Light-controlled Higgs modes found in superconductors; potential sensor, computing uses

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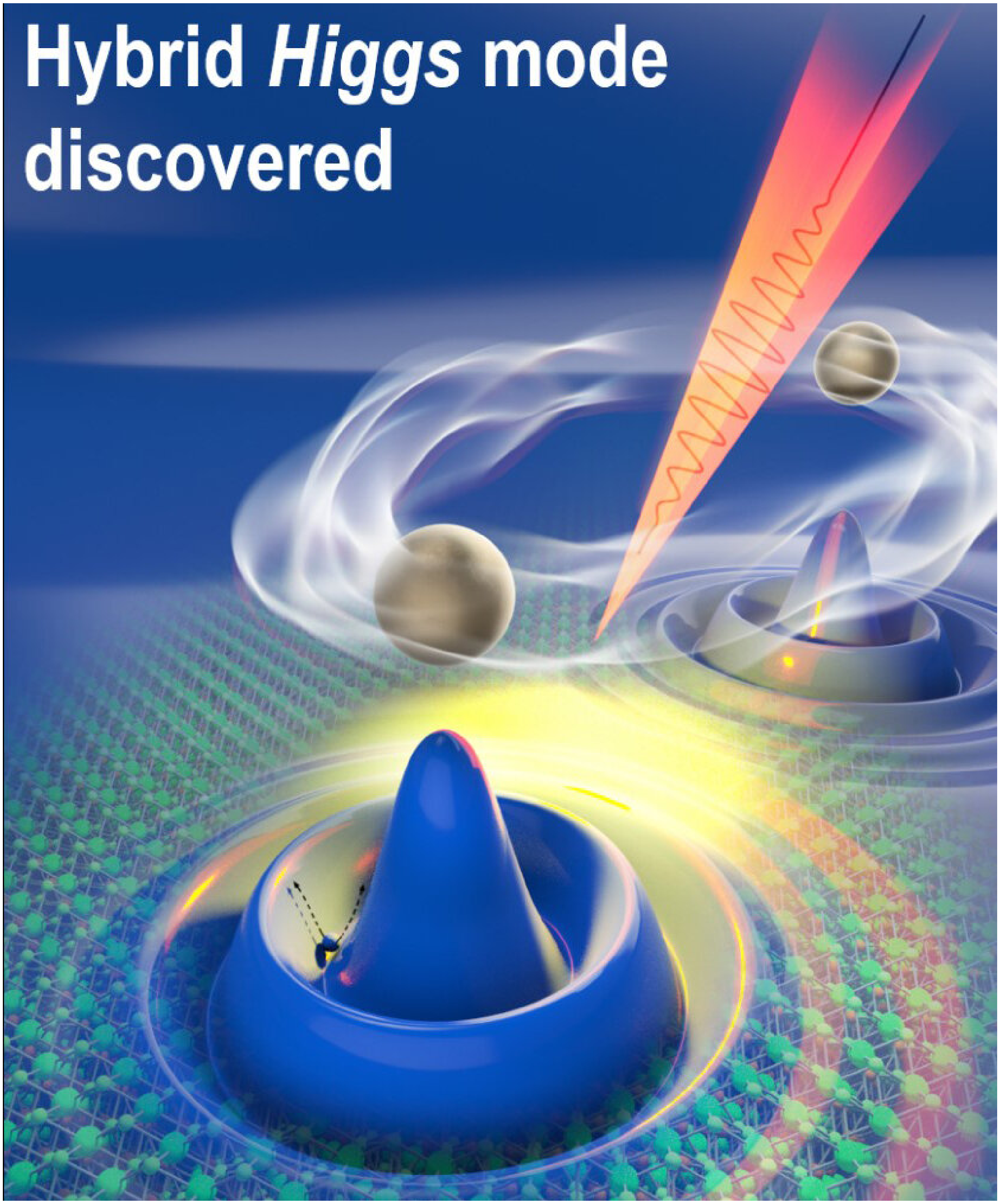

This illustration shows light at trillions of pulses per second (red flash) accessing and controlling Higgs modes (gold balls) in an iron-based superconductor. Even at different energy bands, the Higgs modes interact with each other (white smoke). Credit: Illustration courtesy of Jigang Wang.

Even if you weren't a physics major, you've probably heard something about the Higgs boson.

There was the title of a 1993 book by Nobel laureate Leon Lederman that dubbed the Higgs "The God Particle." There was the search for the Higgs particle that launched after 2009's first collisions inside the Large Hadron Collider in Europe. There was the 2013 announcement that Peter Higgs and Francois Englert won the Nobel Prize in Physics for independently theorizing in 1964 that a fundamental particle—the Higgs—is the source of mass in subatomic particles, making the universe as we know it possible.

(Plus, there are the Iowa State University physicists on the author list of a 2012 research paper describing how the ATLAS Experiment at the collider observed a new particle later confirmed to be the Higgs.)

And now Jigang Wang, a professor of physics and astronomy at Iowa State and a senior scientist at the U.S. Department of Energy's Ames Laboratory, and a team of researchers have discovered a form of the famous particle within a superconductor, a material capable of conducting electricity without resistance, generally at very cold temperatures.

Wang and his collaborators—including Chang-Beom Eom, the Raymond R. Holton Chair for Engineering and Theodore H. Geballe Professor at the University of Wisconsin-Madison; Ilias Perakis, professor and chair of physics at the University of Alabama at Birmingham; and Eric Hellstrom, professor and interim chair of mechanical engineering at Florida State University—report the details in a paper recently published online by the journal *Nature Communications*.

They write that in lab experiments they've found a short-lived "Higgs mode" within iron-based, high-temperature (but still very cold), multi-energy band, unconventional superconductors.

A quantum discovery

This Higgs mode is a state of matter found at the quantum scale of atoms, their electronic states and energetic excitations. The mode can be accessed and controlled by laser light flashing on the superconductor at terahertz frequencies of trillions of pulses per second. The Higgs modes can be created within different energy bands and still interact with each other.

Wang said this Higgs mode within a superconductor could potentially be used to develop new quantum sensors.

"It's just like the Large Hadron Collider can use the Higgs particle to detect dark energy or antimatter to help us understand the origin of the universe," Wang said. "And our Higgs mode sensors on the table-top have the potential help us discover the hidden secrets of quantum states of matter."

That understanding, Wang said, could advance a new "quantum revolution" for high-speed computing and information technologies.

"It's one way this exotic, strange, quantum world can be applied to real life," Wang said.

Light control of superconductors

The project takes a three-pronged approach to accessing and understanding the special properties, such as this Higgs mode, hidden within superconductors:

Wang's research group uses a tool called quantum terahertz spectroscopy to visualize and steer pairs of electrons moving through a superconductor. The tool uses laser flashes as a control knob to accelerate supercurrents and access new and potentially useful quantum states of matter.

Eom's group developed the synthesis technique that produces crystalline thin films of the iron-based superconductor with high enough quality to reveal the Higgs mode. Hellstrom's group developed deposition sources for the iron-based superconducting thin film development.

Perakis' group led the development of quantum models and theories to explain the results of the experiments and to simulate the salient features that come from the Higgs mode.

The work has been supported by a grant to Wang from the National Science Foundation and grants to Eom and Perakis from the U.S. Department of Energy.

"Interdisciplinary science is the key here," Perakis said. "We have quantum physics, materials science and engineering, condensed matter physics, lasers and photonics with inspirations from fundamental, high-energy and particle physics."

There are good, practical reasons for researchers in all those fields to work together on the project. In this case, students from the four research groups worked together with their advisors to accomplish this discovery.

"Scientists and engineers," Wang wrote in a research summary, "have recently come to realize that certain materials, such as superconductors, have properties that can be exploited for applications in quantum information and energy science, e.g., processing, recording, storage and communication."

More information: C. Vaswani et al, Light quantum control of persisting Higgs modes in iron-based superconductors, *Nature Communications* (2021). DOI: 10.1038/s41467-020-20350-6

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