

# Measuring light and vacuum fluctuations from a time flow perspective

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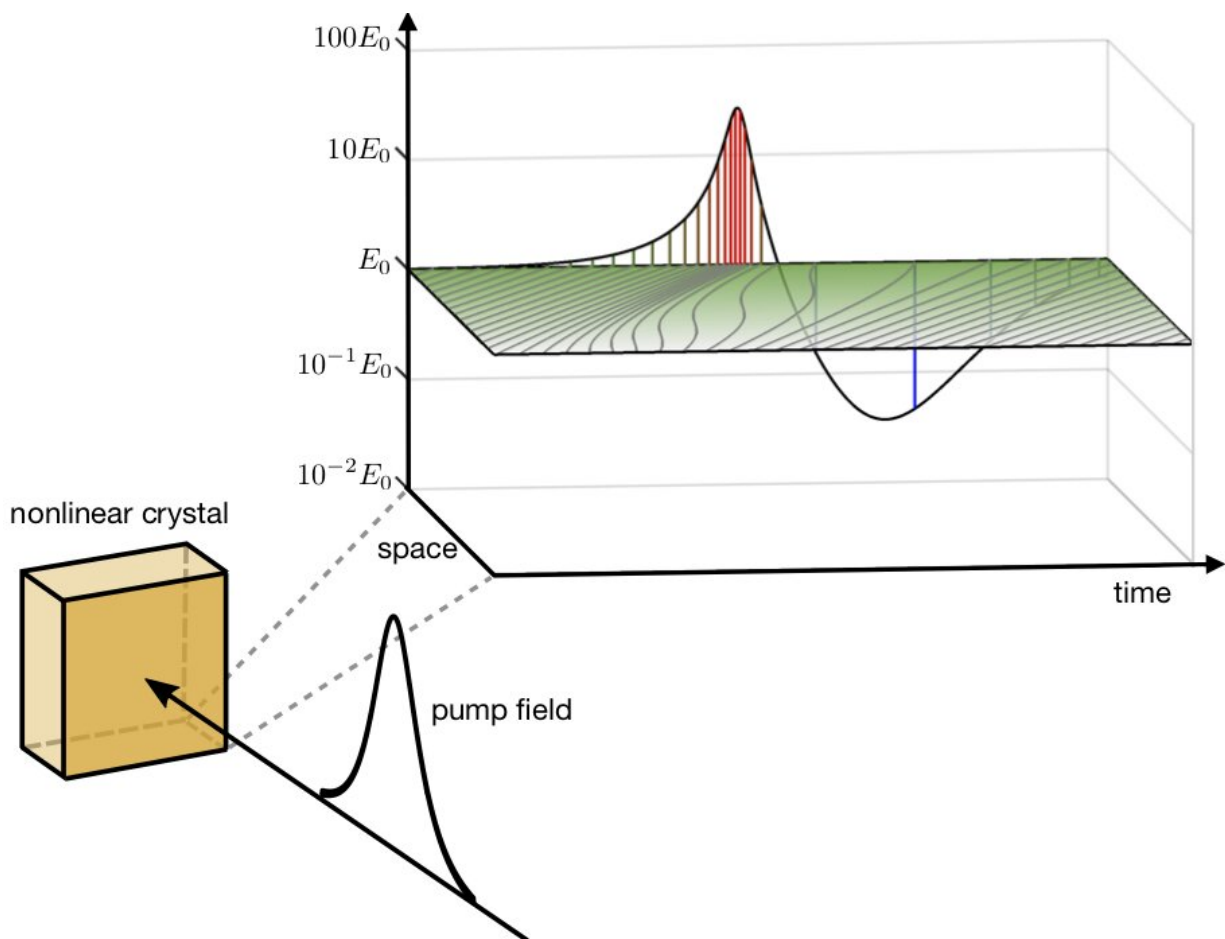


Image 1: Schematic sketch of the process that produces the 'squeezed' states. An ultrashort pump field is sent into a nonlinear crystal, 'squeezing' the vacuum. Different areas of the field are redistributed (accelerated or decelerated) within the crystal (see grey lines in the horizontal plane). Furthermore, the strength of field  $E_0$  (amplitude of vacuum fluctuations) is increased or decreased (z axis).

Credit: Kizmann et al.

Some of the greatest unanswered questions about the nature of the universe are related to light, the vacuum (i.e. space where neither matter nor radiation exists), and their relationship with time. In the past, physicists and philosophers have addressed a variety of complex questions, for instance, what is the nature of the vacuum, and how is the propagation of light connected to the passing of time?

Researchers at the University of Konstanz have recently carried out a study exploring the quantum states of light and [vacuum](#) fluctuations, as well as their interplay with time. Their paper, published in [Nature Physics](#), introduces a new theoretical framework to describe the quantum states of both light and vacuum on ultra-short timescales.

The researchers' study focuses on "squeezed light," which is essentially composed of light impulses with redistributed or 'squeezed' electromagnetic fluctuations. Kizmann and his colleagues were able to unveil the existence of a direct dependency between the electromagnetic fields of light or vacuum and time.

"Around 2015, our colleagues Professor Alfred Leitenstorfer and his group, also from the University of Konstanz, were [the first to demonstrate experimentally](#) that the vacuum fluctuations of light can be measured directly," Matthias Kizmann one of the researchers who carried out the study, told Phys.org. "Since then, we have been interested in developing a new theory to describe vacuum fluctuations taking place over very short durations. This led us to the question of whether vacuum fluctuations could also be manipulated on very short durations to generate so-called squeezed light."

In their paper, the researchers describe the interaction between a strong field called a "pump" field, and the electromagnetic vacuum inside a nonlinear crystal. As a result of this interaction, the field redistributes the vacuum fluctuations in time, resulting in time intervals in which these fluctuations are either enhanced or repressed. This process is known as squeezing.

"Usually, one has to calculate the entire electric field in order to describe the resulting effects, but now we found how to describe the squeezing as a change in the flow of time," Kizmann explained. "Squeezed states belong into a broader class of so-called nonclassical states of light. These kinds of states exhibit various fascinating and new characteristics as opposed to more classical laser light. As such, nonclassical states of light play an important role in the development of future technologies in the area of quantum information or quantum spectroscopy."

Kizmann and his colleagues have gathered interesting observations describing how light and vacuum are related to time. They developed a physical model that can be used to describe quantum states of the electromagnetic field for both light and vacuum on ultrashort timescales. Their paper also outlines how the electromagnetic field in a vacuum, known as vacuum fluctuations, can be manipulated.

Essentially, light consists of waves, or oscillating electric and magnetic fields. In the 19th century, people believed that in the dark, these fields are equal to zero. Quantum theory, however, states that a dark empty space is in fact not entirely empty, as it contains small fluctuations that prompt slight movements in the fields, known as vacuum fluctuations. These fluctuations are known to be redistributed from one variable to another (e.g. from electric to magnetic fields), which is the squeezing of the vacuum.

"We have studied how the [vacuum fluctuations](#) can be manipulated in

time and found that we can also redistribute fluctuations from one moment in time to another," Guido Burkard, lead researcher for the study, told Phys.org. "It turns out that the flow of time as seen from the light pulse can be modified in a nonlinear optical material, and this change in the flow of time is directly related to the change in fluctuations."

The observations gathered by Kizmann, Burkard and their colleagues bear some similarities to the relativity of time in relativity theory. In their paper, they draw an analogy between quantum mechanics and the theory of relativity, two areas in physics that past studies have often struggled to reconcile. Their observations and the analogy they presented could ultimately enhance our current understanding of the relationship between quantum physics and relativity. The researchers also believe that ultrashort pulses of squeezed quantum light could soon be demonstrated and observed in the lab.

"We think that states of quantum light of minute duration down to one femtosecond ( $10^{-15}$  seconds) will soon be realized and characterized experimentally," Andrey Moskalenko, another researcher involved in the study, told Phys.org. "Then they can be used as a new quantum tool in ultrafast spectroscopy, probing processes in matter on such short durations. This would give access to a presently hidden but very important plethora of ultrafast phenomena, which determine key properties of novel quantum devices."

The study offers fascinating new insights about the quantum states of light and vacuum, and their relationship with time. The theory they developed could ultimately facilitate the use of time-dependent quantum states of [light](#) in quantum optics and quantum information applications. In their future work, the researchers plan to explore this topic further, investigating the relationship between the slight movements that occur in a vacuum and a phenomenon called quantum entanglement.

"We are curious how these redistributions of quantum fluctuations are related to quantum entanglement, the phenomenon that fuels quantum computers and represents a resource for secure [quantum communication](#)," Burkard said. "We'd also like to know how measuring (i.e. 'looking at') the vacuum fields influences these fluctuations, and how squeezed states can be used for ultrafast spectroscopy."

**More information:** Matthias Kizmann et al. Subcycle squeezing of light from a time flow perspective, *Nature Physics* (2019). [DOI: 10.1038/s41567-019-0560-2](#)

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