Active cavity solitons: Ultra-stable, high-power optical pulses for measuring light waves

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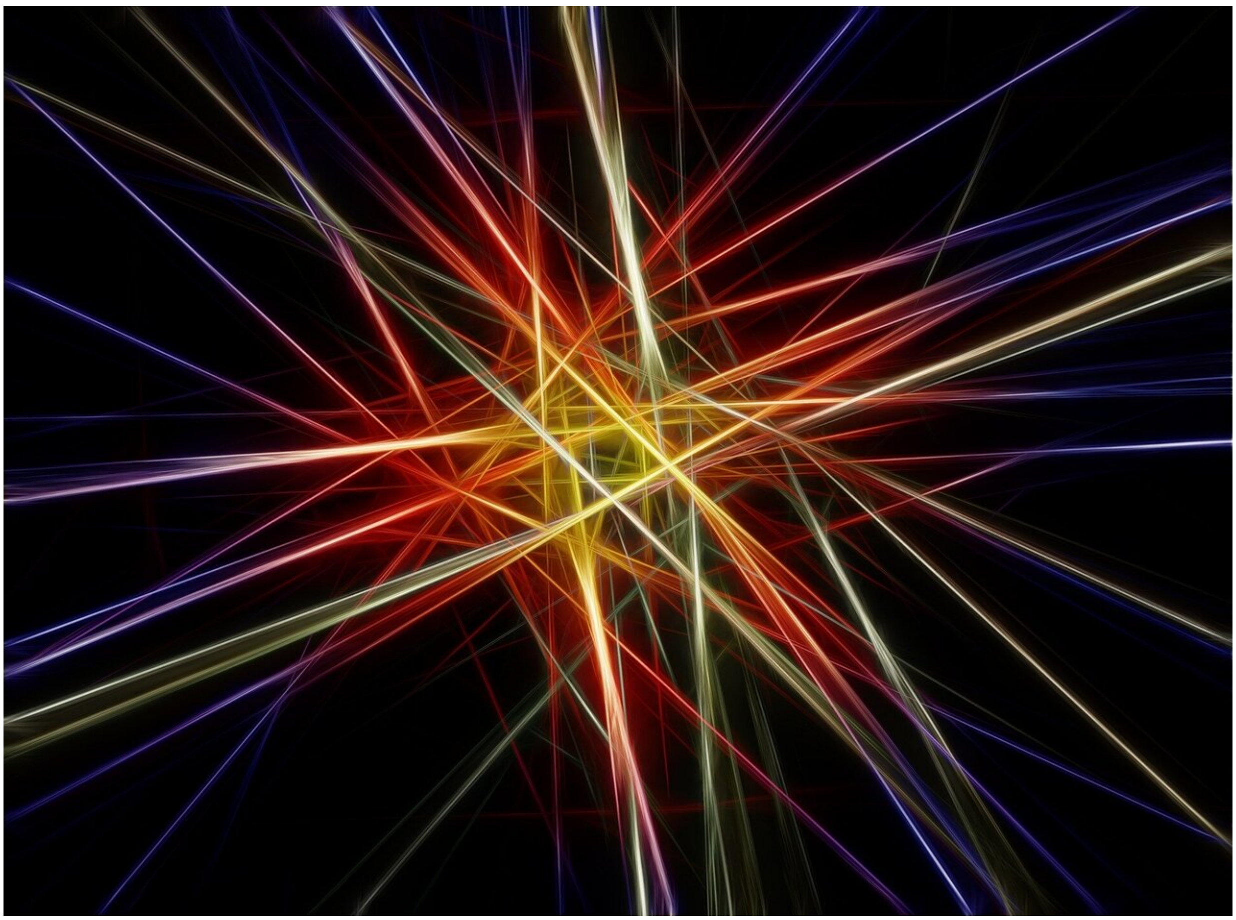

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Unlike the oscillations of sound waves, the oscillations of light are so fast that extremely complex equipment is needed to observe them directly. However, it is possible to measure the frequencies of these oscillations indirectly with frequency combs. These combs are made up of a set of regularly spaced 'teeth' where each tooth corresponds to a frequency. Used as a graduated ruler, they offer the possibility of measuring an optical frequency with great precision. This makes it possible, among other things, to measure variations in the distance between the Earth and the Moon with an accuracy equivalent to the size of a hair.

It can be shown that the time signal corresponding to a frequency comb consists of a regular succession of light pulses, called a pulse train. These pulses are ultra-short and have a duration of one millionth of a billionth of a second or less.

There are currently two main methods of generating a pulse train either via a pulsed laser or via a passive optical cavity.

"Some lasers can directly generate a pulse train. Some lasers can directly generate a very energetic pulse train but the delay between two successive pulses is subject to variations even in the absence of external disturbances," explains Nicolas Englebert—OPERA-Photonics Laboratory—Ecole polytechnique de Bruxelles.

The other solution is based on passive optical resonators, made, for example, using optical fibers. It allows the generation of a pulse that propagates indefinitely, a cavity soliton, when a continuous laser beam is injected at its input. The period of the resulting train, in the absence of any external disturbance, is fixed here, unlike with pulsed lasers. Unfortunately, its energy is limited.

Each platform therefore has its advantages and disadvantages. However, for certain applications, e.g., LiDAR, it is necessary to have a pulse train that is both energetic and ultra-stable.

Recent research carried out by the ULB OPERA-Photonics Laboratory, published in the journal *Nature Photonics*, shows the existence of new ultra-stable, high-power cavity solitons: active cavity solitons.

"These solitons emerge within a signal-injected resonator in which there is a finely designed amplification section. The purpose of this section is to compensate for some of the losses that the wave (the soliton) experiences at each roundtrip. If the amplification is too low compared to the losses, the soliton cannot exist. On the other hand, if the amplification is greater than the losses, a laser emission will occur. Thanks to this partial compensation of the losses, it is possible to extract a large part of the soliton's energy (more than 30%!) without compromising its existence," Nicolas Englebert points out.

Moreover, as the amplification section is chosen such that lasing does not occur, the pulse train inherits the stability properties of passive resonators. The active cavity soliton thus combines the advantages of pulse trains generated by pulsed lasers and passive resonators.

This new type of universal and hybrid soliton could trigger many experiments on different platforms, especially in the field of integrated optics where passive resonators dominate the landscape but applications lag behind because very little power can be extracted from the chips. This new concept is not limited to the generation of solitons. Thanks to this new hybrid cavity, components that induce a lot of losses (crystal, particular fiber, etc.) can now be placed in a resonator, opening the way to the study of phenomena that were previously inaccessible experimentally. The invention is the subject of a patent application filed in the name of ULB.

More information: Temporal solitons in a coherently driven active resonator, *Nature Photonics* (2021). DOI: 10.1038/s41566-021-00807-w

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