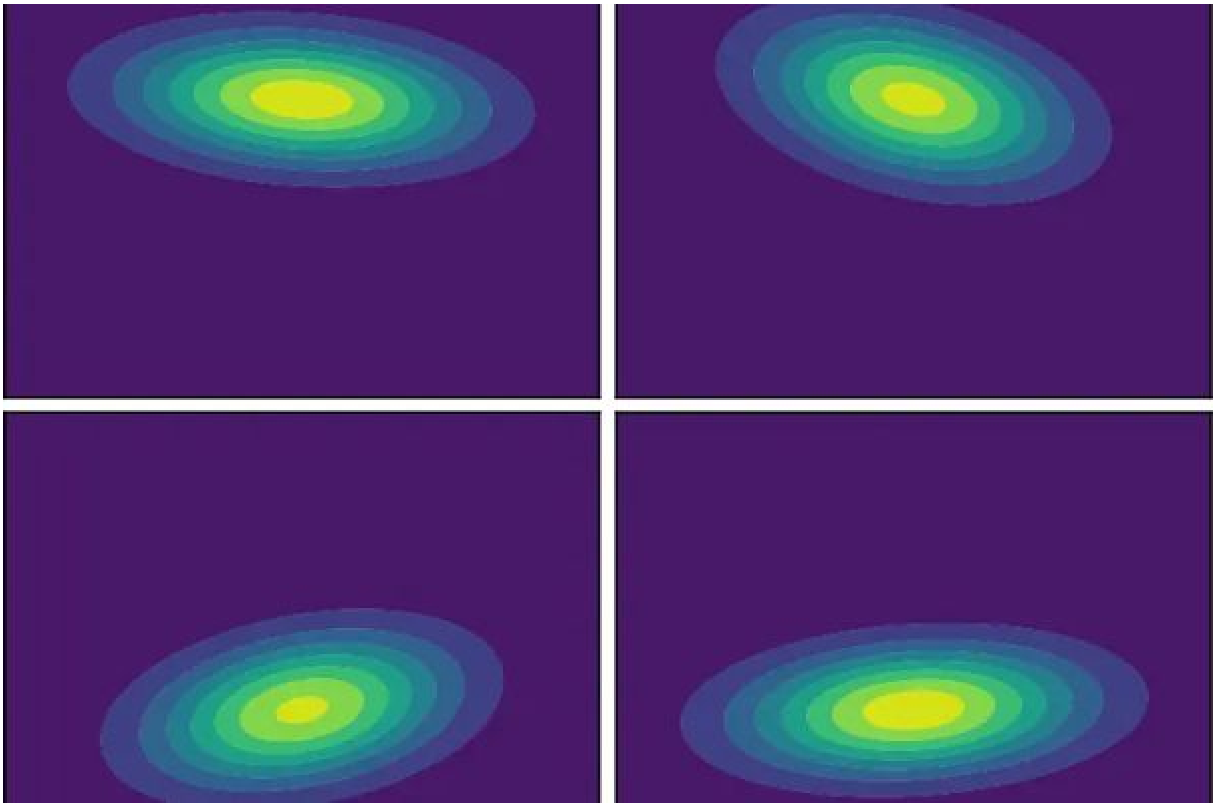

Researchers theoretically unveil high harmonic generation as a new source of squeezed quantum light

A team of researchers theoretically prove that the emitted light after a high harmonic generation (HHG) process is not classical, but quantum and squeezed. The study unveils the potential of HHG as a new source of bright entangled and squeezed light, two inherent quantum features with several cutting-edge applications within quantum technologies.

April 09, 2024

High harmonic generation is a highly non-linear phenomenon where a system (for example, an atom) absorbs many photons of an incoming laser and emits a single photon of much higher energy.

This process is crucial for attoscience (the science of the ultrafast processes), since it generates attosecond pulses of ultraviolet light, an essential ingredient for many applications within the field. In this regime, HHG experiments can be explained by means of semi-classical theory with great success: matter (the electrons of the atoms) is treated quantum-mechanically, while the incoming light is treated classically. According to this approach, unsurprisingly the emitted light turns out to be classical, something which was in agreement with all previous observations.?

However, physicists tend to feel uncomfortable when using two different theories (quantu and classical) to describe the same phenomenon. During the last years, the efforts t understand HHG from a full quantum optical perspective have kept growing, but a mor general description to show different aspects of the quantum nature of the outgoin radiation remained an elusive milestone

Now, ICFO researchers **Philipp Stammer**, **Javier Rivera**, **Dr. Javier Argüello** led by **Prof. ICREA Maciej Lewenstein**, together with researchers from other institutions (the Aarhus University, University of Crete, ELI-ALPS, Guadong Technion-Israel Institute of Technology) have theoretically described high-harmonic generation using just quantum physics and, for the first time, they have found squeezing and entanglement features simultaneously in the emitted light. The study, published in Physical Review Letter, explains why previous classical descriptions were not in disagreement with the observations and, at the same time, unveils a new method to generate quantum optical resources with **squeezing** and **massive entanglement** in a new bright frequency regime, two features of current technological interest.

A new method to generate entanglement and squeezing in light

Entanglement is at the core of quantum physics, one of its defining features. Roughly speaking, when two particles are entangled, measuring one of them influences the results that will be obtained after measuring the other. Counter-intuitively, this still holds when these particles are arbitrarily separated, which causes the so-called ï¿½non-local correlationsï?½. Nowadays, entanglement is not seen as a mere curious phenomenon. Instead, there is g eat consensus about its key role within quantum technologies. That is why the qua tum community is seeking ways to generate entanglement, not just between two particles, but also between a higher amount of them (ï¿½multipartite entanglemen ï¿½). Another defining quantum feature is the unavoidable noise when one measu es some specific pairs of properties of a physical system (for example, the position and the momentum). For quasi-classical states, also called ï¿½coherent statesï¿½, t e amount of uncertainty is equal for both quantities and its product is minimal. However, with **squeezed states** one can decrease the noise of one property (for instance, the position) at the expense of increasing the other one (the momentum), while its product is still kept at its lowest value. This feature, which is a direct manifestation of the quantum nature of squeezed states, makes them desirable for several quantum technology applications.

Traditional theoretical quantum optical models of HHG described the modes of the resulting light beam (that is, the different frequencies at which the electromagnetic field oscillates) as coherent states without entanglement, independent from each other. In this context, the recently published paper has brought two valuable insights.

In the first place, it points out that previous studies neglected the states the electron can occupy during HHG process and that the final state of light was not showing any quantum features because of that. Even though this assumption was reasonable in most experiments, it was not providing the most general explanation of the phenomenon.

Secondly, researchers improved the whole calculation by explicitly taking into account the different states the electron can occupy. The resulting final state of light turned out to be quantum in the sense that the modes are squeezed, as opposed to coherent; and that they are no longer independent, but show multipartite entanglement instead. ICFO researchers indicate how this situation, although not standard for attosecond experiments, could be relatively easy to engineer in the laboratory.

All in all, the team has proved that, under specific -but feasible- experimental conditions, one can use HHG as a source of squeezed light with multipartite entanglement. The first author of the paper, Philipp Stammer, explains that ï¿½massive entangled states are important f
r optical quantum technologies, and open a new field of research, which is generating extre
e light fields with quantum propertiesï¿½. The applications could include qua
tum spectroscopy, non-linear optics or quantum metrology, where entanglement and squee
ing can provide an advantage over classical lasers. Now, an experimental realization of t
eir discovery is needed to be able to exploit this new source of quantum light in all its potential.