



Ultrafast Electron Microscopy

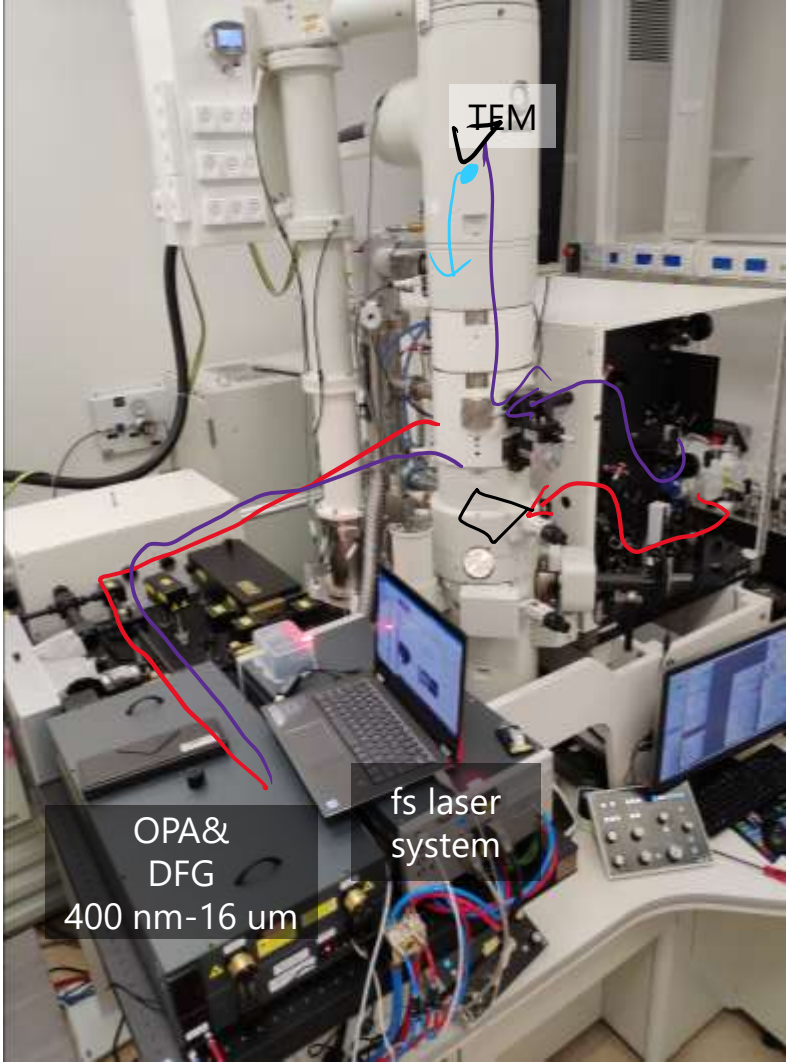
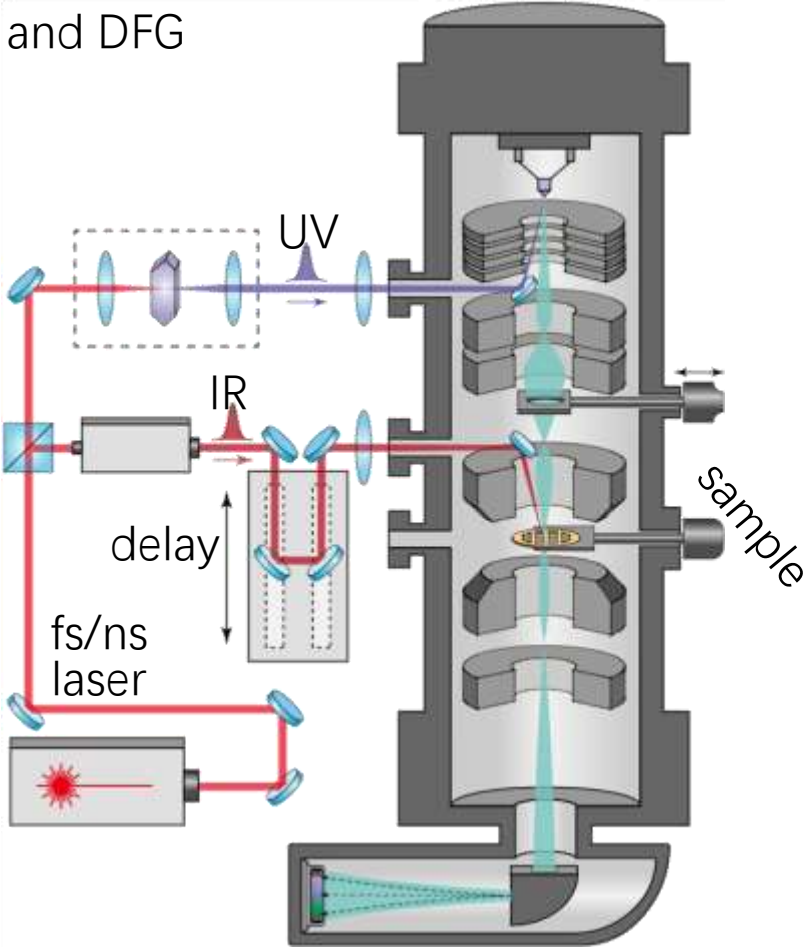
Yaniv Kurman Technion–Israel Institute of Technology
EPIC Online Technology Meeting March 11, 2021

The Ultrafast Electron Microscope

Ahmed Zewail and his colleagues



JEOL 2100 Plus Thermionic
 Light-Conversion Carbide fs laser
 (1030nm, 40W, 1MHz rep rate) OPA
 and DFG



Electron Microscope

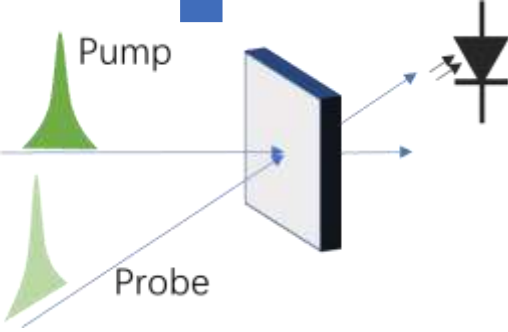
nanometer spatial resolution



10 meV energetic resolution

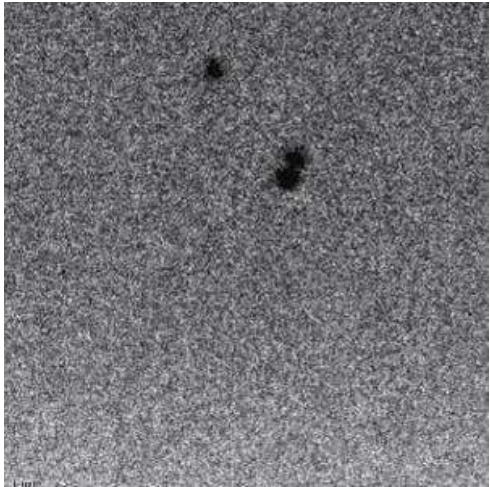


fs temporal resolution

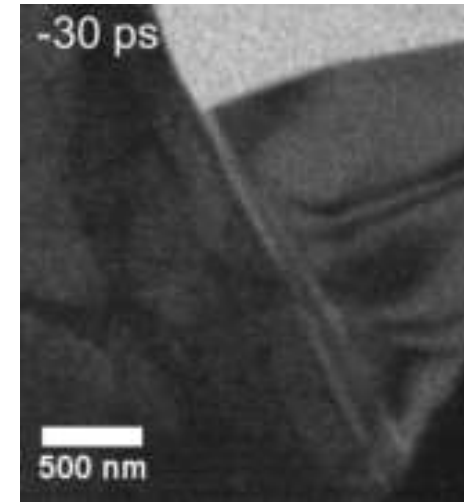
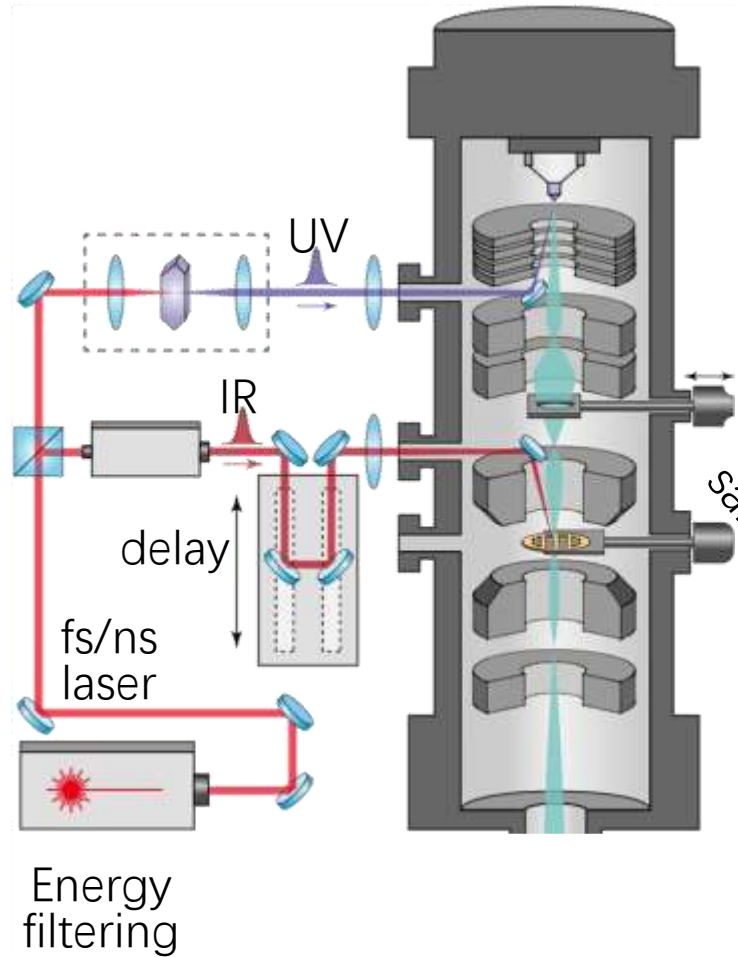
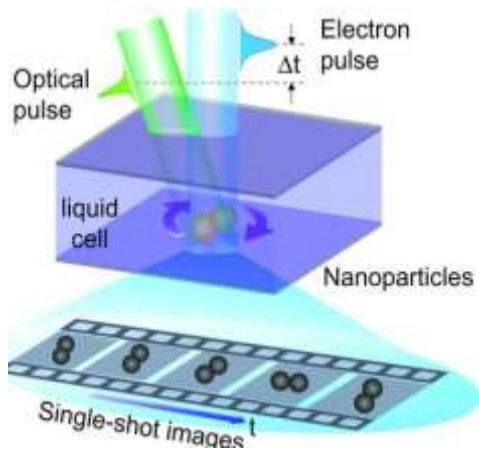


Perfect for imaging Dynamics – ps timescale + nm length scale

Imaging Rotation of nanoparticles in liquid

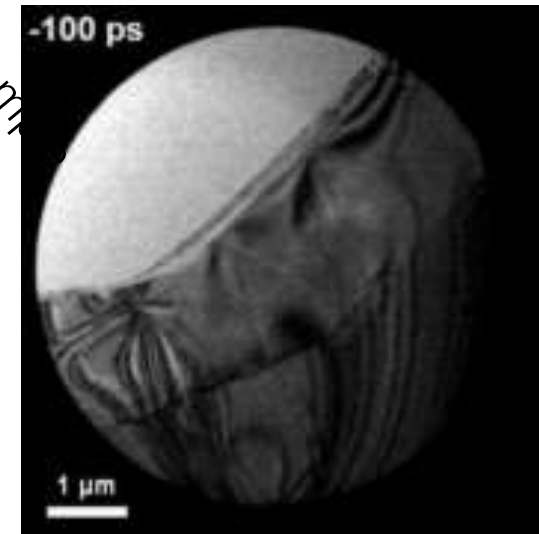


X. Fu, A. Zewail, **Science** 355, 494 (2017)



Phonons in TaS₂

D. Flannigan, Struct. Dyn. 2017, 4, 044019.



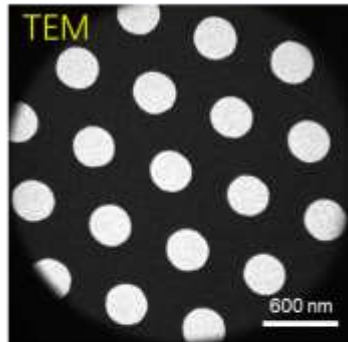
Phonons in WSe₂

D. Flannigan, Nature Commun. 2016, 7, 11230.

Energy-filtering: Imaging the dynamics of light!

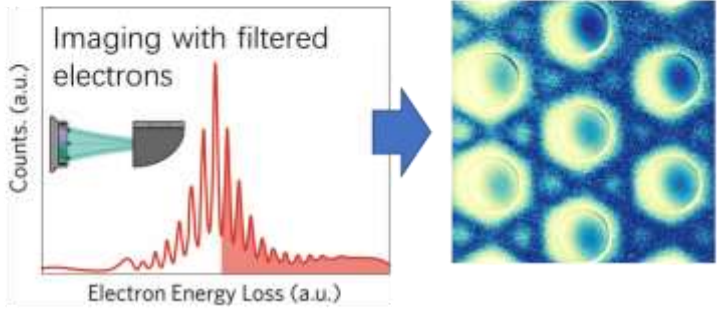
1

TEM Imaging with **all electrons**

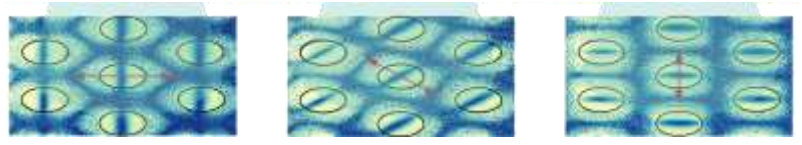


2

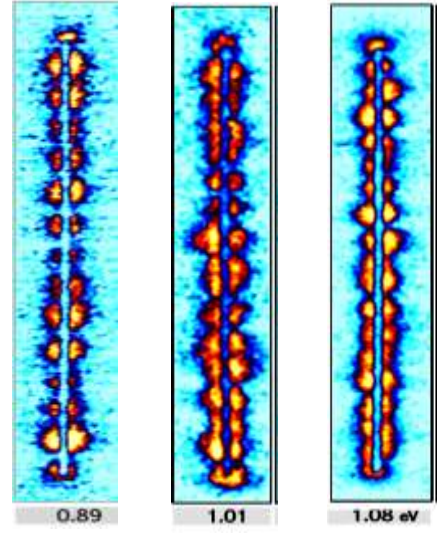
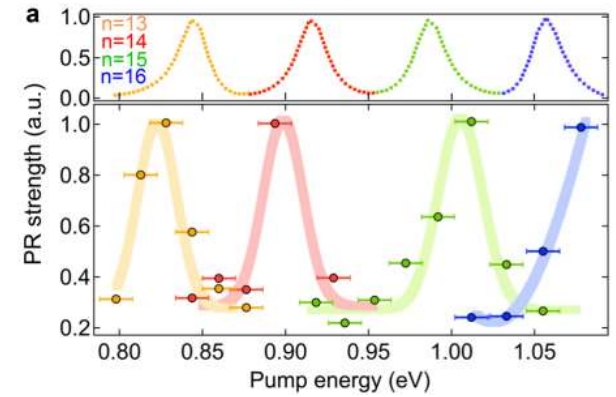
PINEM Imaging with **energy-filtered electrons**



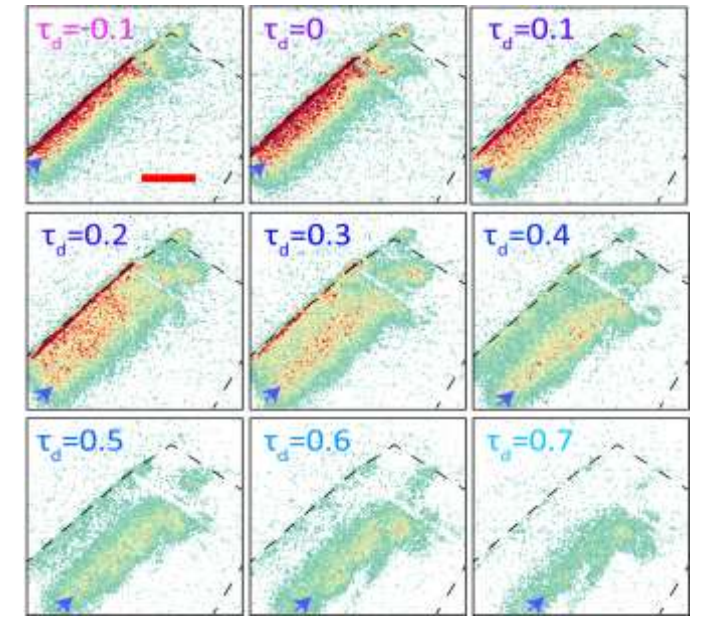
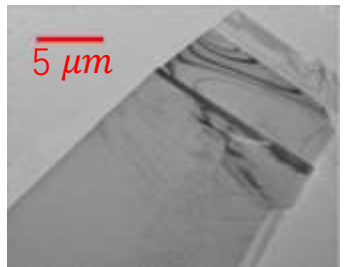
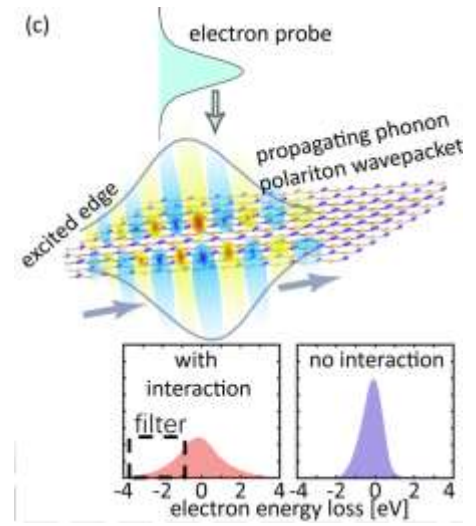
K Wang et al, **Nature** 582, 50 (2020)



meV spectroscopy

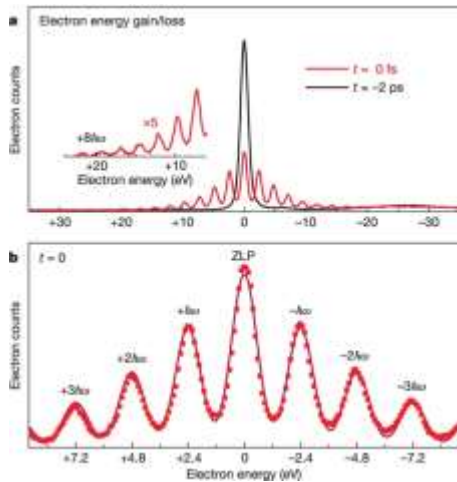


Carbone, **ACS Photonics** 5, 759 (2018)

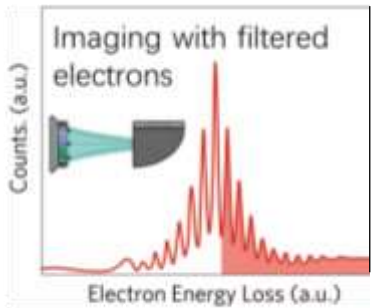


Yaniv Kurman, Technion, EPIC Online Technology Meeting

The quantum interactions



Barwick et al, **Nature**, 462, 902 (2009)



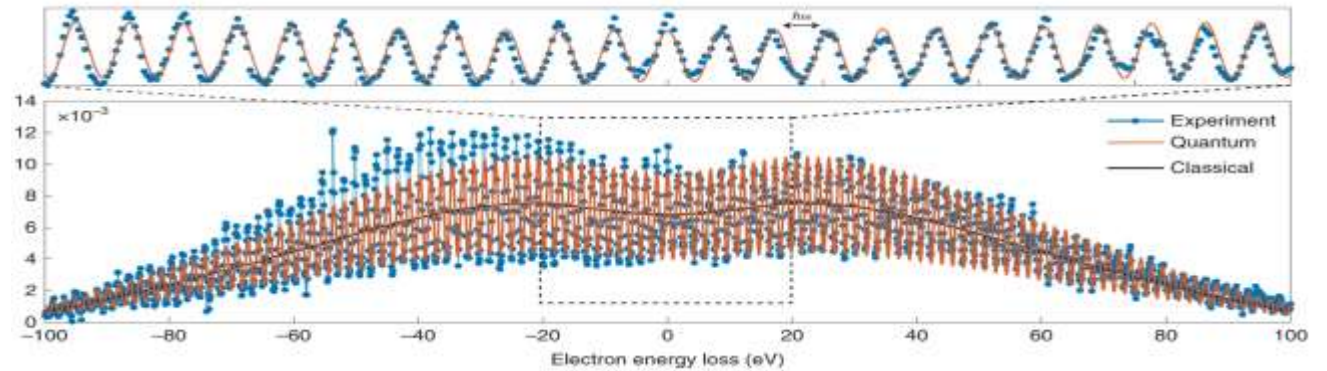
Park, Lin, and Zewail, **New Journal of Physics** 12, 123028 (2010)

García de Abajo, Asenjo-Garcia, and Kociak, **Nano Letters** 10, 1859 (2010)

Theory:

Yaniv Kurman, Technion, EPIC Online Technology Meeting

Free-electron energy comb



Dahan et al, **Nature physics** 16, 1123 (2020)



Molecular fingerprinting with bright, broadband infrared frequency combs

HENRY TIMMERS,^{1,*,†} ABHIR KOWLI,^{1,†} ALEX LIND,^{1,*,†} FLAVIO C. CRUZ,^{1,2} NIMA NADER,³ MYLES SILFIES,⁴ GABRIEL YCAS,³ THOMAS K. ALLISON,⁴ PETER G. SCHUNEMANN,⁵ SCOTT B. PAPP,^{1,6} AND SCOTT A. DIDDAMS^{1,6}

Massively parallel sensing of trace molecules and their isotopologues with broadband subharmonic mid-infrared frequency combs

A. V. Muraviev, V. O. Smolski, Z. E. Loparo & K. L. Vodopyanov

Nature Photonics 12, 209–214(2018) | Cite this article

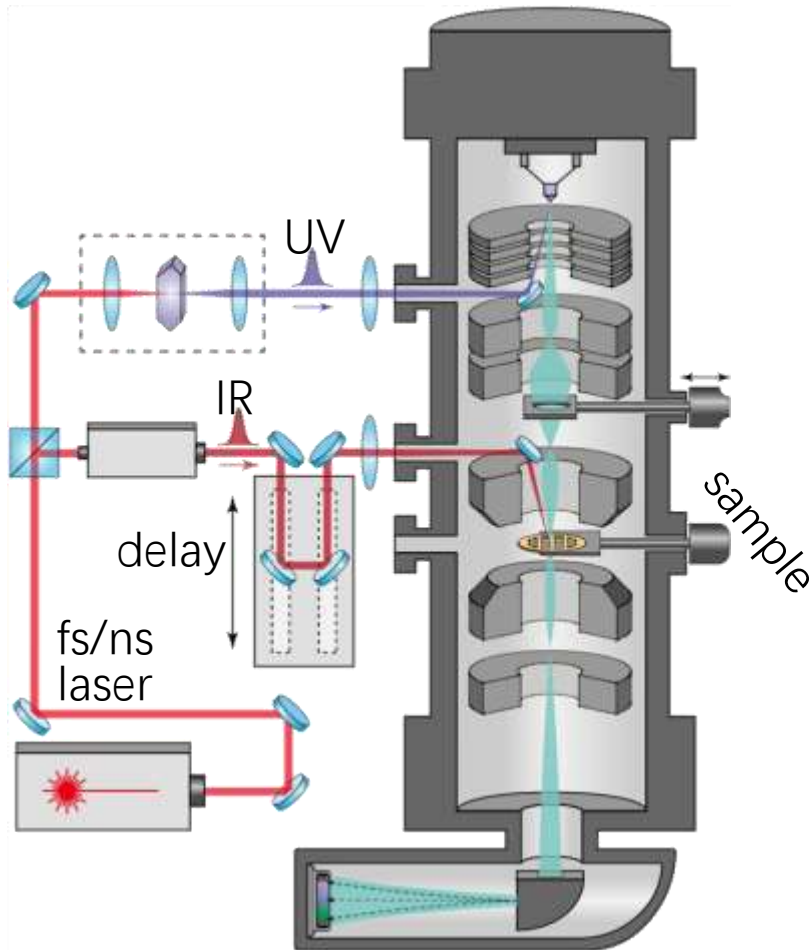
Photonic chip-based soliton frequency combs covering the biological imaging window

Maxim Karpov, Martin H. P. Pfeiffer, Junqiu Liu, Anton Lukashchuk & Tobias J. Kippenberg

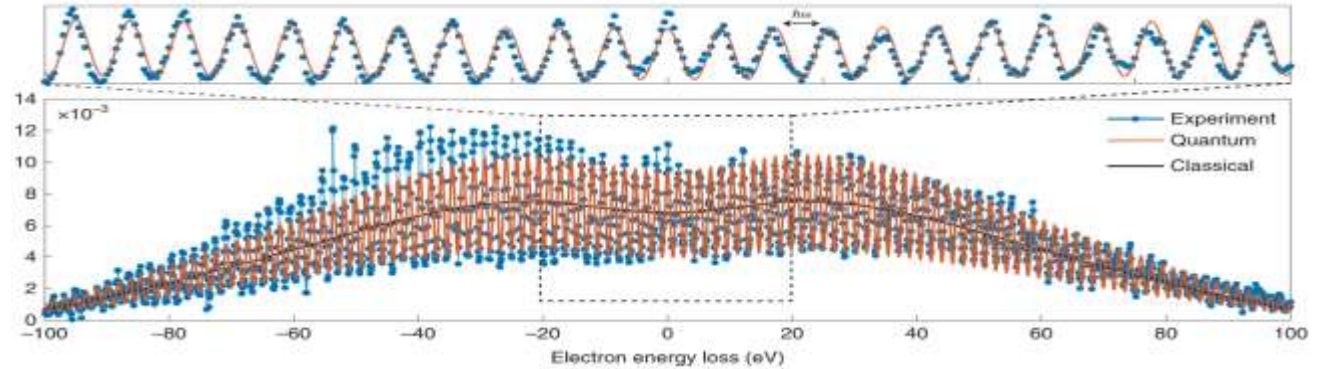
Nature Communications 9, Article number: 1146 (2018) | Cite this article

Thank you for listening!

Ultrafast electron microscope



Free-electron energy comb



Spatiotemporal energy-filtered dynamics

