Fluctuations in the void

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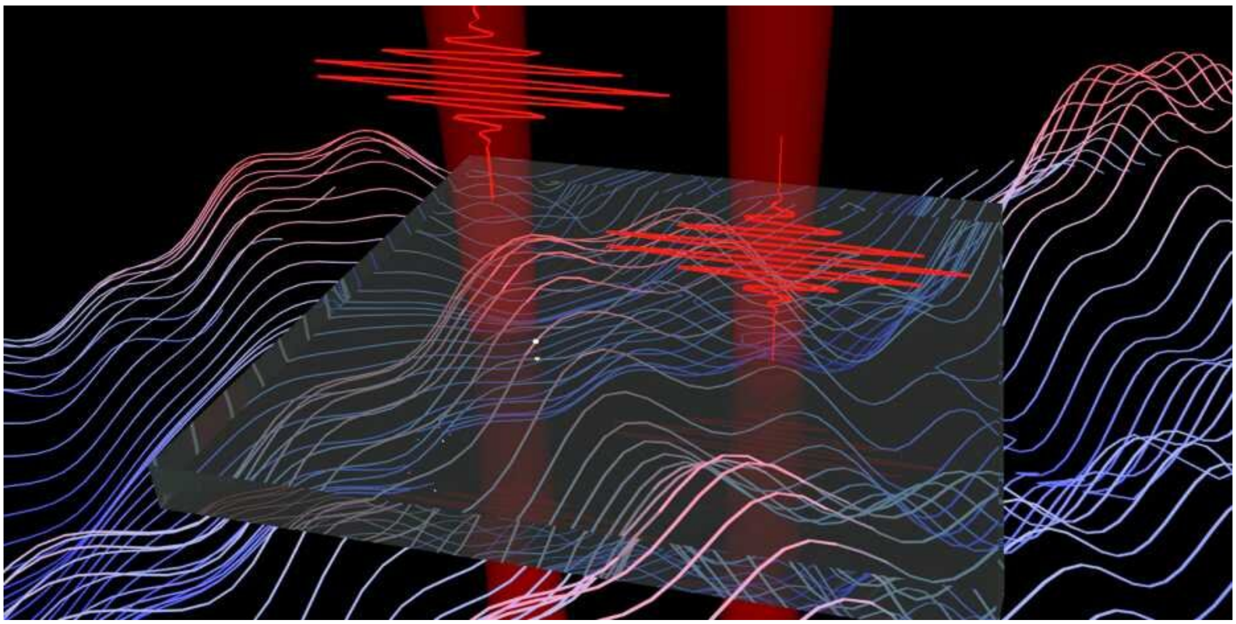

Vacuum fluctuations of the electromagnetic field (coloured lines) can be measured through their effect on two laser beams (red) that propagate through a crystal. Credit: ETH Zurich

In quantum physics, a vacuum is not empty, but rather steeped in tiny fluctuations of the electromagnetic field. Until recently it was impossible to study those vacuum fluctuations directly. Researchers at ETH Zurich have developed a method that allows them to characterize the fluctuations in detail.

Emptiness is not really empty – not according to the laws of quantum physics, at any rate. The vacuum, in which classically there is supposed to be "nothing," teems with so-called vacuum fluctuations according to quantum mechanics. Those are small excursions of an electromagnetic field, for instance, that average out to zero over time but can deviate from it for a brief moment. Jérôme Faist, professor at the Institute for Quantum Electronics at ETH in Zurich, and his collaborators have now succeeded in characterizing those vacuum fluctuations directly for the first time.

"The vacuum fluctuations of the electromagnetic field have clearly visible consequences, and among other things, are responsible for the fact that an atom can spontaneously emit light," explains Ileana-Cristina Benea-Chelmus, a recently graduated Ph.D. student in Faists laboratory and first author of the study recently published in the scientific journal *Nature*. "To measure them directly, however, seems impossible at first sight. Traditional detectors for light such as photodiodes are based on the principle that light particles – and hence energy – are absorbed by the detector. However, from the vacuum, which represents the lowest energy state of a physical system, no further energy can be extracted."

Electro-optic detection

Faist and his colleagues therefore decided to measure the electric field of the fluctuations directly. To that end, they used a detector based on the so-called electro-optic effect. The detector consists of a crystal in which the polarisation (the direction of oscillation, that is) of a light wave can be rotated by an electric field – for instance, by the electric field of the vacuum fluctuations. In this way, that electric field leaves a visible mark in the shape of a modified polarization direction of the light wave. Two very short laser pulses lasting for a fraction of a thousandth of a billionth of a second are sent through the crystal at two different points and at slightly different times, and afterward, their polarisations are measured. From those measurements, the spatial and temporal correlations between the instantaneous electric fields in the crystal can finally be calculated.

To verify that the electric fields thus measured actually arise from the vacuum fluctuations and not from the thermal black body radiation, the researchers cooled the entire measurement apparatus down to -269 degrees centigrade. At such low temperatures, essentially no photons of the thermal radiation remain inside the apparatus, so that whatever fluctuations of the electric field are left over must come from the vacuum. "Still, the measured signal is absolutely tiny," ETH-professor Faist admits, "and we really had to max out our experimental capabilities of measuring very small fields." According Faist, another challenge is that the frequencies of the electromagnetic fluctuations measured using the electro-optic detector lie in the terahertz range, that is, around a few thousand billion oscillations per second. In their experiment, the scientists at ETH still managed to measure quantum fields with a resolution that is below an oscillation cycle of light in both time and space.

Measuring exotic vacuum fluctuations

The researchers hope that in the future they will be able to measure even more exotic cases of vacuum fluctuations using their method. In the presence of strong interactions between photons and matter, which can be achieved, for instance, inside optical cavities, according to theoretical calculations the vacuum should be populated with a multitude of so-called virtual photons. The method developed by Faist and his collaborators should make it possible to test those theoretical predictions.

More information: Andrey S. Moskalenko et al. Correlations detected in a quantum vacuum, *Nature* (2019). DOI: 10.1038/d41586-019-01083-z

Ileana-Cristina Benea-Chelmus et al. Electric field correlation measurements on the electromagnetic vacuum state, *Nature* (2019). DOI: 10.1038/s41586-019-1083-9

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