynamics.

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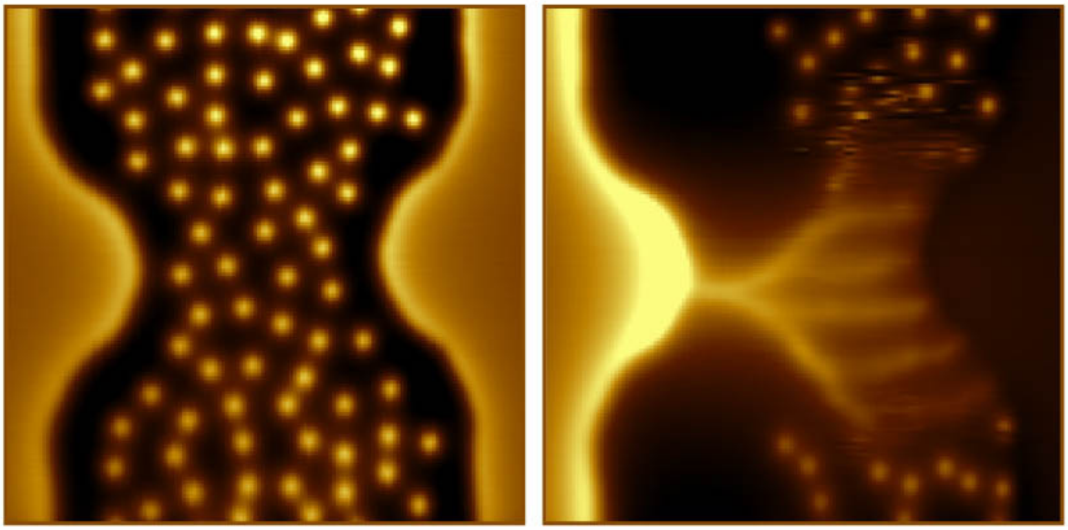
Although all superconductors screen magnetic fields, many—including high-T_c cuprates and thin-film superconductors—allow a sufficiently strong field to penetrate as quantized vortices, supercurrent eddies that each surround a fixed amount of magnetic flux. As long as the vortices remain stationary, an applied current can flow across the material without resistance. Currents induce a force on a vortex, however, and above some critical current, the vortex will become liberated and dissipate energy as it moves quickly across the material. Just how quickly? Rough calculations suggest that vortices in a thin lead film could reach speeds of 40 km/s, two orders of magnitude faster than the perpendicular supercurrent driving them.



Little theory has been developed for such superfast vortices. But Eli Zeldov (Weizmann Institute of Science) and colleagues now report the first direct microscopic imaging of them. Crucial to the observations was a novel scanning probe: a nanoscale superconducting quantum interference device, or SQUID, residing on the apex of a sharp tip. That tool allowed the researchers to map, with single-vortex resolution, the vortex patterns in a Pb thin film designed with a 5.7-μm-wide constriction. The figures show the vortices in a 2.7 mT field at zero current (left) and at the onset of vortex flow (right) above the critical current (flowing upward). The right image, capturing the time-averaged vortex motion from left to right, reveals the formation of vortex channels with cascading bifurcations. From their observations, the researchers extracted vortex speeds approaching 20 km/s. Minimal-model simulations corroborated the team's suspicions that weak local heating dynamically aligns the vortices and that repulsive vortex interactions cause the channels to buckle and split. Moreover, the simulations predicted that vortices could reach yet higher speeds, beyond the team's experimental capabilities, and metamorphose into new forms, with exciting implications for superconducting electronics. (L. Embon et al., *Nat. Commun.* **8**, 85, 2017.)

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