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Low-frequency excitations could soon be mapped with nanometer precision

ICFO researchers have proposed a technique that could, for the first time, detect low-frequency excitations in nonlinear materials while simultaneously mapping them in space with nanometer resolution. Through realistic examples, they demonstrate how far-infrared molecular fingerprints could be recovered at the nanometer scale. The theoretical framework, reported in Nature Communications, could be implemented using visible light and existing electron microscopes.

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Atoms never remain perfectly fixed, even inside solid materials. Instead, they vibrate around their equilibrium positions, giving rise to collective excitations known as phonons. These and other fundamental excitations are extremely hard to measure with nanoscale spatial resolution, mainly because their frequencies are too low for conventional optical techniques to resolve. Indeed, a method capable of accessing information in the far-infrared to terahertz regime with nanometer resolution does not yet exist.

Now, ICFO researchers, **Leila Prelat** and **Dr. Eduardo Dias**, led by **ICREA Prof. F. Javier Garcia de Abajo**, have theoretically proposed a new technique called **wave-mixing cathodoluminescence (WMCL) to map low-frequency** (far-infrared to terahertz) **excitations in nonlinear materials with nanometer resolution**. The approach, reported in Nature Communications, relies exclusively on **visible light**, eliminating the need for specialized low-frequency light sources and detectors.

The WMCL method begins by directing an electron beam onto the sample, where it gives rise to low-frequency excitations, such as phonon vibrations. At the same time, the specimen is illuminated with visible laser light. Because of the material's nonlinear optical response, the laser light and the low-frequency excitations interact rather than evolving independently, becoming mixed through a wave-mixing process. This interaction produces a tiny but detectable frequency shift in the scattered laser light, which nevertheless remains in the visible range.

? In this way, **the small frequency offset encodes the terahertz information, even though the detected light is still visible**. ï¿½In other words, nonlinear mixing allows invisib
e low-frequency excitations to imprint themselves onto visible photons,ï¿½ explains L

ila Prelat, first author of the article. Prof. Javier Garcia de Abajo, lead researcher of the st dy, adds: ï¿½This method opens a new low-frequency measurement channel in a field wh re no existing techniques can meet the required combination of spatial and spectral resolut on.ï¿½ The team has also shown how WMCL could be used to identify different chemical components within thin molecular layers deposited on nanostructures. In particu ar, they analyzed silver nanorods (elongated one-dimensional nanostructures) coat d with a molecular layer of retinal. An experimental realization is now needed to valid te these predictions and explore additional applications, including extending WM L beyond molecular vibrations to probe other types of low-frequency exc

Reference:

Prelat, L., Dias, E.J.C. & Garcia de Abajo, F.J. Wave-mixing cathodoluminescence microscopy of low-frequency excitations. Nat Commun **16**, 11551 (2025).
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