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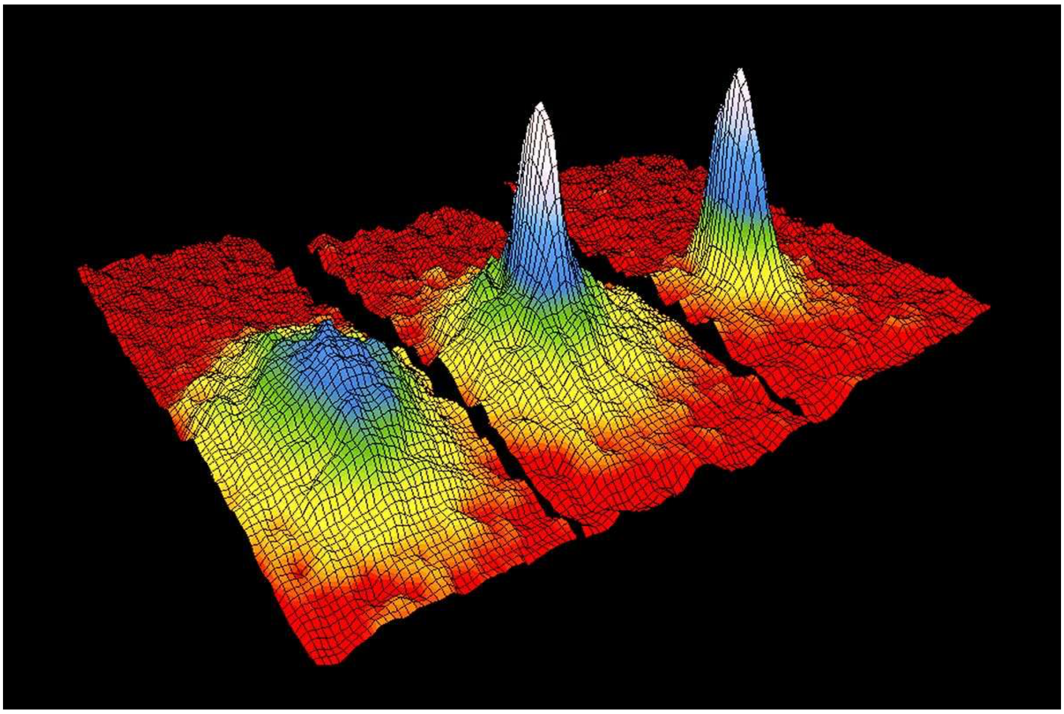
Entangled clouds of atoms are quantum record-breakers



In a Bose-Einstein condensate atoms coalesce, behaving as if they were one single 'super atom.' Here, red, yellow and green areas are less dense, and blue and white areas are very dense.
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By **Anil Ananthaswamy**

Entanglement between particles – a link created after they interact that intrinsically connects the behaviour of one to another – lets us instantly influence a particle by measuring its entangled partner. We've seen this work in pairs of particles separated by large distances. Now, three teams have independently shown, for the first time, the existence of entanglement between spatially separated clouds of ultracold atoms.

The experiments differed in the total number of entangled atoms, from about 590 to about 11,000. Unlike usual entanglement experiments with massless photons, "we really have entanglement between clouds of massive rubidium atoms, and quite a lot of them," says Martin Gärttner at the University of Heidelberg in Germany.

This opens the door to exploring quantum phenomena in systems with more and more mass, to try and understand if quantum effects disappear past some upper mass limit.

Suspended atom clouds

Entanglement is possible even in a so-called Bose-Einstein condensate (BEC), which is a cloud of atoms that are trapped and confined using lasers and cooled down to near absolute zero. In a BEC, all the atoms behave as particles with identical properties and hence have the same quantum state.

In earlier experiments on BECs, entangled particles were always in the same cloud, and the entanglement was considered a global property of the condensate, rather than of individual bits of the BEC.

"Can we also get entanglement between two different spatially localized parts of the BEC?" says Gärttner. "This was not entirely clear."

This question was tackled by three teams, the first led by Carsten Klempt at Leibniz University Hannover in Germany, the second by Philipp Treutlein at the University of Basel in Switzerland and the third by Markus Oberthaler at the University of Heidelberg.

While the experiments differ in their details, they are similar conceptually. They start by creating a Bose-Einstein condensate of rubidium atoms. The teams then induce interactions between the particles to get them entangled in their spin states, for example.

Next, the trap confining the atoms is relaxed, so that the cloud expands, and eventually separates into sub-clouds. Does the separation preserve or destroy the entanglement?

Twin spins

To find out, the teams manipulated the particles, say, by using radio frequency waves, so that they could observe certain spin states of the particles in each sub-cloud. If entanglement is preserved, the spin states of the particles in one sub-cloud should be highly correlated with the spin states of the particles in the other. That's because observing the spin states on one side immediately fixes the spin states on the other, and vice-versa.

This is exactly what the teams found. The entanglement allows for something called quantum steering, in which measurements made on one part of the entanglement system can be used to "steer" the other part into a particular state, something that was demonstrated in two of the three experiments.

"The experiments represent a big step towards having more control over the BECs," says Daniel Cavalcanti at The Institute of Photonic Sciences in Spain. "The fact that only global measurements were used in previous experiments was always thought to be a limitation of BECs. The three experiments now overcome this barrier and open up the possibility of using BECs for a range of new studies."

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