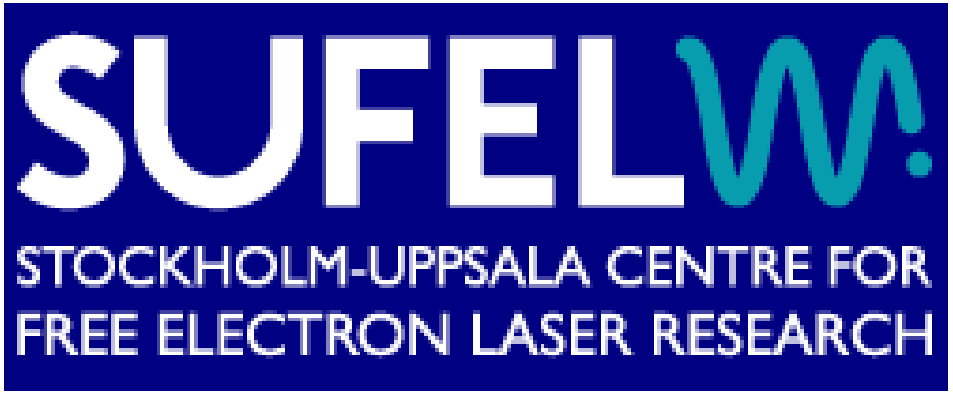
Applications of strong-field single-cycle THz pulses



Peter Salén

White Paper on THz Coherent Light Source in Uppsala

Stockholm-Uppsala Centre for

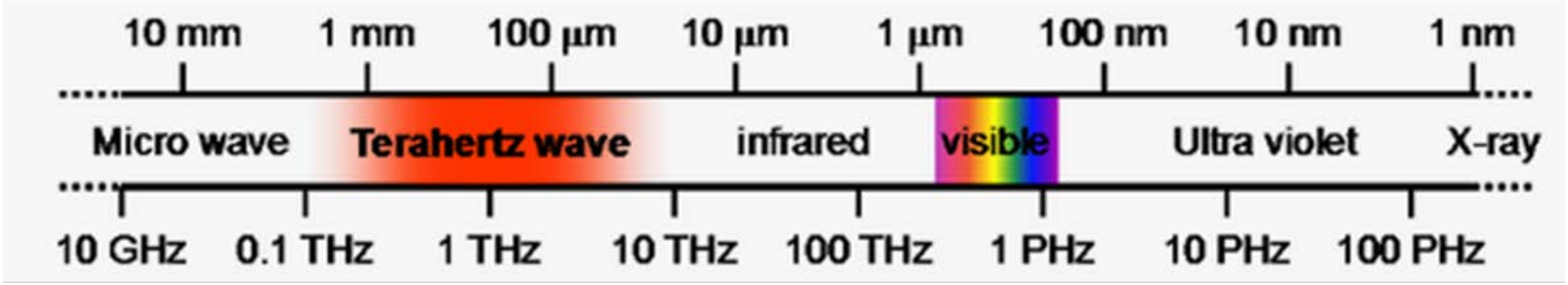
Free Electron Laser Research

Version 1, February 2016

Contents

www.frielektronlaser.se

THz radiation



1 THz = 300 μm = 33 cm^{-1} = 4.1 meV = 1 ps

THz resonances

- Plasmons
- Phonons
- Collective spin excitations (magnons)
- Collective molecular vibrations
- Excitons in semiconductors

Short THz pulses for strong-field control

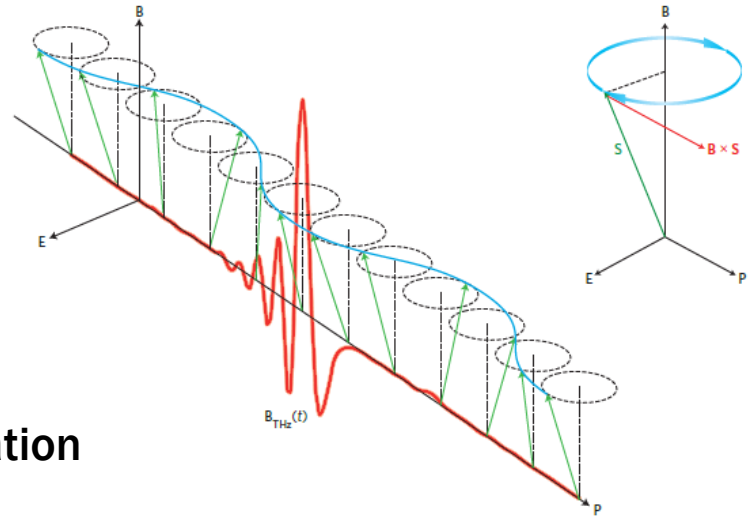
THz provides finer tool to control the system compared with optical energies!

Magnetism

Control of spin excitation is relevant for high-speed data storage and processing

THz pulses => manipulate spins through B-field

High enough B-field (10 T) => switch magnetization



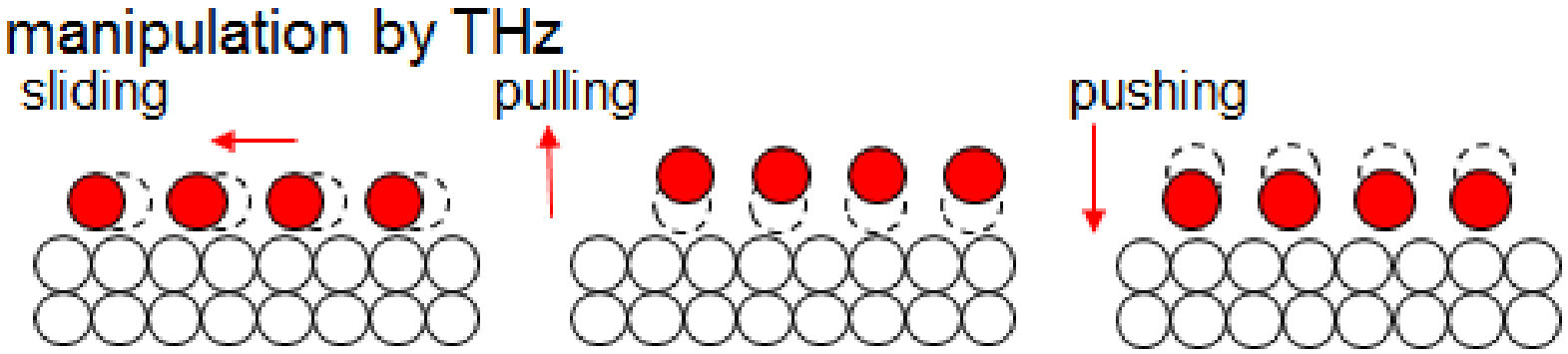
T. Kampfrath *et al.*, *Nature Phot.*, **5**, 31 (2011)

Surface chemistry

THz couples to surface phonons and vibration of the molecules bound to the surface

Strong-field half-cycle THz pulses (GV/m) => initiate coherent motion =>

control of surface chemistry

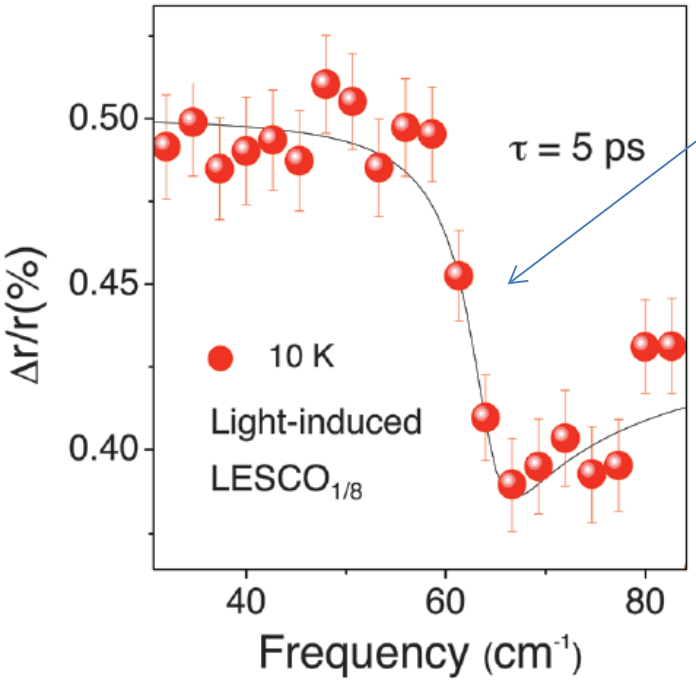


No hot electrons as for optical excitation - so more control !

THz-induced CO oxidation: PRL 115, 036103 (2015)

Superconductivity

Photo-induced superconductivity

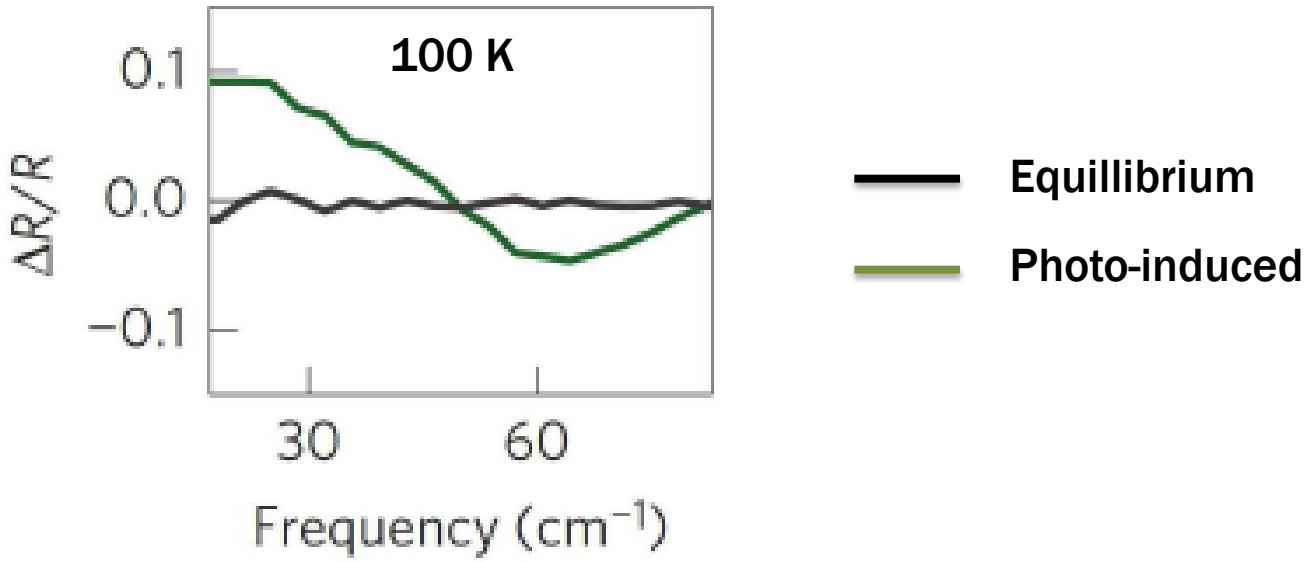


Josephson plasma edge - drop in r at 60 cm^{-1} signature of superconductive state

D. Fausti *et al.*, *Science* **331**, 189 (2011)

Superconductivity

Photo-induced superconductivity far above T_c



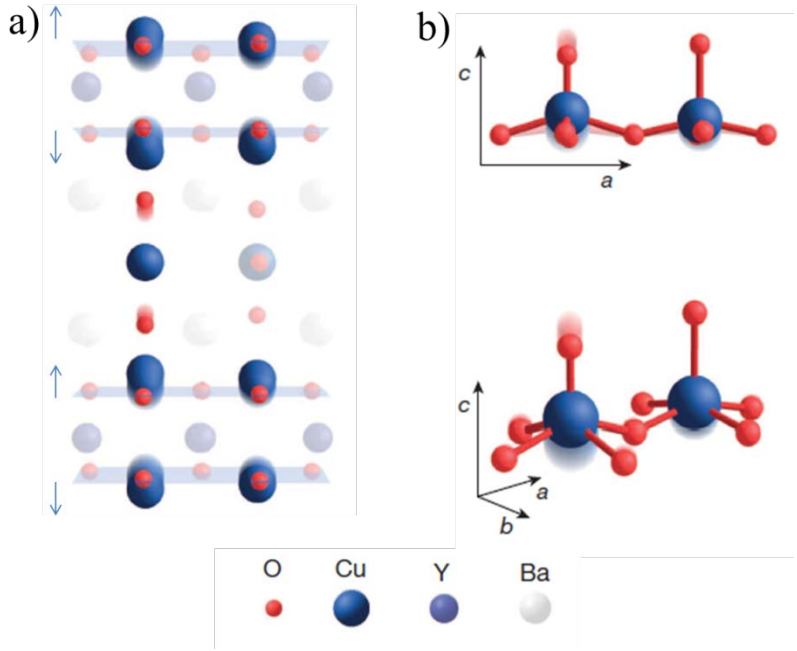
Signatures observed even up to 300 K !

High average-power (1 W) broadband pulses wanted for probing

W. Hu *et al.*, Nature Mat. 13, 705 (2014)

Superconductivity

X-ray diffraction => lattice structure

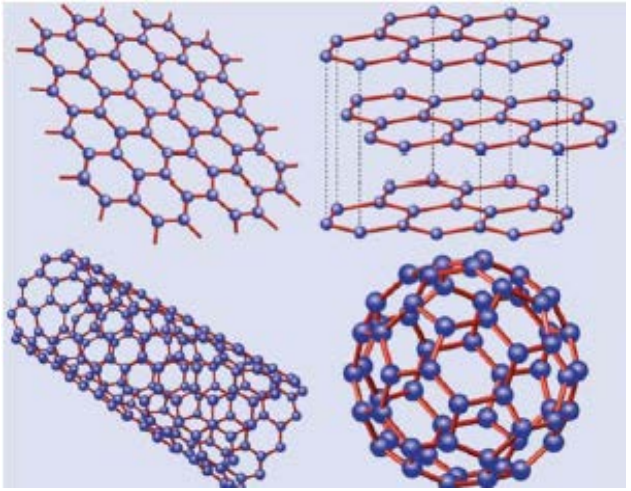


R. Mankowsky *et al.*, Nature 516, 71 (2014)

Dirac materials - graphene

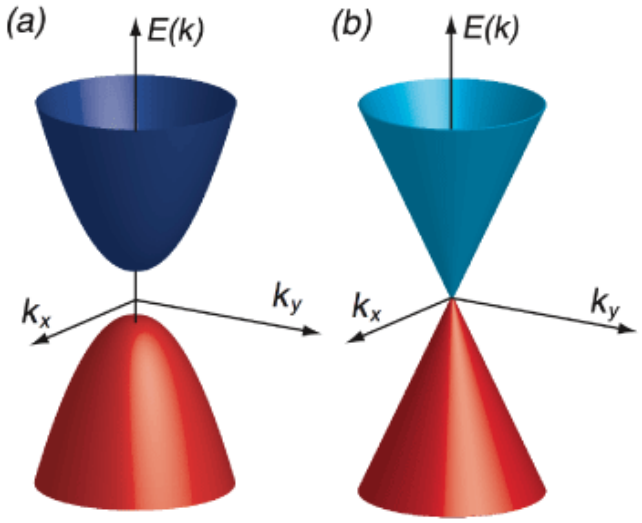
Basic building block for other carbon nanomaterials

Exceptional electronic properties and THz transitions
-> promising for optoelectronic devices



Graphene is gapless –
Bandgap required for many optoelectronic applications

Circ. polarized THz pulses can create and tune a bandgap

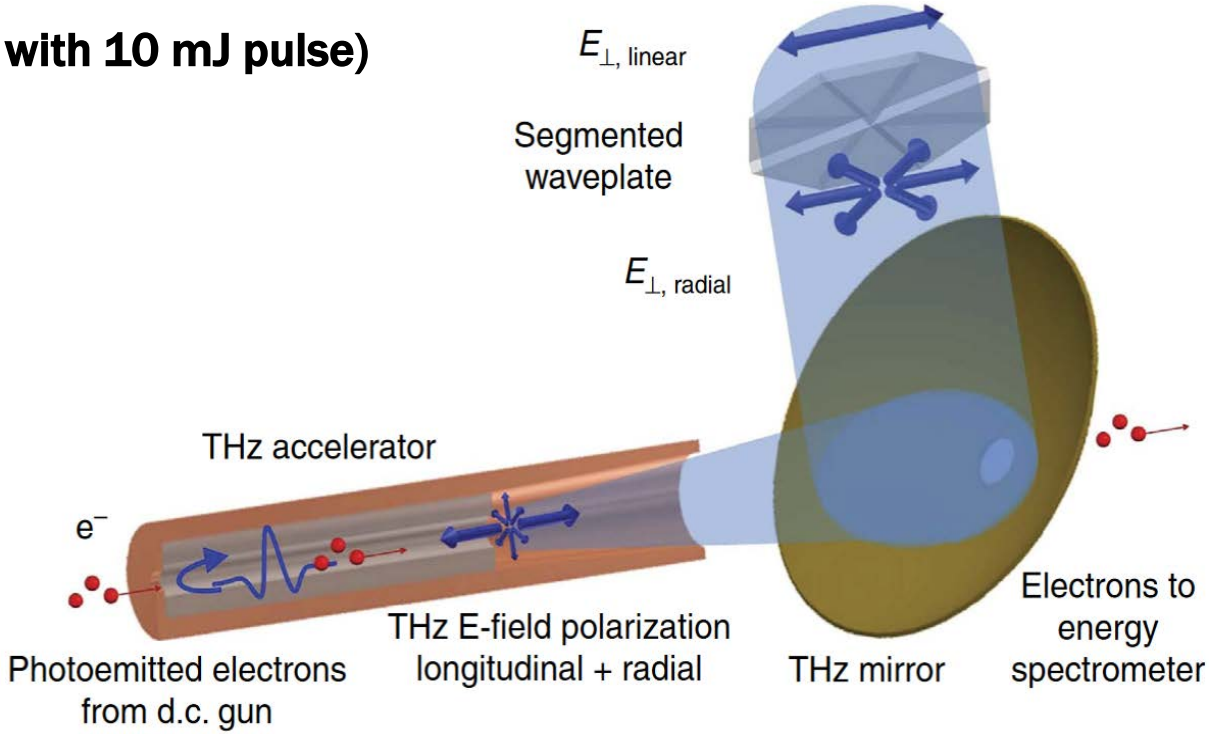


H. Calvo *et al.*, *APL* **98**, 232103 (2011)

THz-driven accelerators

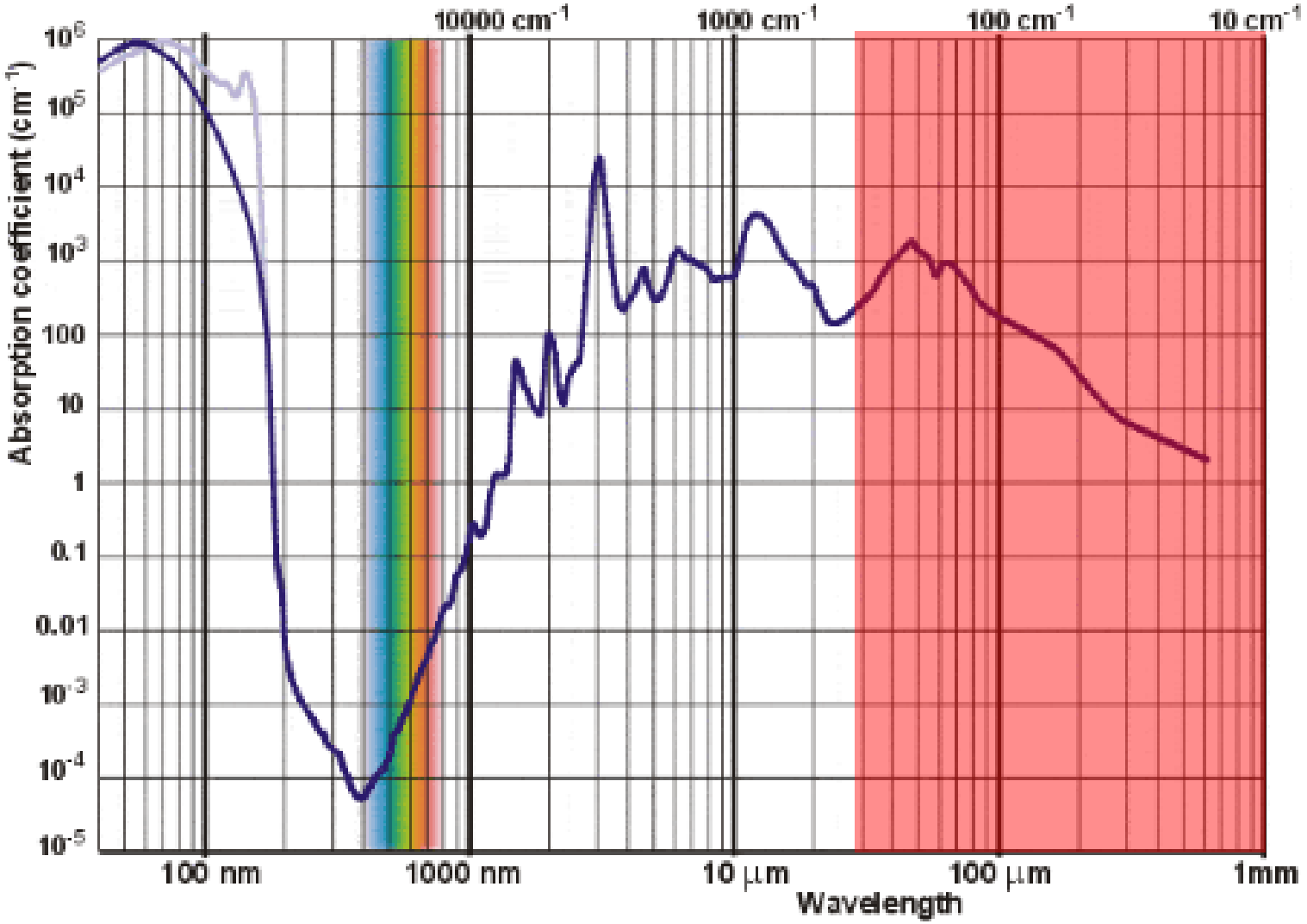
High-field single-cycle THz pulses enable

- **High gradient (GeV/m with 10 mJ pulse)**
- **High repetition rate**
- **High charge**



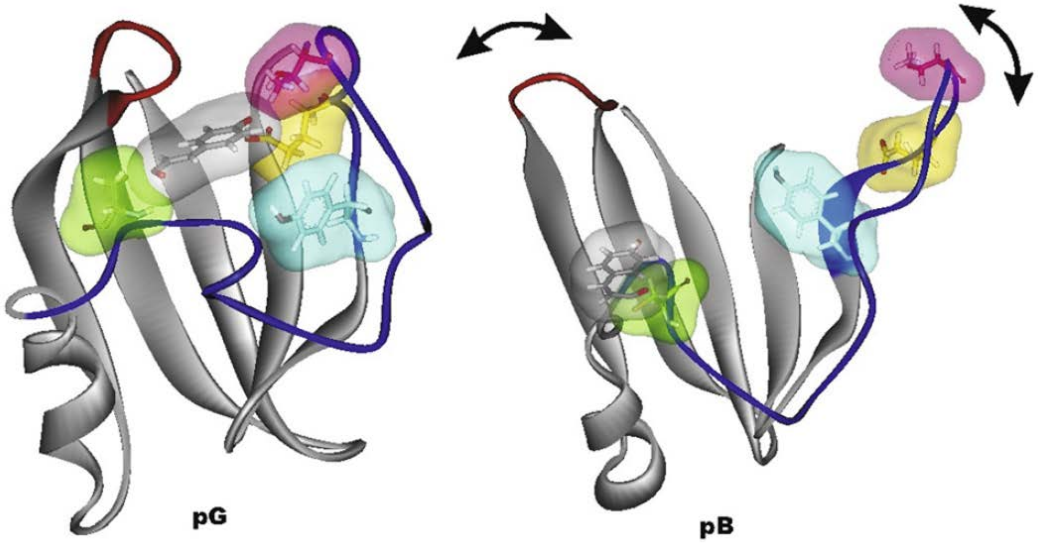
E. Nanni *et al., Nat. Comm.* **6**, 8486 (2015)

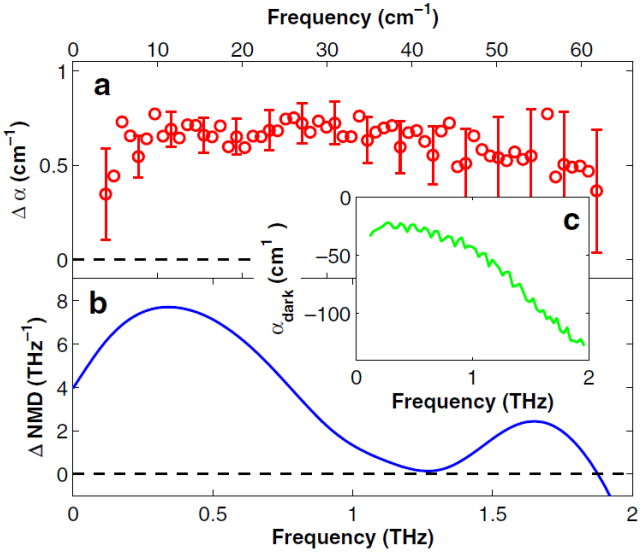
Biology


10000 cm-1
1000 cm-1
100 cm-1
10 cm-1
Absorption coefficient (cm-1)
10^6
10^5
10^4
10^3
100
10
1
0.1
0.01
10^-3
10^-4
10^-5
100 nm
1000 nm
10 μm
100 μm
1mm
Wavelength

Biology

Protein dynamics



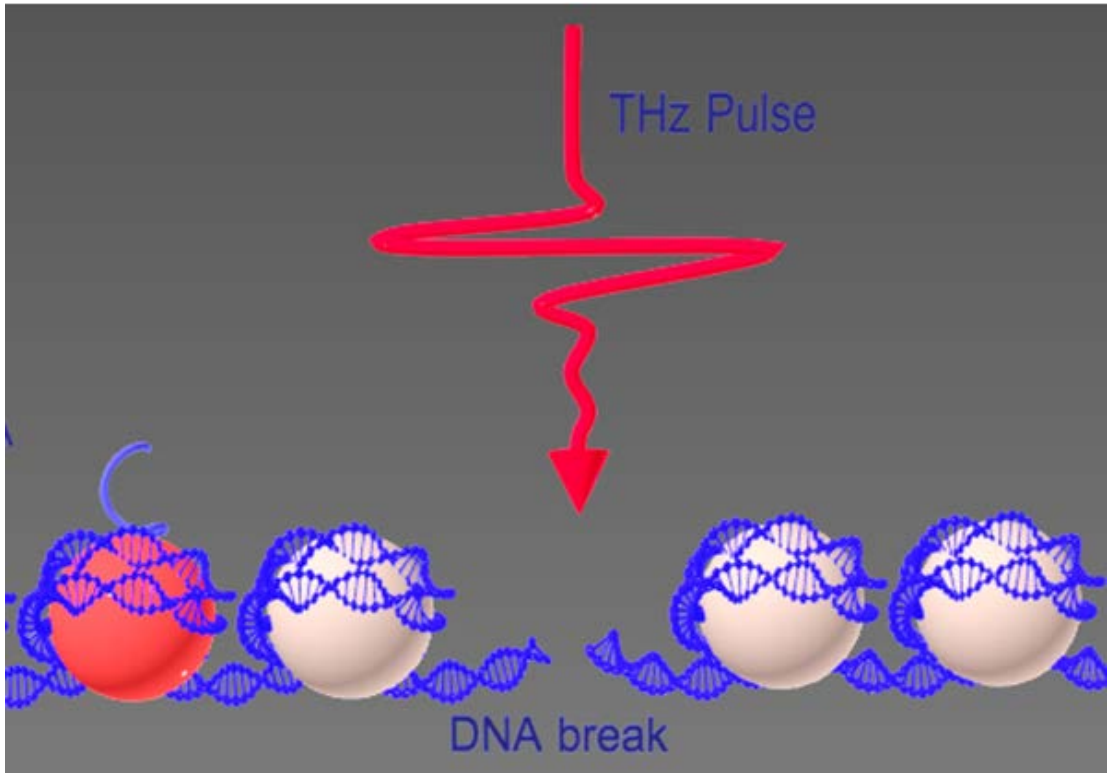


Visible light induces folding of PYP – detected by THz absorption

Castro-Camus *et al.* Chem Phys Lett **455**, 289 (2008)

Biology

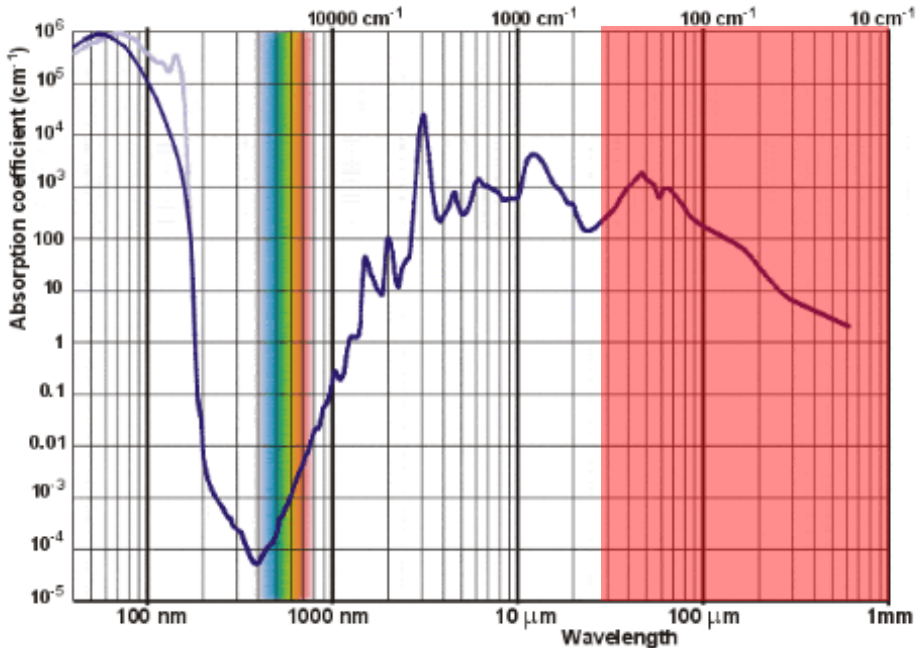
Biological effects of THz radiation?

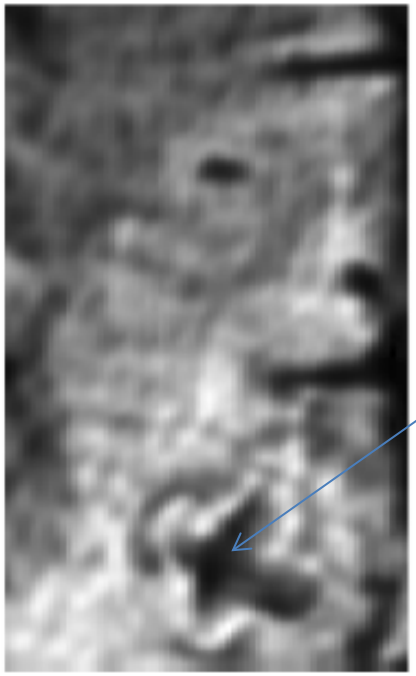


Titova *et al.* Biomedical Opt Exp **4**, 559 (2013)

Medicine

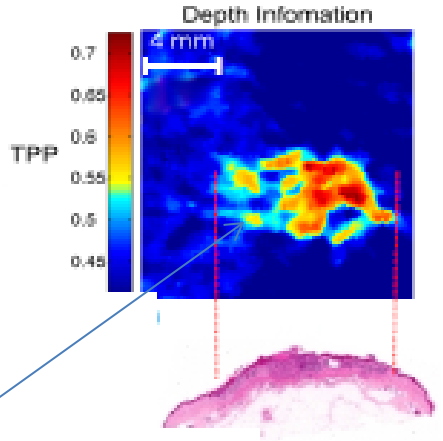
High water absorption





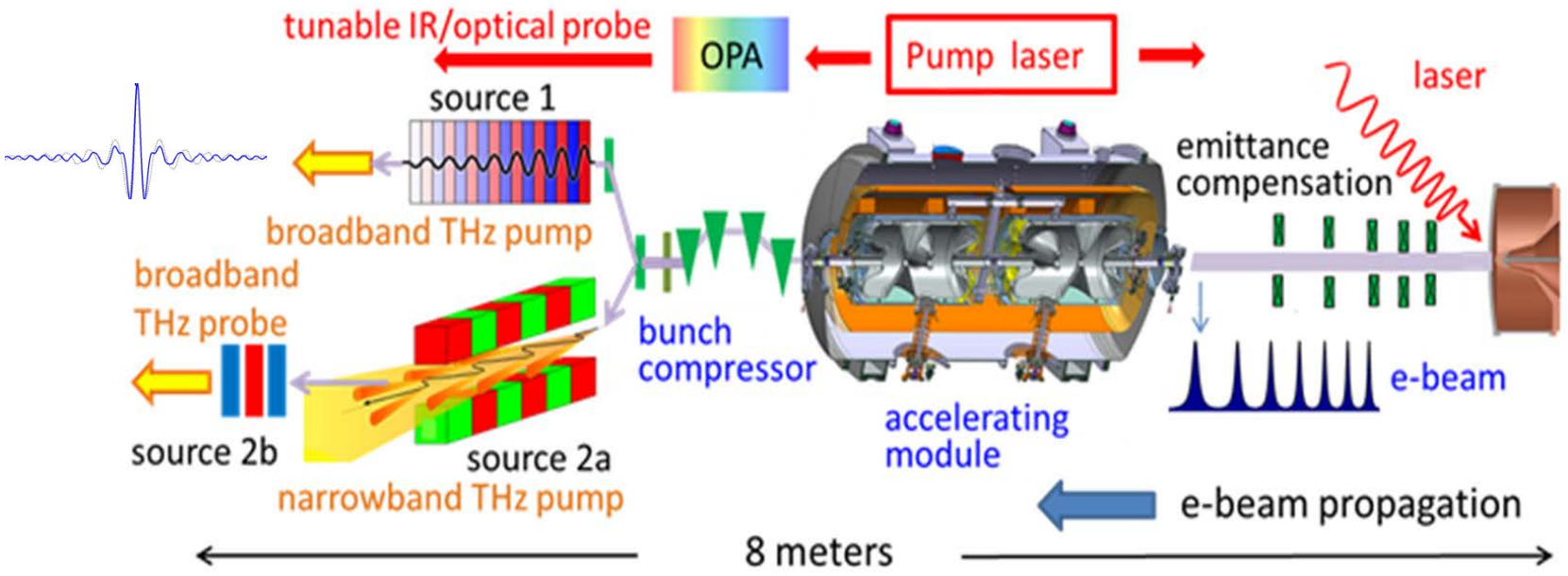
Skin burn

Medical imaging



Skin cancer

Suggested THz Light Source



Vitaliy Goryashko

Uniqueness:

- The first THz-source designed specifically for pump-probe experiments
- Covers the range of 1.5 - 15 THz, exceeding laser-based THz sources
- It will generate quasi-half-cycle pulses with field strength (GV/m) and repetition rate (1-100 kHz) far beyond any existing or planned source

Summary

Strong-field single-cycle THz applications:

- **Magnetic switching** (3 GV/m. Half-cycle pulses.)
- **Control of surface chemistry** (1 GV/m. Half-cycle pulses.)
- **Superconductivity (THz** both for pump and probe.)
- **High-gradient THz electron acceleration** (high field radial polarization.)
- **Biology** (penetrate water absorption -> high peak power.)