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A novel approach to frequency comb generation promises simplicity and precision

Researchers present a novel approach for the generation of frequency combs with excellent temporal and spectral properties, based on different nonlinear materials and laser pump sources. This advancement opens the door to the realization of compact, simplified and cost-effective frequency combs.

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Atoms, molecules and other species interact with light by emitting and absorbing specific frequencies, which together constitute their spectra. A spectral line is a brighter or darker band within an otherwise uniform and continuous spectrum. When a laser system exhibits a series of evenly spaced spectral lines, it is referred to as a frequency comb.

Frequency combs have become essential tools in numerous fields, including spectroscopy, frequency metrology, and optical communications. Despite the great success of frequency combs generated by traditional methods, they still face challenges in terms of complexity, cost, operational flexibility, and widespread accessibility. Developing high-quality frequency combs meeting such requirements would most likely have a significant impact across all such applications.

In a Physical Reviews Research article, **Dr. Alfredo Sanchez**, ICFO researcher, together with Dr. Chaitanya Kumar Suddapalli, from Tata Institute of Fundamental Research Hyderabad, led by **ICREA Prof. at ICFO Dr. Majid Ebrahim-Zadeh**, theoretically propose a novel approach for generating frequency combs with excellent temporal and spectral characteristics.

In particular, the simulated combs exhibit a broadband and phase-locked spectrum - meaning it covers a wide frequency range, and the phases of the waves corresponding to different frequency components remain fixed relative to one another. The phase-locking ensures the frequency lines stay evenly spaced and coherent over time. This is crucial for several applications that require high-resolution measurements and zero signal interference, such as metrology, spectroscopy or communication technologies.

Moreover, when the researchers analyze the evolution of the signals in time, they observe femtosecond quadratic solitons -extremely short (femtosecond-scale) waveforms that travel without changing their shape (solitons), following a specific quadratic mathematical relationship. Understanding and controlling these solitons enables the design of advanced optical devices for high-speed data transmission, precision measurement and information processing, among others.

The proposed approach consists in shining with a continuous-wave (cw) laser an optical parametric oscillator (OPO) -a nonlinear optical device that converts a single incoming photon into two lower-energy photons. But, according to ICREA Prof. Dr. Majid Ebrahim-Zadeh, ï¿½the key to the successful operation of this unique source is the control f group velocity dispersion, a new concept explored in cw OPOs for the first timeï¿½. G oup velocity dispersion makes different frequency components of a light pulse travel at diffe ent speeds through a medium. Without proper control, this dispersion can distort the out ut, undermining the coherence and stability of the generated frequency combs, and there ore degrading their quality. The technique proposed by the team is proved to be effectiv to counteract the effects of group velocity dispersion, and essential for the generation f a coherent, broadband and phase-locked spect

Overall, the study's results pave the way for a new class of high-performance frequency comb sources, potentially enabling more compact, simplified and cost-effective designs. This, in turn, could lower the barrier to entry for laboratories and industries looking to implement this kind of technology.

Reference:

A. D. Sanchez, S. Chaitanya Kumar, M. Ebrahim-Zadeh, Quadratic frequency comb based on phase-modulated cw-driven optical parametric oscillator with intracavity dispersion control, Phys. Rev. Research 7, 023110 (2025).

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Energy diagram of the process and the cavity modes without (left) and with (right) dispersion compensation. Source: Physical Review Research.