Novosibirsk ERL based FEL as User Facility

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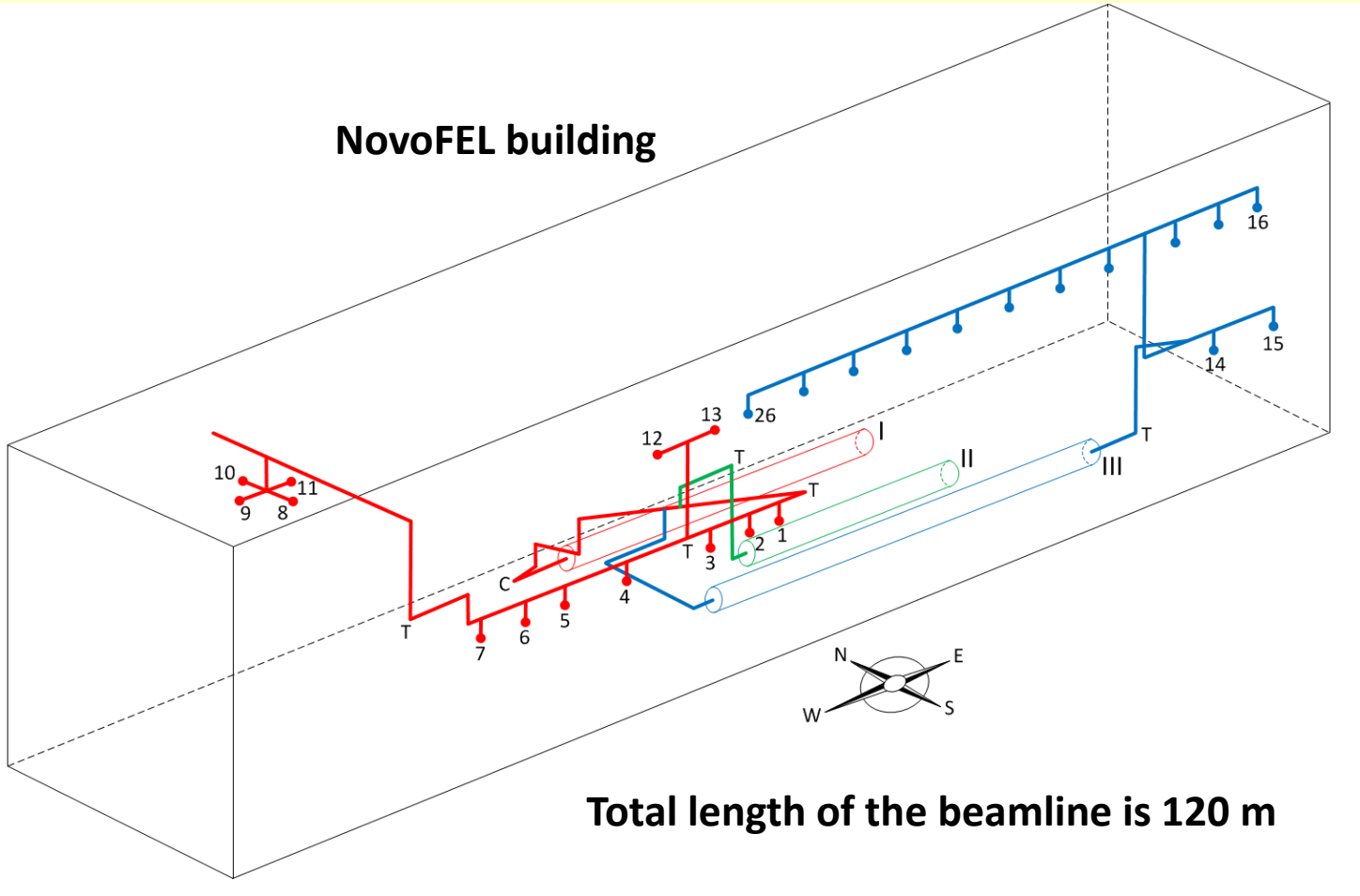
ERL-2017, 18-23 June 2017, CERN

Beamline system at NovoFEL



1, 2,…, 13 – working user stations

14, …, 26 – developing user stations

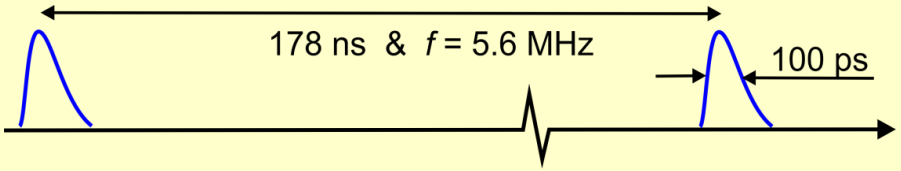
I (red) - Terahertz FEL
II (green) - Far infrared FEL
III (blue) - Infrared FEL

T – Toroidal mirrors
C – Spherical mirror
Other mirrors are plane

NovoFEL radiation parameters

Laser	Terahertz	Far-Infrared	Infrared
Status	In operation since 2003	In operation since 2009	In operation since 2015
Wavelength, μm	90 – 240	37 – 80	8 – 11 (7–30)
Relative line width (FWHM), %	0.2 – 1	0.2 – 1	0.1 – 1
Maximum average power, kW	0.5	0.5	0.1
Maximum peak power, MW	0.9	2.0	10
Pulse duration, ps	30 – 120	20 – 40	10 – 20
Pulse repetition rate, MHz	3.7 – 22.4		
Polarization	Linear, > 99.6 %		
Beams	Gaussian beams with diffraction divergence		

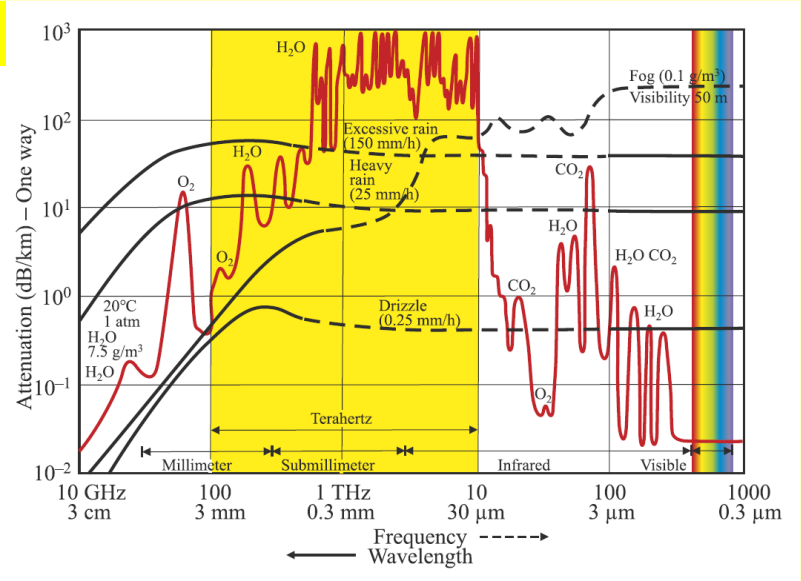
Typical radiation of THz NovoFEL - continuous train of 100 ps pulses:



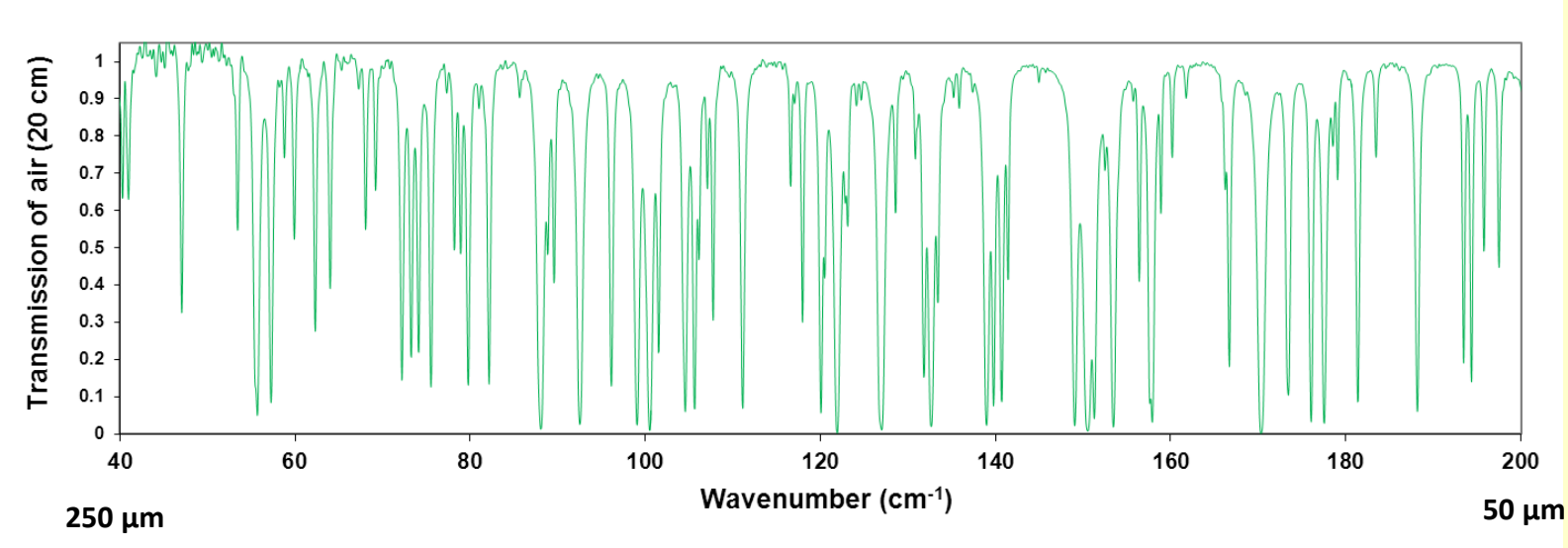
Beamline system at NovoFEL

- **Transmission line is filled with dry nitrogen/air mixture now**
- **Transmission line can easily be transformed to vacuum system**

Attenuation

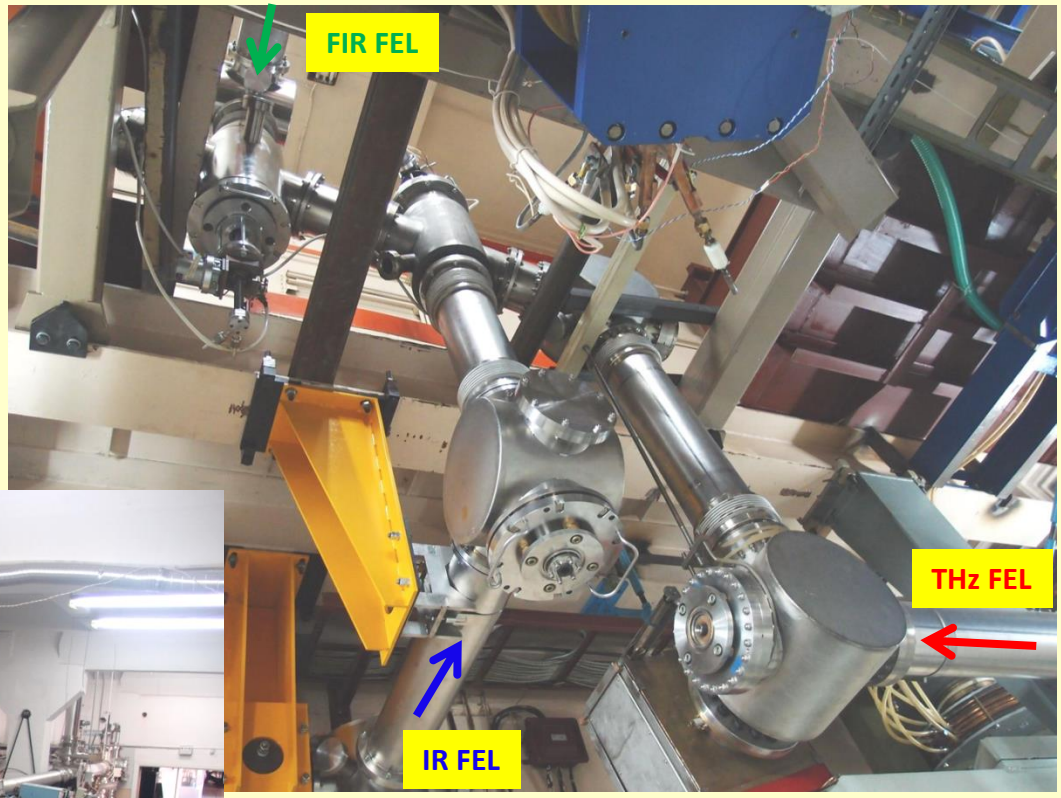


Transmission



Beamline system at NovoFEL

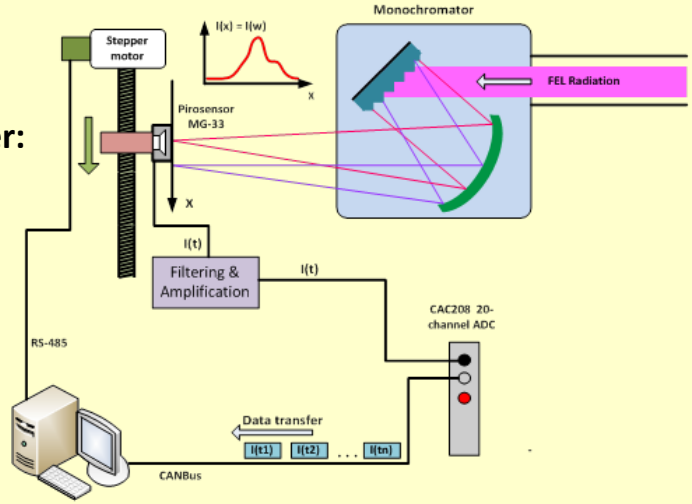
Transport channels in accelerating hall

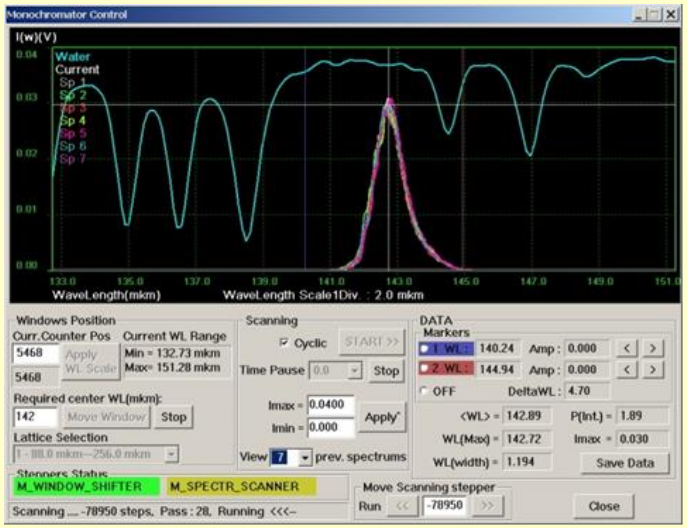


Transport channel in one of user's halls

Diagnostics of NovoFEL radiation

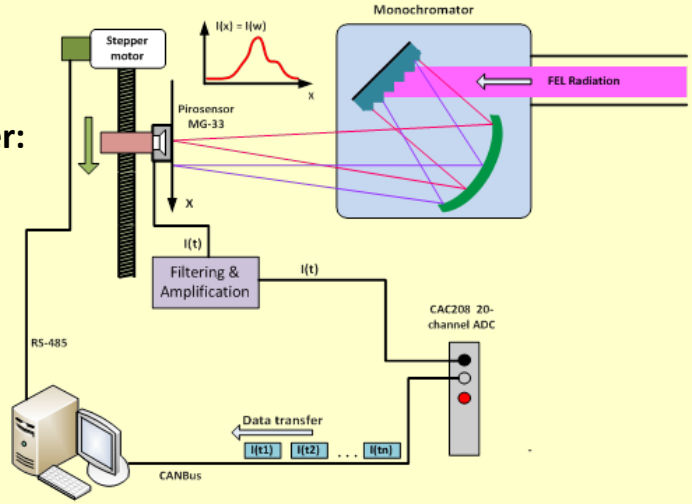
On-line grating spectrometer:

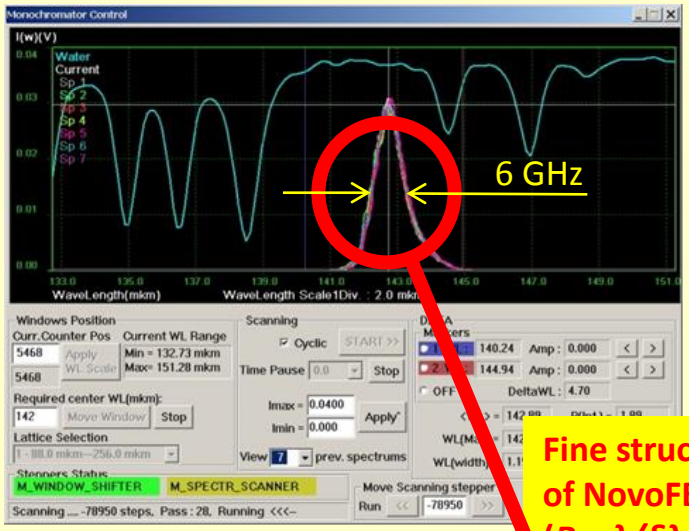




Diagnostics of NovoFEL radiation

On-line grating spectrometer:

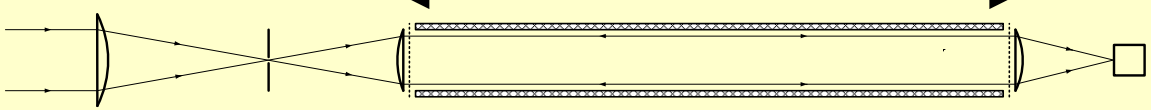


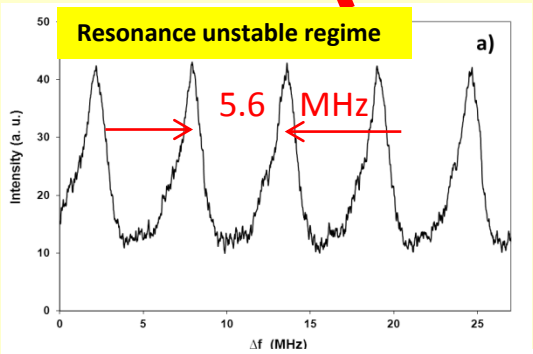


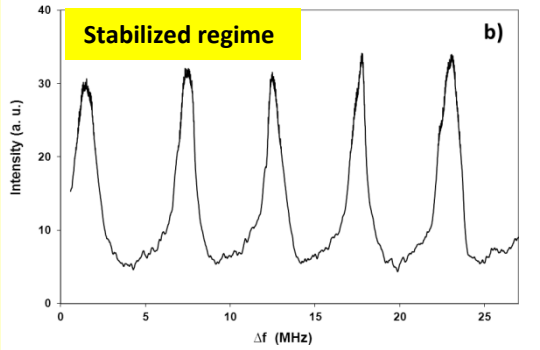
Fine structure of NovoFEL radiation ($R = \lambda/\delta\lambda = 2\cdot10^6–10^7$)

Ultra-long resonance waveguide vacuum Fabry-Perot interferometer:

$L = L_{\text{NovoFEL optical resonator}} / 10$

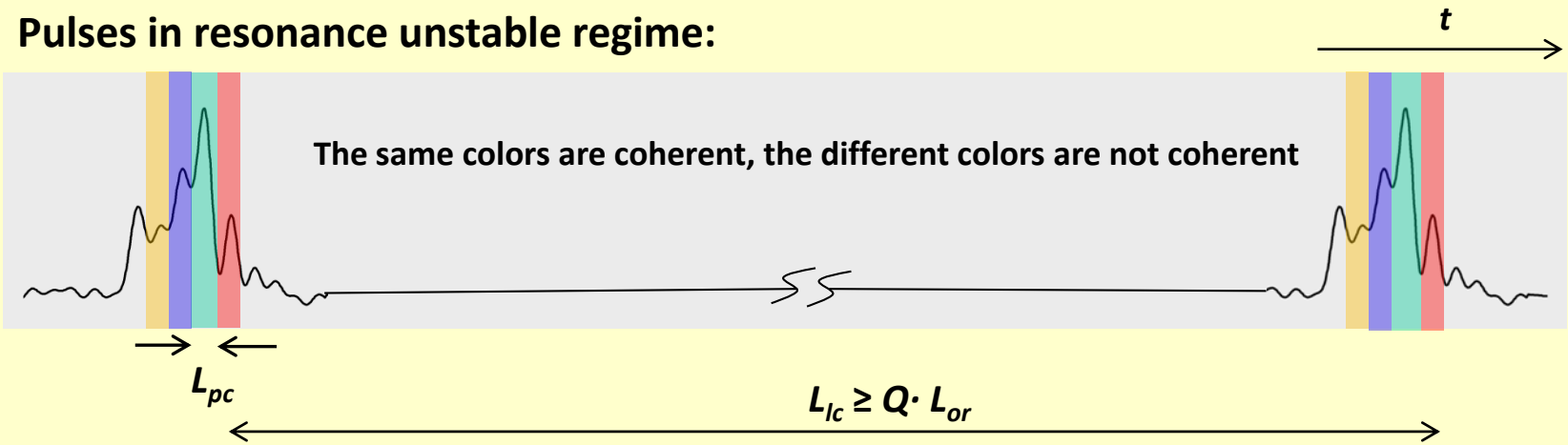






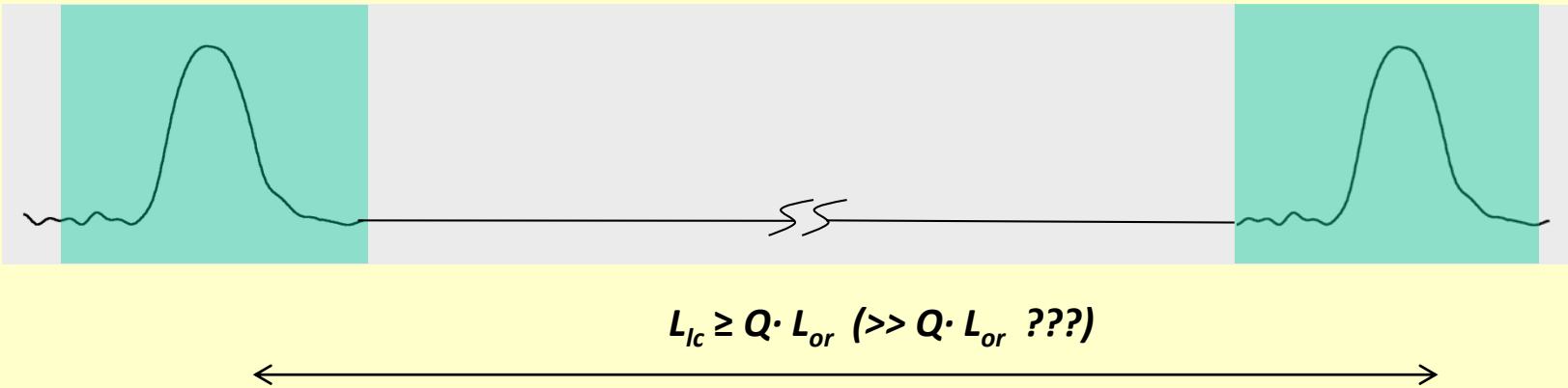
Two lengths of coherency in FEL

Pulses in resonance unstable regime:



L_{pc} – intra-pulse coherency depends on fast side-band instability. Typically L_{pc} = slippage length = $N_{und} \cdot \lambda$
L_{lc} – laser coherency depends on slow laser's instabilities. Typically $L_{lc} \geq Q \cdot L_{or}$ (L_{or} – length of optical resonator, Q – quality of optical resonator)

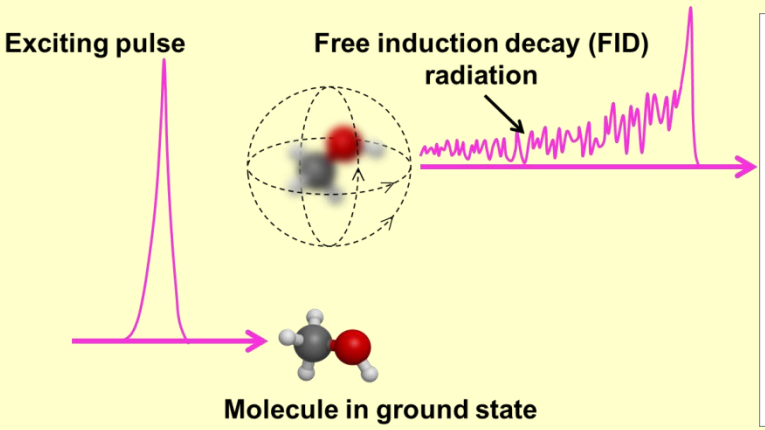
Pulses in stabilized regime (additional detuning of frequencies of electron and light pulse):



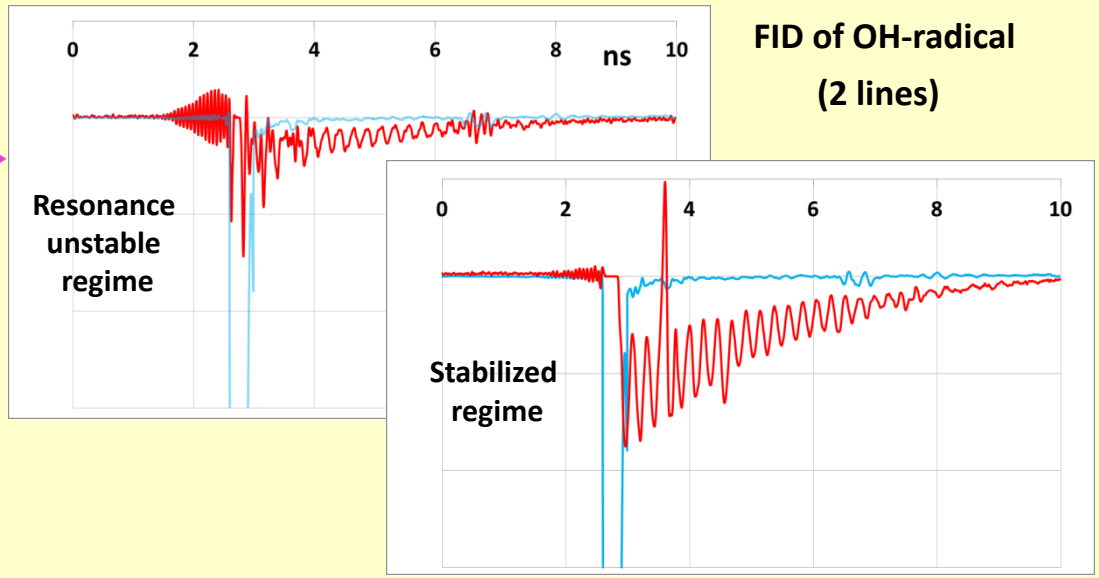
L_{lc}^{MAX} = laser limit = (Laser power/Power of spontaneous emission)$\cdot L_{or} = N \cdot Q \cdot L_{or}$ (N – number of photons in optical resonator)

Importance of radiation coherency

Intra-pulse coherency is important for spectroscopy based on free-induction decay radiation:

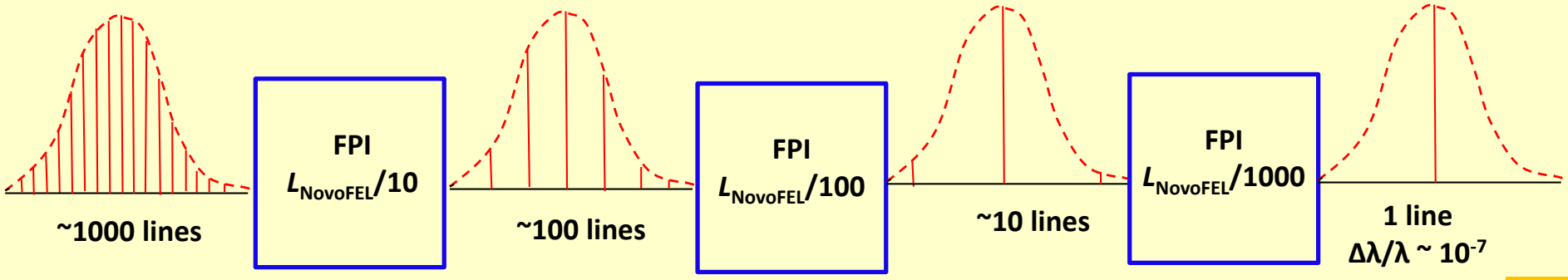


Ultrafast spectroscopy of unrepeatable (unstable, single) phenomena



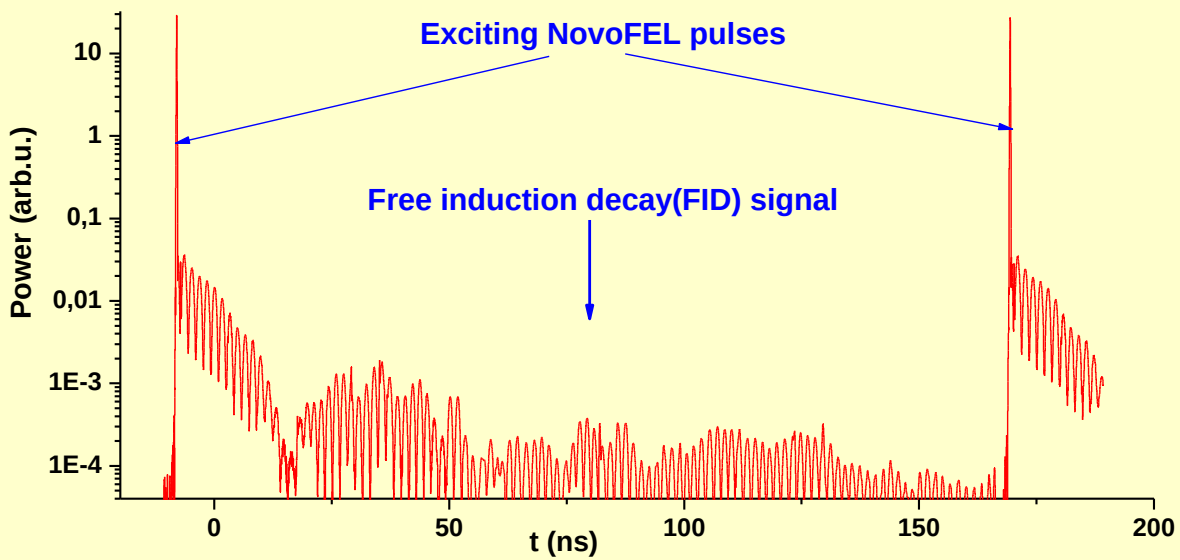
FID of OH-radical (2 lines)

Total laser coherency is important for creation effective monochromatic tunable laser source:

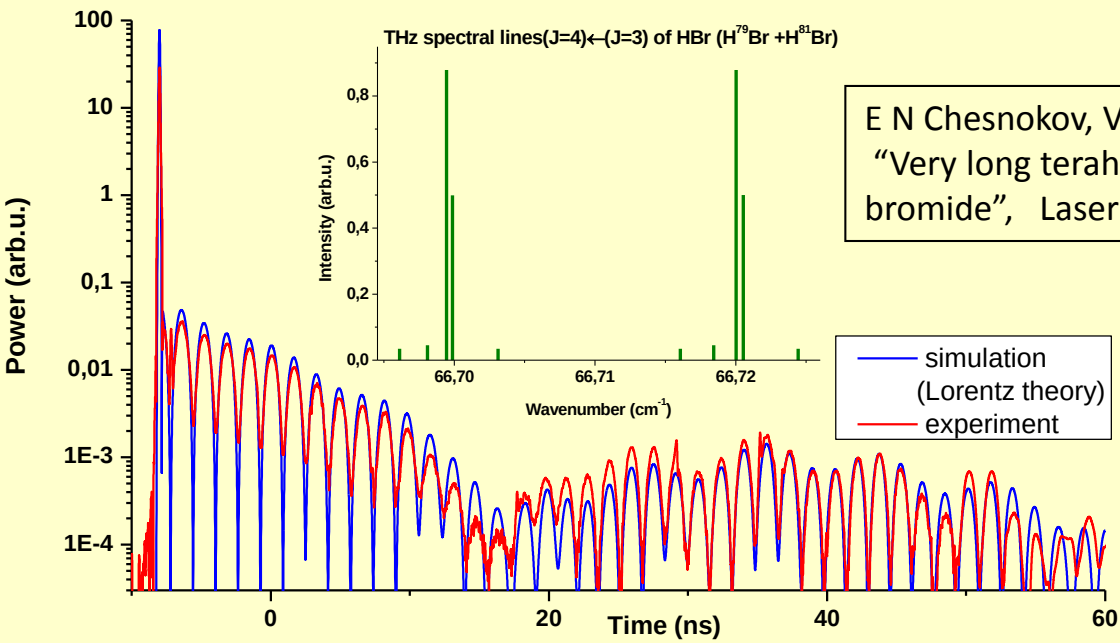


$P \sim L_{lc}$

Very long free induction decay in HBr

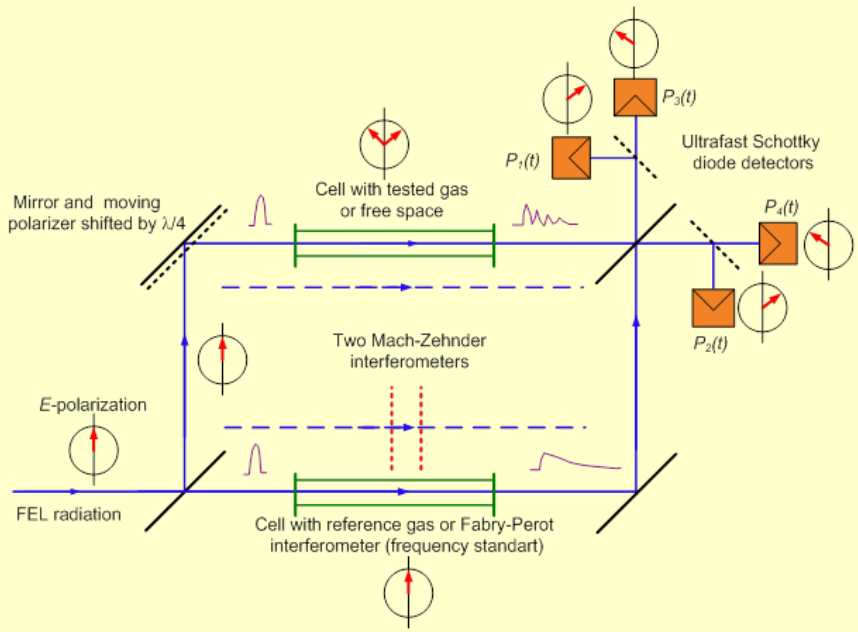


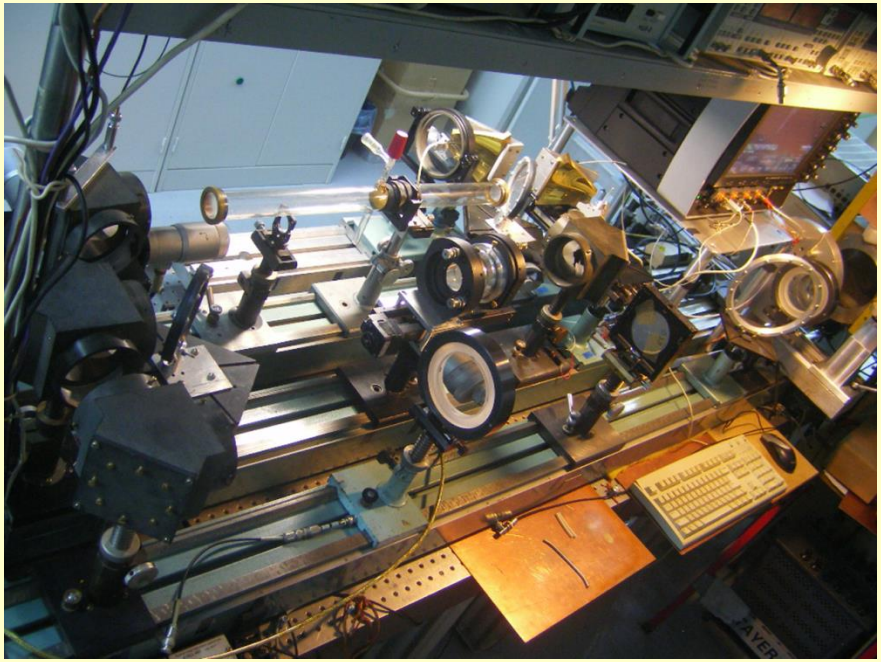
$(\Delta f / f)_{min}=(2\text{-}4)\cdot 10^{-6}$

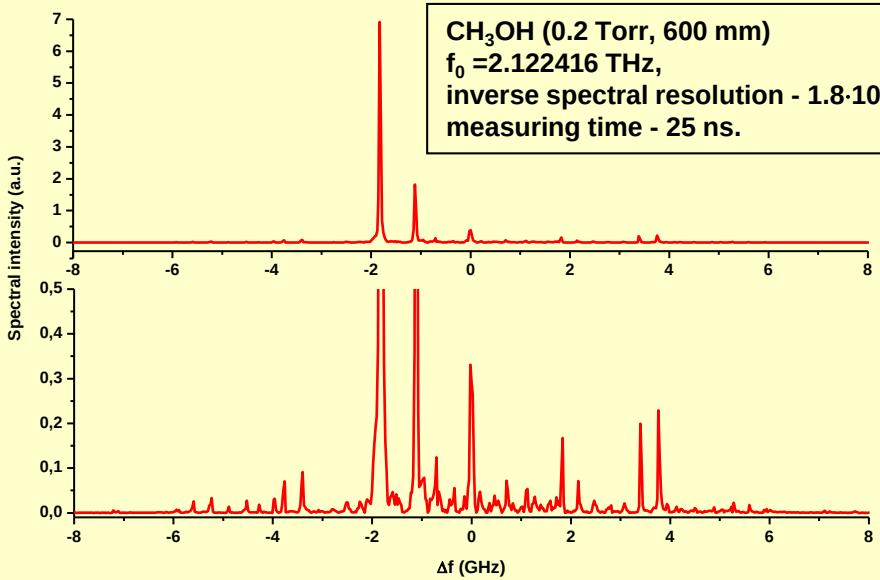


E N Chesnokov, V V Kubarev, P V Koshlyakov and G N Kulipanov, "Very long terahertz free induction decay in gaseous hydrogen bromide", Laser Phys. Lett. 10, 055701 (2013).

Ultrafast (single pulse) time-domain spectrometer

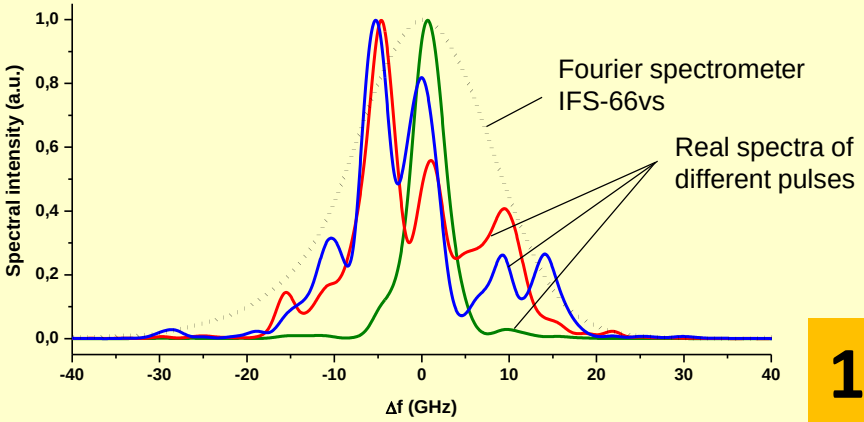




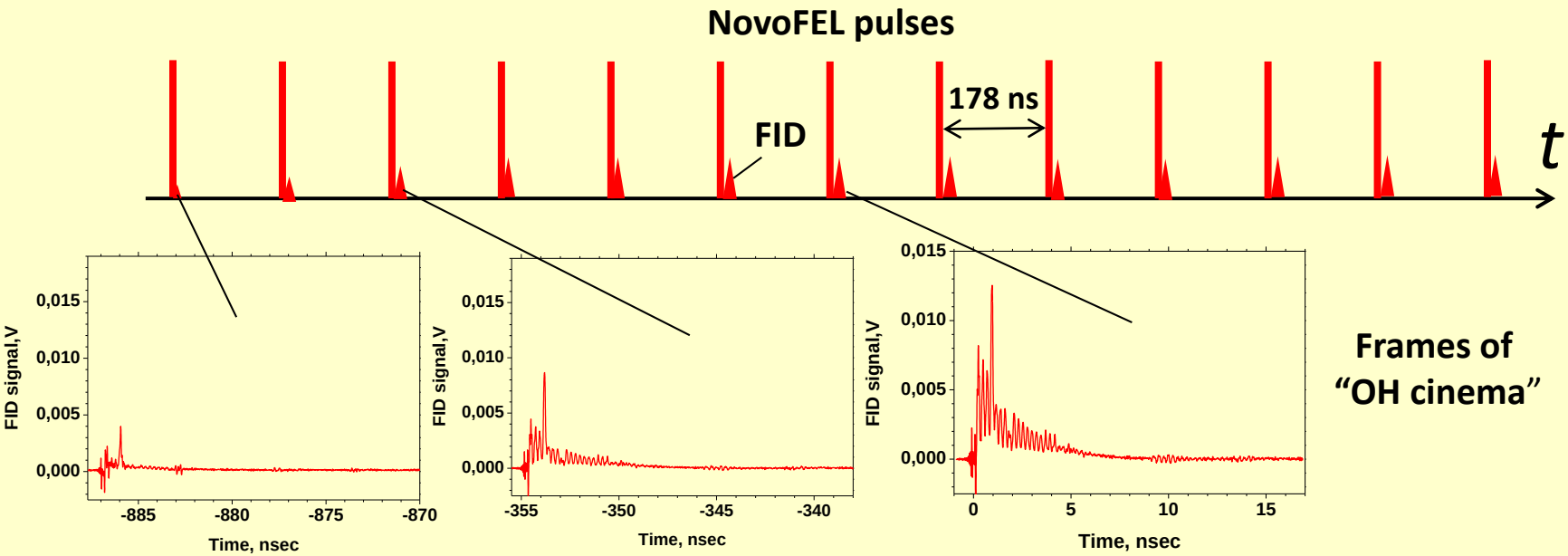


CH_3OH (0.2 Torr, 600 mm)
f_0 =2.122416 THz,
inverse spectral resolution - $1.8 \cdot 10^{-5}$,
measuring time - 25 ns.

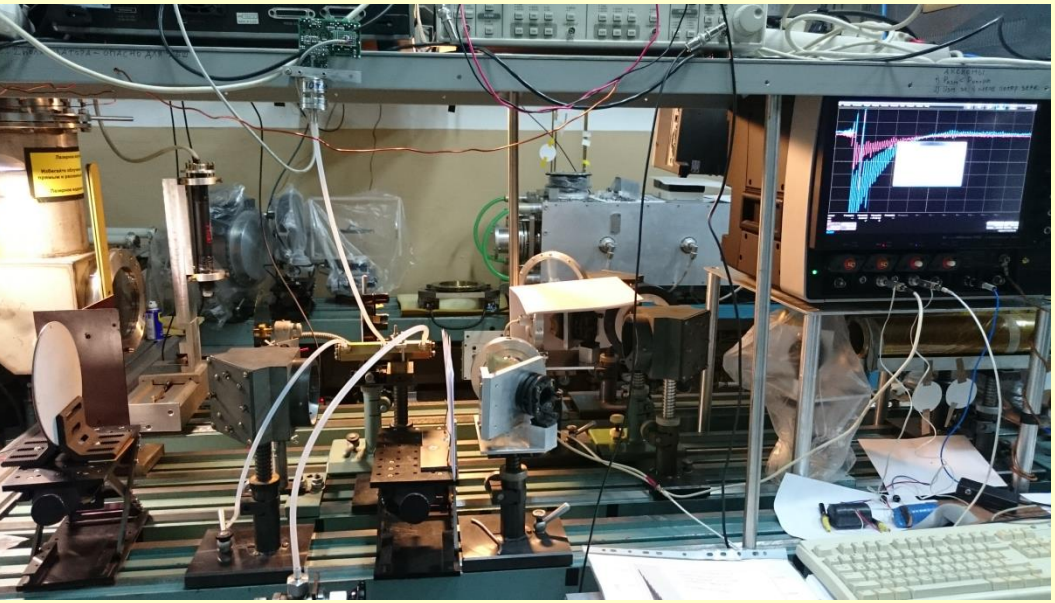
NovoFEL spectra, Regime of strong SB-instability:
Integral spectral width – $9 \cdot 10^{-3}$ (18 GHz)
f_0 = 2.12 THz,
Inverse spectral resolution – $1.2 \cdot 10^{-3}$,
Measuring time – 0.4 ns.



Fast photochemistry: Dynamics of OH radical

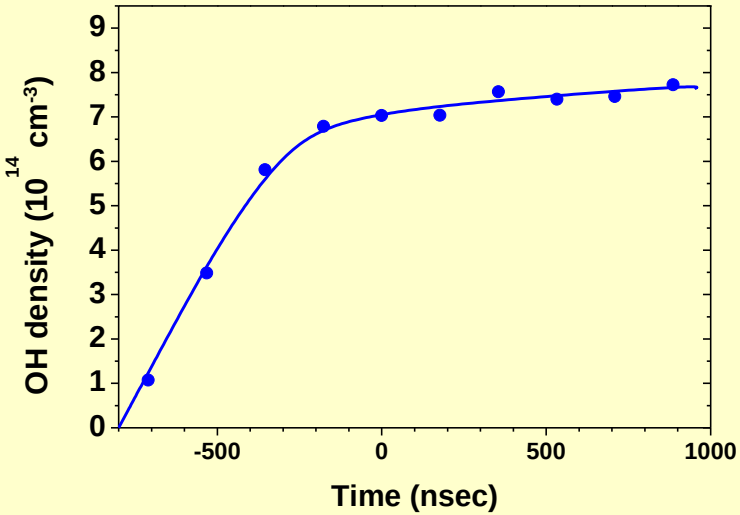


Frames of "OH cinema"



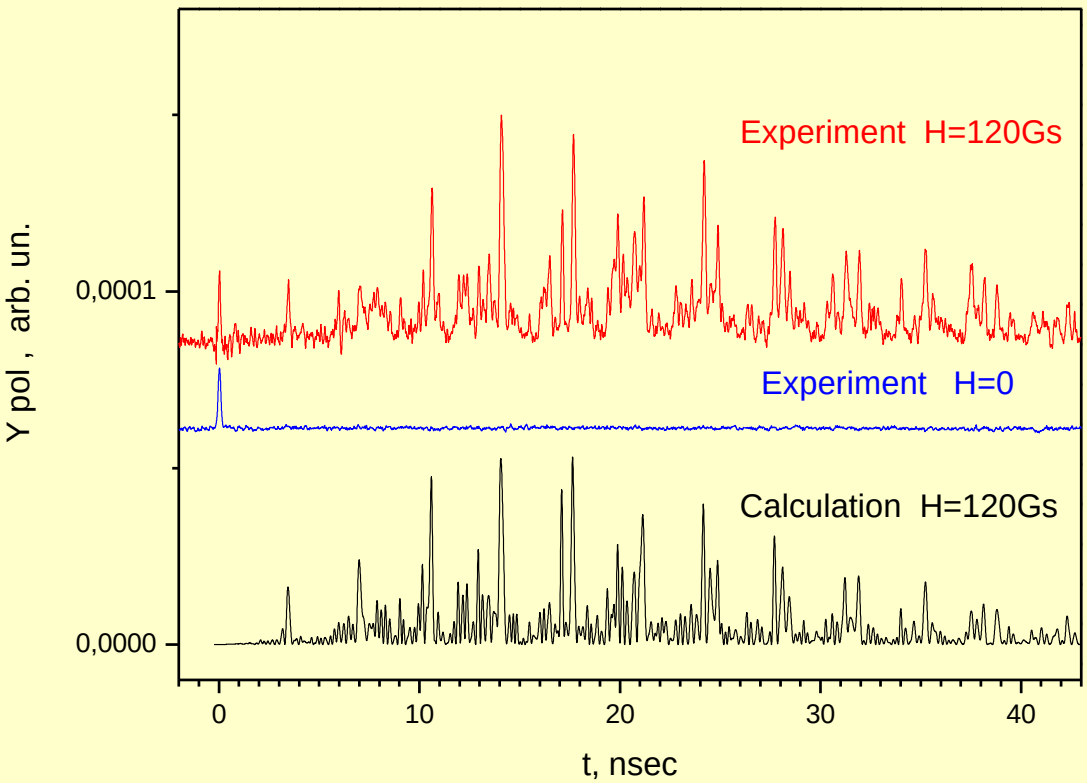
Generation of OH radicals:

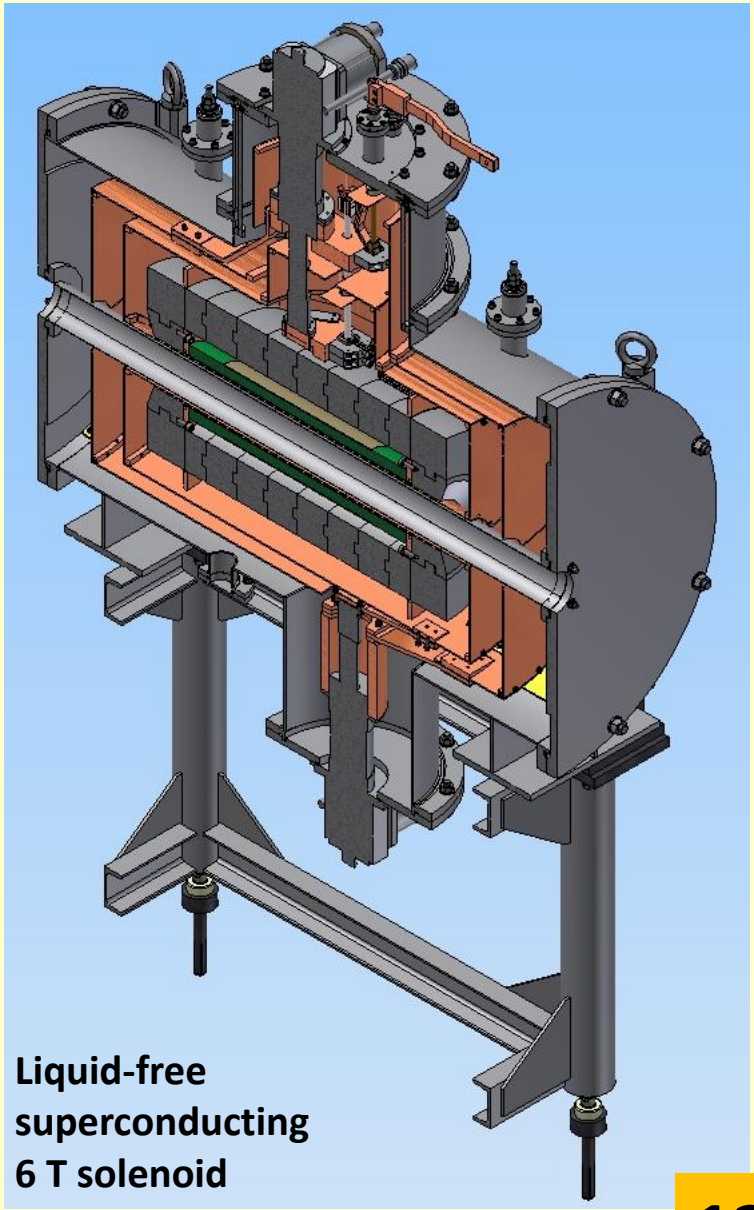
$$O_3 + (h\nu = 266\ \text{nm}) \rightarrow O(^1D) + O_2$$
$$O(^1D) + H_2O \rightarrow 2\ OH$$



Sensitive FID spectroscopy in magnetic fields

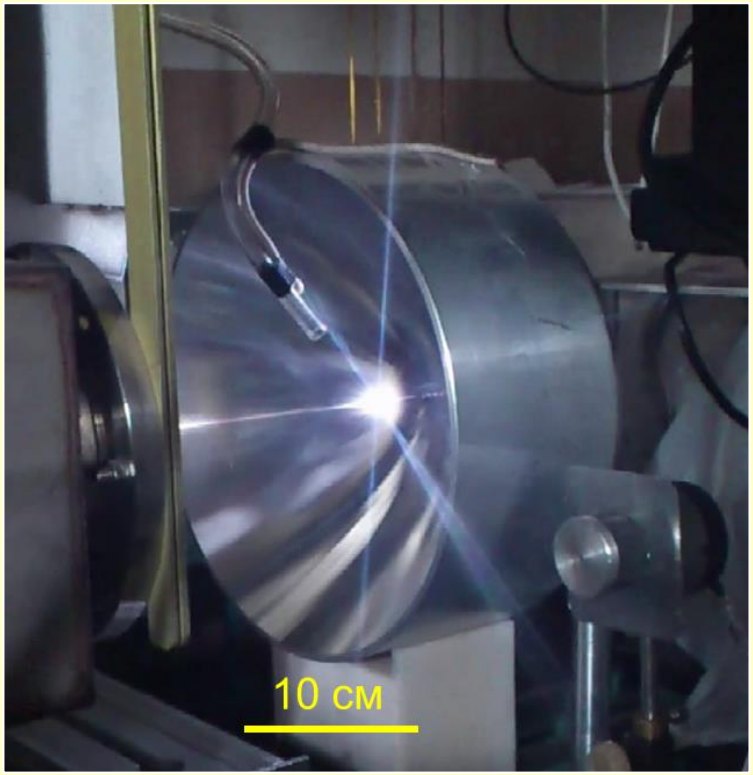
$P(NO_2)$= 1 Torr
L = 40 cm
Fully closed polarizer

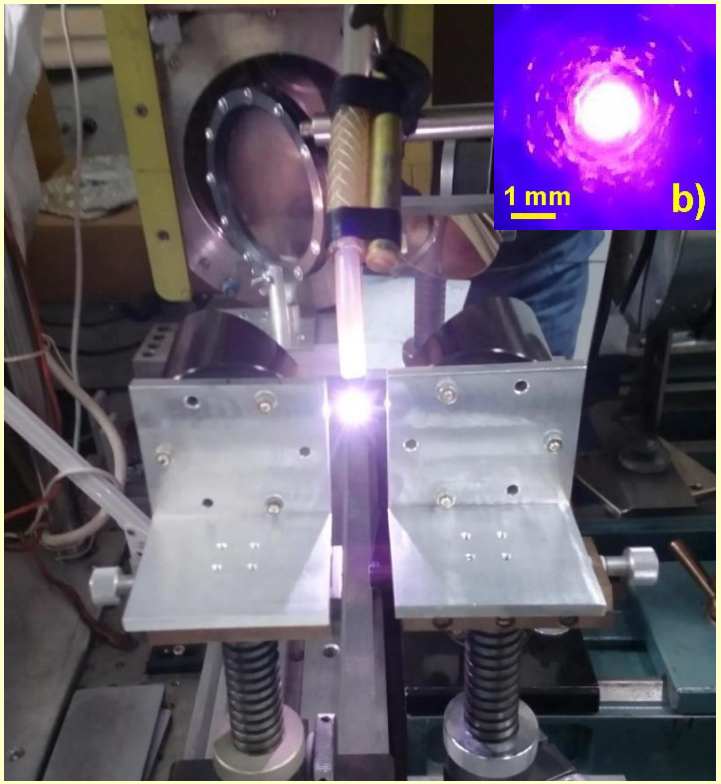




Liquid-free superconducting 6 T solenoid

Terahertz optical discharge





Intensities for ignition and quenching of CW optical discharge sustained by 66-ps pulses of NovoFEL at λ = 130 mm

Gas	Ar	He	N_2	Air	CO_2
Breakdown threshold (GW/cm^2)	1.1	1.18	1.23	1.36	1.38
Quenching intensity (GW/cm^2)	0.51	0.91	1.00	0.90	1.20

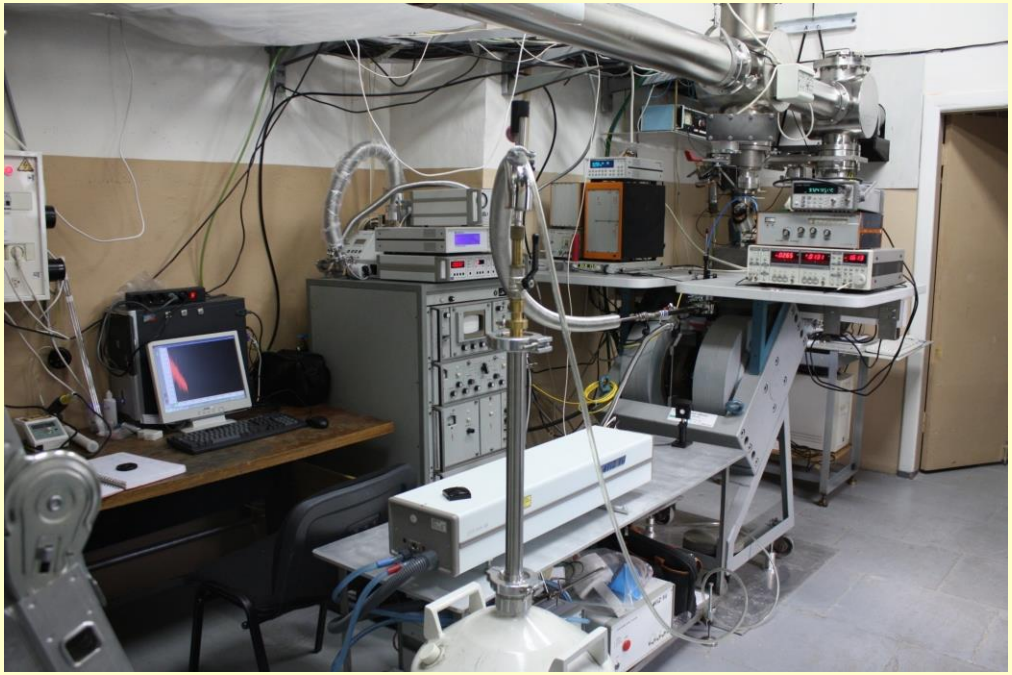
High-temterature point stabilized CW optical discharge in argon:

P = 1 atm

T = 30 000 K° (record value)

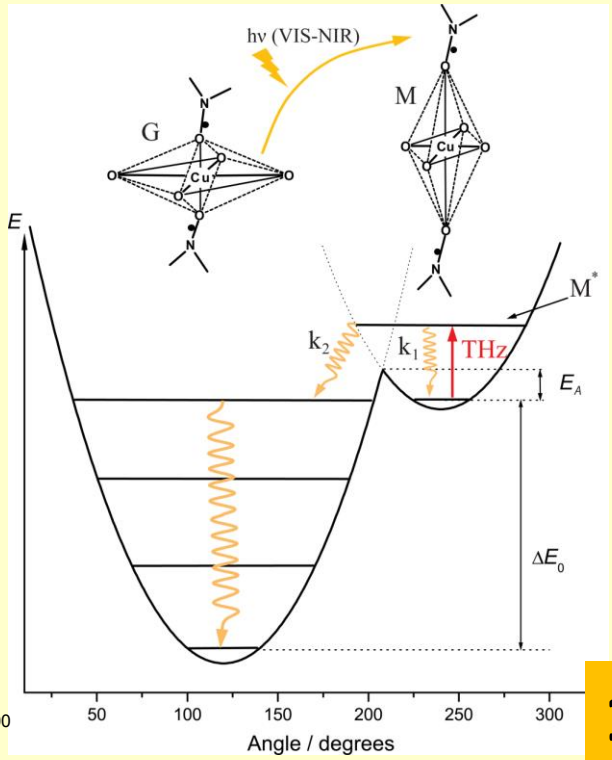
THz range is optimal for high-temperature optical discharge

EPR spectroscopy. Spintronics of magnetoactive materials

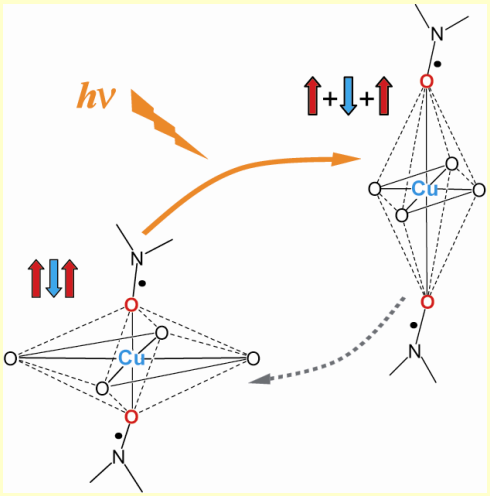


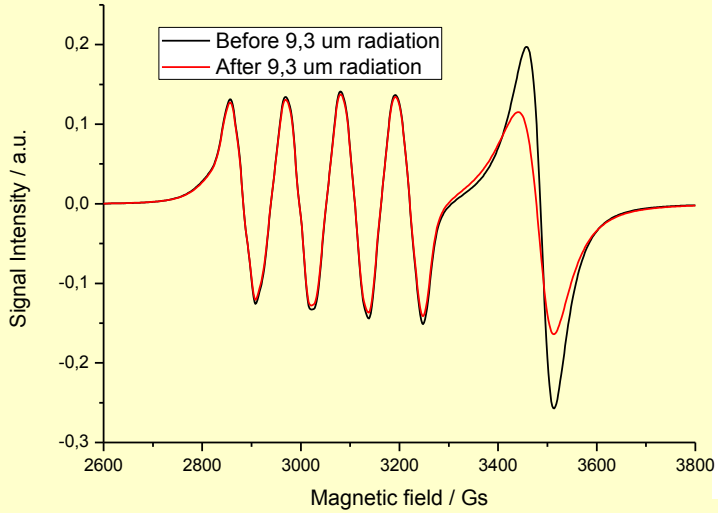
Infrared NovoFEL: switch up
Terahertz NovoFEL: switch down

THz-induced backward conversion of the metastable states in $Cu(hfac)_2L^{Pr}$



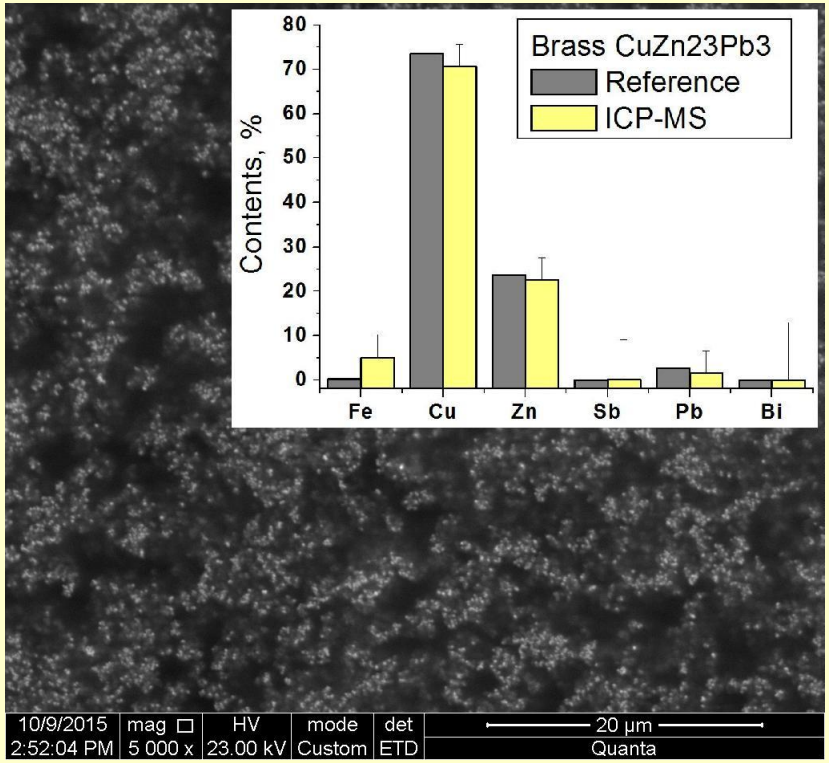
Influence of IR-light to the spin state of photoswitchable copper(II)-nitroxide magnetoactive compound $Cu(hfac)_2L^{Pr}$

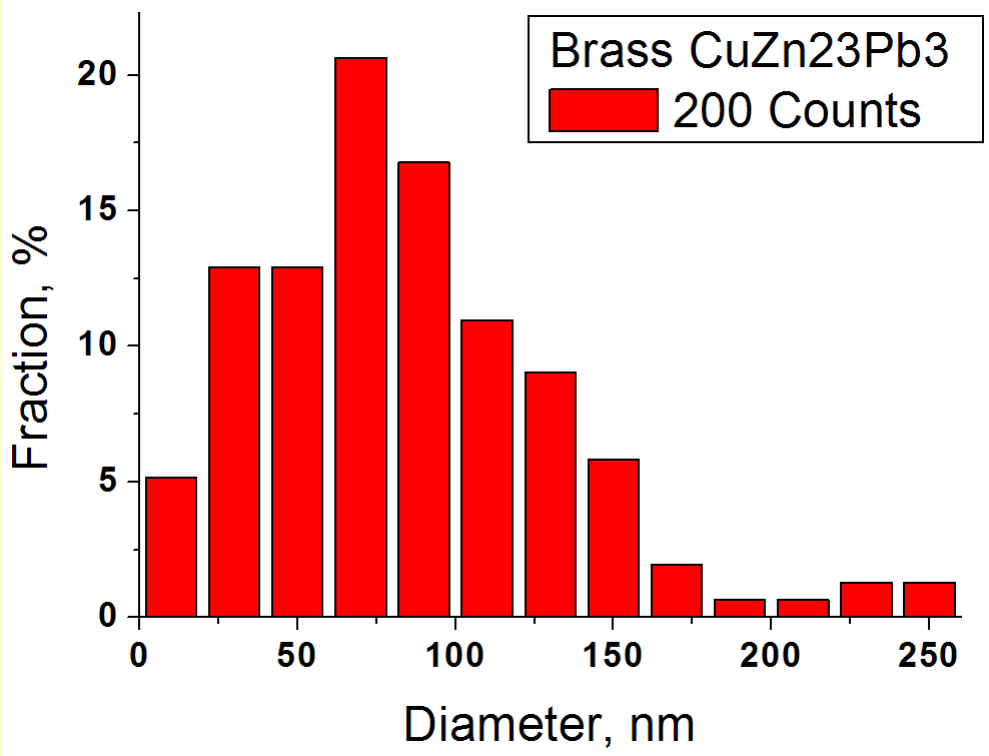




Nanoparticles. Ablation by ultra-sonic waves in water

Terahertz irradiation (5.6 MHz) of water results in formation of nanosized hydrosols of cell material



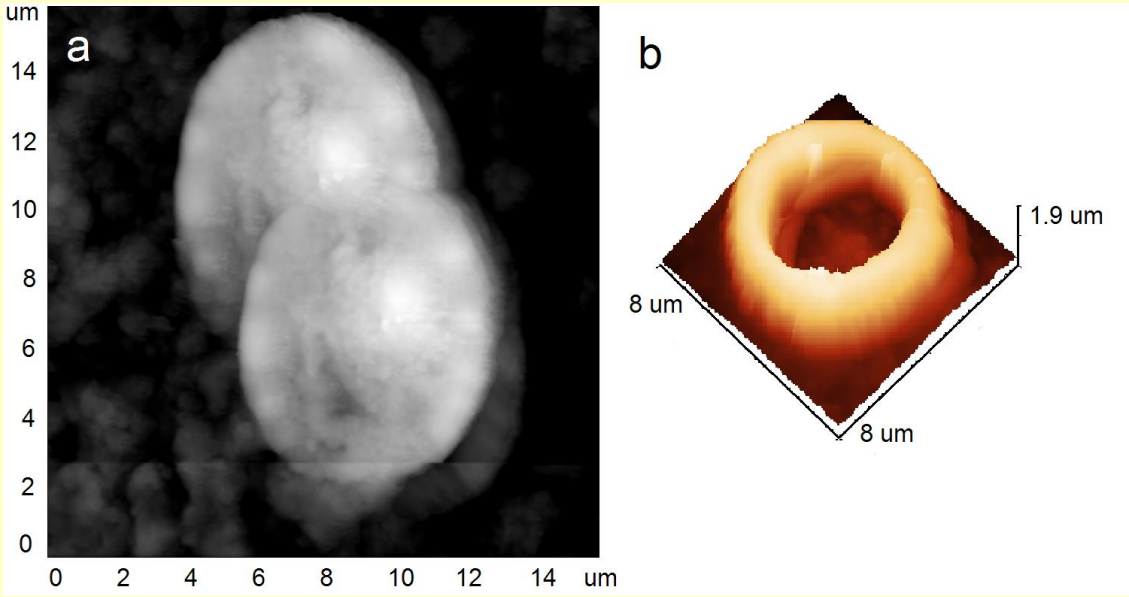


Laser: Wavelength: 130±2 µm. Average power: 20W.
Pulse power: <1MW. Pulse length: 30-100ps. Repetition rate 5.6MHz.
Exposition conditions: atmospheric pressure, room temperature. Duration: 5-10sec.
Materials: Inert alloys, ceramics, graphite, etc., distilled water: 50-100µl.
Particle diameters (N½): 50-80nm. Concentration: $<10^{10}cm^{-3}$ (1-2mg/l)

Specific damage of living systems by ultra sonic waves unduced pulse-periodical THz radiation

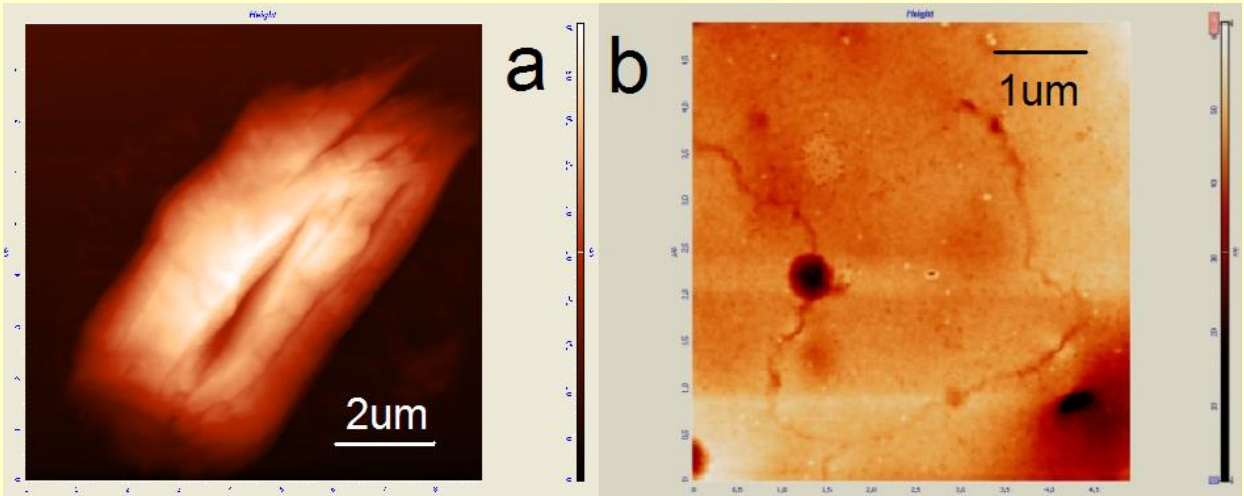
AFM characterization showed that morphological changes are completely destructive after 15-seconds of THz radiation exposition

Initial:
a - hepatocytes
b - erythrocyte

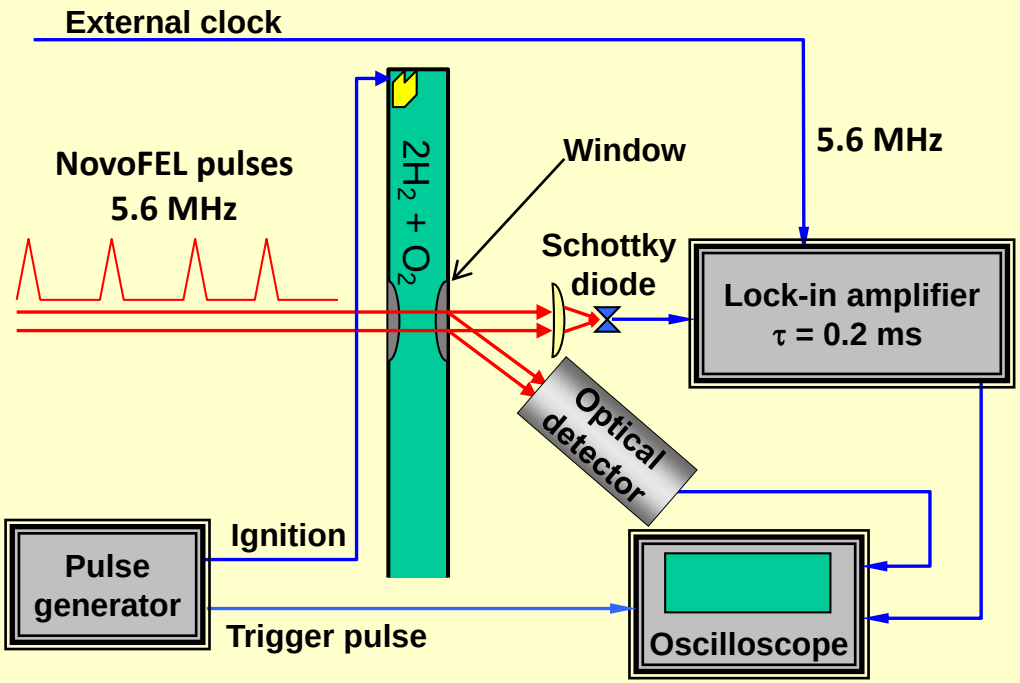


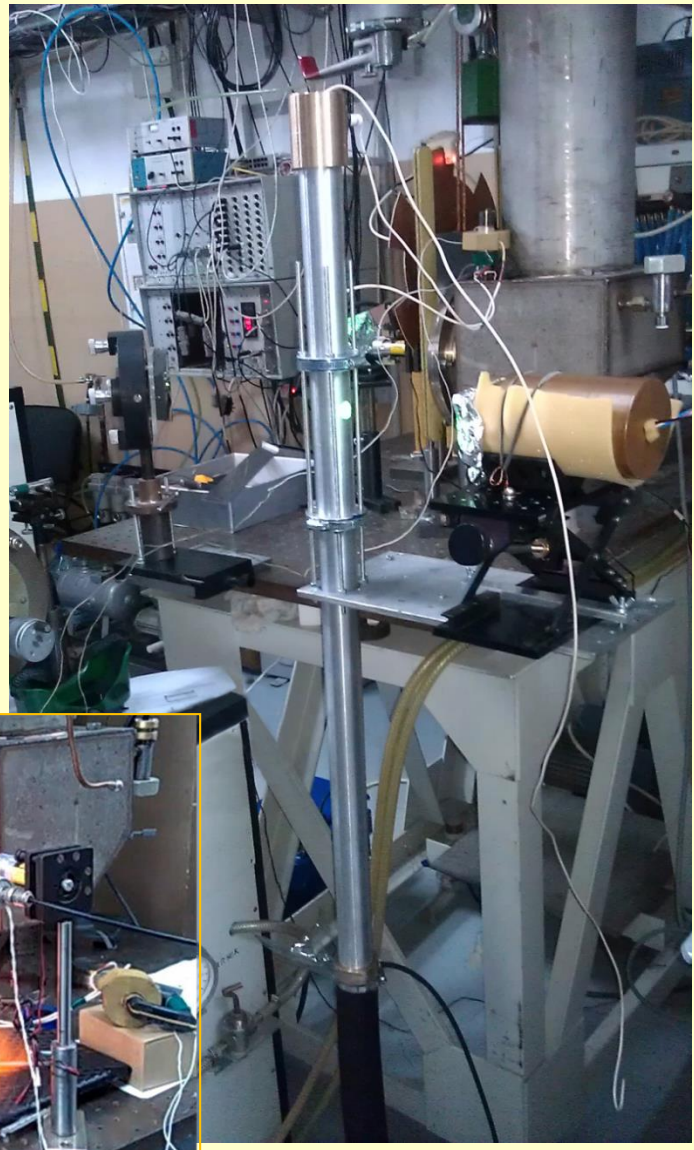
Exposed 15sec
1ml, 20W/cm^2:

Membrane pores and cracks



Dynamics of burning and detonation in hydrogen-oxygen mixture

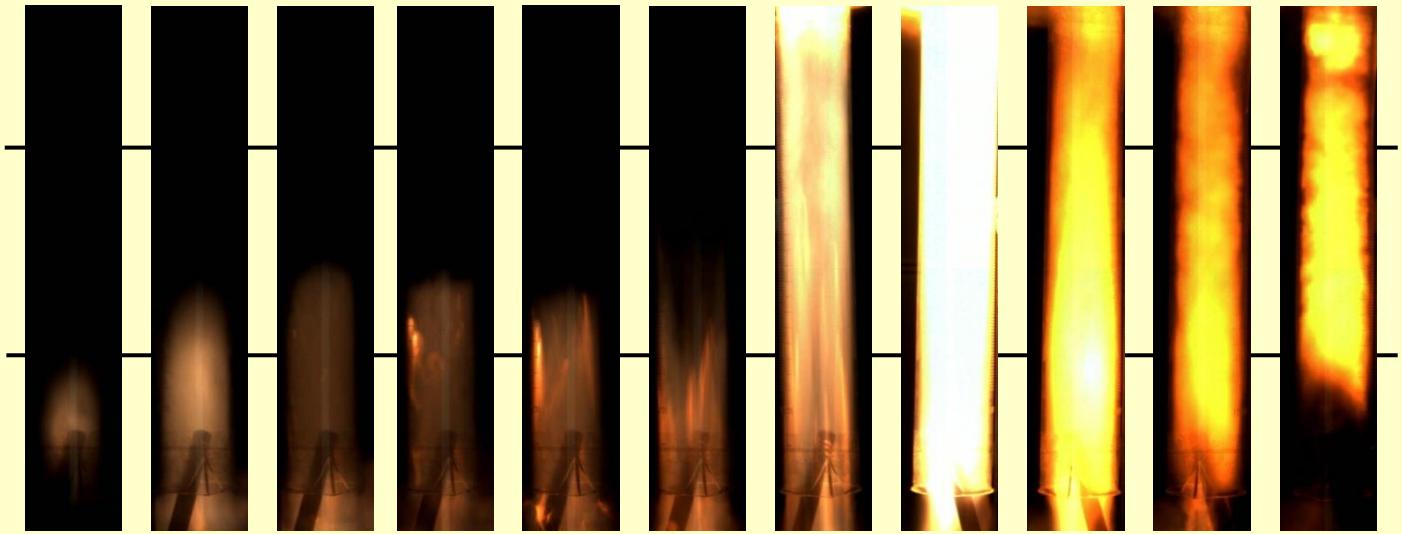




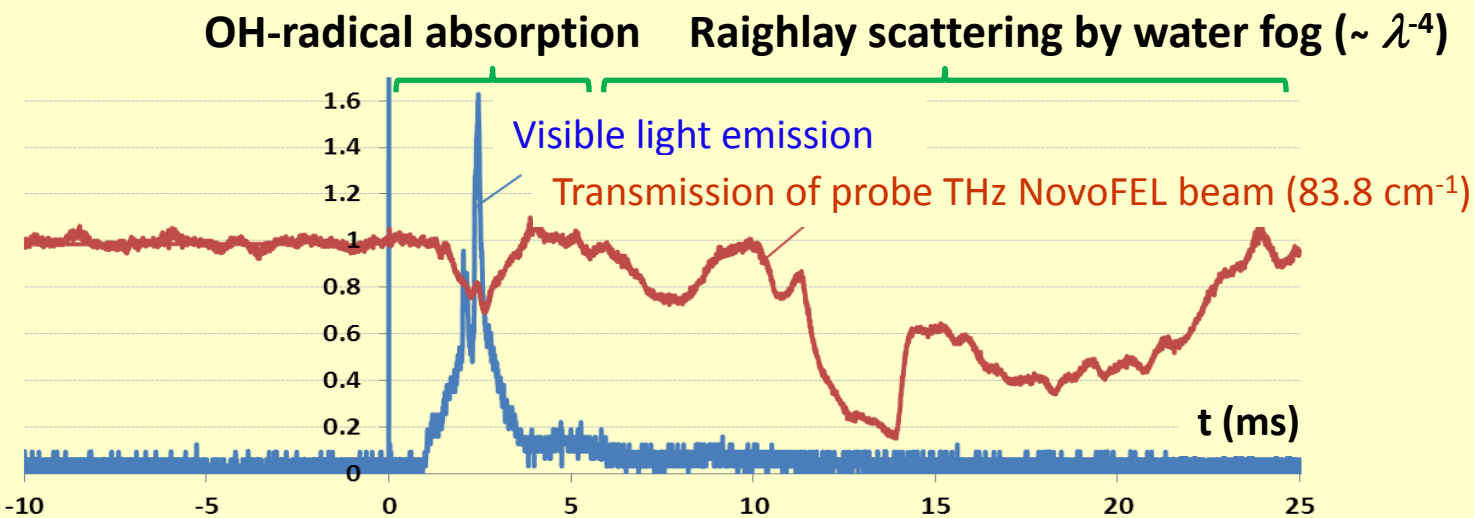
Wavelength of NovoFEL is tuned to a determined absorption line of H_2O or OH radical

Dynamics of burning and detonation in hydrogen-oxygen mixture

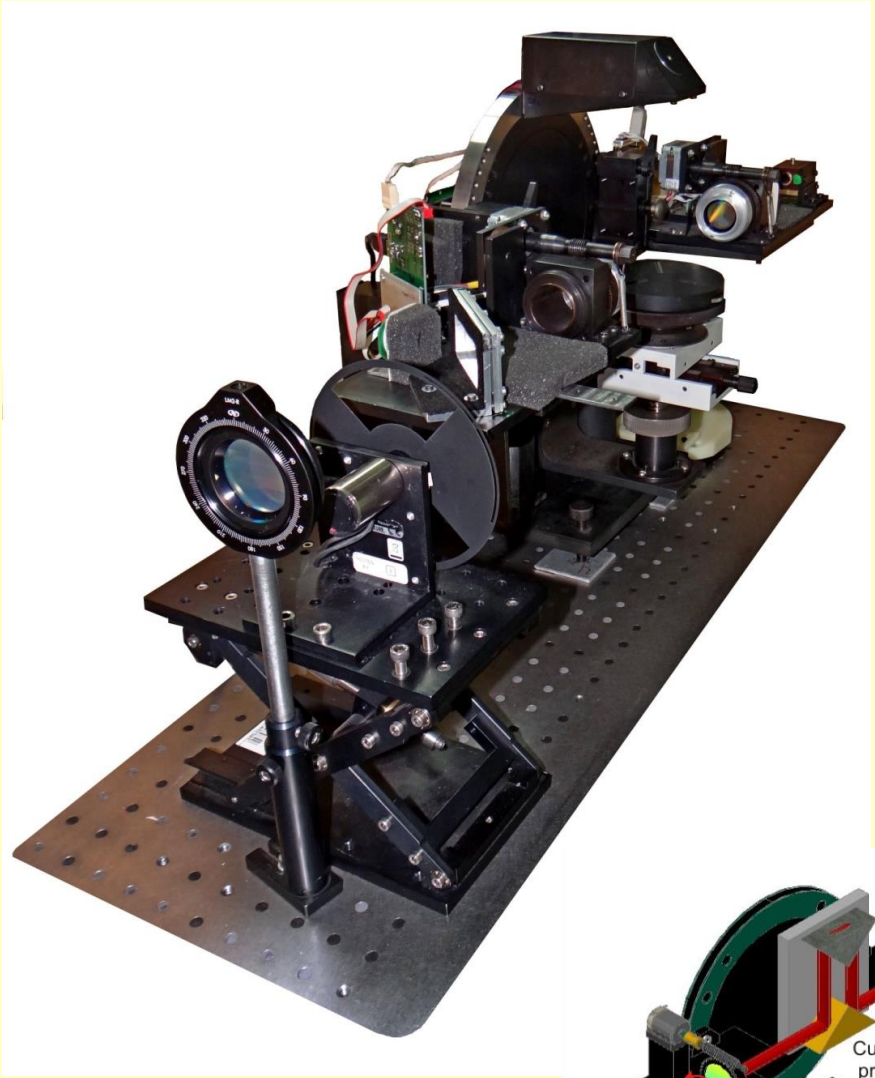
High-speed image acquisition of detonation in transparent pipe



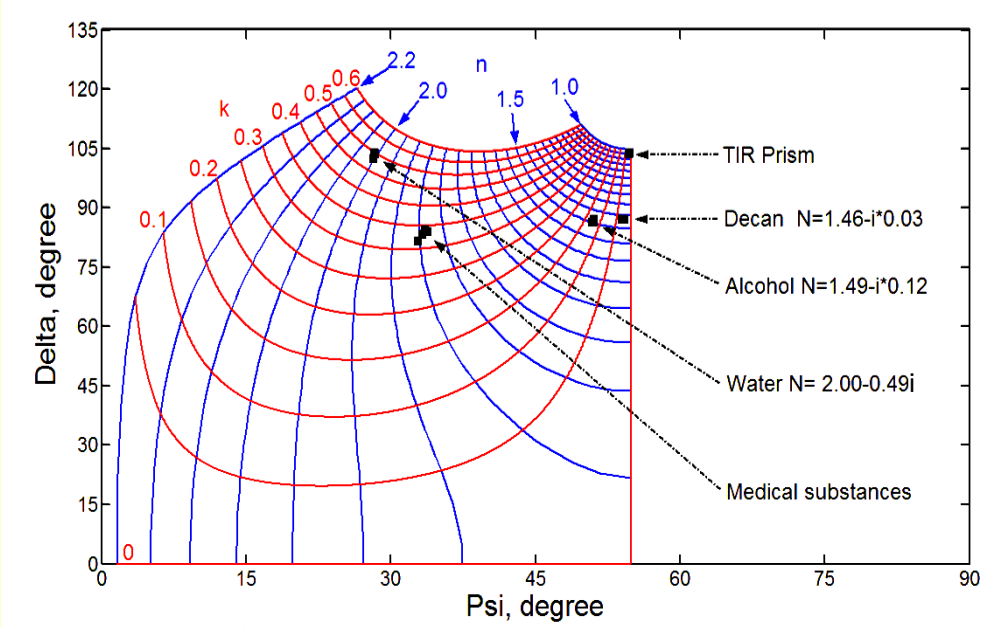
1 ms 4 ms

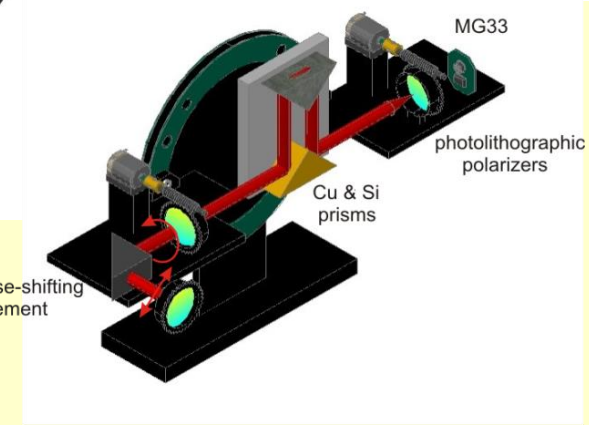


Material optical properties. THz ellipsometry

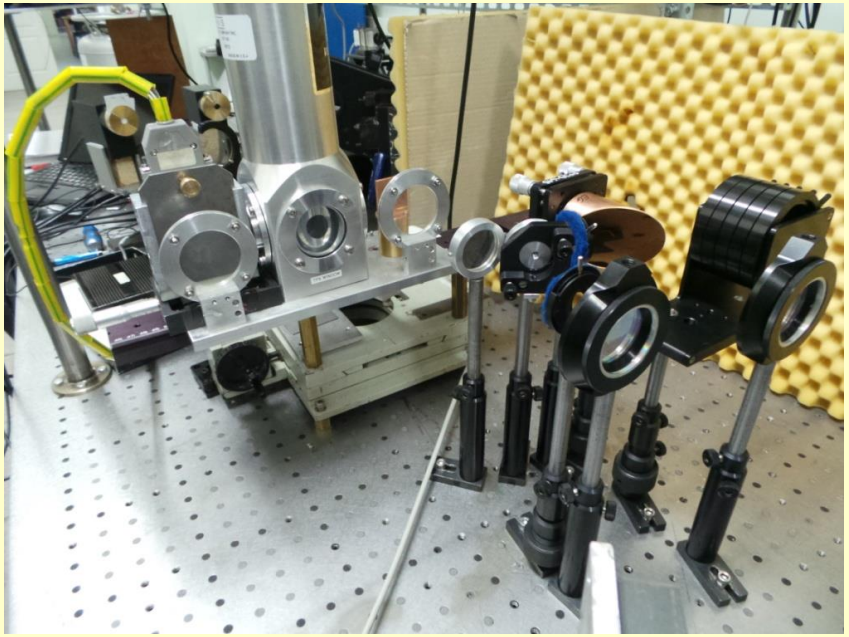


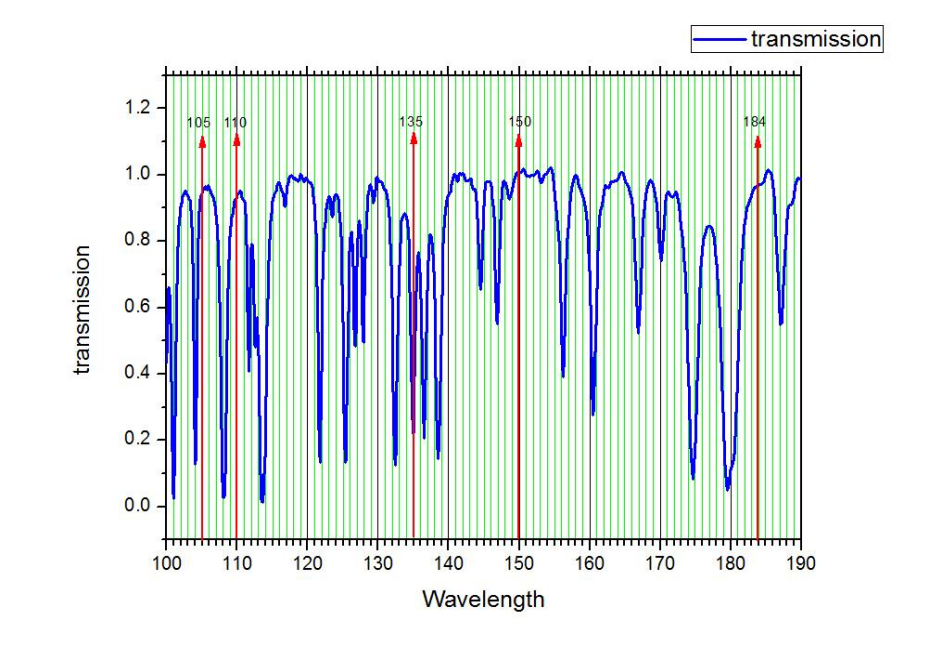
Accuracy of measurements of ellipsometric parameters is 0.5° for ψ and 0.03 for cos(Δ)

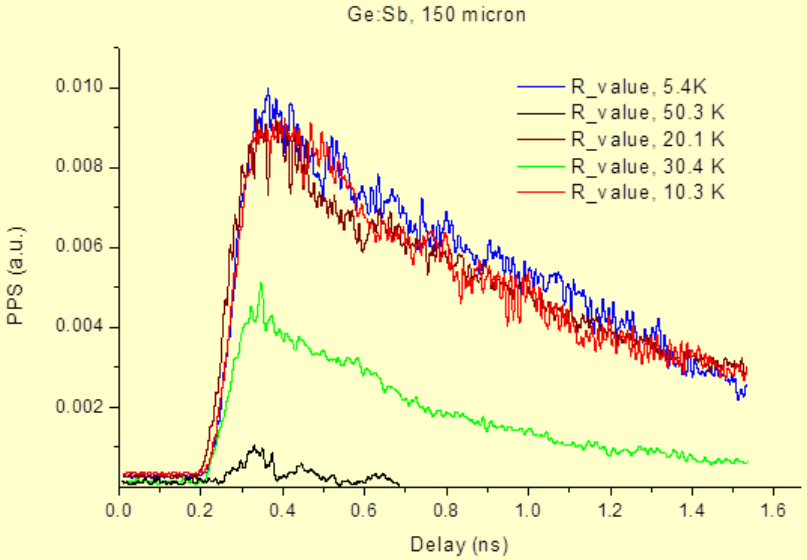


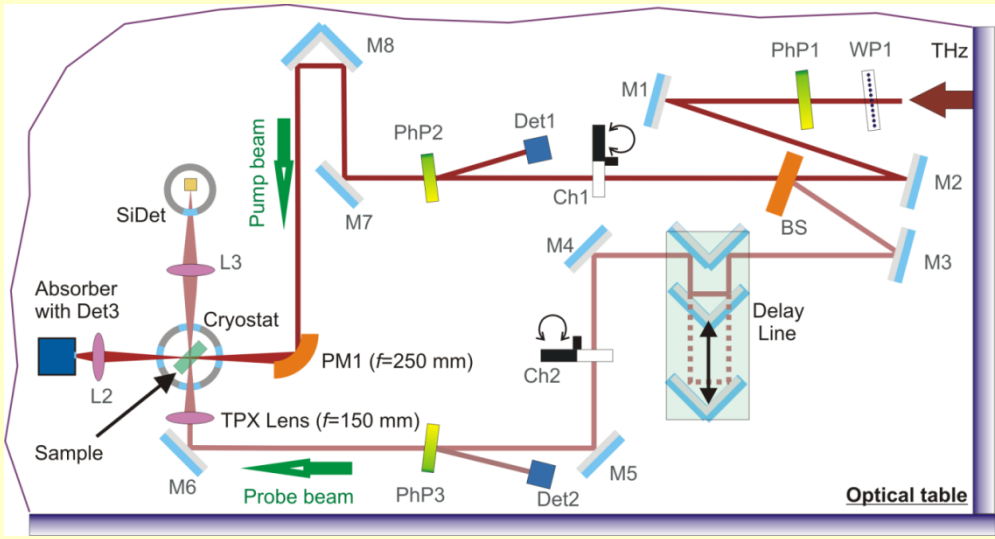


Semiconductors. One-color THz pump-probe spectroscopy



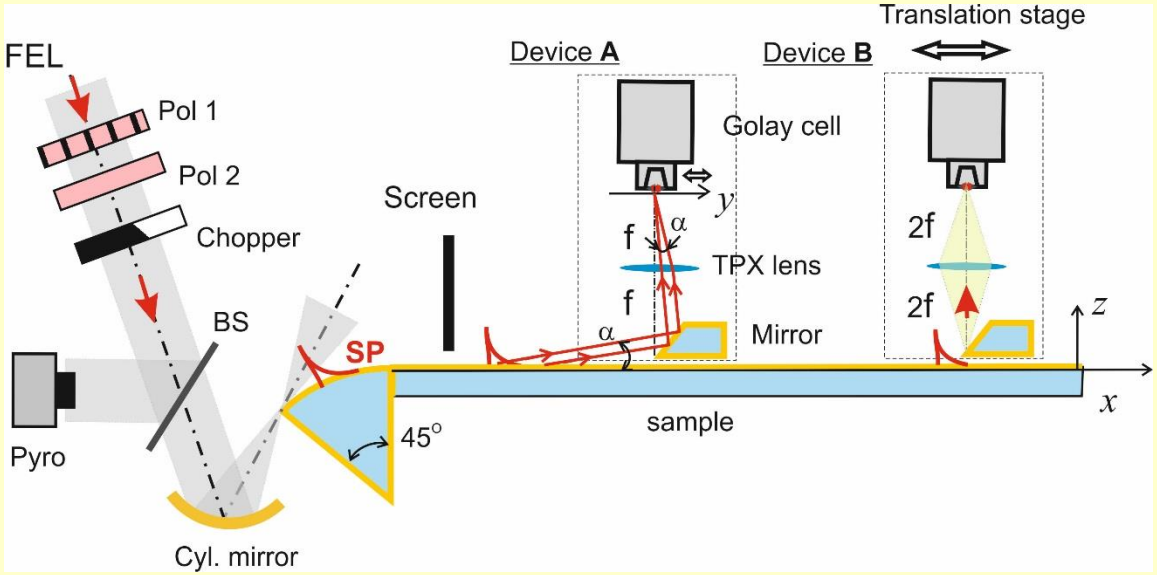




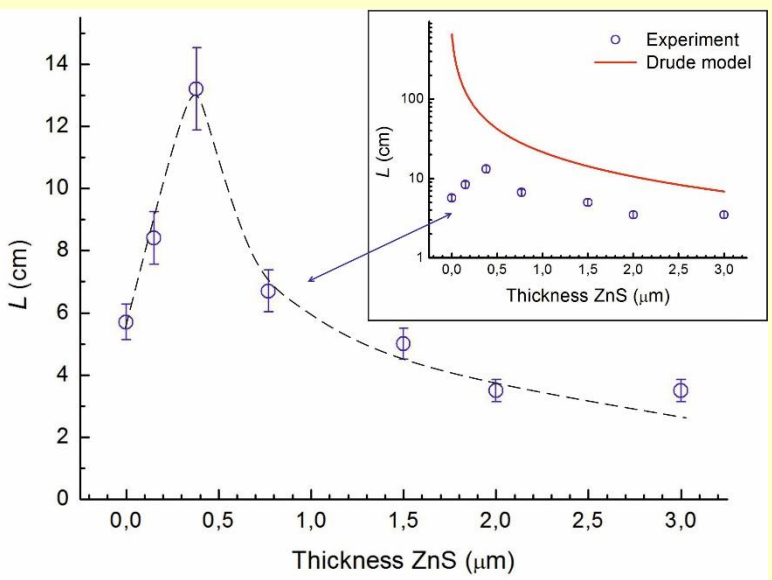


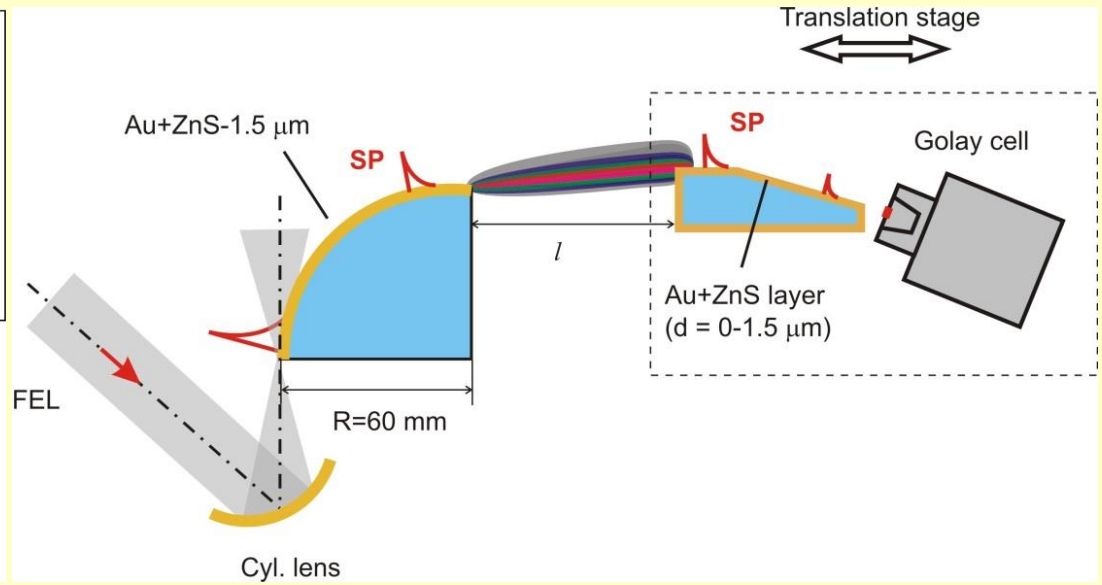
Relaxation time of excited states in GeSb (GeGa, GeAs) is important for creation of detectors and lasers

Surface plasmon polaritons (SPPs) in the terahertz range



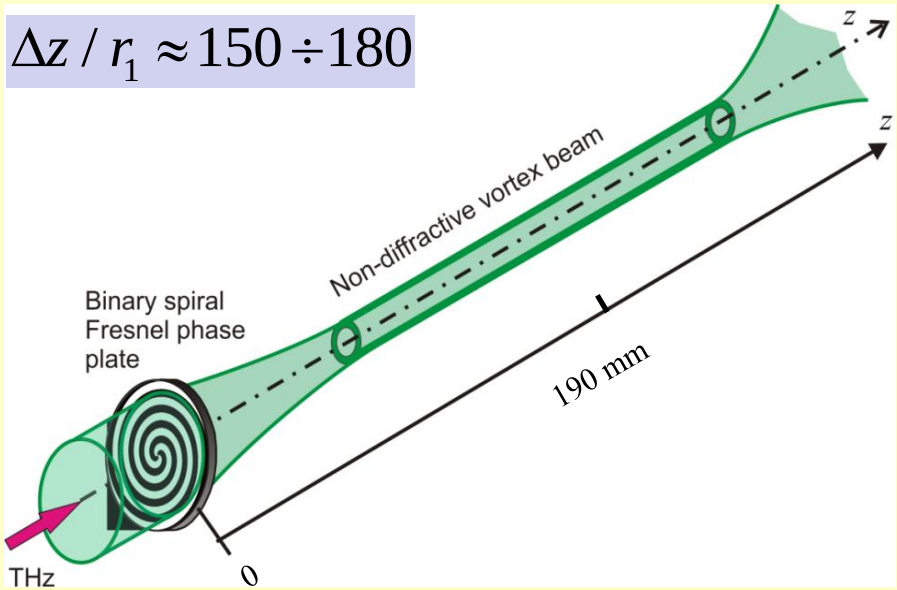
- Techniques for study SPP in the terahertz range have been developed
- Peculiarity of SPP propagation along metal-dielectric in THz

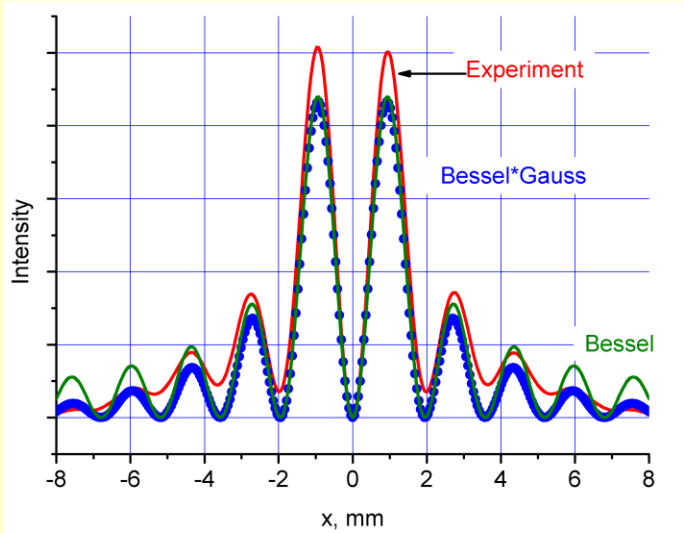




THz Bessel beams with angular orbital momentum

$$\Delta z / r_1 \approx 150 \div 180$$





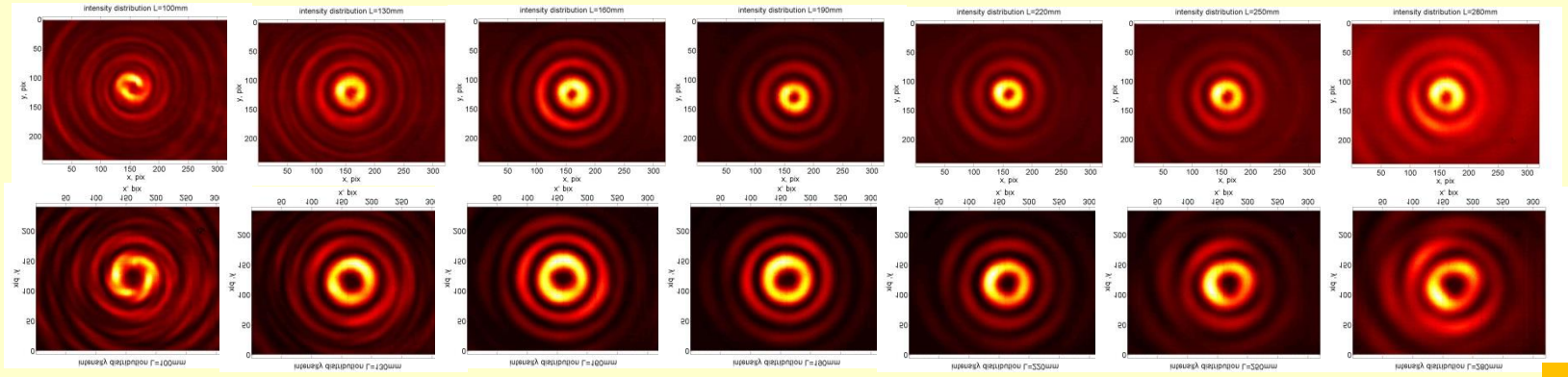
$$BG_{|l|}(r,\varphi,z=0) = J_{|l|}(\alpha_l r)\,\mathrm{e}^{-\frac{r^2}{\omega_0^2}+il\varphi}$$

Experiment:

z = 100 130 160 190 220 250 280 mm

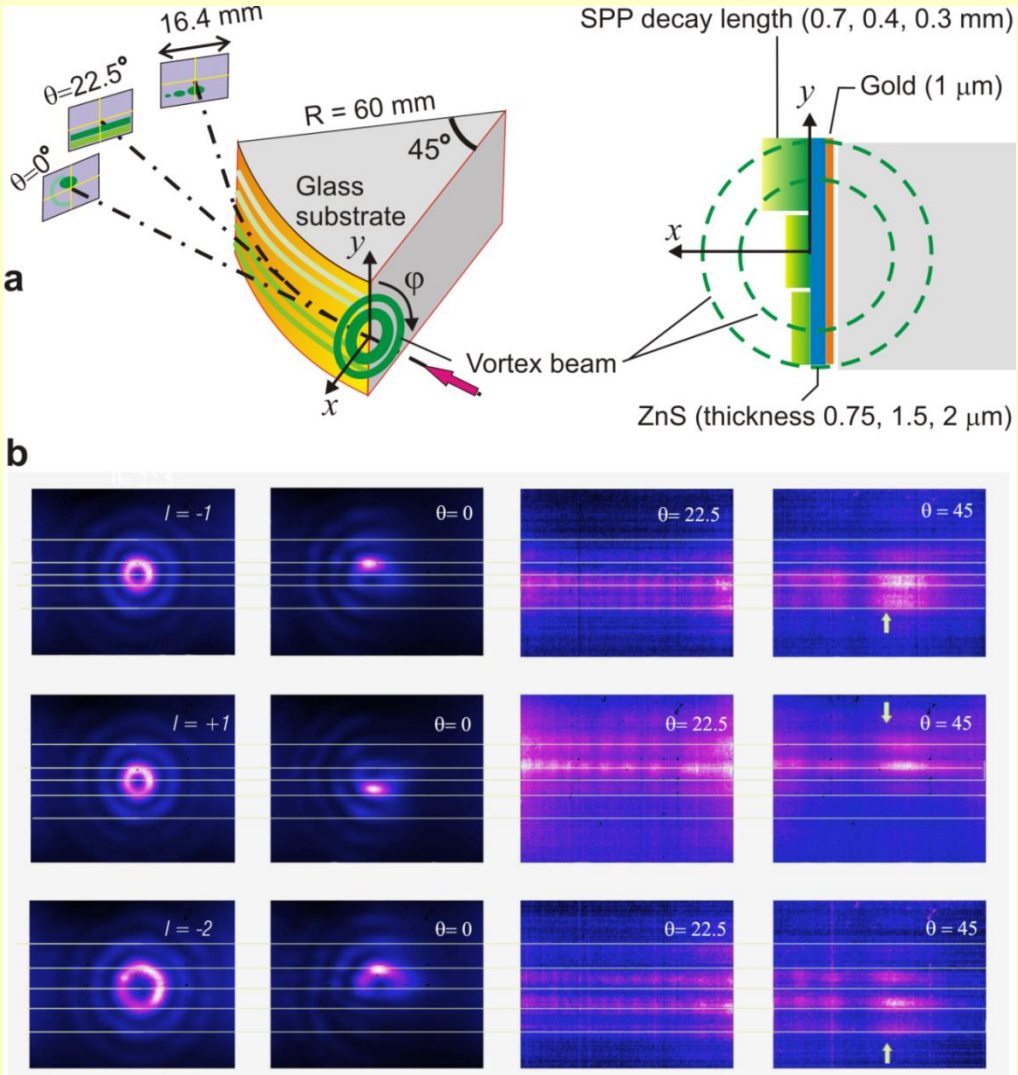
$l = +1$

$l = +2$

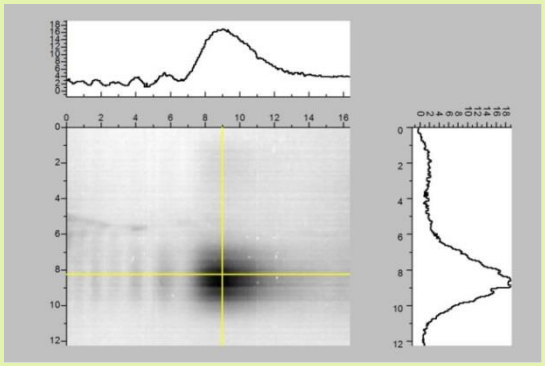


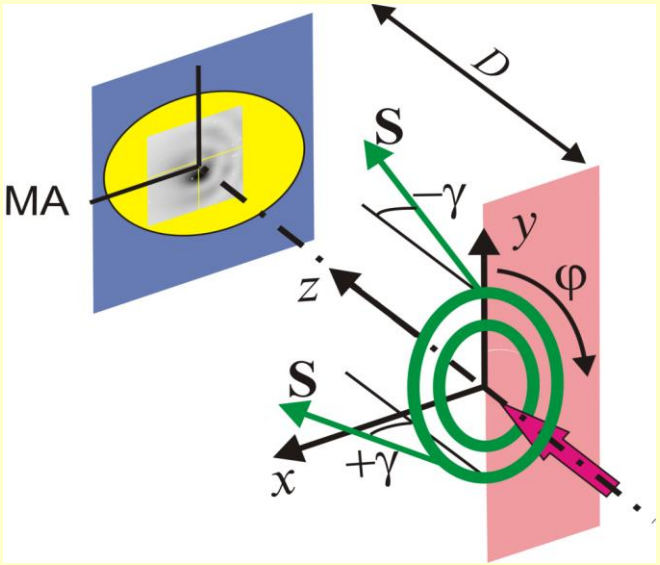
Surface plasmon polaritons and beams with angular orbital momentum

Efficiency of the generation of SPPs depends on direction of beam rotation



Diffraction of conventional beam, θ = 45 degrees

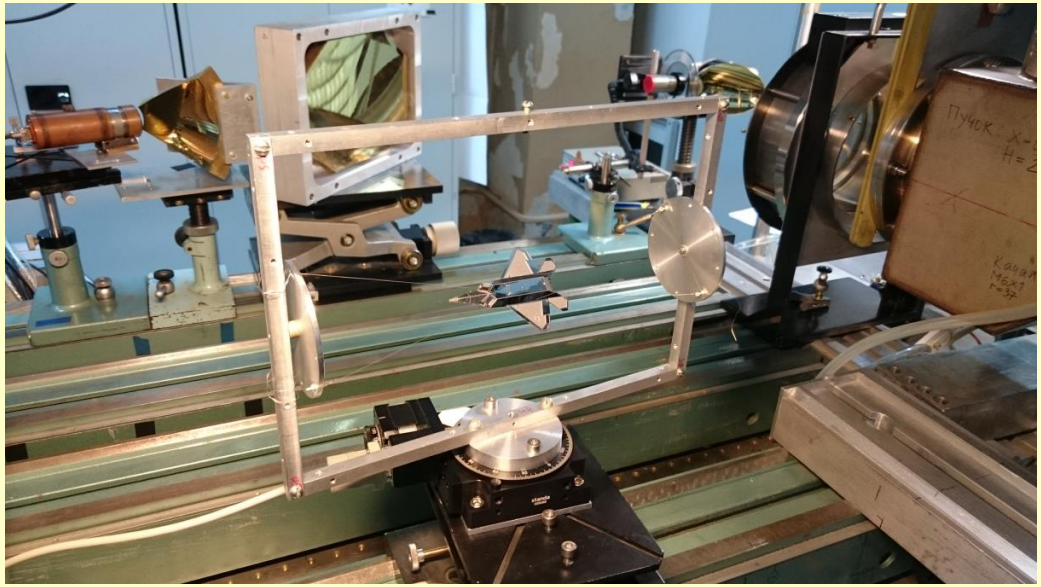


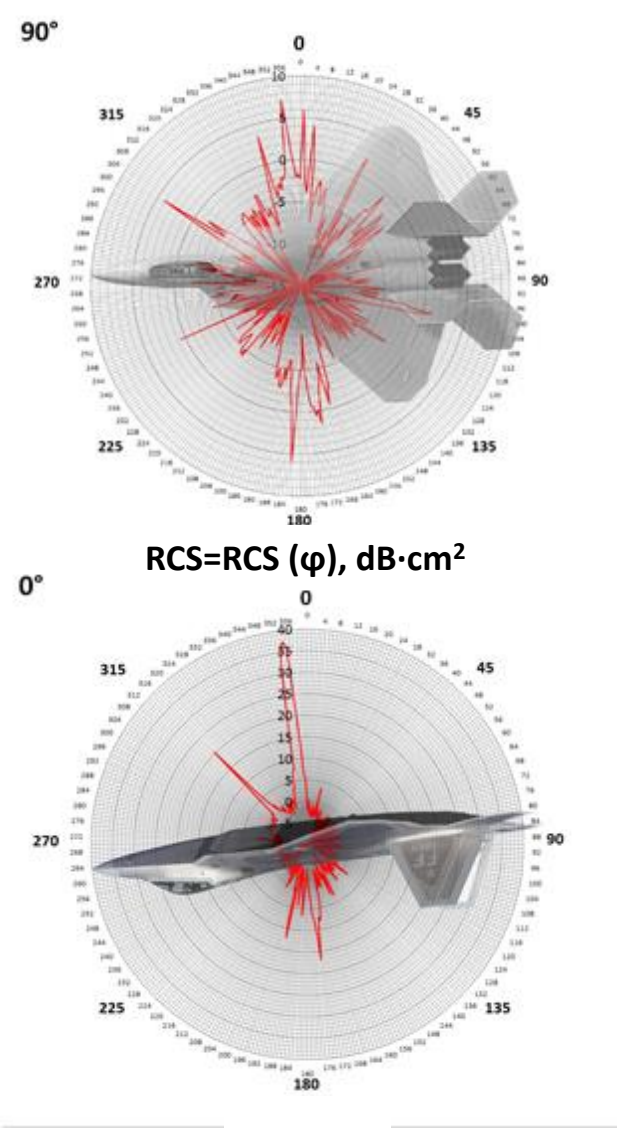


B. A. Knyazev, at al., Phys. Rev. Letters, V. 115, 163901, 2015, 5p.

Measuring of radar cross-section (RCS)

Scale modelling: $L_0^* = \frac{\lambda_0}{\lambda_M} L_M^*; \quad S_0^* = \frac{\lambda_0^2}{\lambda_M^2} S_M^*;$ λ_0 – GHz, λ_M - THz





Thank you for your attention !