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H. Jeffrey Kimble (1949–2024)

By Eugene Polzik & Jun Ye

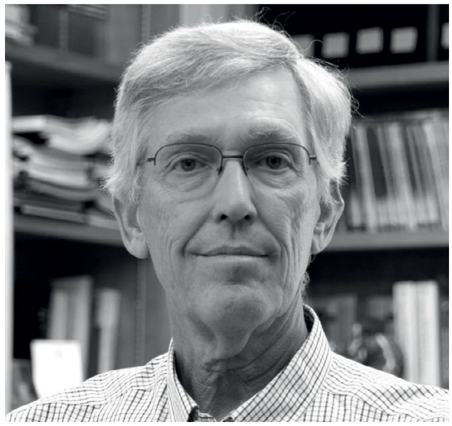
Champion experimentalist of quantum optics and squeezed-light pioneer has sadly passed away.

Harry Jeff Kimble, known as Jeff to his family, colleagues and friends, was a pioneer in quantum optics and quantum information science and a devoted husband, father, and grandfather. He passed away in Austin, Texas, on 2 September 2024, aged 75.

Jeff was born on April 23, 1949, in Floydada, Texas, to Joyce and John Kimble and was the second of four sons, alongside John, Jim, and Joel. Jeff earned his bachelor's degree from Abilene Christian University in Texas on a basketball scholarship and received his Ph.D. in physics from the University of Rochester in 1978. He was a professor at the University of Texas at Austin from 1979 to 1989 and joined Caltech faculty in Pasadena, California, in 1989. He was appointed the William L. Valentine Professor of Physics in 1997 and became a Professor Emeritus in 2021. He was also the inaugural director of Caltech's Institute for Quantum Information and Matter.

Jeff had an astonishing breadth of interest, insightful vision, and profound impact in the field of quantum optics. His research insights often helped define entire areas of research and pushed the boundary between classical and quantum systems. He established a practical approach for tackling the important subject of squeezed light and its application to interferometers. His work brought unifying clarity to fundamental questions concerning quantum noise and back-action in the general setting of quantum measurement. He has profoundly influenced the research directions of modern atomic physics and quantum optics, including the increasingly active fields of quantum information and quantum metrology. He has also inspired an extremely large number of scientists to explore fundamental physics and push the frontiers of measurement beyond their previously presumed limits.

Jeff's scientific footprints have been deep since the beginning of his career. His early work on photon antibunching, performed together with his advisor Leonard Mandel, laid an important foundation of photon statistics for quantum optics[1]. His pioneering contributions to research into squeezed states of light has turned into one of his long-standing scientific legacies. By the early 1980s, the field of quantum optics had already witnessed the generation of non-classical states of light, including photon antibunching and correlated photons for testing Bell's inequality. The theoretical physicist Carl Caves proposed the idea of injecting squeezed vacuum into the dark port of an interferometer, suggesting that it should be possible to reduce the optical power for a certain standard quantum limit (SQL) for the mirror displacement measurement. William Unruh and others proposed the idea of using correlated noise between the two quadratures of an optical field to actually beat the SQL.



Jeff Kimble was a distinguished pioneer of experimental quantum optics.

Jeff played a pioneering role in applying these important theory concepts to actual experimental implementations. In the mid 1980s he first introduced parametric down-conversion as an experimental platform to deliver squeezed light, and subsequently demonstrated its realization in collaboration with John Hall, who provided critical expertise on low-noise photodetection[2]. Early squeezing demonstrations, for example, based on atomic beams and optical fibres, were limited by fundamental fluctuations inherent to the nonlinear process that generated the squeezing, such as atomic spontaneous decay and/or inherent technical noise, such as spontaneous Brillouin and Raman scattering in fibres.

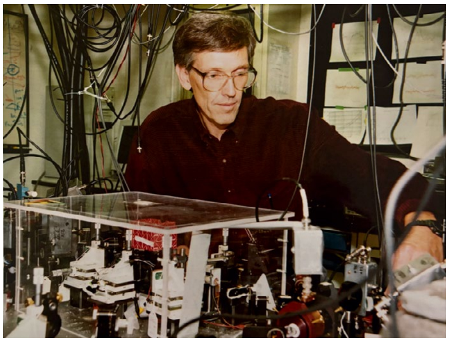
Advances in Jeff's experimental platform ultimately led to a practical squeezing that is beneficial for gravitational wave detection because the laboratory process of parametric down-conversion so closely implements the simple underlying theory by Carl Caves.

Jeff's group was also the first to demonstrate Caves' scheme for sensitivity enhancement with squeezing in an optical interferometer, laying the experimental foundation for quantum-enhanced metrology. Building on Unruh's insight of beating the SQL using correlation, Jeff, in collaboration with Kip Thorne, found a way to tailor the frequency spectra of squeezed light using a simple filter function from an optical cavity[3]. This has led to the modern demonstration of genuine quantum advantage in Advanced LIGO for more sensitive detection of gravitational waves.

Extending quantum measurement concepts to atomic spectroscopy, Jeff and his co-workers demonstrated the benefits of using correlated photon pairs. Jeff studied the Einstein–Podolsky–Rosen (EPR) paradox[4] and implemented quantum entanglement 'on demand'. In 1998, in collaboration with researchers from University of Aarhus and University of Bangor, Jeff's research group realized bona fide quantum teleportation of continuous variables using EPR photon pairs[5].

In later years, Jeff and co-workers achieved robust demonstrations of quantum entanglement between distantly separated atomic systems[6]. Armed with the capability of producing strongly correlated pairs of photon fields with his optical parametric oscillator, Jeff created quantum entanglement between large-scale atomic systems using the photon as the flying quantum messenger. This work brought the community to the entry point of a 'quantum network', a topic actively being pursued today.

Jeff is also renowned for his groundbreaking work in cavity quantum electrodynamics, or cavity QED, in which single atoms confined in cavities interact strongly with individual photons. A key challenge in quantum physics is to maintain quantum coherence despite the presence of dissipation. Jeff's work on achieving strong coupling in the quantum regime thus takes on central importance[7–9]. This is truly another one of Jeff's lasting legacies, since it laid the foundations for hardware



Jeff Kimble in the lab, circa 1993.

research into quantum networks and quantum computers.

Back in the 1980s, Jeff launched a new research effort to achieve strong coupling between individual photons and atoms. This capability permits transfer of the quantum states between light and matter with high fidelity, a key component for the quantum information processing infrastructure[10].

Jeff investigated ultra-high-finesse cavities of very small dimensions for increased coupling between a single atom and a cavity mode, and outstanding technical innovations resulted. He and his colleagues were the first to demonstrate the strong coupling regime in the optical domain in 1991, culminating in the observation of the 'vacuum-Rabi' splitting for a single atom in an optical cavity in 1992.

This opened the door for tremendous growth of quantum mechanical systems beyond the perturbative regime. A list of notable achievements along this line includes:

- Measurement of photon antibunching.
- Demonstration of a quantum phase gate in cavity QED for quantum logic.
- Nonlinear optics with single atoms and photons.
- Invention of the atom-cavity microscope, which traps and tracks an atom with single photons.
- Realization of a one-atom laser in a regime of strong coupling.
- Generation of single photons on demand from a single atom trapped in an optical cavity.
- Creation of measurement-induced entanglement for excitation stored in remote atomic ensembles, and the observation of photon-blockade in an optical cavity with a single trapped atom.

We note that these experimental developments pioneered by Jeff paralleled the historical achievements of other world-leading groups in the same field, most notably Serge Haroche of Paris and Herbert Walther of Garching, who studied cavity QED with microwave fields.

Jeff's scientific heritage is not limited to those remarkable achievements. Throughout the course of his academic career, he nurtured and helped to launch the successful research careers of nearly one hundred physicists. The impressive list of his former PhD students and postdoctoral fellows now features more than forty professors and group leaders at leading universities in North and South America, Europe, Japan, China, Australia, and New Zealand. Counting the second generation of Jeff's school – students and group members of those whom he mentored – easily results in many hundreds of researchers that bear the mark of Jeff's influence.

Jeff's impact on the scientific careers of the authors of this article has been profound. Building on their joint early work, Polzik continues to look for new ways to use entanglement to achieve measurement precision beyond the standard quantum limit and to develop quantum interfaces between disparate macroscopic objects. During his postdoctoral time in the late 1990s, Ye worked with Jeff to develop the idea of the so-called magic wavelength optical trapping to minimize the disturbance of the light shift on the atom's narrow transition[7]. This is the technique that has brought us today's best atomic clocks.

Always inspired by the idea of climbing another challenging scientific mountain, over the last decade of Jeff's scientific career he focused on migrating cavity QED into integrated photonics platforms. He developed innovative photonics structure to accommodate the loading of an array of atoms to achieve strong coupling. The work is now being carried out by a number of young researchers who worked with Jeff at Caltech before his retirement.

Jeff received numerous honours and awards throughout his academic career, including Doctor Scientiarum Honoris Causa from the University of Copenhagen and an Honorary Professorship from Nanjing University. He is a Member of the National Academy of Sciences (NAS), a Fellow of the American Association for the Advancement of Science, a Fellow of the American Physical Society (APS), and a Fellow of OPTICA. Some of his most notable prizes include the Einstein Prize for Laser Science, Albert A. Michelson Medal of the Franklin Institute, Max Born Award of OSA, Julius Lilienfeld Prize of APS, and the Herbert Walther Award jointly by OSA and German Physical Society. Jeff was recently honoured as the inaugural recipient of OPTICA's Leonard Mandel Quantum Optics Award for his groundbreaking work on the quantum interactions of light and matter and for establishing the core technologies based on squeezed light for quantum sensing and quantum communications. It was a bittersweet moment to celebrate this pair of intellectual giants who helped lay the foundation of modern quantum science.

Family was always Jeff's top priority. He is survived by his wife Margaret Smith-Kimble; his two daughters, Megan Kimble and Katherine Grooms; his son-in-law, Tyler Grooms; and his three granddaughters. To many of us, Jeff was a dear friend, a daring explorer, an intellectual inspiration, and a fun conversational partner. He was one of the most honourable men we have ever met. His dedication to science and to his collaborators, along with his ingenuity and perseverance, were unparalleled. His legacy and our memories of him will remain with us, his friends and colleagues.

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Competing interests

The authors declare no competing interests.