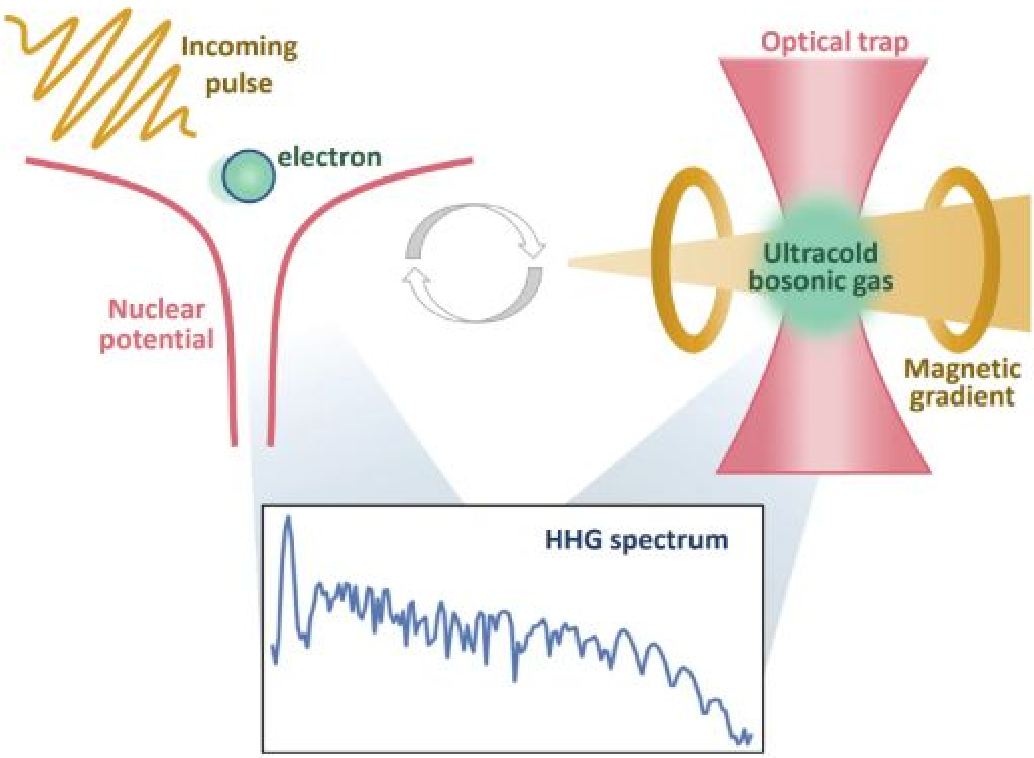

New analog simulators can facilitate the study of ultrafast dynamics processes

A team of researchers has theoretically proposed a new experimental platform based on analog simulation with atom clouds to study high-harmonic generation, an ultrafast dynamic process whose study challenges conventional computational methods. Their simulator can be adapted to approach a wide range of complex phenomena, opening the door to regimes that theory and direct experimentation are struggling to reach.

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Despite all the successes in understanding electron dynamics at their natural attosecond (one quintillion of a second) time scale, one of the fundamental processes core to this field, high-harmonic generation (HHG), raises new challenges for cold-atom simulation. It consists in a highly non-linear phenomenon where a system absorbs many photons of an incoming laser and emits a single photon of much higher energy.

The unique characteristics of HHG make it an exceptional source of extreme ultraviolet radiation and consequently of attosecond pulses of light, which has important applications to various fields such as nonlinear optics or attosecond science.

The main obstacle hindering the study of this process, apart from the ultrafast speed at which it occurs, is the high number of variables involved. In any given material, many atoms and electrons are present, so to study most of the occurring chemical processes in all its complexity would require not only to describe all these components, but also their interactions with external fields and even among themselves. This turns out to be an extremely challenging task for any current classical computer. An alternative route is to use quantum devices, building the so-called analog simulators, whose nature allow them to better capture the complexity of the system.

Now, **ICFO** researchers **Javier Argüello**, **Javier Rivera**, **Philipp Stammer** led by the **ICREA Prof. at ICFO Maciej Lewenstein** and in collaboration with other institutes all over the globe (Aarhus University, University of California and Guangdong Technion-Israel Institute of Technology) have proposed, in a Physical Review X Quantum publication, an analog simulator to access the emission spectrum of HHG using ultracold atomic clouds. Besides showing that an accurate replication of the key characteristics of the HHG processes in atoms was possible, they also provide details on how to implement it to specific atomic targets and discuss the main sources of errors.

The potential of analog simulation

An analog simulator allows scientists to study a complex quantum system (computationally challenging) through the control and manipulation of a much simpler one, which can be addressed experimentally. However, not every choice is valid, a connection between both systems must exist.

In this particular work, the complex phenomenon they chose in order to benchmark their idea was the high-harmonic generation. In there, the atomic bound electrons tunnel out the barrier formed by the atomic Coulomb potential and a laser electric field. Then, those free electrons are accelerated, causing the emission of radiation of characteristic harmonic frequencies upon recombination with their parent ions. This is the emission spectrum of the HHG that the researchers wanted to recover.

On the other hand, the connection to a much simpler quantum system was obtained by conveniently replacing certain components. Instead of an electron and a nuclear potential, they proposed to use an atomic gas that was trapped by a laser beam; and instead of the incoming light and its electric field, they suggested an external magnetic gradient that could be tuned at will. It turns out that the absorption images of this engineered system coincide with the desired emission yield.

Therefore, by taking absorption images of the analog simulator, the emission spectrum of the atomic high-harmonic generation can be indirectly studied.

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A new platform for ultrafast simulation

In the end, the research group has paved the way to prove the potential of their alternative method to address complex systems that otherwise could only be theoretically approximated. They showed that state-of-the-art analog simulators are able to retrieve the HHG emission spectrum, a correspondence between the experimental and simulated parameters could be established and even an exhaustive experimental analysis was provided. Moreover, the platform advantages are twofold. In the first place, the elements that emulate the incoming field and the nuclear potential can be easily tuned. And secondly, th simulation also provides a temporal magnification. This implies a high level of accessibility a the attosecond time-scale can be avoided, allowing the scientists to work in a much slowe (and thus practical) frame

The team highlights the adaptability power of their approach, which is not restricted t simulating HHG exclusively, but could be extended to other, more exotic configurations. I particular, the simulation of ultrafast processes, such as multielectronic dynamics or th reaction of matter to non-classical light, are the ones that could benefit the most

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