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Full Vibrational Spectroscopy for Simultaneous Mechanical, Structural and Chemical Analysis

Raman spectroscopy is widely used for label-free chemical and structural analysis, but conventional implementations access only part of the vibrational spectrum. Here, we introduce full-vibrational spectroscopy, an all-optical, non-destructive technique that combines Brillouin, ultra-low-frequency Raman (ULFR), and conventional Raman spectroscopy from 0.1 to $>3,500\text{ cm}^{-1}$ [1]. Enabled by integrating a birefringence-induced phase-delay filter [2] into a confocal microscope, mechanical, structural, and chemical information is retrieved from the same illumination voxel. We demonstrate its potential using solid-state active pharmaceutical ingredients (API), where distinguishing crystalline, amorphous, and formulation-dependent states is critical. The approach provides a multidimensional fingerprint. Extended to imaging (Fig. 1), full-vibrational mapping reveals microscale API and excipient distributions together with mechanical and structural heterogeneity, offering new opportunities for pharmaceutical analysis and multimodal materials characterization.

References

- [1] Behrouzitabar, Morteza, et al. *Nature Communications*, 17 (2026) 5632 “Full vibrational spectroscopy for simultaneous mechanical, structural and chemical analysis”
- [2] Antonacci, Giuseppe, et al., *Nature Communications* 15 (2024) 5202 “Birefringence-induced phase delay enables Brillouin mechanical imaging in turbid media.”

Figures

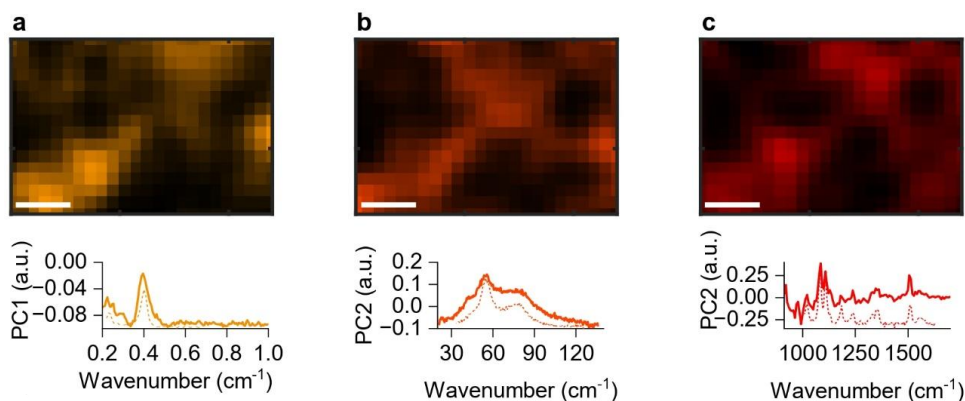


Figure 1: Full-vibrational spectral maps of an ibuprofen tablet. **a–c** Brillouin, ULFR, and Raman maps with loading plots associated with the relevant principal component (PC) show the mechanical, structural and chemical distribution of ibuprofen across the same field of view of a reference tablet. Scale bar corresponds to 100 μm .