3-D trapping of Rydberg atoms in holographic optical bottle beam traps

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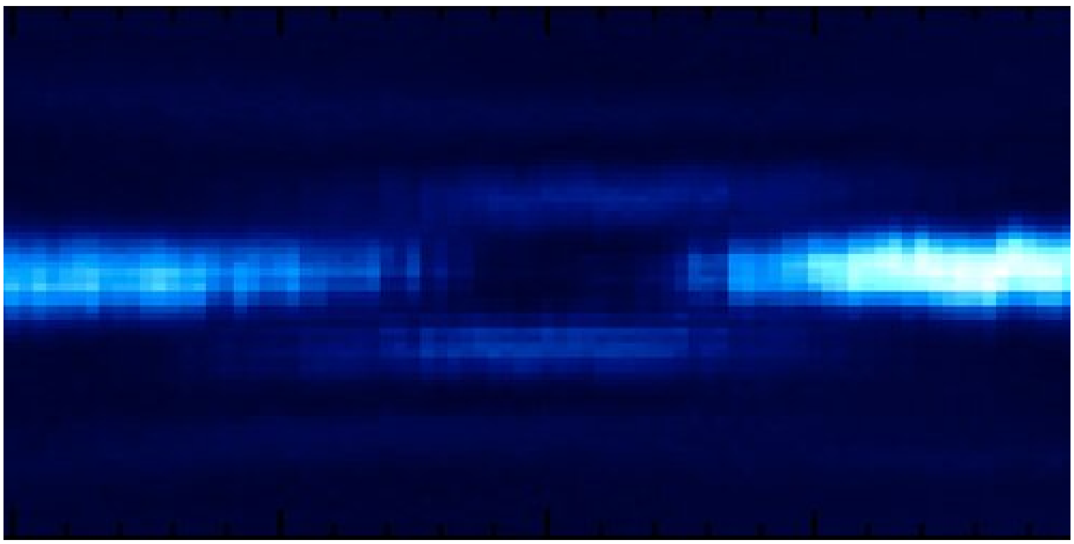

Image 1: This 2D-cut through the bottle beam shows the intensity distribution of light around the dark central region: one has a sort of light 'tube', plugged by two 'corks' along the axis (the full distribution is cylindrically symmetric around the horizontal axis). Credit: Barredo et al.

Researchers at CNRS, Université Paris-Saclay in France have recently demonstrated the 3-D trapping of atoms in a Rydberg state inside holographic optical bottle beam traps. Their demonstration, outlined in a paper published in *Physical Review Letters*, could have important implications for the future realization of quantum simulations.

In their study, the researchers used laser-cooled atoms that can be manipulated one by one. Manipulating laser-cooled atoms individually enables the creation of artificial, fully controlled systems inspired by solid-state physics, achieving what is referred to as a quantum simulation .

Quantum simulations can be carried out with experimental platforms, including trapped ions and superconducting qubits. The approach adopted by this research team entails the use of neutral atoms trapped in microscopic optical traps (i.e., optical tweezers), which are prompted to interact by exciting them to highly excited atomic levels known as Rydberg states.

"So far, during the short time the atoms are in the Rydberg states, we had to switch off the optical tweezers because Rydberg atoms are actually repelled by the light," Thierry Lahaye, one of the researchers who carried out the study, told Phys.org. "This limits the time over which the atoms can be kept in the Rydberg levels to just a few microseconds, because the atoms fly away from the trapping position. Our study made it possible to extend considerably this time, by trapping the atoms even when they are in a Rydberg state."

As Rydberg atoms are repelled by light, Lahaye and his colleagues shaped their laser beam in such a way that a dark region surrounded by light in all directions appeared exactly where each individual atom was located just after they were excited to the Rydberg level. This so-called 'bottle-beam' was created using a diffractive element known as a spatial-light modulator (SLM), which can be controlled using a computer.

This procedure allowed the researchers to prolong the time during which the atoms in a Rydberg state could be used for quantum simulation. While bottle beams have previously been used in several other physics studies, this is the first time they were specifically used to confine individual Rydberg atoms.

"With this trapping, the time over which we could keep our Rydberg atoms was extended to several hundreds of microseconds (typically a 40-fold improvement), only limited by the natural lifetime of the Rydberg levels," Lahaye explained. "An important feature of the scheme is that it is compatible with the goal of quantum simulation, something we checked by simultaneously trapping two atoms in two different traps and measuring whether they interacted in exactly the same way as they would in the absence of a trap—albeit for a much longer time, of course."

In the future, the bottle beam-based method used by Lahaye and his colleagues could prove very useful in both quantum simulations and quantum logic operations involving Rydberg atoms, enhancing their precision in reproducing physical systems. The researchers are now planning to carry out further studies to investigate potential applications of bottle beam traps.

"A natural continuation of this work would be to go beyond this proof of principle and create large arrays of such bottle beam traps, with many atoms, to perform an actual quantum simulation experiment while benefiting from the extended trapping time," Lahaye said.

More information: D. Barredo et al. Three-Dimensional Trapping of Individual Rydberg Atoms in Ponderomotive Bottle Beam Traps, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.124.023201