Researchers succeed in imaging quantum events

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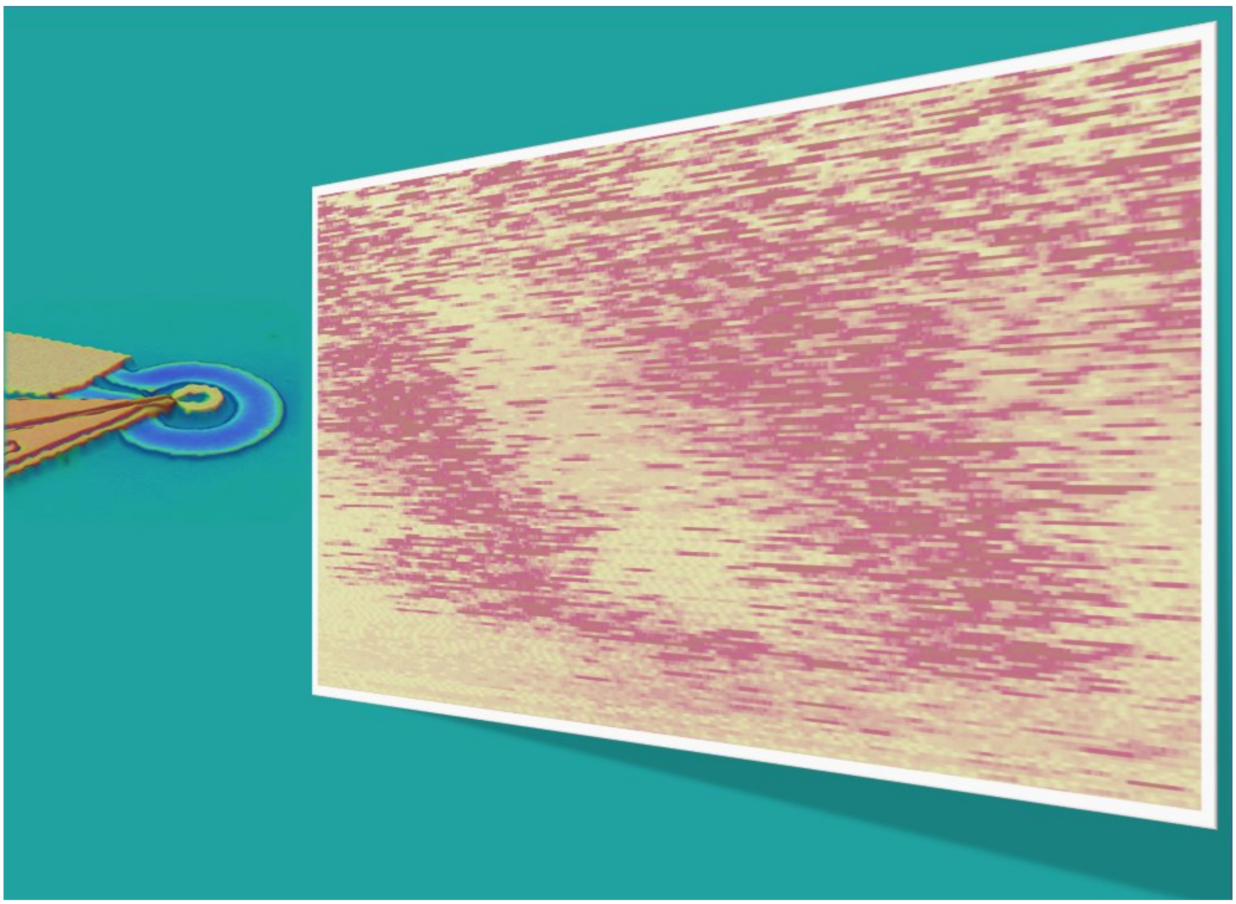

Scanning a SQUID sensor detects fluctuations near a quantum phase transition. Credit: Beena Kalisky

Quantum technology is a growing field of physics and engineering which utilizes properties of quantum mechanics as a basis for advanced practical applications such as quantum computing, sensors, information, communication and medicine. This promises to lead to a new era of technology unlike anything we've known. Computers will be much more powerful, medical treatment will be non-invasive and far safer than today, and even teleportation can be envisioned. A phenomenon that stands at the core of this development is the Quantum phase transition.

Phase transitions are present in our day-to-day life, starting from the water boiling for our morning coffee to the melting of an ice cube in our drink. In these phase transitions between solid, liquid, and gas phases, we can directly visualize certain aspects of the transition. We see bubbles of one phase in the other—for example bubbles of air in boiling water, or droplets of water in ice slush. In order to see these phase transitions, we need nothing but our eyes. These "classic" phase transitions, with which we are all familiar, have a common characteristic which is that their driving force is temperature. Ice melts at zero degrees Celsius and evaporates at a hundred degrees. How cool would it be if instead of heating water in a kettle for a cup of tea we could take a glass of cold water and boil it by bringing it close to a magnet! In our world this is impossible but in the quantum world it works.

The scientific community has recently gained increasing interest in a different type of phase transitions—"quantum phase transitions"—which occur at the absolute zero temperature (minus two hundred and seventy three degrees). These transitions are not driven by the temperature, but by changing a different physical property such as mechanical pressure or magnetic field. Similar to classical phase transitions, quantum phase transitions are also accompanied by the presence of "bubbles" of one phase in the other. The scientific term for these bubbles is Quantum fluctuations. Unlike the classic case, where a change in the temperature is responsible for the bubbles, in the quantum case the bubbles arise due to the uncertainty principle which is one of the basic rules in quantum physics. This principle, developed by German physicist Werner Heisenberg, states that contrary to our intuition, vacuum is not empty but contains temporary changes in the amount of energy in a point in space. These changes lead to quantum bubbles of one phase into a second phase even at the absolute zero temperature.

Until now it has been impossible to take pictures of these quantum fluctuations. They occur at very low temperatures, and many times involve physical phases which cannot be seen by a regular microscope. Though indirect evidence for their presence appears in many measurements, no one has actually seen them. But an international group led by Prof. Beena Kalisky and Prof. Aviad Frydman, from the Department of Physics and the Institute for Nanotechnology at Bar-Ilan University in Israel, has succeeded in imaging quantum fluctuations for the first time. In their experiment, published today in *Nature Physics*, not only were quantum fluctuations visualized, but new information about the sizes, times and distributions of quantum events was extracted.

The researchers employed a unique microscope that can operate at very low temperatures to examine a material that undergoes a quantum phase transition. This microscope, called a scanning SQUID (Superconducting QUantum Interference Device), can detect very small magnetic signals and plot a map of their location with sub-micron resolution. The microscope uses quantum phenomena to convert magnetic signals to voltage and it is an ideal tool for investigating complex phenomena at the nano-scale.

The experiment was performed by graduate student Anna Kremen who used the sensitive magnetic measurements to identify different phases in the material. At very low temperatures, close to zero, the sample was pushed towards the region where quantum behavior is expected, while the scanning SQUID microscope was used to take pictures. Remarkably, quantum bubbles appeared at random locations. They switched on and off with time or appeared sporadically at different places. We are used to this behavior of air bubbles in boiling water, but now similar bubbles can also be seen in quantum matter.

This experiment opens a door to detailed investigations of quantum events. Images allow the extraction of physical quantities such as size, dynamics, distributions, and interactions with other phenomena. This novel ability to look at quantum fluctuations is expected to be a fundamental tool for the future development of quantum technology.

More information: A. Kremen et al, Imaging quantum fluctuations near criticality, *Nature Physics* (2018). DOI: 10.1038/s41567-018-0264-z , DOI: 10.1038/s41567-018-0264-z

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