Scientists unveil first quantum simulation of 3-D topological matter with ultracold atoms

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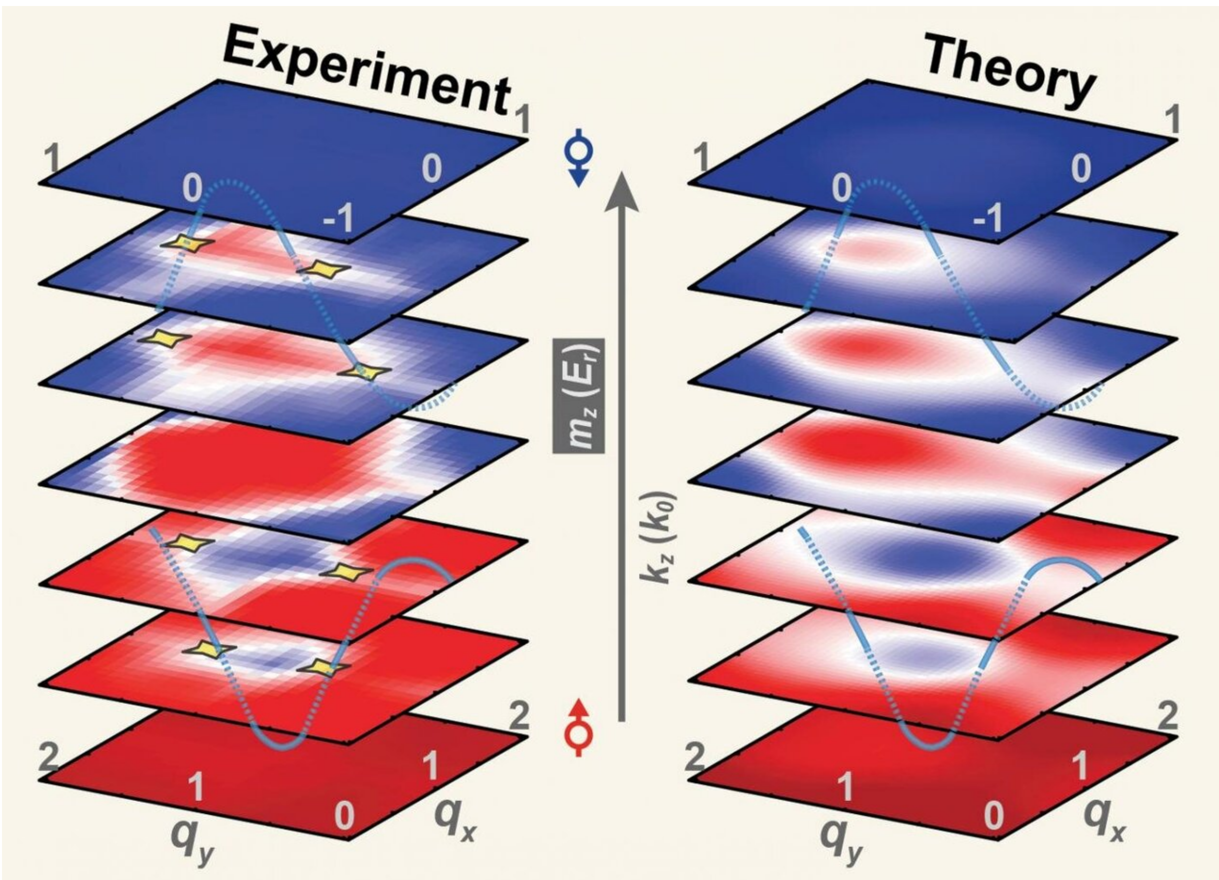

Three-dimensional band topology is experimentally mapped out showing nodal lines in good agreement with theoretical prediction. Credit: HKUST

Physicists from the Hong Kong University of Science and Technology

(HKUST) and Peking University (PKU) have successfully created the world's first 3-D simulation of topological matter consisting of ultracold atoms. Previous attempts at topological matter simulations were limited to lower dimensions, due to challenges on how to characterize 3-D band topology in atomic systems. This breakthrough paves an opening to further examining new topological matter that cannot be well realized in solids. Such never-before-done engineering of artificial material with ultracold atoms may now allow physicists to model unusual phases of matter.

Prof. Gyu-Boong Jo, Associate Professor from the Department of Physics at HKUST collaborated with Prof. Xiong-Jun Liu, Professor from the School of Physics at PKU and devised an artificial crystal lattice structure, previously proposed by the PKU group, to model ultracold atoms prepared at 30 billionths of a degree above absolute zero. This new synthetic quantum matter is a 3-D spin-orbit coupled nodal-line topological semimetal, and exhibits an emergent magnetic group symmetry. The researchers correlated the atom spin with the direction of atomic motion, which made the overall atom behavior topological. With such symmetry the researchers proved that the 3-D band topology can be resolved by only imaging 2-D spin patterns on the symmetric planes, and further successfully observed the 3-D topological semimetal in experiment. The detection techniques used here can be generally applied to exploring all 3-D topological states of similar symmetries when those become available.

The research was recently published online in *Nature Physics* on July 29, 2019.

Complex topological matter has become the focus of both industrial and academic research because it is seen as a way to pave the way to making quantum computing more noise free and robust. Today's physical quantum computers are still noisy, and quantum error correction is a growing field of research. The goal of fault tolerant quantum computing has driven investment into complex topological matter.

Topological matter is classified by the geometric properties of the quantum state in material. The topological nature of the material means that it tends to withstand imperfections within an operating system and also holds the potential for other yet unknown exotic properties.

"Our work opens up many possibilities for developing new topological materials that do not occur naturally," said Prof. Jo. "This development demonstrates there is a new possibility to explore complex topological material in 3-D, and will provide a useful platform for quantum simulation."

"This is a breakthrough progress for quantum simulation with ultracold atoms," said Prof. Liu. "It enables the experimental investigation and observation of nontrivial phases of all physical dimensions, including various insulating, semimetal, and superfluid phases with nontrivial topology in ultracold atoms."

More information: Bo Song et al, Observation of nodal-line semimetal with ultracold fermions in an optical lattice, *Nature Physics* (2019). DOI: 10.1038/s41567-019-0564-y

Provided by Hong Kong University of Science and Technology

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