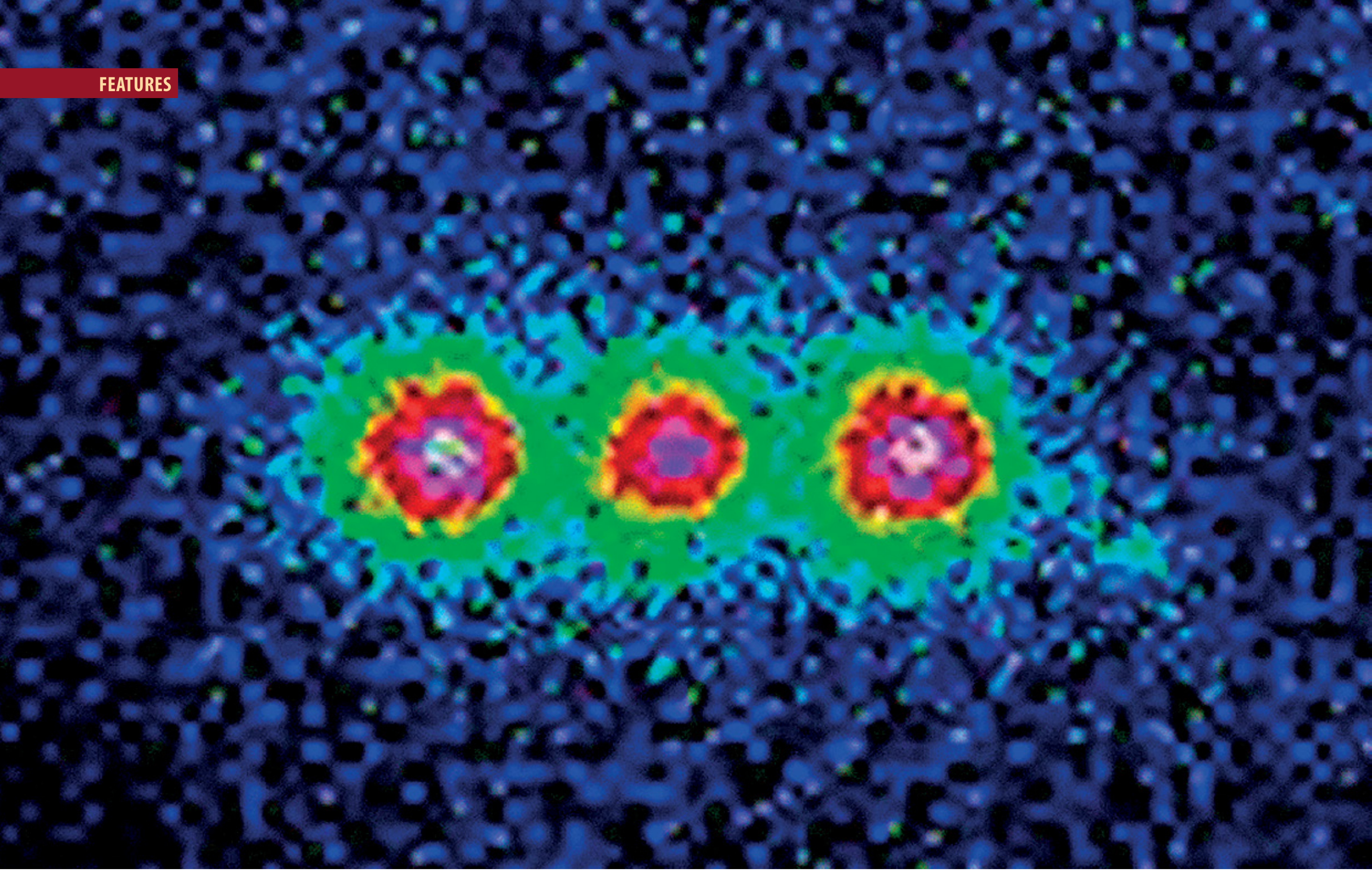

Nobel 2012:
Trapped ions and photons

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▲This colorized image shows the fluorescence from three trapped beryllium ions illuminated with an ultraviolet laser beam. Black and blue areas indicate lower intensity, and red and white higher intensity. NIST physicists used three beryllium ions to demonstrate a crucial step in a procedure that could enable future quantum computers to break today's most commonly used encryption codes. Image courtesy: National Institute of Standards and Technology

The 2012 Nobel prize in physics has been awarded jointly to Serge Haroche (Collège de France and Ecole Normale Supérieure) and David Wineland (National Institute for Standards and Technology, USA) *"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"*.

What are these methods, why are they jointly recognized?

The key endeavour in the last century of quantum physics has been the exploration of the coupling between matter and electromagnetic radiation. For a long time, the available experimental techniques were limited to a large number of atoms and a very large number of photons. It was only in thought experiments that one envisioned the manipulation of well-controlled individual quantum systems, dreamed of experimenting with a single atom or a single photon. For instance, Einstein and Bohr once imagined weighing a photon trapped forever in a box, covered by perfect mirrors. These gedankenexperiments and their "ridiculous consequences", as Schrödinger once stated, played a considerable role in the genesis of quantum physics interpretation. The technical progress made these experiments possible. One can now realize some of the founding fathers' thought experiments. D. Wineland's ion traps and S. Haroche's Cavity Quantum Electrodynamics (CQED) have pioneered this domain, which is now thriving worldwide.

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Wineland and his team at NIST trap ions in a Paul trap, in which a linear string of a few ions can be kept for weeks in electric fields. The collective ion motion in the trap is laser-cooled down to its quantum ground state. The ions internal states are manipulated by resonant laser beams and read out, 'seen' with a unit efficiency by laser-induced fluorescence. Finally, these internal states can be coupled, also via laser beams, to the joint quantum motion of the string in the trap, which acts as a 'quantum bus' interfacing the ions. Very complex manipulations of weird entangled quantum states have been realized.

Haroche and colleagues (including JMR and MB) work on a radically different system at Laboratoire Kastler Brossel (ENS, CNRS, UMPC, Collège de France). Instead of trapping matter particles, he traps individual microwave photons. This is even more challenging than trapping matter. Photons roam the Universe forever, but it is difficult to hold them for a long time in a modern equivalent of Einstein's "photon box". Haroche uses superconducting microwave cavities. Their long development led from a few μs storage time in the 90s to cavities that can now hold a photon for 0.13 s, a time interval in the macroscopic range. While stored in the cavity, the field is repeatedly probed by sensitive atoms (circular Rydberg atoms) crossing the cavity one at a time. These atoms carry away information on the field quantum state. They can be used to count photons in a Quantum Non Demolition way (to 'see' a photon without destroying it), or to create and probe weird quantum states of the field.

There is a beautiful duality between Wineland's and Haroche's experiments. In the former, trapped quantum matter is probed by light. In the latter, trapped quantum light is probed by matter. Both have the same goal: testing the most intimate features of quantum mechanics. Both have reached, sometimes simultaneously, similar achievements. For instance, both prepared in 1996 mesoscopic quantum superpositions. For the ion, it is a motional state in which the ion moves in two directions at the same time. For the field, it is a superposition of two semi-classical coherent states with opposite phases. These superpositions are quite reminiscent of the Schrödinger cat, discussed in another famous thought experiment. Studying how these superpositions are rapidly transformed into a statistical mixture by decoherence sheds light on the transition between the quantum and classical worlds.

What are the applications of Haroche's and Wineland's achievements? This is naturally a quite frequent question from the media. It is to some extent irrelevant. Both experiments are exploring the most fundamental quantum features. This understanding of the quantum world is utterly important, even if practical applications do not follow on a short time scale. All applications of the quantum so far (lasers, transistors...) were developed long after the corresponding conceptual tools. The most fascinating outcome on the long term might be quantum information processing, but the road to a quantum computer is still a long one. In the way, the exquisite control achieved in ions experiments, for instance, led already to the most precise atomic clock ever.

These achievements, recognized by the Nobel Prize, did not appear out of the blue. They rely on a long-term development led by teams of experienced researchers working in close connection for extended periods. Wineland created his atomic-clock team at NIST 37 years ago, after his post-doc with Hans Dehmelt. Haroche started his work on Rydberg atoms at ENS in 1973 after his PhD work on the dressed atom approach supervised by one of us (CCT), and a post-doc with A. Schawlow. This fundamental research develops thus on a long time scale of tens of years, much longer than the duration of ordinary grants and funding plans. It requires a lot of efforts for teaching to generations of students the basic concepts of quantum physics. It is also clear that nothing would have been possible without the regular funding and support from institutions recognizing the importance of fundamental, curiosity-driven research.

In Haroche's case, the stimulating atmosphere created by the two founders of the laboratory, Alfred Kastler and Jean Brossel, was also an essential element. It allowed this laboratory to be awarded by three Nobel Prizes, in 1966 for Alfred Kastler, in 1997 for one of us (CCT) and, finally, in 2012 for Serge Haroche. ■

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