**DTU Fotonik**
Department of Photonics Engineering

# Ultrafast Infrared and Terahertz Science

## Student projects

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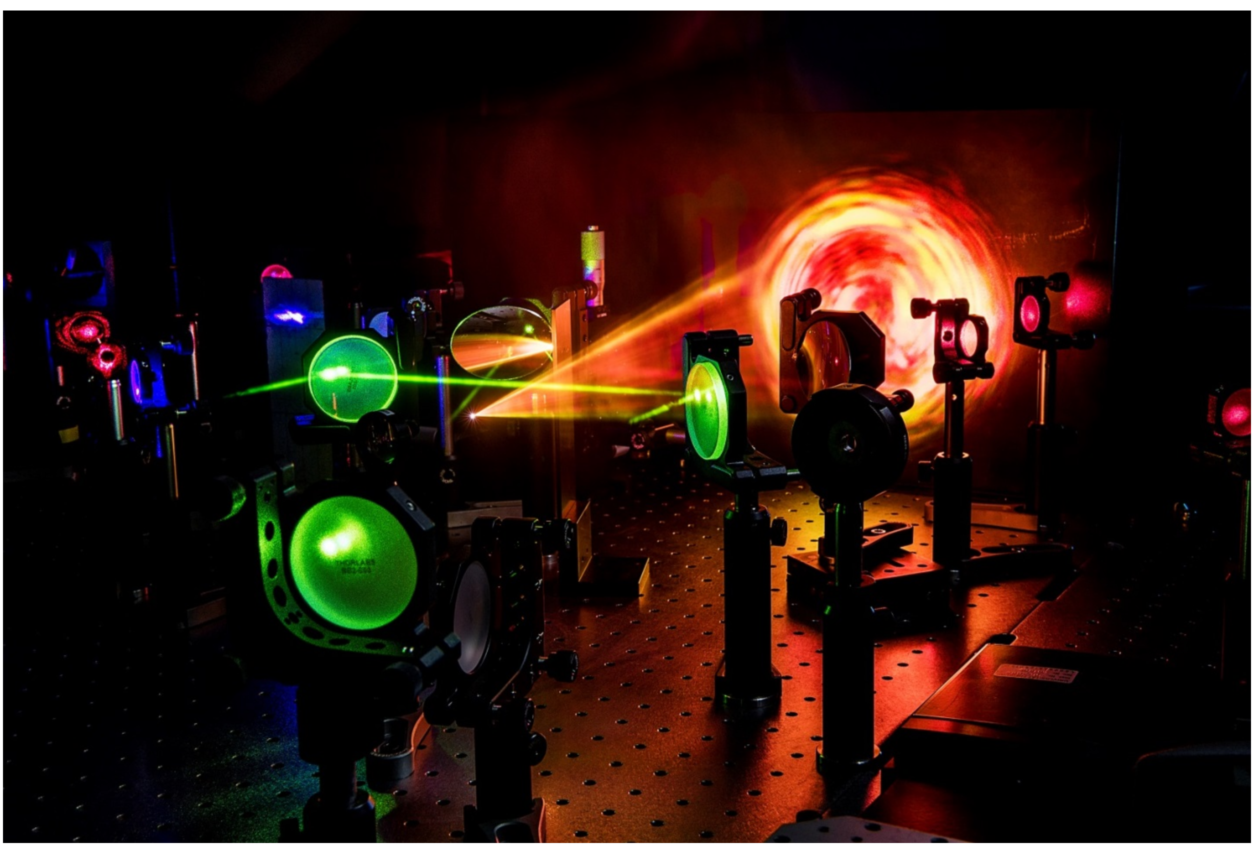
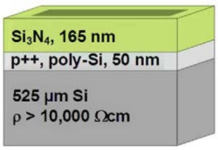
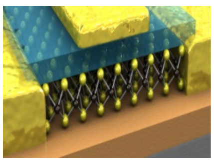


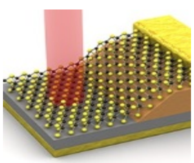
# THz transport properties in novel 2D materials




Preparation of terahertz compatible substrates in Danchip facilities



Transfer of 2D materials from the growth substrate to the target substrates

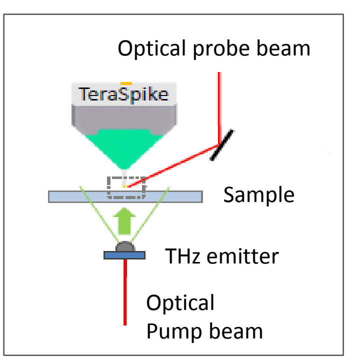


Measurement of the 2D materials response under THz light using state-of-the-art setups

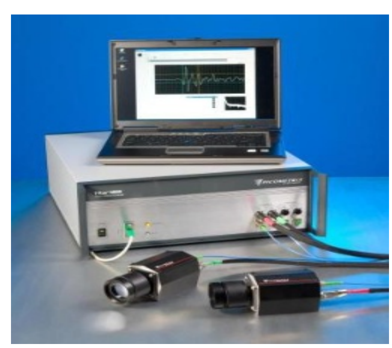
Understanding properties of 2D materials

## THz setups

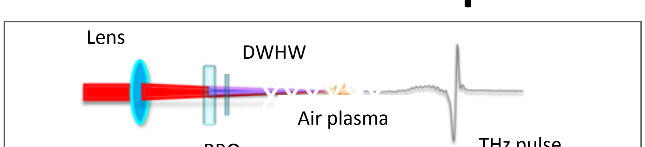
### Near-field THz microscopy



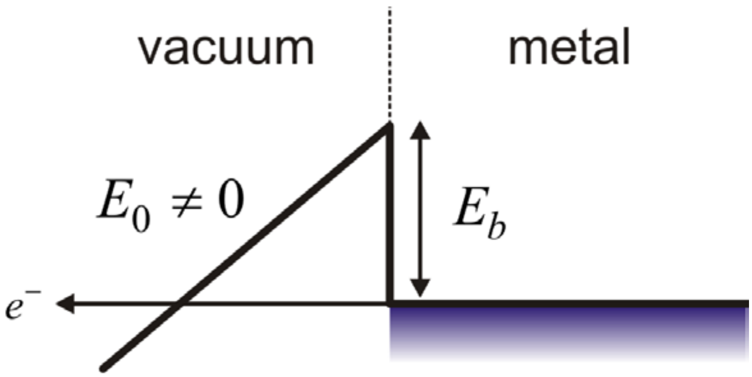

### Broadband THz spectroscopy

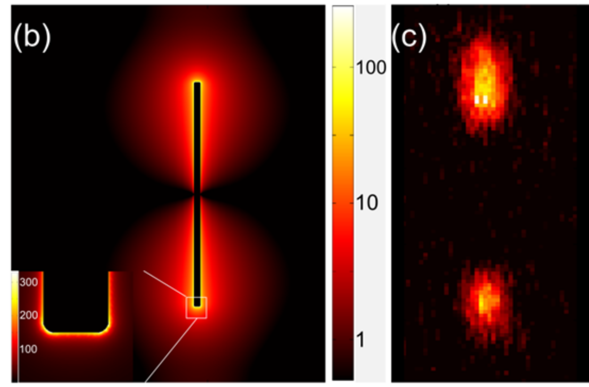


### Ultra-broadband THz spectroscopy

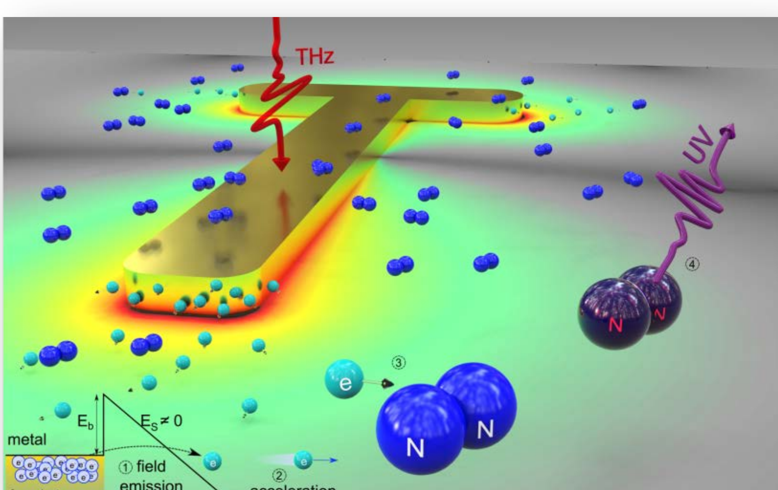


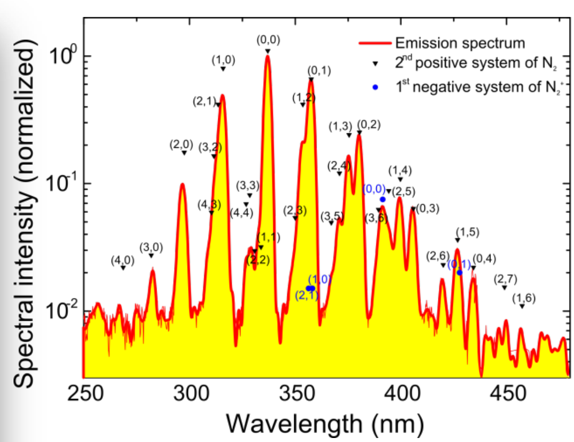
# THz-induced ultrafast electron optics



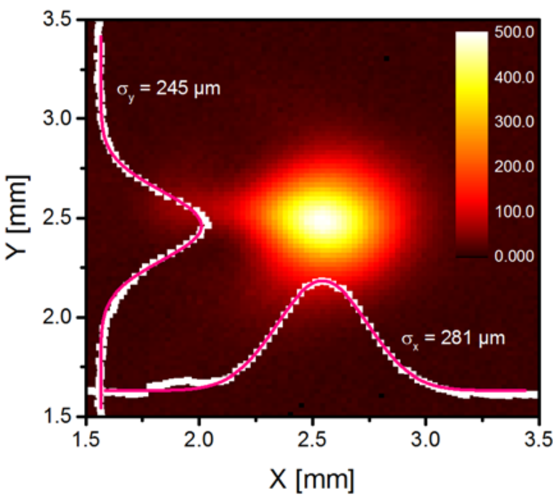



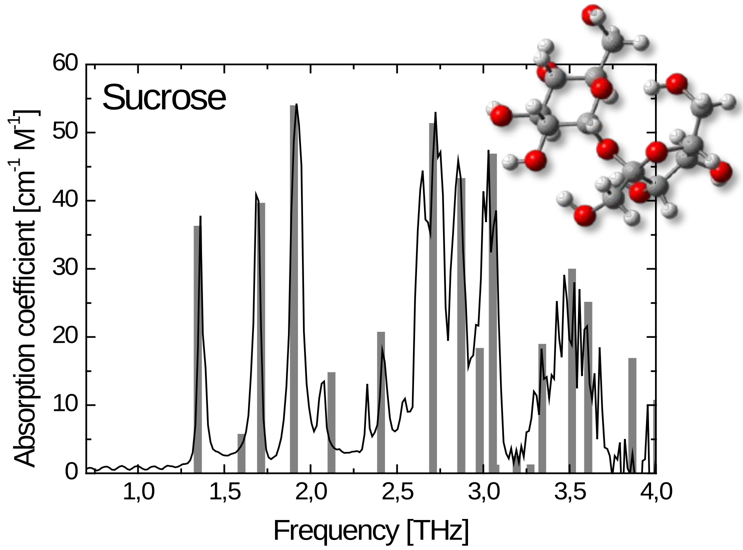

- Use strong THz pulses to induce ultrafast electron bunch emission from metals
- Understand material degradation under strong-field conditions
- Simulate and control electron behavior in strong, transient fields
- Investigate collision processes between ultrafast electron bunches and molecules



# Nonlinear THz molecular spectroscopy




Intense THz pulses for nonlinear vibrational spectroscopy

Ab-initio density functional theory

Molecular dynamics simulations

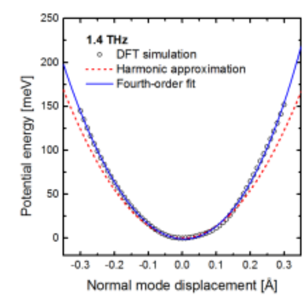
Vibrational anharmonivity

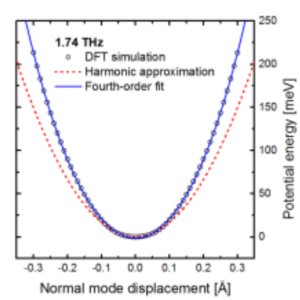
Energy flow in complex, coupled systems

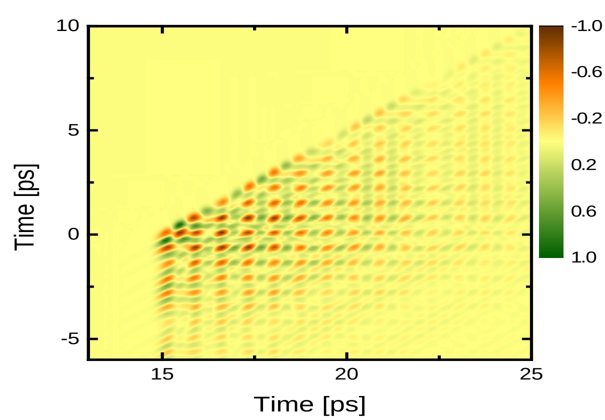
Time-dependent quantum mechanics

$$\tilde{H} = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x) - \mu E(t) = \tilde{H}_0 - \mu E(t)$$

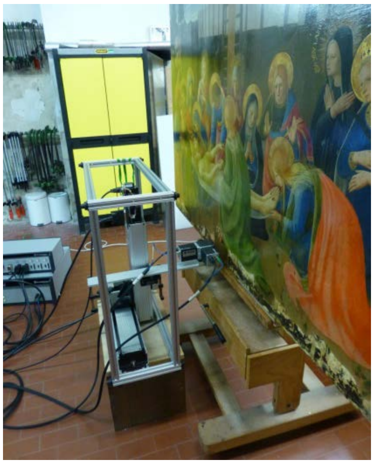
$$\frac{\partial \tilde{\rho}}{\partial t} = -\frac{i}{\hbar}[\tilde{H}, \tilde{\rho}] = -\frac{i}{\hbar}\left(\tilde{H}\tilde{\rho} - \tilde{\rho}\tilde{H}\right)$$

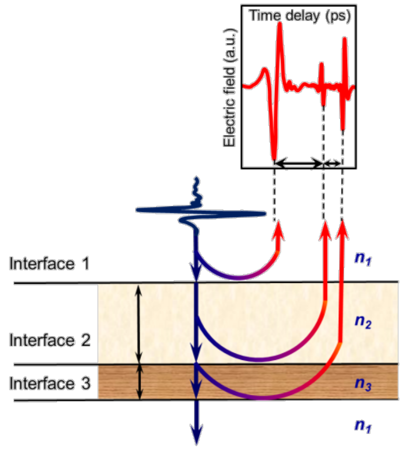


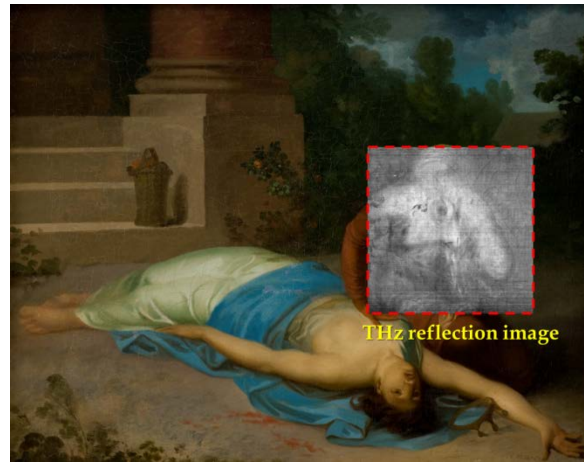



# THz imaging applications

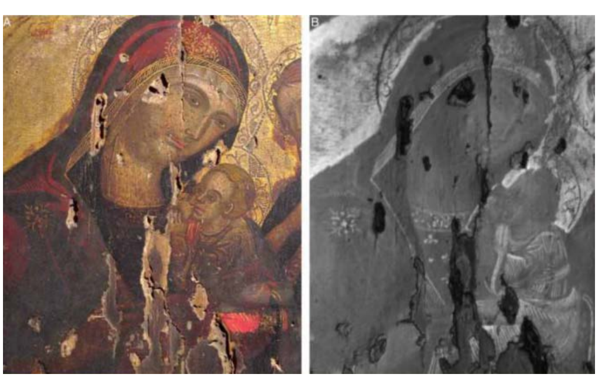




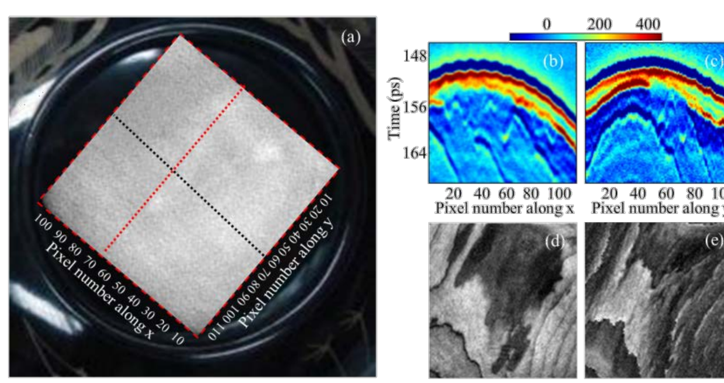




**Neoclassical easel painting**

- THz pulses penetrate many materials that are opaque to visible and infrared wavelengths
- Use portable THz imaging system for investigation of art objects
- Develop image analysis software for detailed inspection of internal structure
- Applications also in fundamental science and industry

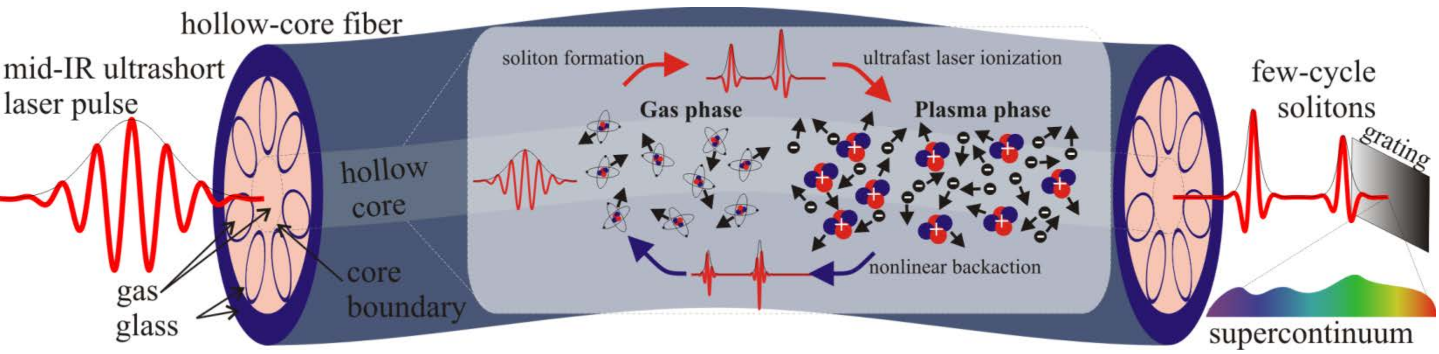


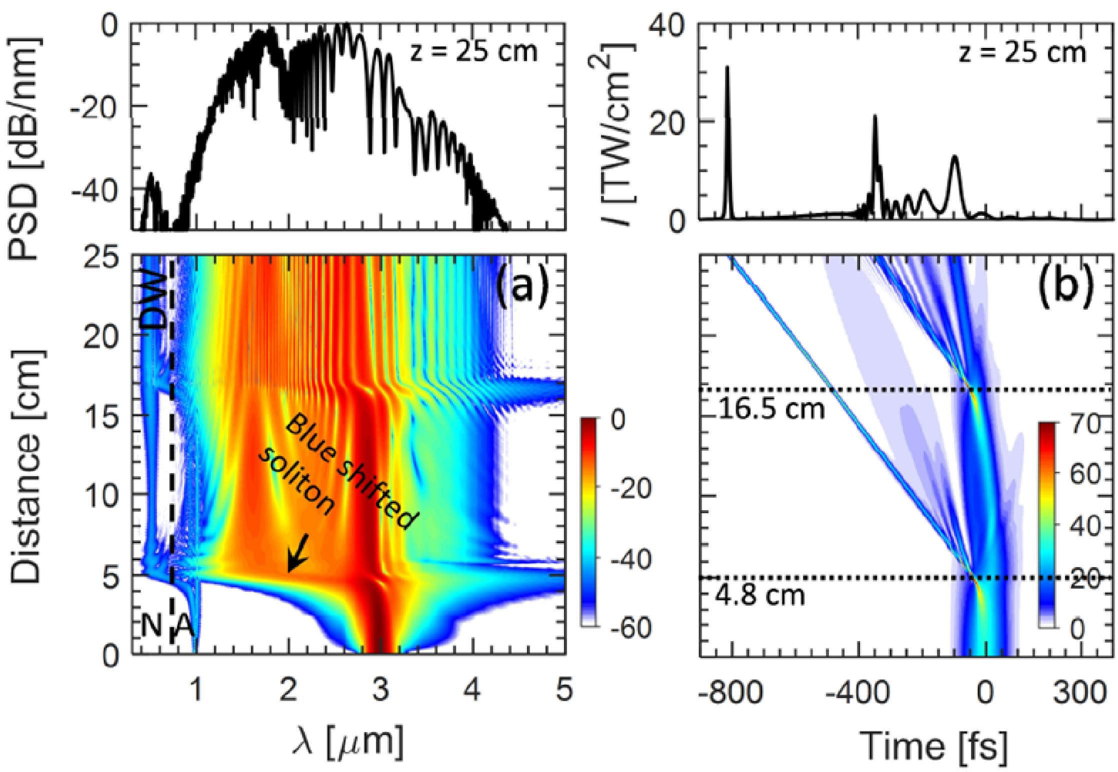
**Gilded panel painting**




**Japanese laquerware**

# Nonlinear optics in hollow-core gas-filled fibers

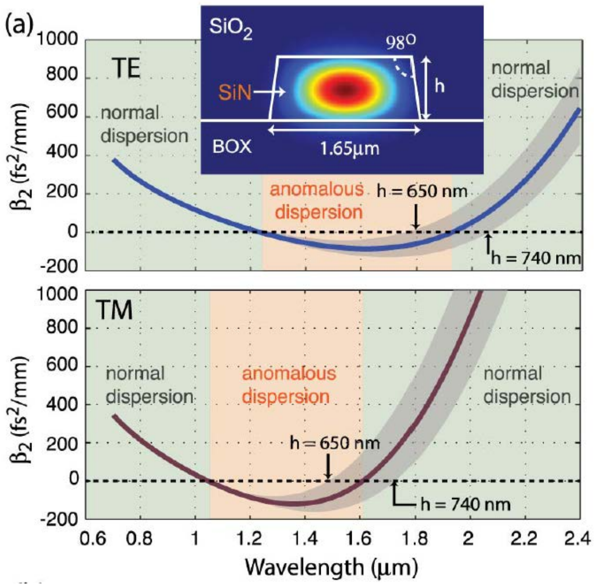


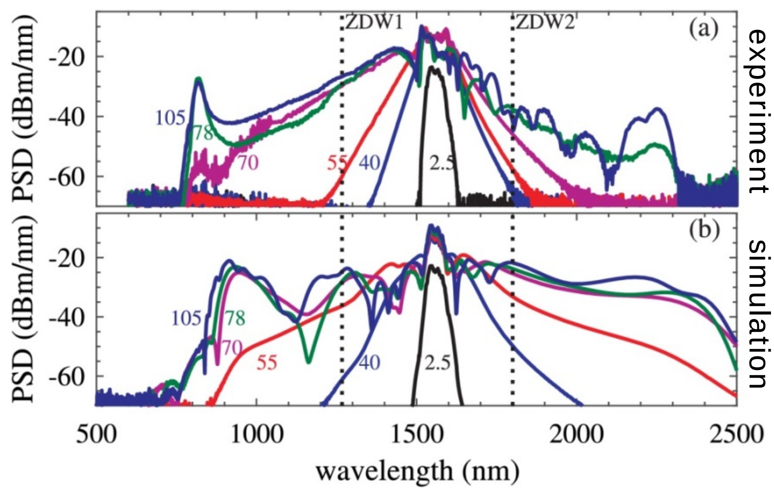




- Investigate fundamental properties of ultrafast gas-plasma interaction in the mid-IR
- Goal: High-energy mid-IR few-cycle soliton pulses and supercontinuum generation
- Tasks: Fiber design (COMSOL) and characterization, numerical simulation of nonlinear Schrödinger equation, experiments with fs lasers

# Ultrafast nonlinearities in nanophotonic devices

## Silicon nitride waveguides

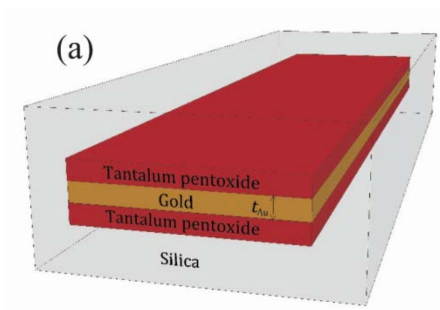


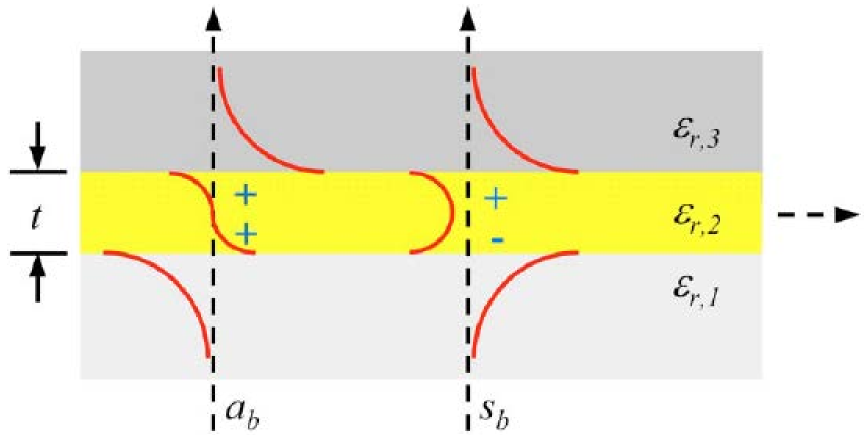




- Chip-scale waveguides for photonic integrated circuits
- Silicon nitride: new king of silicon photonics
- Goal: ultrabroadband octave-spanning spectra (supercontinuum) using femtosecond fiber lasers with ultra-low peak powers
- Mid-IR range (>2.5 µm) next target
- Tasks
  - Simulations of waveguides (COMSOL)
  - Experimental waveguide characterization
  - Simulation of nonlinear Schrödinger equation
  - Experiments

# Ultrafast nonlinearities in nanophotonic devices

## Nanoscale plasmonic waveguides



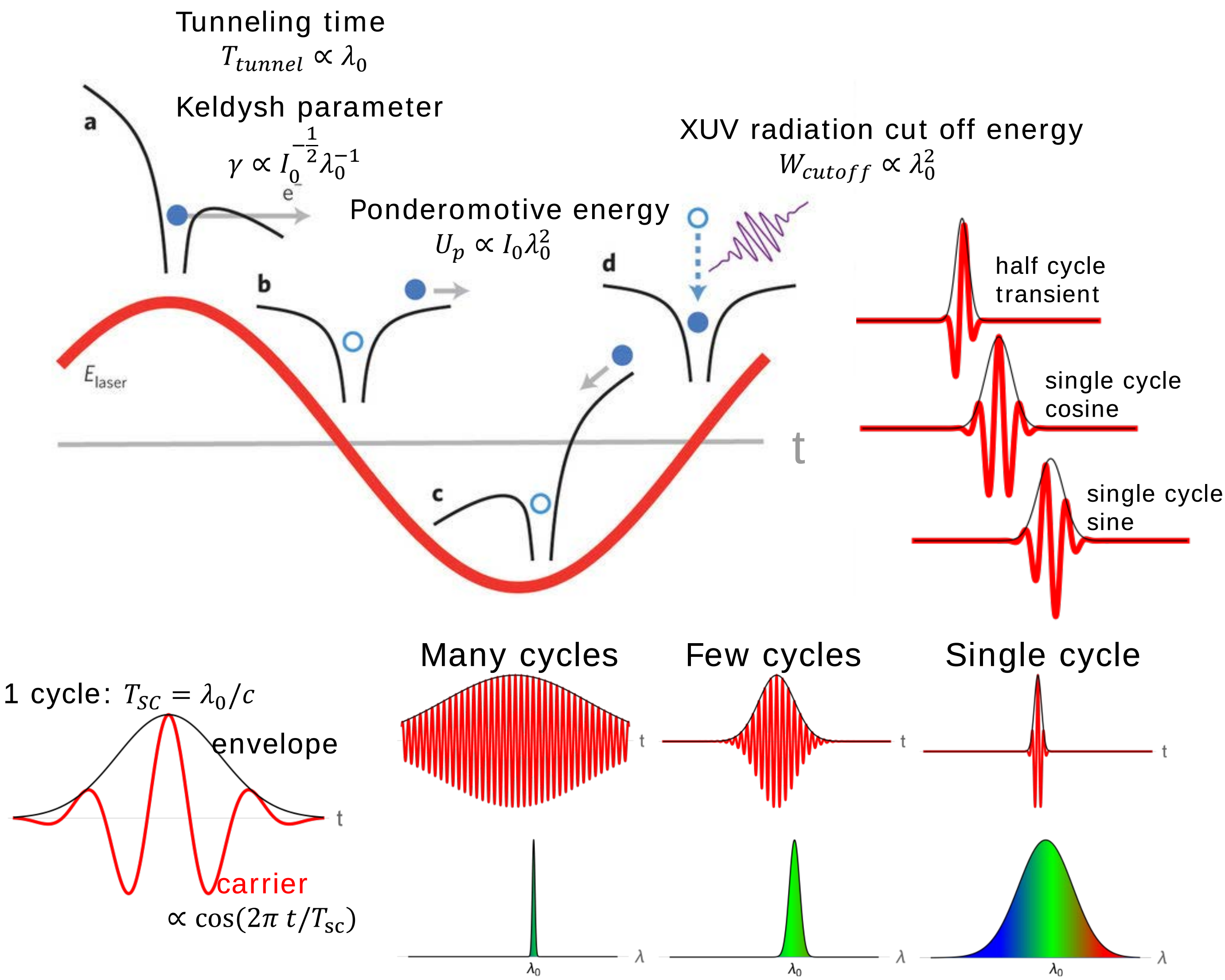

**<1 fs**
Absorption,
"cold" electrons

**~100 fs**
Hot electrons
$\chi^{(3)}$ nonlinearity

**>1 ps**
Electrons decay
to lattice

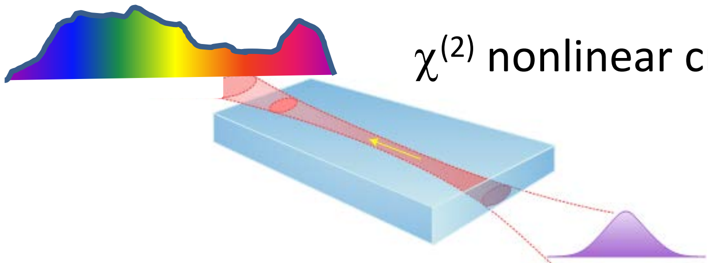
- Motivation: long-range surface plasmon polaritons promise compact nonlinear photonics devices
- Goal: Investigate metal ultrafast nonlinearities
- Mid-IR range (>2.5 μm) next target
- Tasks
  - Theory of metal response to ultrafast interaction
  - Simulations of waveguides (COMSOL)
  - Waveguide fabrication (clean room)
  - Experimental waveguide characterization
  - Simulation of nonlinear Schrödinger equation
  - Experiments

# Few-cycle mid-IR pulses

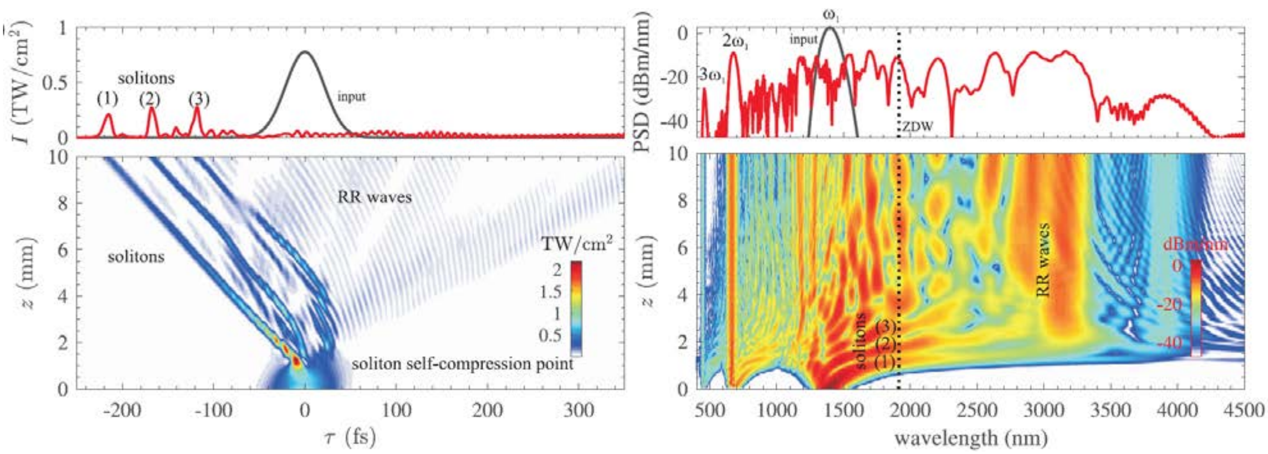



- Motivation: mid-IR favorable scaling laws for ultrafast atomic physics
- Goal: use nonlinear optics to compress many-cycle laser pulses to few-cycle or single-cycle pulses
- Tasks: Simulations of nonlinear Schrödinger equation, experiments in glasses, crystals and gases investigating high-energy fs pulse compression

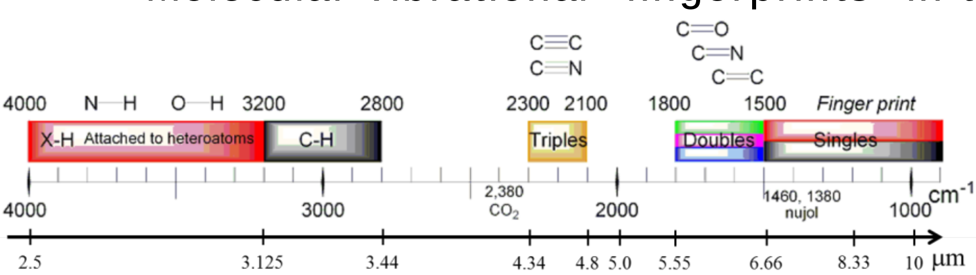
# Ultrafast mid-IR nonlinear optics

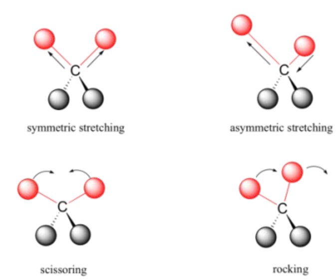


$\chi^{(2)}$ nonlinear crystals




Molecular vibrational “fingerprints” in the mid-IR




- $\chi^{(2)}$ nonlinear optics: Filament-free interaction, parametric control over nonlinearity
- Goal: high-energy mid-IR coherent laser pulses, targeting ultrafast spectroscopy of vibrational modes
- Tasks: Simulations of nonlinear Schrödinger equation, experiments in crystals investigating high-energy fs pulse compression and supercontinuum generation