Physicists observe competition between magnetic orders

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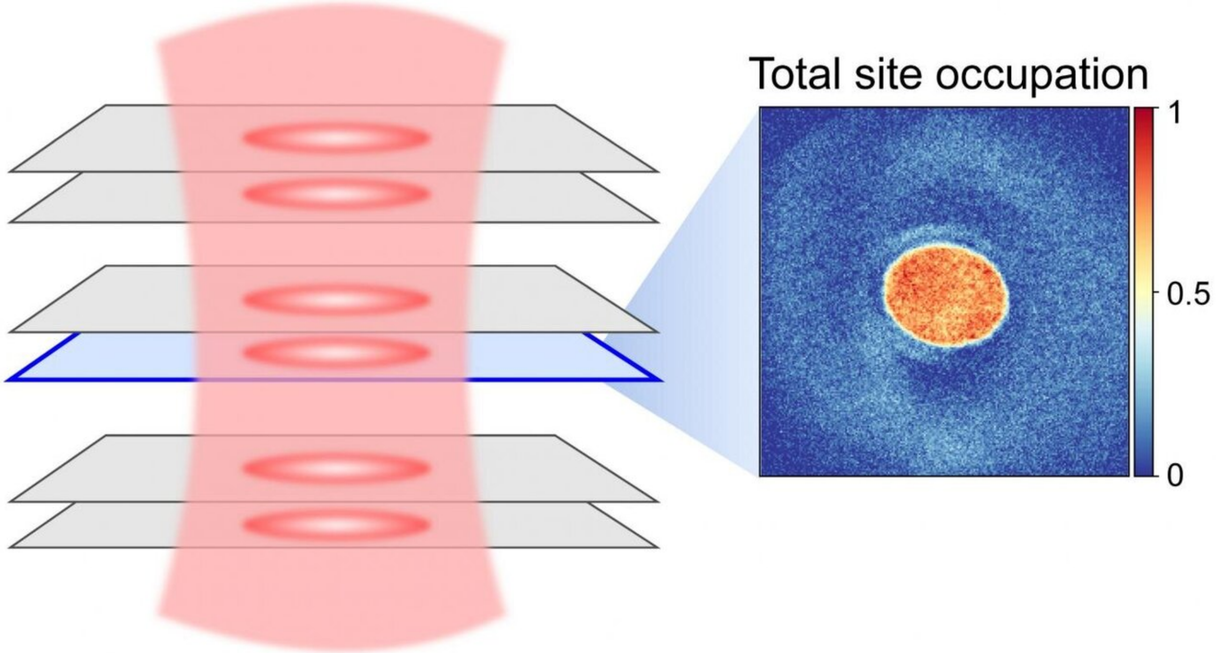


The system: A crystal lattice made of light traps atoms in several bilayer sheets.Tomographic images show the (spin-) densities in a single layer. They provide information about the magnetic ordering of the atoms. The image on the right shows the density of one layer averaged over twelve realizations (orange red). Credit: Marcell Gall, Nicola Wurz et al./ Nature

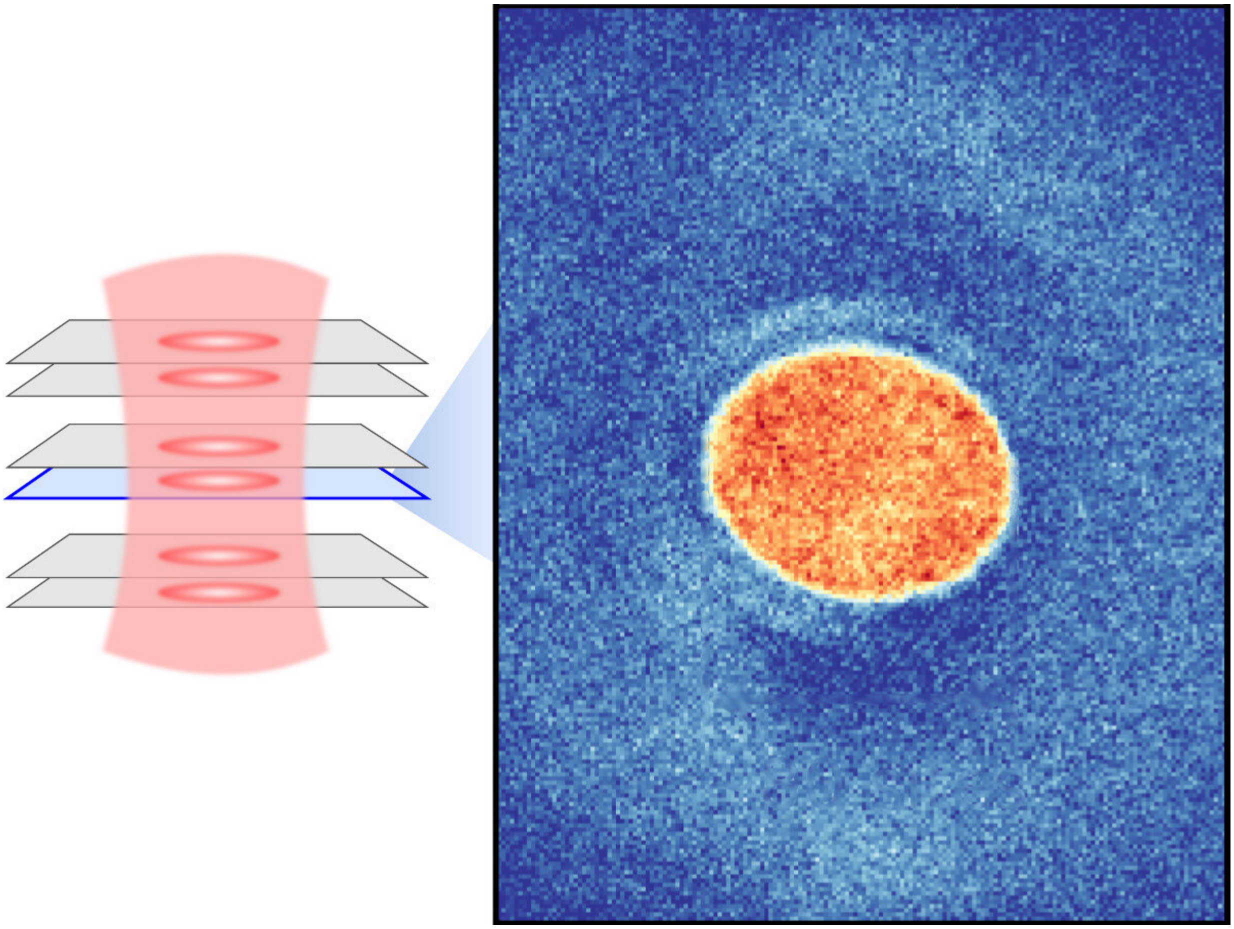
They are as thin as a hair, only a hundred thousand times thinner—so-called two-dimensional materials, consisting of a single layer of atoms, have been booming in research for years. They became known to a wider audience when two Russian-British scientists were awarded the Nobel Prize in Physics in 2010 for the discovery of graphene, a building block of graphite. The special feature of such materials is that they possess novel properties that can only be explained with the help of the laws of quantum mechanics and that may be relevant for enhanced technologies. Researchers at the University of Bonn (Germany) have now used ultracold atoms to gain new insights into previously unknown quantum phenomena. They found out that the magnetic orders between two coupled thin films of atoms compete with each other. The study has been published in the journal *Nature*.

Quantum systems realize very unique states of matter originating from the world of nanostructures. They facilitate a wide variety of new technological applications, e.g. contributing to secure data encryption, introducing ever smaller and faster technical devices and even enabling the development of a quantum computer. In the future, such a computer could solve problems which conventional computers cannot solve at all or only over a long period of time.

How unusual quantum phenomena arise is still far from being fully understood. To shed light on this, a team of physicists led by Prof. Michael Köhl at the Matter and Light for Quantum Computing Cluster of Excellence at the University of Bonn are using so-called quantum simulators, which mimic the interaction of several quantum particles—something that cannot be done with conventional methods. Even state-of-the-art computer models cannot calculate complex processes such as magnetism and electricity down to the last detail.

Ultracold atoms simulate solids

The simulator used by the scientists consists of ultracold atoms—ultracold because their temperature is only a millionth of a degree above absolute zero. The atoms are cooled down using lasers and magnetic fields. The atoms are located in optical lattices, i.e. standing waves formed by superimposing laser beams. This way, the atoms simulate the behavior of electrons in a solid state. The experimental setup allows the scientists to perform a wide variety of experiments without external modifications.



The system: A crystal lattice made of light traps atoms in several bilayer sheets. Tomographic images show the (spin-) densities in a single layer. They provide information about the magnetic ordering of the atoms. The image on the right shows the density of one layer averaged over twelve realizations (orange red). Credit: © Marcell Gall, Nicola Wurz et al./ Nature

Within the quantum simulator, the scientists have, for the first time, succeeded in measuring the magnetic correlations of exactly two coupled layers of a crystal lattice. "Via the strength of this coupling, we were able to rotate the direction in which magnetism forms by 90 degrees—without changing the material in any other way," first authors Nicola Wurz and Marcell Gall, doctoral students in Michael Köhl's research group, explain.

To study the distribution of atoms in the optical lattice, the physicists used a high-resolution microscope with which they were able to measure magnetic correlations between the individual lattice layers. In this way, they investigated the magnetic order, i.e. the mutual alignment of the atomic magnetic moments in the simulated solid state. They observed that the magnetic order between layers competed with the original order within a single layer, concluding that the more strongly layers were coupled, the more strongly correlations formed between the layers. At the same time, correlations within individual layers were reduced.

The new results make it possible to better understand the magnetism propagating in the coupled layer systems at the microscopic level. In the future, the findings are to help make predictions about material properties and achieve new functionalities of solids, among other things. Since, for example, high-temperature superconductivity is closely linked to magnetic couplings, the new findings could, in the long run, contribute to the development of new technologies based on such superconductors.

The Matter and Light for Quantum Computing (ML4Q) Cluster of Excellence

The Matter and Light for Quantum Computing (ML4Q) Cluster of Excellence is a research cooperation by the universities of Cologne, Aachen and Bonn, as well as the Forschungszentrum Jülich. It is funded as part of the Excellence Strategy of the German federal and state governments. The aim of ML4Q is to develop new computing and networking architectures using the principles of quantum mechanics. ML4Q builds on and extends the complementary expertise in the three key research fields: solid-state physics, quantum optics, and quantum information science.

The Cluster of Excellence is embedded in the Transdisciplinary Research Area "Building Blocks of Matter and Fundamental Interactions" at the University of Bonn. In six different TRAs, scientists from a wide range of faculties and disciplines come together to work on future-relevant research topics.

More information: Marcell Gall et al, Competing magnetic orders in a bilayer Hubbard model with ultracold atoms, *Nature* (2021). DOI: 10.1038/s41586-020-03058-x

Provided by University of Bonn

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