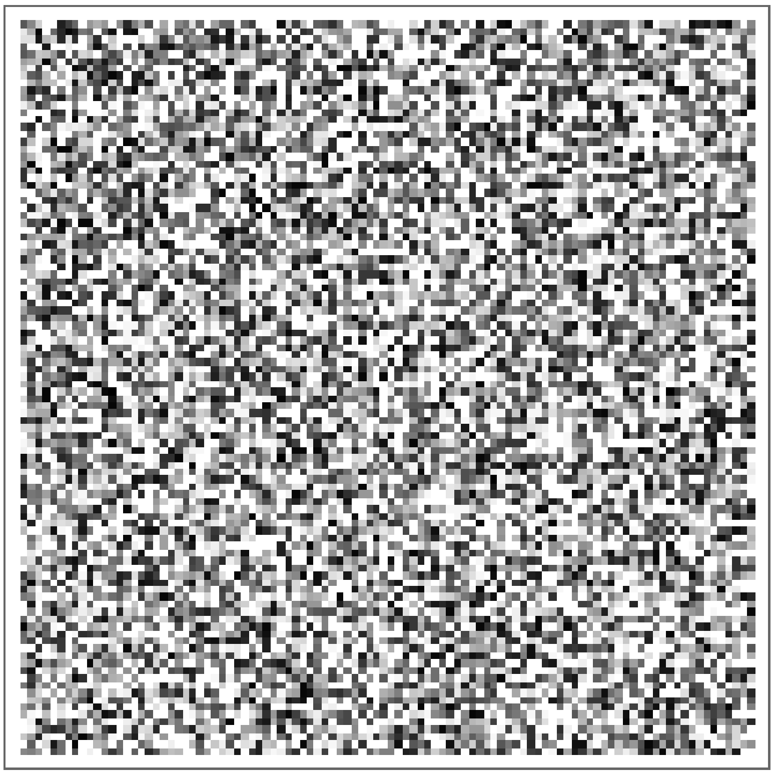
World's quietest gas lets physicists hear faint quantum effects

August 4 2015, by Robert Sanders



When the noise or entropy in a system is reduced, subtle information becomes visible, such as the faint word 'Berkeley.' Credit: Ryan Olf image.

Physicists at the University of California, Berkeley, have cooled a gas to the quietest state ever achieved, hoping to detect faint quantum effects lost in the din of colder but noisier fluids.

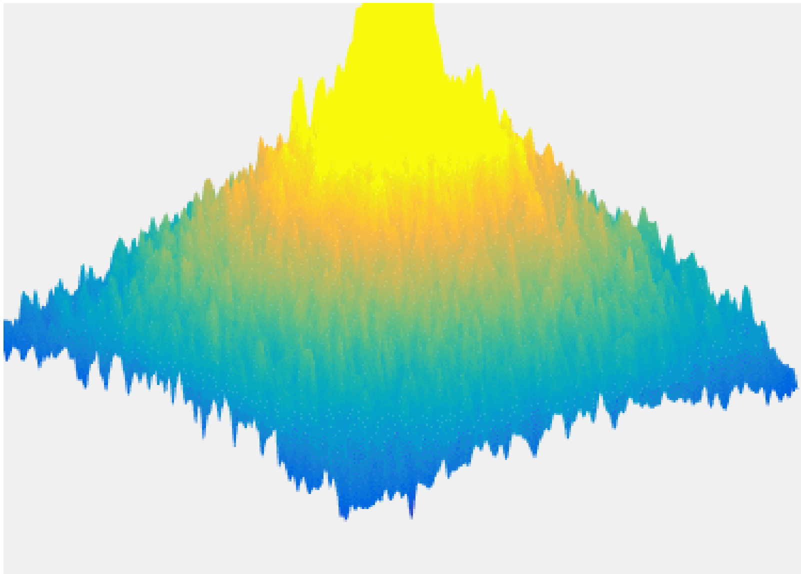
While the ultracold gas's temperature - a billionth of a degree above absolute zero - is twice as hot as the record cold, the gas has the lowest entropy ever measured. Entropy is a measure of disorder or noise in a system; a record low temperature gas isn't necessarily the least noisy.

"This 'lowest entropy' or 'lowest noise' condition means that the quantum gas can be used to bring forth subtle quantum mechanical effects which are a main target for modern research on materials and on many-body physics," said co-author Dan Stamper-Kurn, a UC Berkeley professor of physics. "When all is quiet and all is still, one might discern the subtle music of many-body quantum mechanics."

The quantum gas, a so-called Bose-Einstein condensate, consisted of about a million rubidium atoms trapped by a beam of light, isolated in a vacuum and cooled to their lowest energy state. The entropy and temperature were so low that the researchers had to develop a new type of thermometer to measure them.

While achieving extremely low temperatures may make the record books, UC Berkeley graduate student Ryan Olf said, what scientists aim for today are low-entropy states they can study to understand more interesting but difficult-to-study materials.

The UC Berkeley team's ability to manipulate ultracold, low-entropy gases will allow them to study these quantum systems, including quantum magnets - potentially useful in quantum computers - and high-temperature superconductors. High-temperature superconductors are experimental materials that display superconductivity - electrical flow without resistance - at relatively high temperatures compared to the 3 or 4 degrees Celsius above absolute zero typical of today's conventional superconductors.



In most ultracold Bose-Einstein Condensates (BEC), the quantum gas (yellow peak) is accompanied by normal gas jiggling with thermal noise (the blue hump below the peak). As the noise or entropy is decreased, however, the jiggling disappears to leave an almost pure quantum gas. Credit: Ryan Olf graphic.

"One of the holy grails of modern physics is to understand these exotic materials well enough to design one that is superconducting without requiring any cooling at all," Olf said. "By studying the properties of low-entropy gases in various configurations, our community of researchers hope to learn what makes these fascinating materials work the way they do."

Olf said that the entropy per particle, rather than the temperature, is the pertinent parameter when comparing systems, and the ultracold gases that had been produced until now struggled to reach the low entropies that would be required to test models of these materials.

"In a very real sense, this constitutes the coldest gas ever produced, at 50 times lower than the temperature at which quantum statistical effects become manifest, the Bose-Einstein condensation temperature," he said.

The details of the experiment were published online last month and will appear in a future print edition of the journal *Nature Physics*.

Reducing the rumble

Stamper-Kurn and his laboratory team chill gases to temperatures so low that quantum effects take over, which leads to strange "superfluid" behavior, such as frictionless flow. Superfluid helium is famous for climbing up and over the lip of a cup. Superfluid gases exhibit vortices - tiny tornadoes like those created when you stir a cup of coffee - that live forever.

At these low temperatures, Stamper-Kurn said, the low-energy excitations or jiggling of the atoms are sound waves. "Temperature generates something like a constant rumble of sound in the gas, and the entropy is like a count of how many sound-wave excitations remain. The colder a gas becomes, the less entropy it has and the quieter it is."

Normally, a Bose-Einstein condensate is a mixture of a quantum gas and a normal gas. Its temperature is determined by measuring the thermal properties of the normal gas. A low-entropy gas is almost all quantum gas, however, so the team had to find a different way to measure the temperature. They did so by tilting the magnetization of the atomic spins and measuring thermal properties of the tilted magnetization, essentially creating a magnon thermometer.

The tilted spins also helped them cool the gas to its low-entropy state by enhancing the evaporative cooling that researchers have long relied on to produce ultracold gases. In addition to removing hot atoms to reduce the average temperature of the gas, they used evaporative cooling of the thermalized spins to reduce the temperature to 1 nanoKelvin (one-billionth of a degree above absolute zero), corresponding to an entropy 100 times lower than previous experiments, Olf said.

More information: Thermometry and cooling of a Bose gas to 0.02 times the condensation temperature, Ryan Olf, Fang Fang, G. Edward Marti, Andrew MacRae & Dan M. Stamper-Kurn, *Nature Physics* (2015) DOI: 10.1038/nphys3408

Provided by University of California - Berkeley