Quantum 'curvature' warps electron flow, hinting at new electronics possibilities

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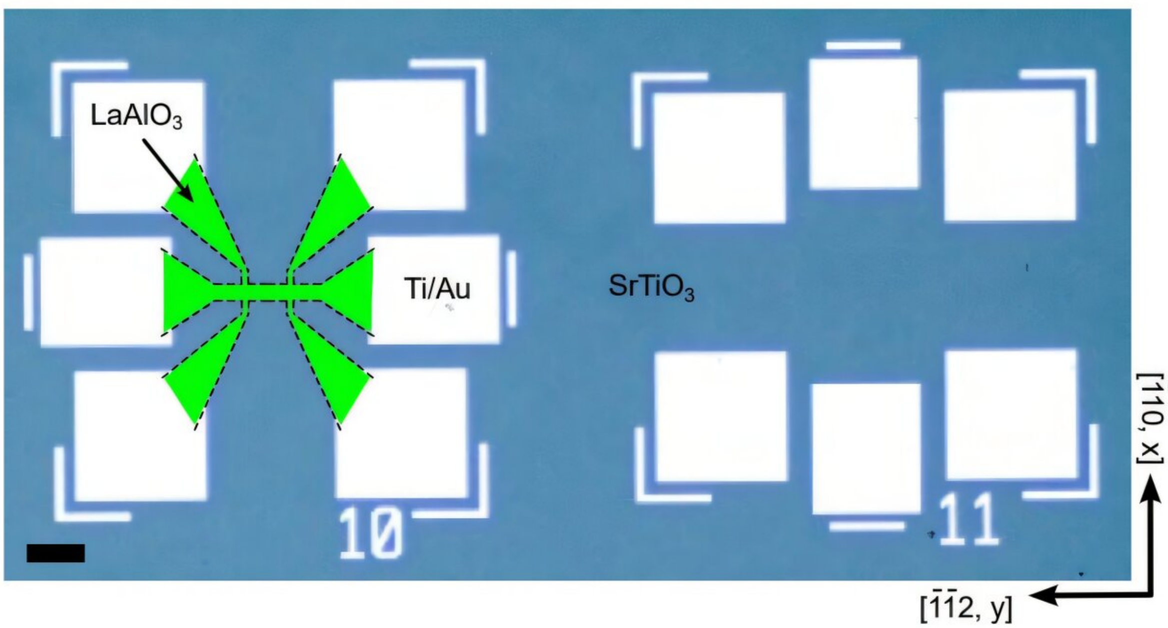

Optical image of two patterned Hall bar devices oriented along orthogonal directions on the $SrTiO_3$ surface. The green area indicates the position and shape of the devices. Note that the $LaAlO_3$ layer cannot be distinguished by eye from the substrate. The black scale bar corresponds to 60 µm. Credit: *Science* (2025). DOI: 10.1126/science.adq3255

How can data be processed at lightning speed, or electricity conducted without loss? To achieve this, scientists and industry alike are turning to quantum materials, governed by the laws of the infinitesimal. Designing such materials requires a detailed understanding of atomic phenomena, much of which remains unexplored.

A team from the University of Geneva (UNIGE), in collaboration with the University of Salerno and the CNR-SPIN Institute (Italy), has taken a major step forward by uncovering a hidden geometry—until now purely theoretical—that distorts the trajectories of electrons in much the same way gravity bends the path of light. The work, published in *Science*, opens new avenues for quantum electronics.

Future technologies depend on high-performance materials with unprecedented properties, rooted in quantum physics. At the heart of this revolution lies the study of matter at the microscopic scale—the very essence of quantum physics. In the past century, exploring atoms, electrons and photons within materials gave rise to transistors and, ultimately, to modern computing.

New quantum phenomena that defy established models are still being discovered today. Recent studies suggest the possible emergence of a geometry within certain materials when vast numbers of particles are observed. This geometry appears to distort the trajectories of electrons in these materials—much like Einstein's gravity bends the path of light.

From theory to observation

Known as quantum metric, this geometry reflects the curvature of the quantum space in which electrons move. It plays a crucial role in many phenomena at the microscopic scale of matter. Yet detecting its presence and effects remains a major challenge.

"The concept of quantum metric dates back about 20 years, but for a long time it was regarded purely as a theoretical construct. Only in recent years have scientists begun to explore its tangible effects on the properties of matter," explains Andrea Caviglia, full professor and director of the Department of Quantum Matter Physics at the UNIGE Faculty of Science.

Thanks to recent work, the team led by the UNIGE researcher, in collaboration with Carmine Ortix, associate professor in the Department of Physics at the University of Salerno, has detected quantum metric at the interface between two oxides—strontium titanate and lanthanum aluminate—a well-known quantum material.

"Its presence can be revealed by observing how electron trajectories are distorted under the combined influence of quantum metric and intense magnetic fields applied to solids," explains Giacomo Sala, research associate in the Department of Quantum Matter Physics at the UNIGE Faculty of Science and lead author of the study.

Observing this phenomenon makes it possible to characterize a material's optical, electronic and transport properties with greater precision. The research team also demonstrates that quantum metric is an intrinsic property of many materials—contrary to previous assumptions.

"These discoveries open up new avenues for exploring and harnessing quantum geometry in a wide range of materials, with major implications for future electronics operating at terahertz frequencies (a trillion hertz), as well as for superconductivity and light–matter interactions," concludes Caviglia.

More information: Giacomo Sala et al, The quantum metric of electrons with spin-momentum locking, *Science* (2025). DOI: 10.1126/science.adq3255

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