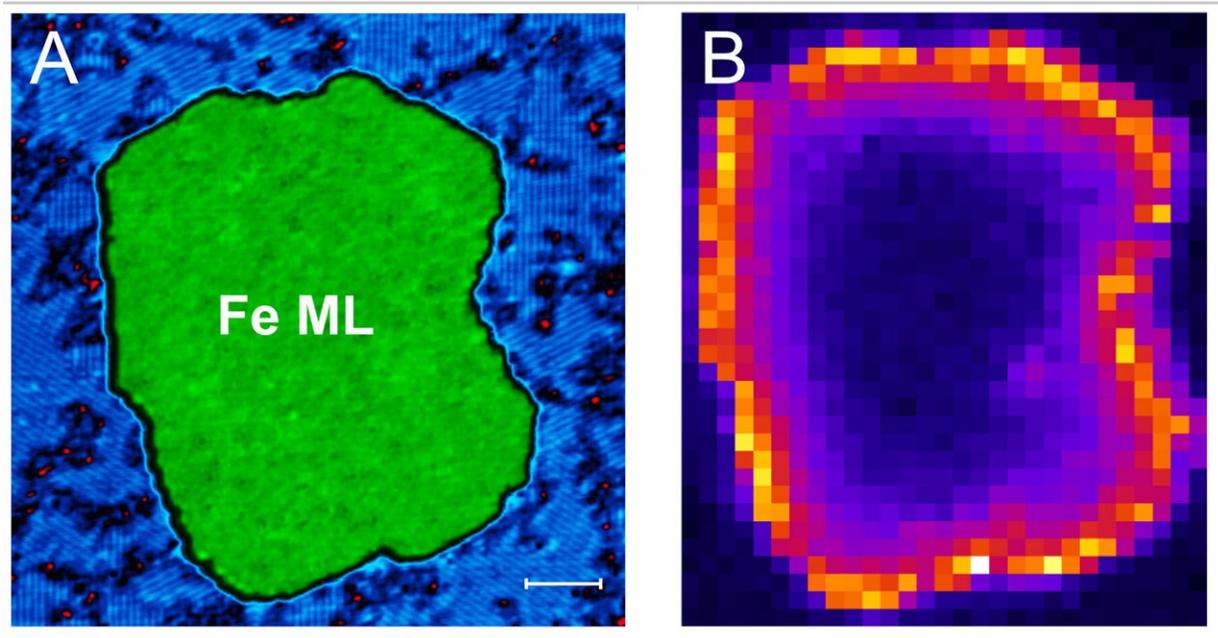


Imaging of exotic quantum particles as building blocks for quantum computing

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A. A monolayer of iron atoms assembled on a rhenium surface. B. Image of a Majorana fermion as a bright line along the edge of the iron using a scanning tunneling microscope. Credit: UIC/Dirk Morr

Researchers at the University of Illinois at Chicago, in collaboration with

their colleagues at the University of Hamburg in Germany, have imaged an exotic quantum particle—called a Majorana fermion—that can be used as a building block for future qubits and eventually the realization of quantum computers. Their findings are reported in the journal *Science Advances*.

More than 50 years ago, Gordon Moore, the former CEO of Intel, observed that the number of transistors on a computer chip doubles every 18 to 24 months. This trend, now known as Moore's Law, has continued to the present day, leading to transistors that are only a few nanometers—one-billionth of a meter—in size. At this scale, the classical laws of physics, which form the basis on which our current computers work, cease to function, and they are replaced by the laws of [quantum](#) mechanics. Making transistors even smaller, which has been used in the past to increase computing speed and data storage, is, therefore, no longer possible.

Unless researchers can figure out how to use quantum mechanics as the new foundation for the next generation of computers.

This was the basic idea formulated in 1982 by Richard Feynman, one of the most influential theoretical physicists of the 20th century. Rather than using classical [computer](#) bits that store information encoded in zeros and ones, one would devise "quantum bits"—or qubits for short—that would utilize the laws of [quantum mechanics](#) to store any number between 0 and 1, thereby exponentially increasing computing speed and leading to the birth of quantum computers.

"Usually, when you drop your [cell phone](#), it doesn't erase the information on your phone," said Dirk Morr, professor of physics at UIC and corresponding author on the paper. "That's because the chips on which information is stored in bits of ones and zeros are fairly stable. It takes a lot of messing around to turn a one into a zero and vice versa. In

quantum computers, however, because there is an infinite number of possible states for the [qubit](#) to be in, information can get lost much more easily."

To form more robust and reliable qubits, researchers have turned to Majorana fermions—quantum particles that occur only in pairs.

"We only need one Majorana fermion per qubit, and so we have to separate them from each other," Morr said.

By building qubits from a pair of Majorana fermions, information can be reliably encoded, as long as the Majoranas remain sufficiently far apart.

To achieve this separation, and to "image" a single Majorana fermion, it is necessary to create a "topological superconductor"—a system that can conduct currents without any energy losses, and at the same time, is tied into a "topological knot."

"This topological knot is similar to the hole in a donut: you can deform the donut into a coffee mug without losing the hole, but if you want to destroy the hole, you have to do something pretty dramatic, such as eating the donut," Morr said.

To build topological superconductors, Morr's colleagues at the University of Hamburg placed an island of magnetic iron atoms, only tens of nanometers in diameter, on the surface of rhenium, a superconductor. Morr's group had predicted that by using a [scanning tunneling microscope](#), one should be able to image a Majorana fermion as a bright line along the edge of the island of iron atoms. And this is exactly what the experimental group observed.

"Being able to actually visualize these exotic quantum particles takes us

another step closer to building robust qubits, and ultimately quantum computers," Morr said. "The next step will be to figure out how we can quantum engineer these Majorana qubits on quantum chips and manipulate them to obtain an exponential increase in our computing power. This will allow us to address many problems we face today, from fighting global warming and forecasting earthquakes to alleviating traffic congestion through driverless cars and creating a more reliable energy grid."

More information: Alexandra Palacio-Morales et al, Atomic-scale interface engineering of Majorana edge modes in a 2D magnet-superconductor hybrid system, *Science Advances* (2019). [DOI: 10.1126/sciadv.aav6600](https://doi.org/10.1126/sciadv.aav6600)

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