Physicists observe new phase in Bose-Einstein condensate of light particles

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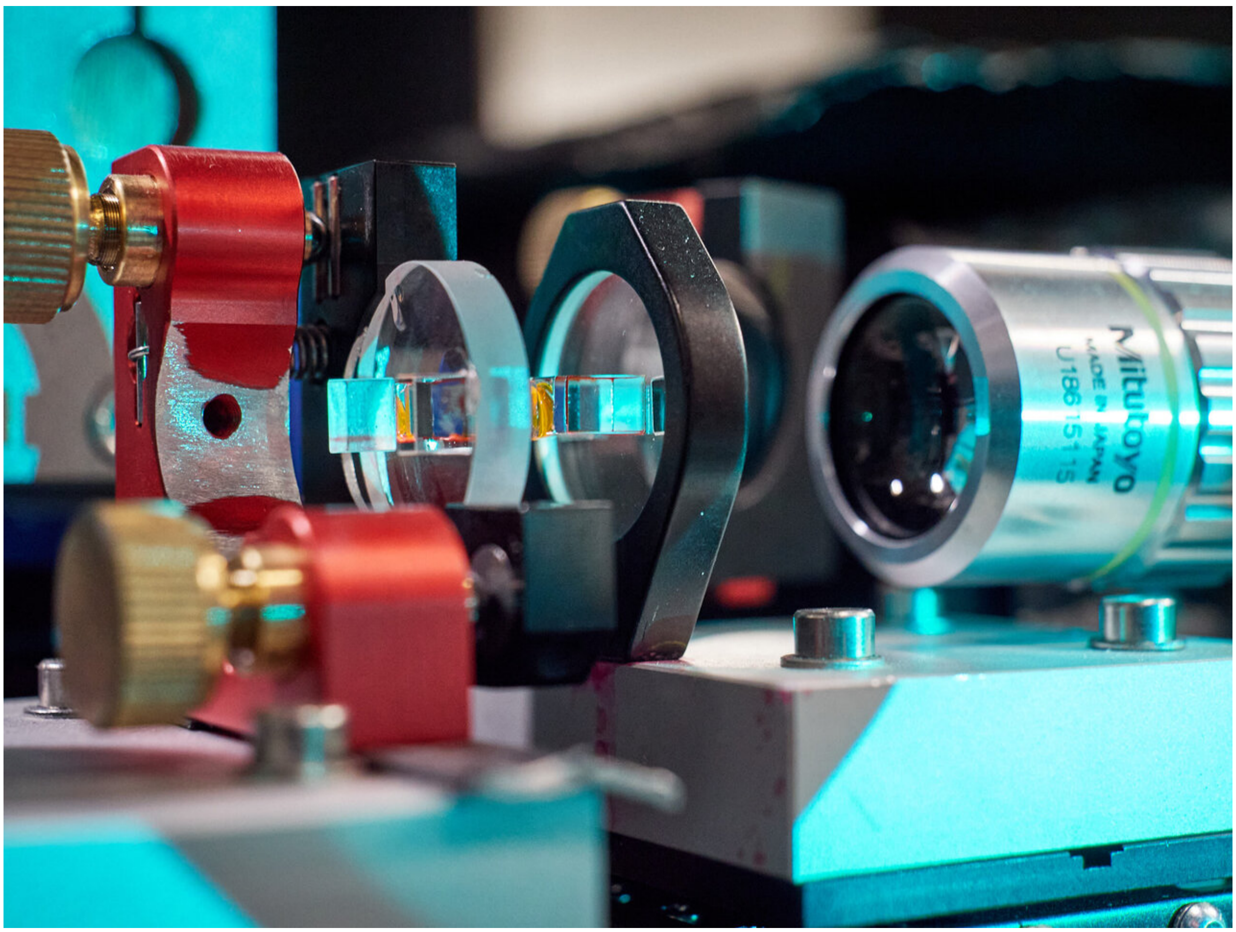
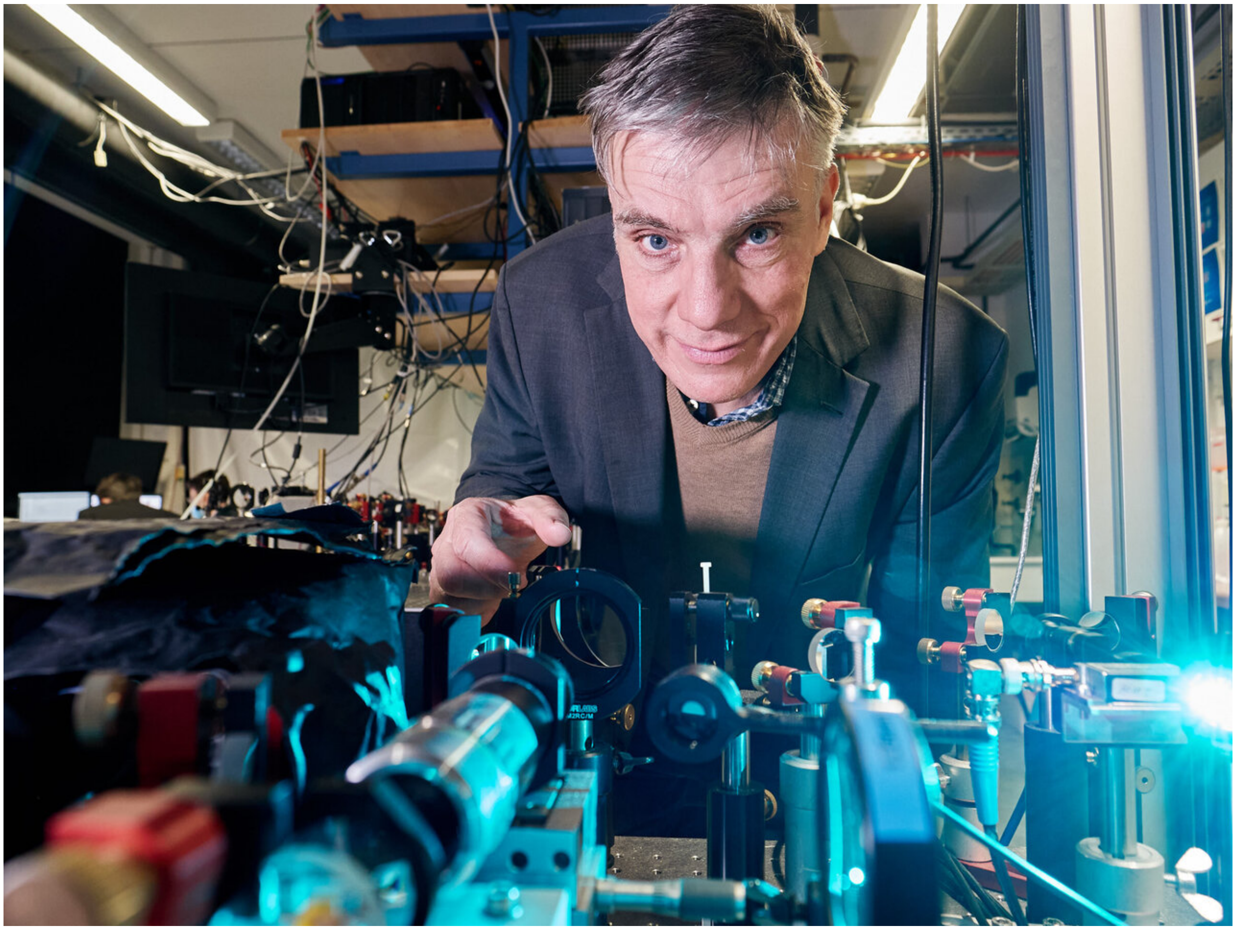


On the right is a microscope objective used to observe and analyze the light emerging from the resonator. Credit: © Gregor Hübl/Uni Bonn

About 10 years ago, researchers at the University of Bonn produced an extreme aggregate photon state, a single "super-photon" made up of many thousands of individual light particles, and presented a completely new light source. The state is called an optical Bose-Einstein condensate and has captivated many physicists ever since, because this exotic world of light particles is home to its very own physical phenomena. Researchers led by Prof. Dr. Martin Weitz, who discovered the super photon, and theoretical physicist Prof. Dr. Johann Kroha now report a new observation: a so-called overdamped phase, a previously unknown phase transition within the optical Bose-Einstein condensate. The study has been published in the journal *Science*.

The Bose-Einstein condensate is an extreme physical state that usually only occurs at very low temperatures. The particles in this system are no longer distinguishable and are predominantly in the same quantum mechanical state; in other words, they behave like a single giant "superparticle." The state can therefore be described by a single wave function.

In 2010, researchers led by Martin Weitz succeeded for the first time in creating a Bose-Einstein condensate from light particles (photons). Their special system is still in use today: Physicists trap light particles in a resonator made of two curved mirrors spaced just over a micrometer apart that reflect a rapidly reciprocating beam of light. The space is filled with a liquid dye solution, which serves to cool down the photons. The dye molecules "swallow" the photons and then spit them out again, which brings the light particles to the temperature of the dye solution—equivalent to room temperature. The system makes it possible to cool light particles because their natural characteristic is to dissolve when cooled.



Credit: Gregor Hübl/Uni Bonn

Clear separation of two phases

A phase transition is what physicists call the transition between water and ice during freezing. But how does the particular phase transition occur within the system of trapped light particles? The scientists explain it this way: The somewhat translucent mirrors cause photons to be lost and replaced, creating a non-equilibrium that results in the system not assuming a definite temperature and being set into oscillation. This creates a transition between this oscillating phase and a damped phase.

Damped means that the amplitude of the vibration decreases.

"The overdamped phase we observed corresponds to a new state of the light field, so to speak," says lead author Fahri Emre Öztürk, a doctoral student at the Institute for Applied Physics at the University of Bonn. The special characteristic is that the effect of the laser is usually not separated from that of Bose-Einstein condensate by a phase transition, and there is no sharply defined boundary between the two states. This means that physicists can continually move back and forth between effects.

"However, in our experiment, the overdamped state of the optical Bose-Einstein condensate is separated by a phase transition from both the oscillating state and a standard laser," says study leader Prof. Dr. Martin Weitz. "This shows that there is a Bose-Einstein condensate, which is really a different state than the standard laser. "In other words, we are dealing with two separate phases of the optical Bose-Einstein condensate," he says.

The researchers plan to use their findings as a basis for further studies to search for new states of the light field in multiple coupled light condensates, which can also occur in the system. "If suitable quantum mechanically entangled states occur in coupled light condensates, this may be interesting for transmitting quantum-encrypted messages between multiple participants," says Fahri Emre Öztürk.

More information: "Observation of a non-Hermitian phase transition in an optical quantum gas" *Science* (2021). science.sciencemag.org/cgi/doi … 1126/science.abe9869

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