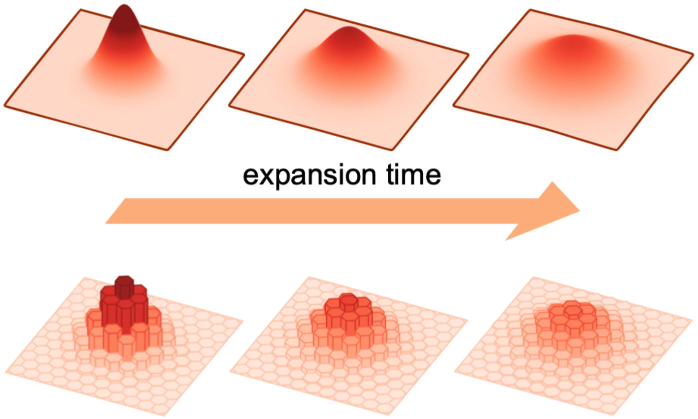
Physics FOCUS

Imaging Quantum Waves

A new imaging technique can show the wave-like behavior of unconfined quantum particles.

By **Philip Ball**

A research team has shown that a method for imaging atoms held in a 2D array of optical traps can be used to reveal the wave-like behavior of the atoms when they are released into free space [**1**]. The team placed atoms in the traps, turned the traps off for a short time, and then turned them back on again. By making many measurements of the atoms' locations after the traps were reactivated, the researchers could deduce the atoms' wave-like behavior. The team plans to use this technique to simulate interacting systems of particles in quantum states that are not well understood.



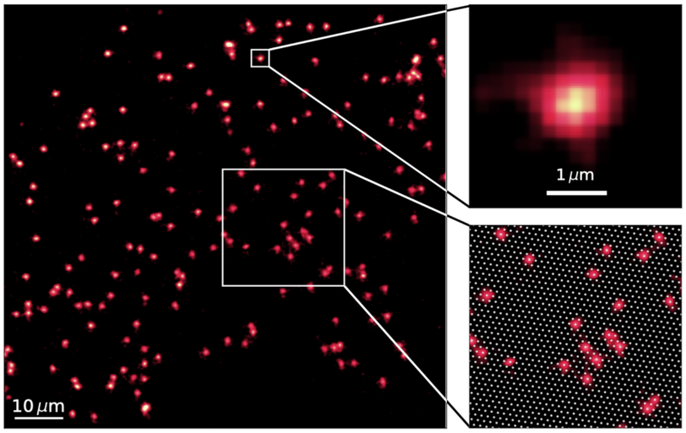
Quantum spreading. The expansion of a single-atom wave packet when released from a trap into free space, as predicted by the Schrödinger equation (top), closely matches that seen by combining many experimental runs (bottom). The hexagonal grid in the experimental results reflects the optical lattice (array of traps) from which the atom was initially released. In each run, after a period of time, the lattice was switched back on, and the atom was detected in one of the traps.
Credit: J. Verstraten *et al.* [**1**]

Systems composed of many quantum particles, such as certain types of electronic or magnetic states of matter, can be investigated by simulating them using atoms distributed within arrays of optical traps, like eggs in a vast egg carton. One method for studying such atom arrays, called quantum gas microscopy, involves probing the positions and the quantum states of the atoms by using laser beams to make them fluoresce [**2**]. Joris Verstraten at the École Normale Supérieure in France and his colleagues have adapted the technique to observe collections of atoms allowed to move in free space, unconstrained by traps.

A localized quantum particle, such as a trapped atom, can be represented in space by a wave packet, a wave function whose amplitude is maximized at the particle's most probable location. If the spatial constraints on such a wave packet are released, the wave function will expand in space rather like an ink droplet diffusing through tissue paper. Verstraten and colleagues have now used such wave-packet spreading as a proof-of-principle case for their free-space imaging technique.

To observe this spreading, the researchers first dispersed lithium atoms within an optical array inside their quantum gas microscope. They trapped a few tens of atoms in the array, which included several thousand wells, ensuring that each occupied well held only a single atom. The team then used a laser-cooling method to ensure that the atoms were in their lowest-energy state. Next, the researchers turned off the beams that formed the optical lattice, while maintaining a sheet of light that confined the atoms to the same plane. The wave packet of each atom could now spread in this plane.

At a later time, Verstraten and colleagues turned the trapping lattice back on, which localized the wave function of each atom within a specific trapping site. Reliably performing this



Lattice gas. Lithium atoms held in a 2D optical lattice are revealed by their fluorescent emission. The size of each bright spot (top inset) is much greater than the physical size of the atom. In each run, a few tens of atoms are scattered across around 6000 trapping sites. The lattice spacing is 709 nm (white dots in the lower inset). **Credit: J. Verstraten *et al.*** [**1**]

"projection" from continuous space onto the lattice for imaging was one of the key experimental challenges. The researchers were able to project more than 99% of the atoms into the nearest lattice site.

Where an atom ends up in this projection is not predictable but depends on the probabilities defined by the wave function; the more it spreads before retrapping, the further from the starting position any given atom might be found. To follow the spreading process, the researchers needed to match the atoms in the second image with those in the first, which they did using a probabilistic technique that can find the most likely set of assignments for all the atoms.

Each run generated many simultaneous snapshots of the expansion of the identical wave packets of all the atoms in the array. The overall behavior of a single-atom wave packet could then be constructed by combining many such runs. The observed rate of spread closely matched that predicted by the Schrödinger equation.

Verstraten says the experiments show that the technique successfully extends quantum gas microscopy to the case of quantum systems evolving in free space. That ability, he says, will permit the study of new quantum phenomena that involve many interacting particles. In work that will be published in *Physical Review Letters* [**3**], the team has already used the new method to investigate the dynamics of a 2D Fermi gas in which the particles can behave in a collective manner. Verstraten says the team's current research involves strongly interacting particles—a situation hard to investigate theoretically.

Selim Jochim, a specialist in atom optics at Heidelberg University in Germany, is impressed with the new work. "It's really beautiful, and they do it in a very accurate and precise way," he says. Jochim says that the ability to freeze the atoms in their new locations when turning the traps back on, so as to give high-resolution snapshots of their movement, is "an enormous technical advance."

Philip Ball is a freelance science writer in London. His latest book is ***How Life Works*** (Picador, 2024).

REFERENCES

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