Novosibirsk free electron laser as a user facility

E. N. Chesnokov, Yu. Yu. Choporova, V. V. Gerasimov, Ya. V. Getmanov, B. G. Goldenberg, B. A. Knyazev, A. S. Kozlov, V. V. Kubarev, G. N. Kulipanov, V. S. Pavelyev, S. E. Peltek, A. K. Petrov, V. M. Popik, T. V. Salikova, M. A. Scheglov, S. S. Serednіakov, O. A. Shevchenko, A. N. Skrinsky, S. L. Veber, N. A. Vinokurov

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SFR-2016, Novosibirsk, July 4 - 7, 2016

Special thanks to our collaborators

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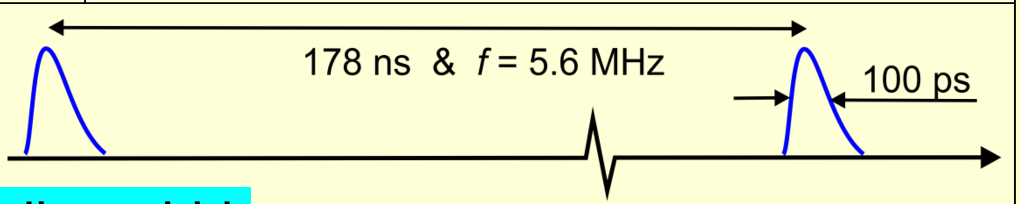
Novosibirsk free electron laser

NovoFEL facility is first multi-turn energy recovery linear accelerator with three individual laser systems

NovoFEL radiation parameters

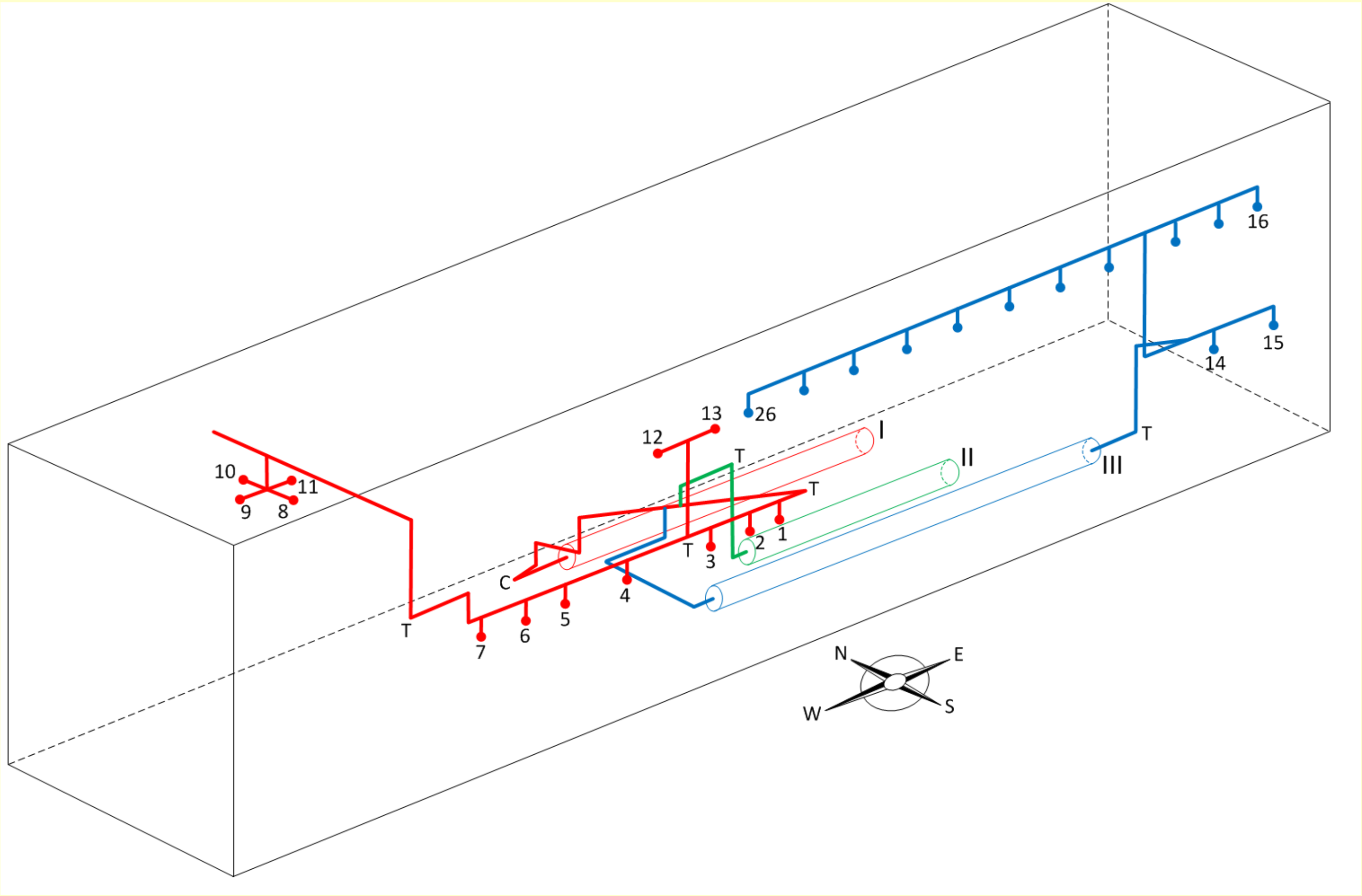
Laser	Terahertz	Far-Infrared	Infrared
Status	In operation since 2003	In operation since 2009	In operation since 2015
Wavelength, μm	90 – 240	37 – 80	8 – 11
Relative line width (FWHM), %	0.2 – 2.0	0.2 - 1	0.1 - 1
Maximum average power, kW	0.5	0.5	0.1
Maximum peak power, MW	0.5	2.0	10
Pulse duration, ps	30 - 120	20 - 40	10 - 20
Pulse repetition rate, MHz	2.8 - 5.6 - 11.2 - 22.4		
Linear polarization degree, %	> 99.6		

- Tunability
- High power
- Relatively narrow line width



Transmission line

Transmission line



Beamline system at NovoFEL

1, 2, 3, …, 26 – workstations

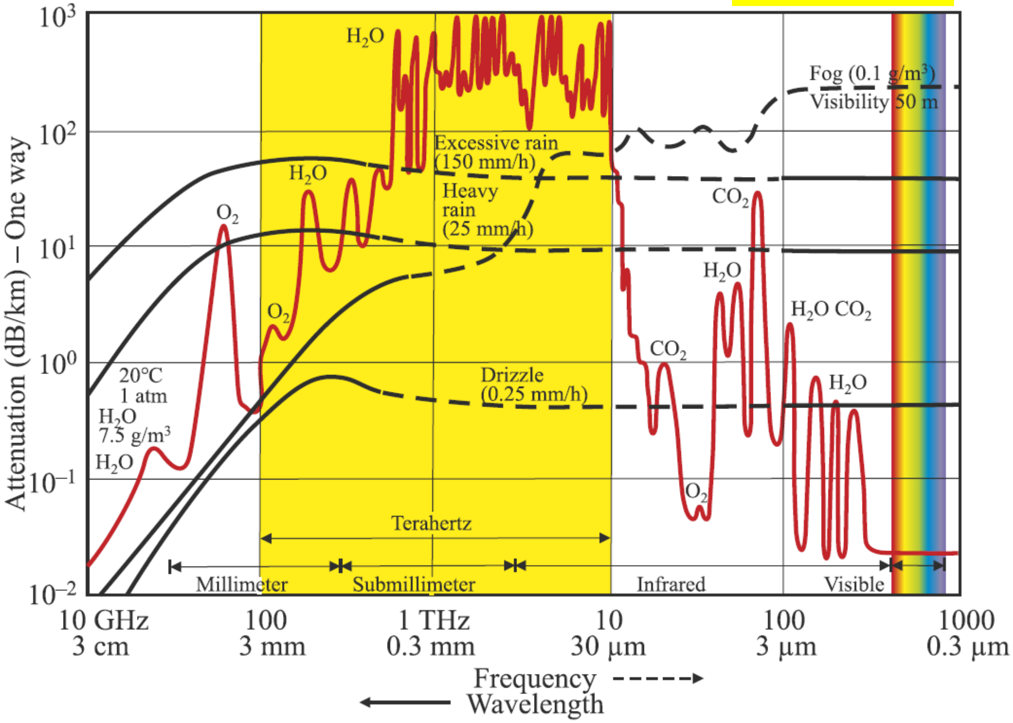
I (red) - Terahertz FEL
II (green) - Far infrared FEL
III (blue) - Infrared FEL

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

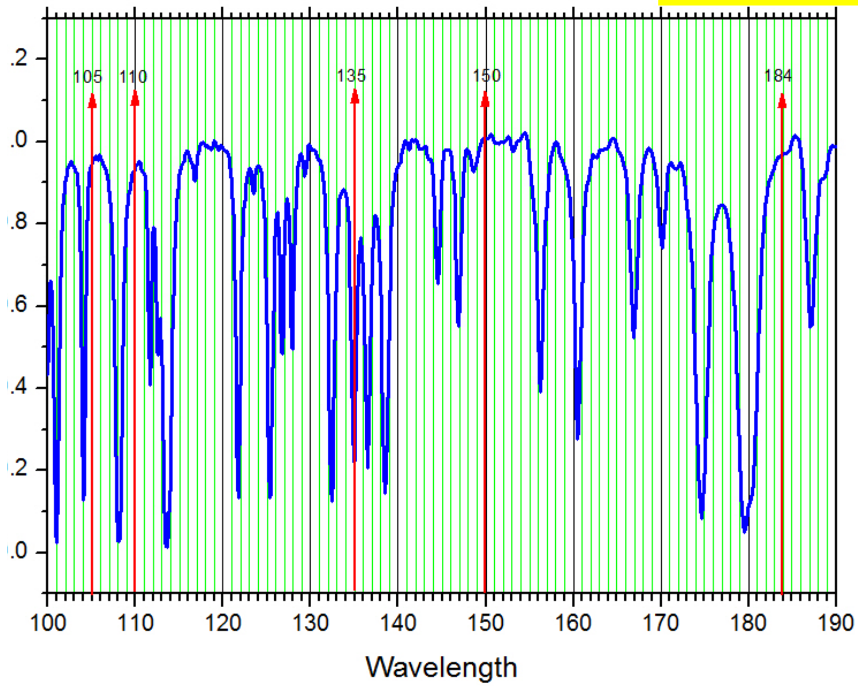
Transmission line

- Transmission line is filled with dry nitrogen
- Total length of the line is 120 m
- Laser radiation can be delivered to any workstation from any of three laser cavities

Attenuation



Transmission

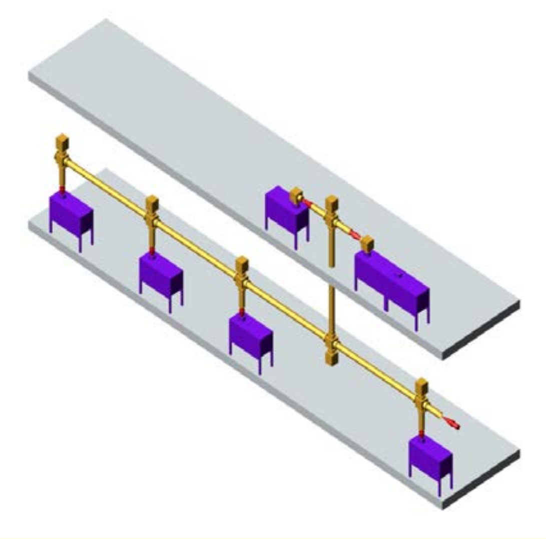


Workstations

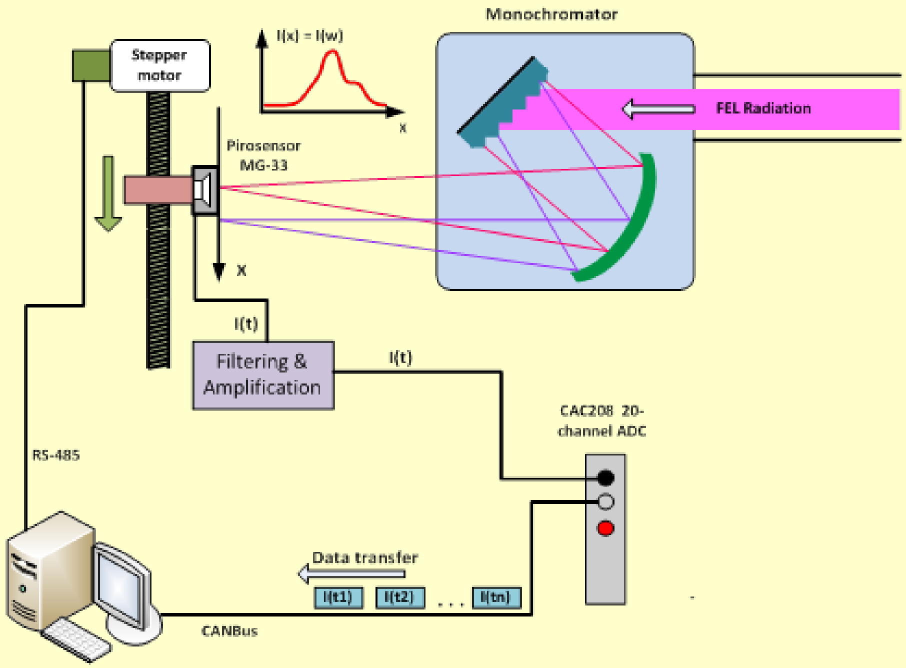
Seven workstation are in operation at NovoFEL
(more than 20 participating institutions)

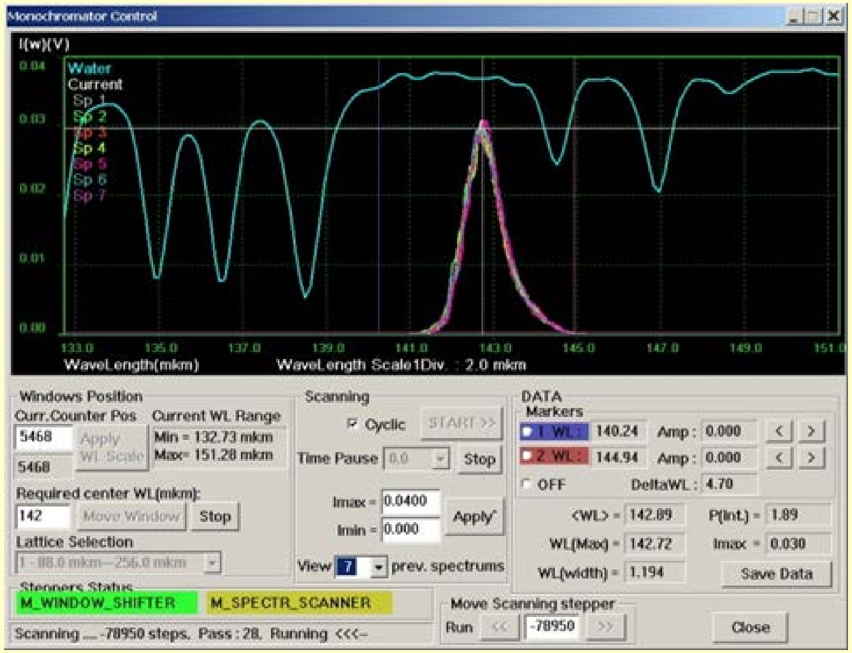
1. Radiation characteristics control
2. EPR spectroscopy
3. Biology and material science
4. Metrology
5. Molecular spectroscopy
6. Spectroscopy and imaging

+ Stations under construction



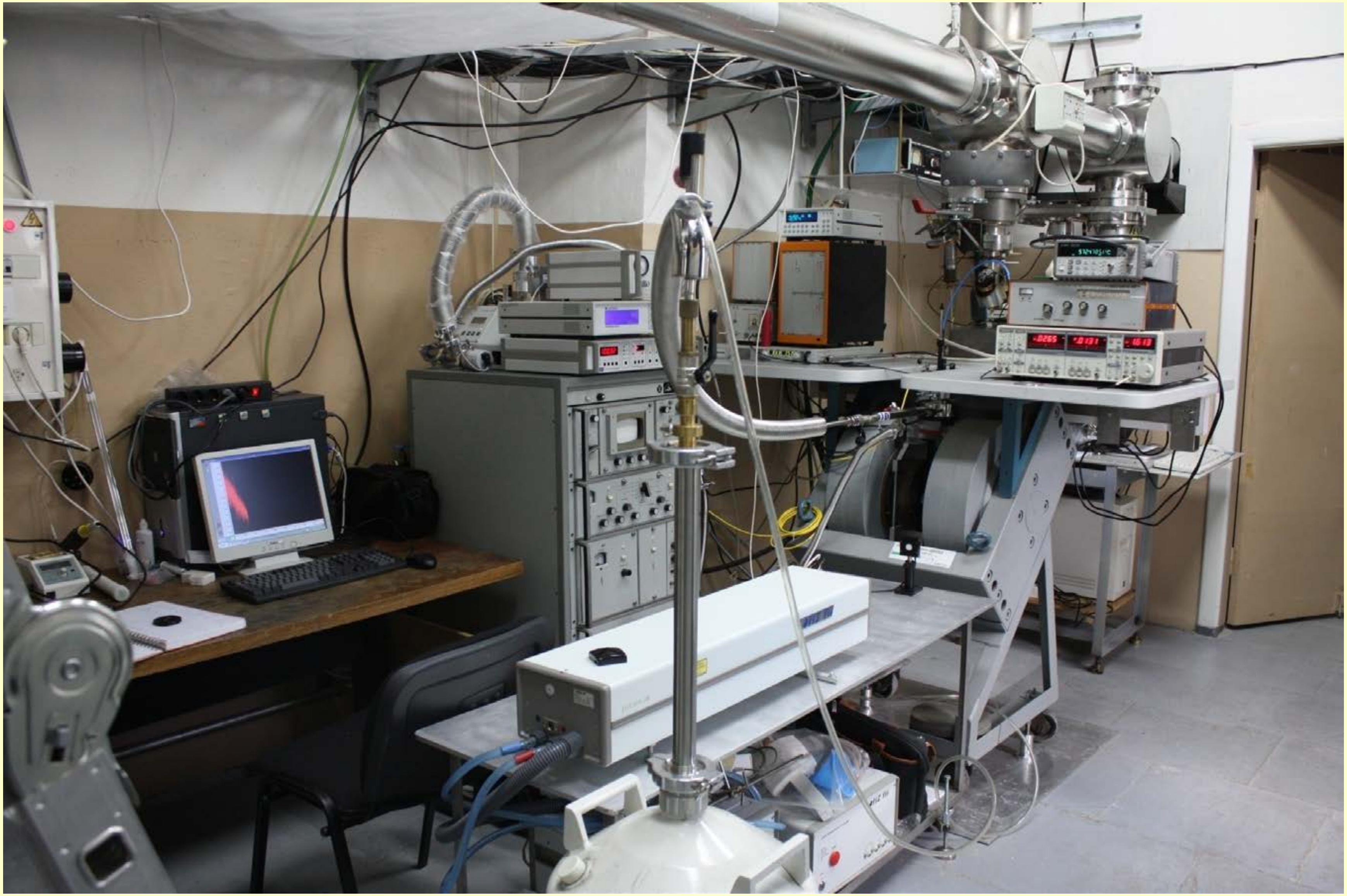
Workstation 1: Radiation characteristics control





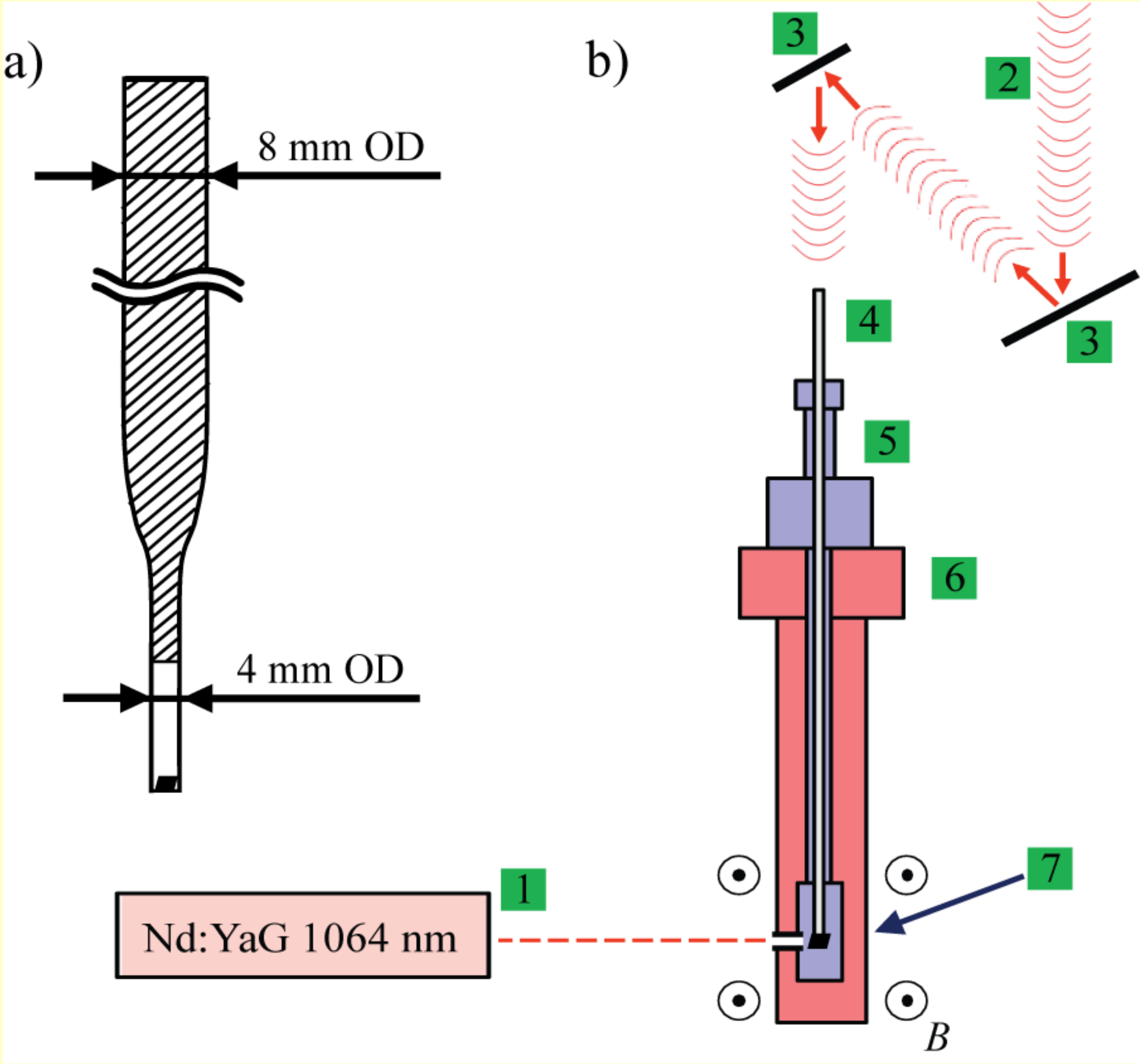
Equipment of the station enables measuring spectrum of emitted radiation and monitoring radiation intensity. This information is transmitted via the intranet to the user workstations.

Workstation 2: EPR Spectroscopy



Terahertz excitation scheme

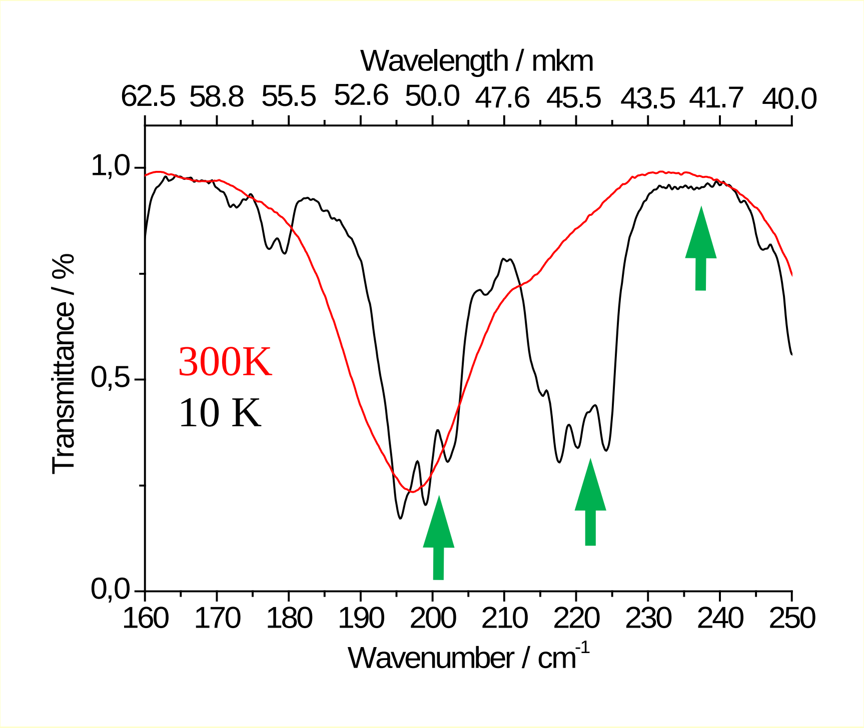
Sample holder used for THz irradiation. Grid lines show silver mirror coating.

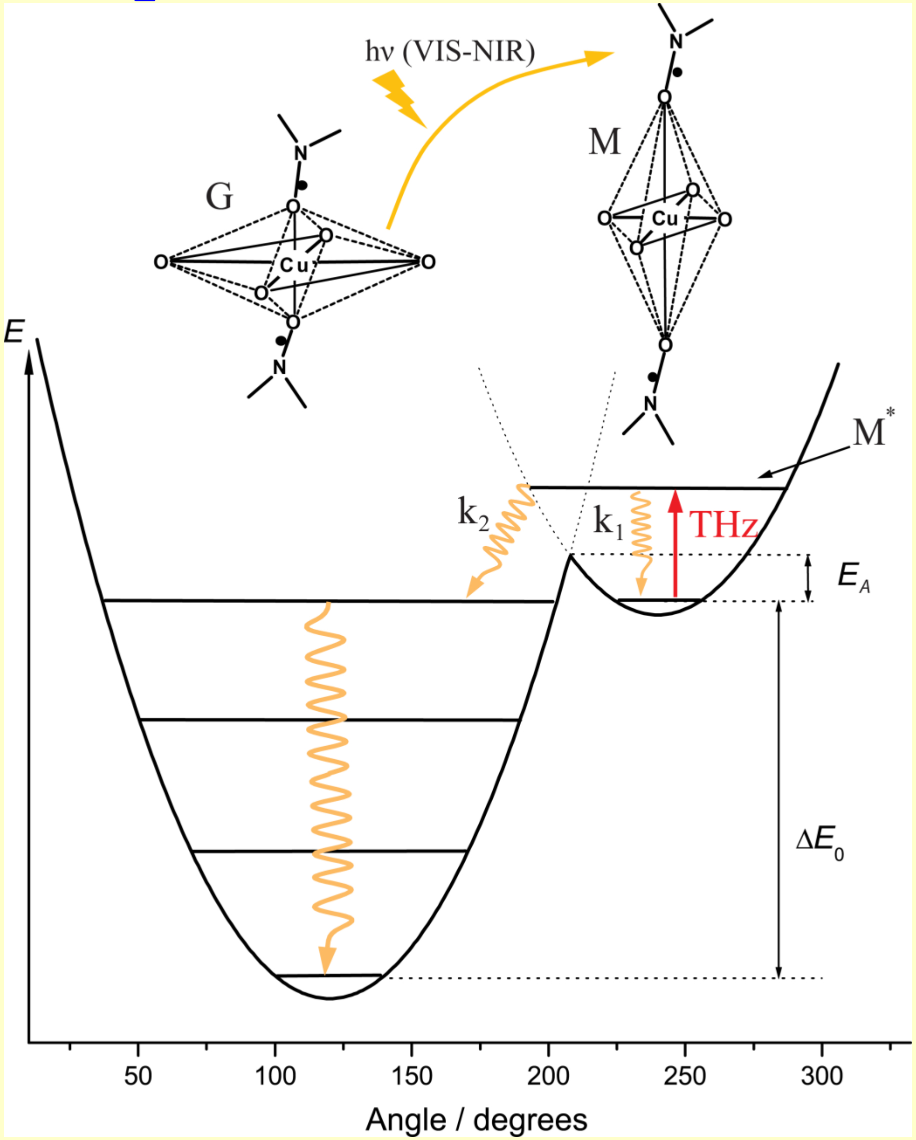


(1) Nd:YaG laser
(2) THz beam
(3) flat copper mirrors
(4) sample holder
(5) probehead of the EPR resonator
(6) EPR cryostat
(7) sample inside the EPR resonator.

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

- Photoswitching of $Cu(hfac)_2L^{Pr}$ to the metastable state at He temp.
- Irradiation of characteristic vibrational bands to induce the backward conversion of $Cu(hfac)_2L^{Pr}$ to ground state



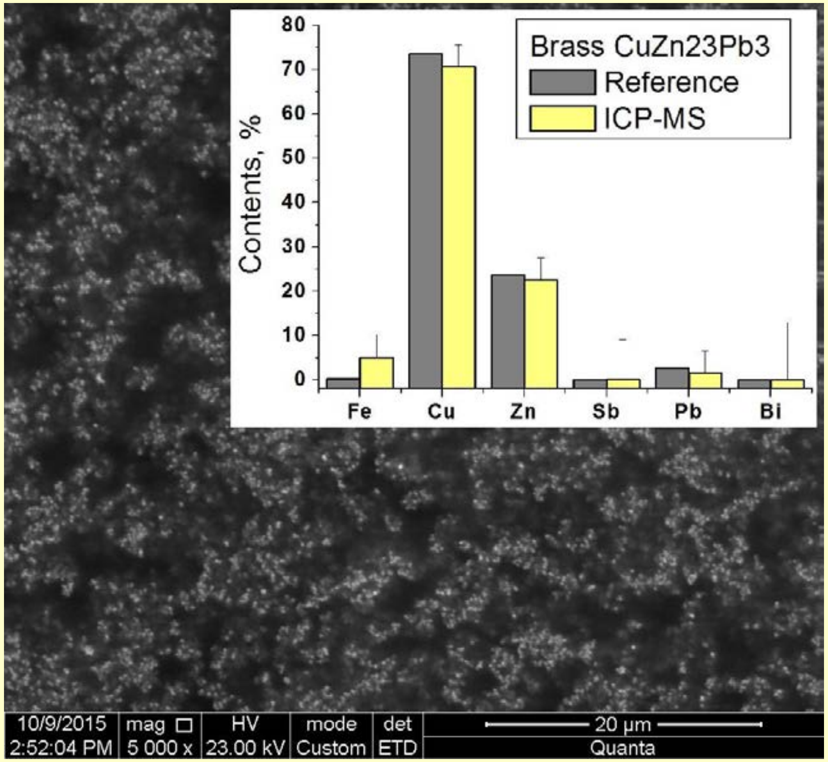


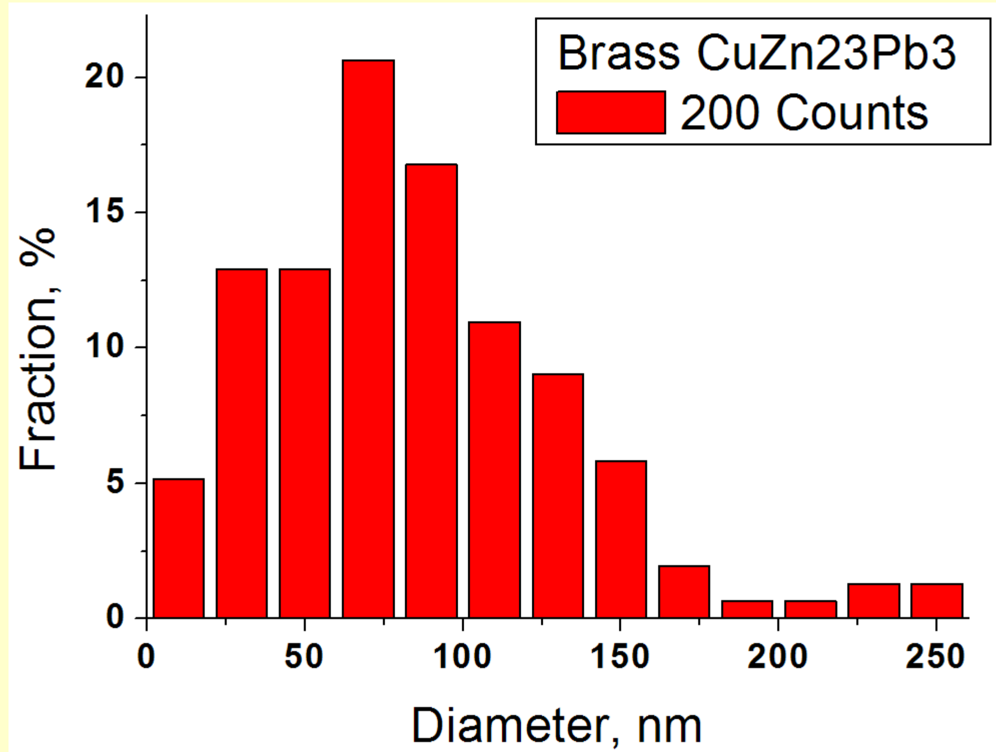
S.L. Veber, et.al. J. Phys. Chem. A 117 (2013) 1483-1491

Workstation-3: Biology and material sciense

Multifunctional station equipped with conditioned air and nitrogen pneumatic supply, wide range aerosol particle counters/sizers : 3nm – 30um, electrostatic particle classifier: 5 – 1100nm, suspended particle samplers – inertial, thermophoretic ...

Terahertz irradiation 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.

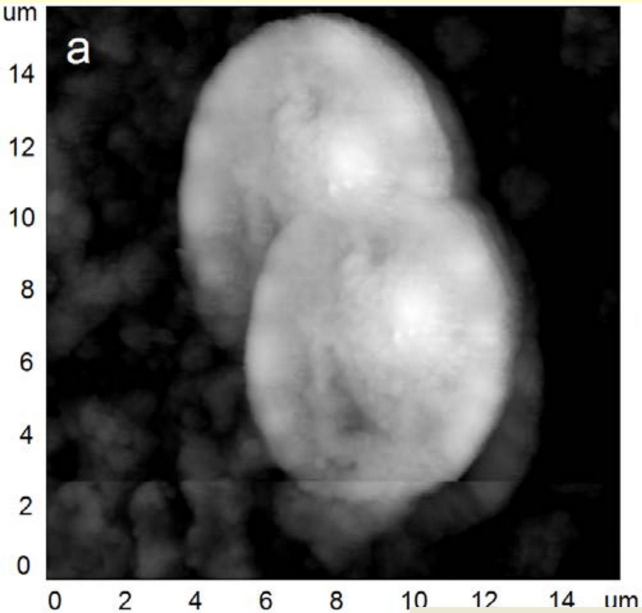
Exposition conditions: atmospheric pressure, room temperature. Duration: 5-10sec.

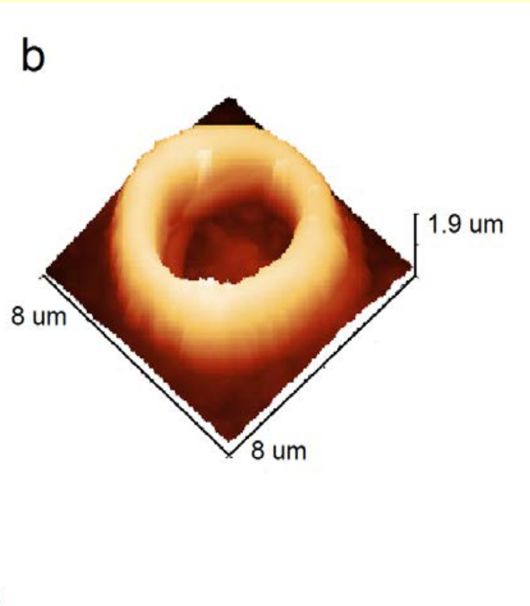
Materials: Inert alloys, ceramics, graphite, etc., distilled water: 50-100µl.

Particle diameters (N½): 50-80nm. Concentration: <10^{10} cm^{-3} (1-2mg/l)

A. Kozlov. Wednesday 17:20, THz section

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





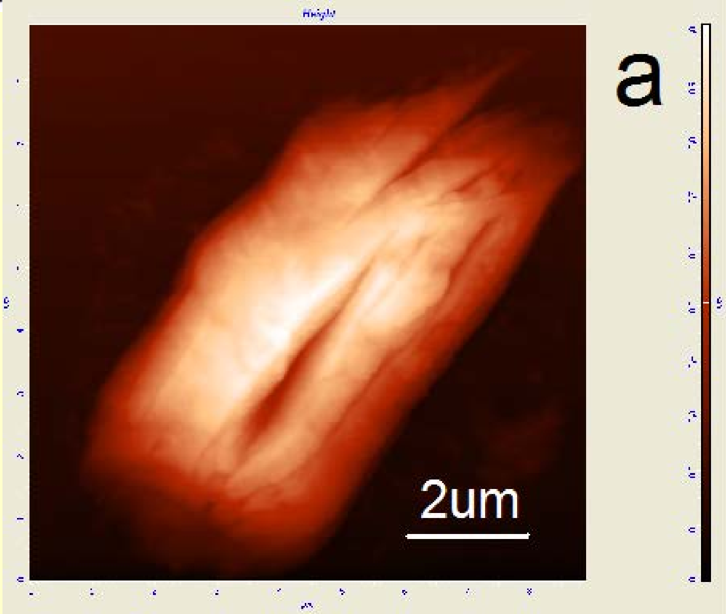
Initial:

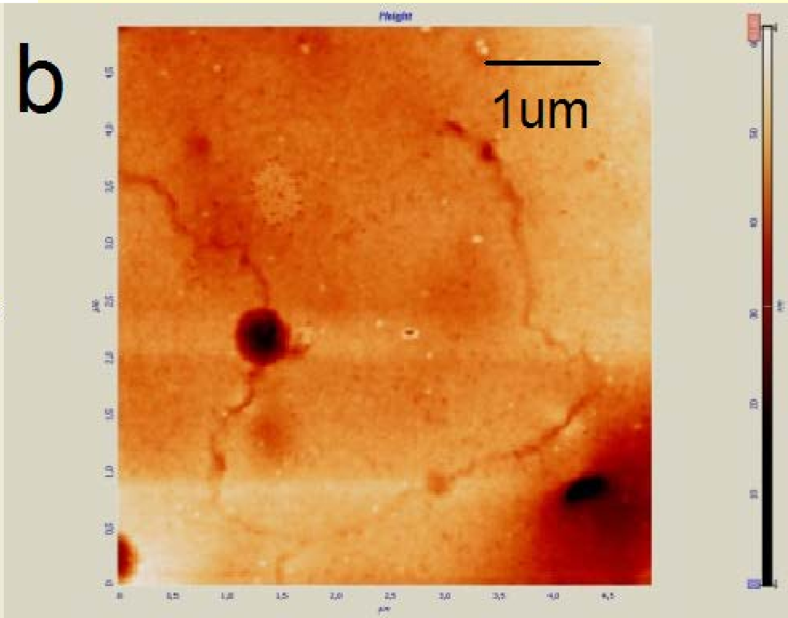
a – hepatocytes

b - erythrocyte

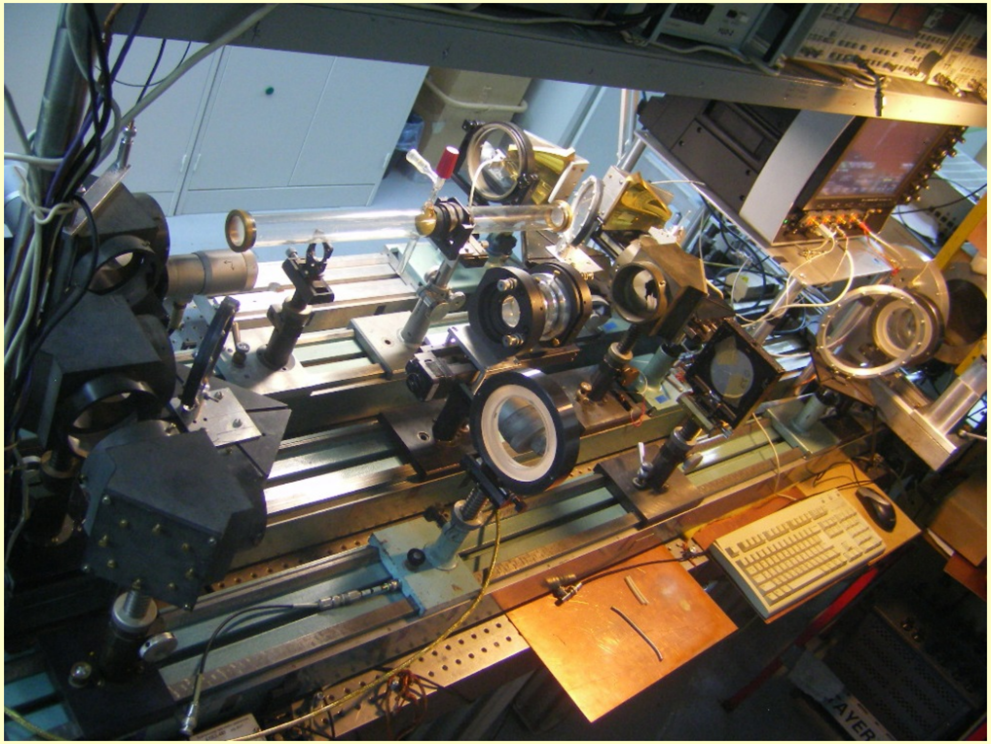
Exposed 15sec 1ml, $20 W/cm^2$:

Membrane pores and cracks



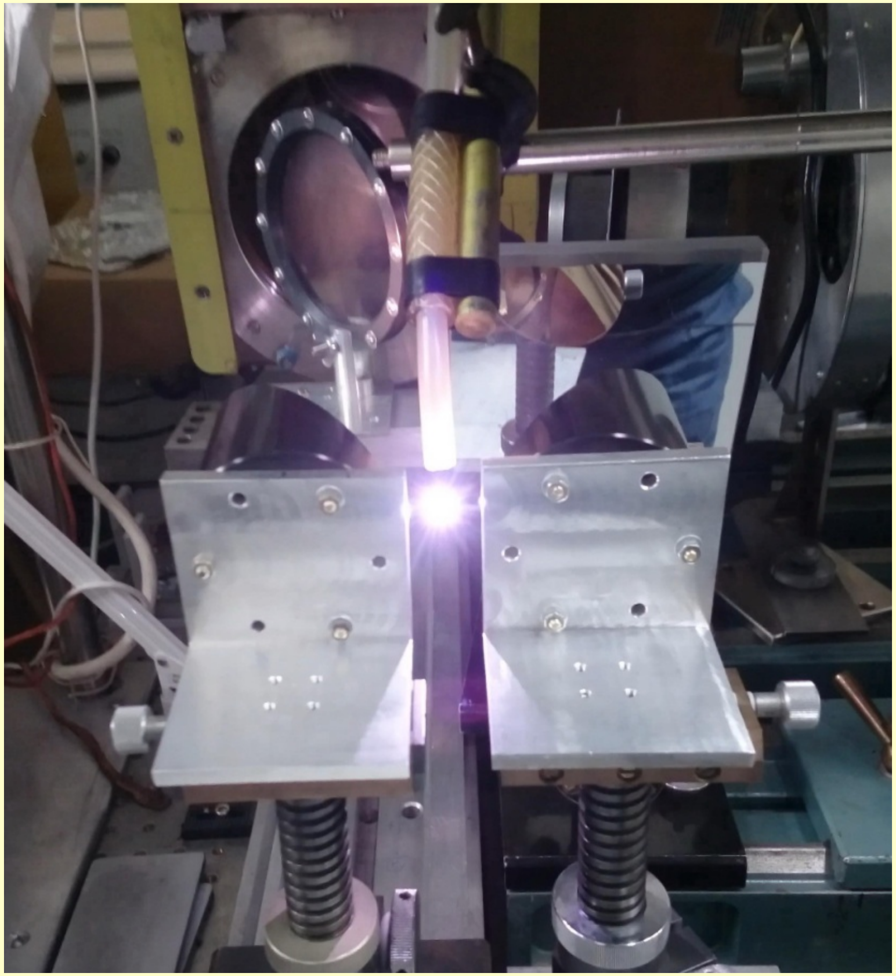


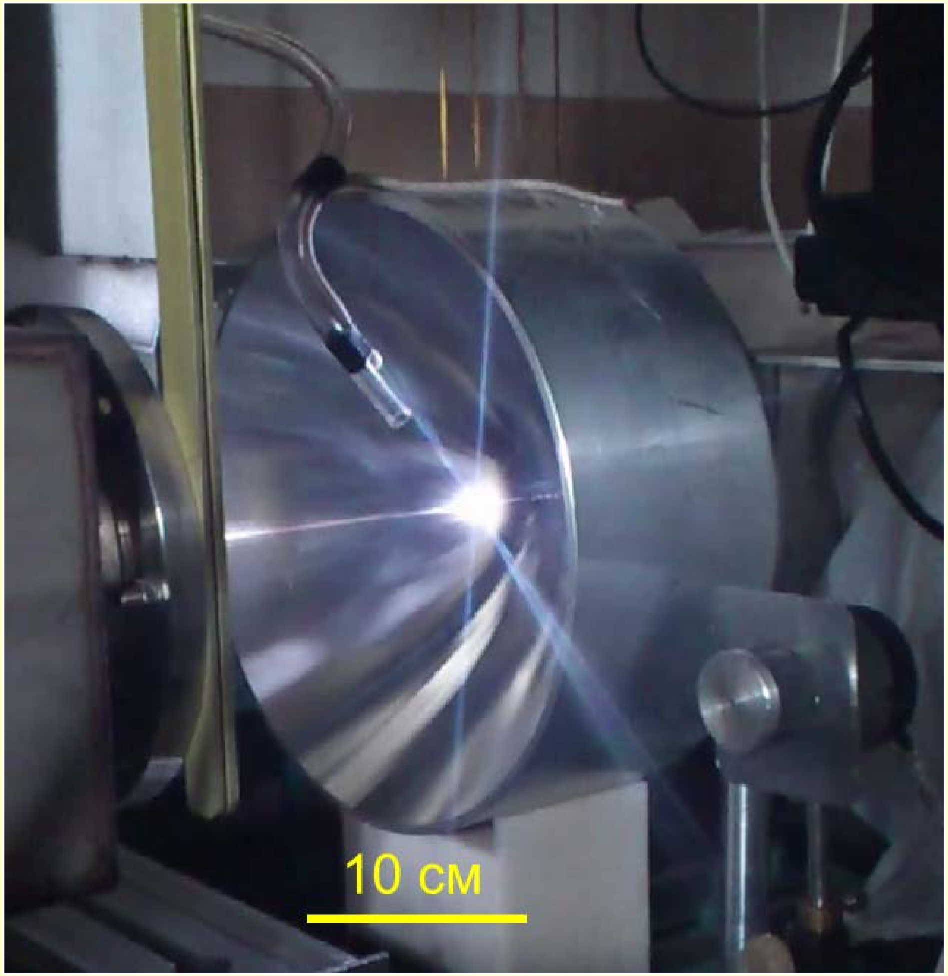
Workstation-4: Metrology



The station is used for measuring of all parameters of NovoFEL radiation (gain, losses in optical resonators, average power, pulse power, form of pulse, spectrum of pulse, 2D beam imaging) and specific experiments with maximal NovoFEL's parameters (ultra-fast spectroscopy, optical discharge, Drummond light, optico-acoustics effect, ablation etc.)

Terahertz optical discharge

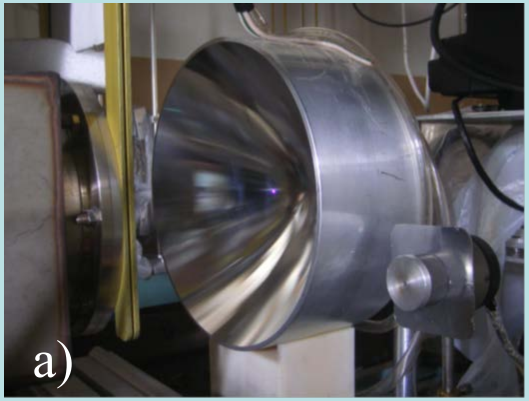


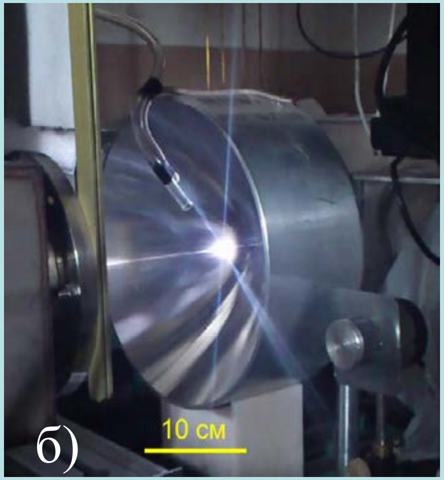


Kubarev V., Getmanov Ya., Shevchenko O.
“High-temperature quasi-stationary terahertz optical discharge on NovoFEL”

V. Kubarev. Wednesday 15:20, THz section

Thresholds of quasi-CW THz optical discharge





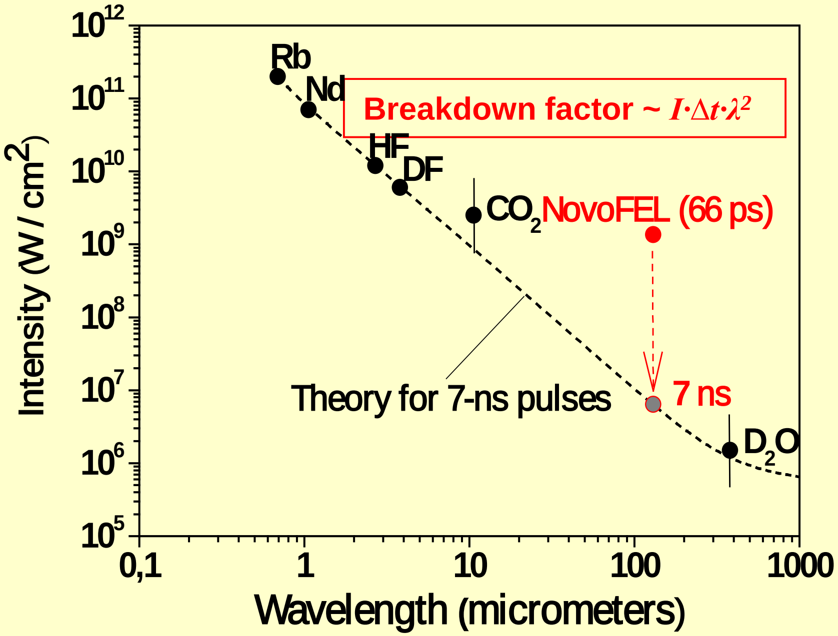
Discharges in different gases:

a) air: Laser power is close to threshold (150 W)

б) argon: Laser power (150-160 W) is 30% higher than threshold

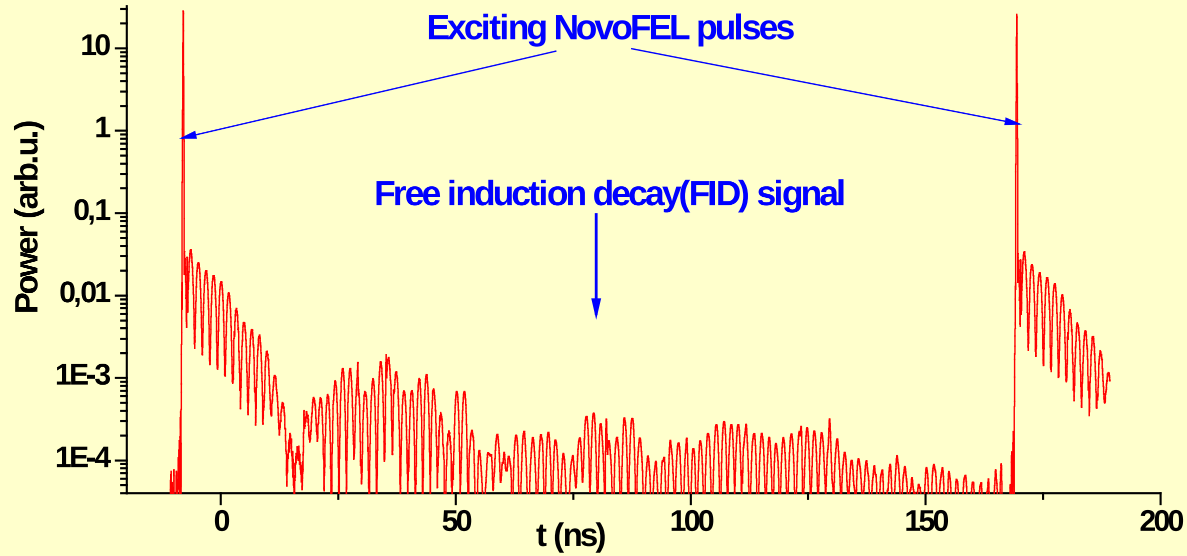
Intensities for ignition and quenching of CW optical discharge sustained by 66-ps pulses of NovoFEL at λ = 130 μm

	Ar	He	N_2	Air	CO_2
Breakdown threshold (GW/cm²)	1.1	1.18	1.23	1.36	1.38
Quenching intensity (GW/cm²)	0.51	0.91	1.00	0.90	1.20



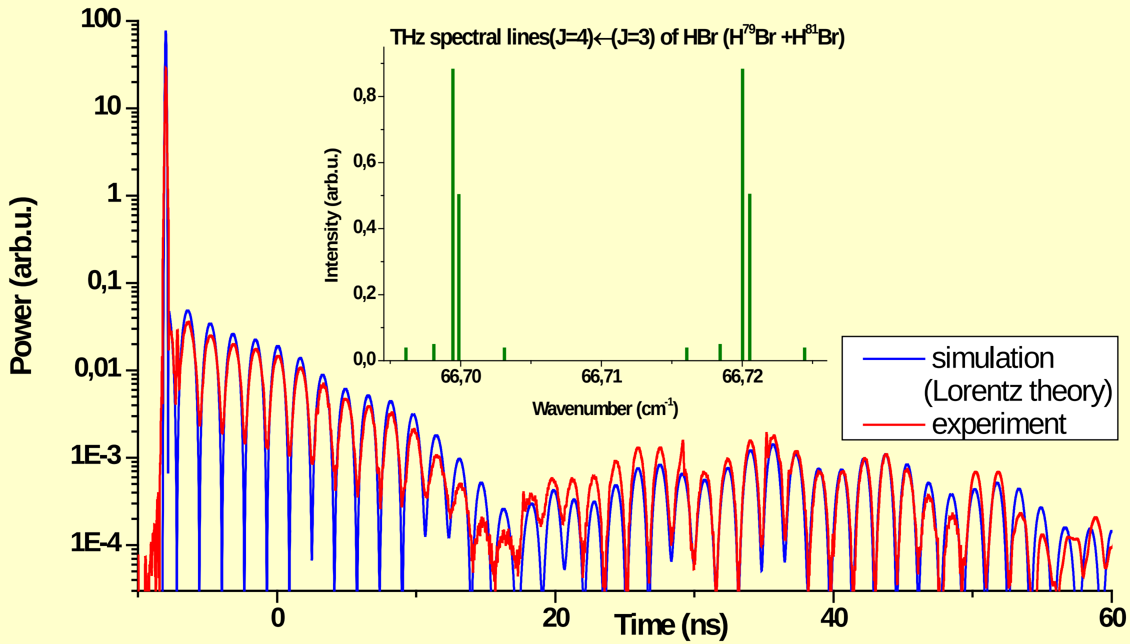
V. Kubarev. Wednesday 15:20, THz section

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).

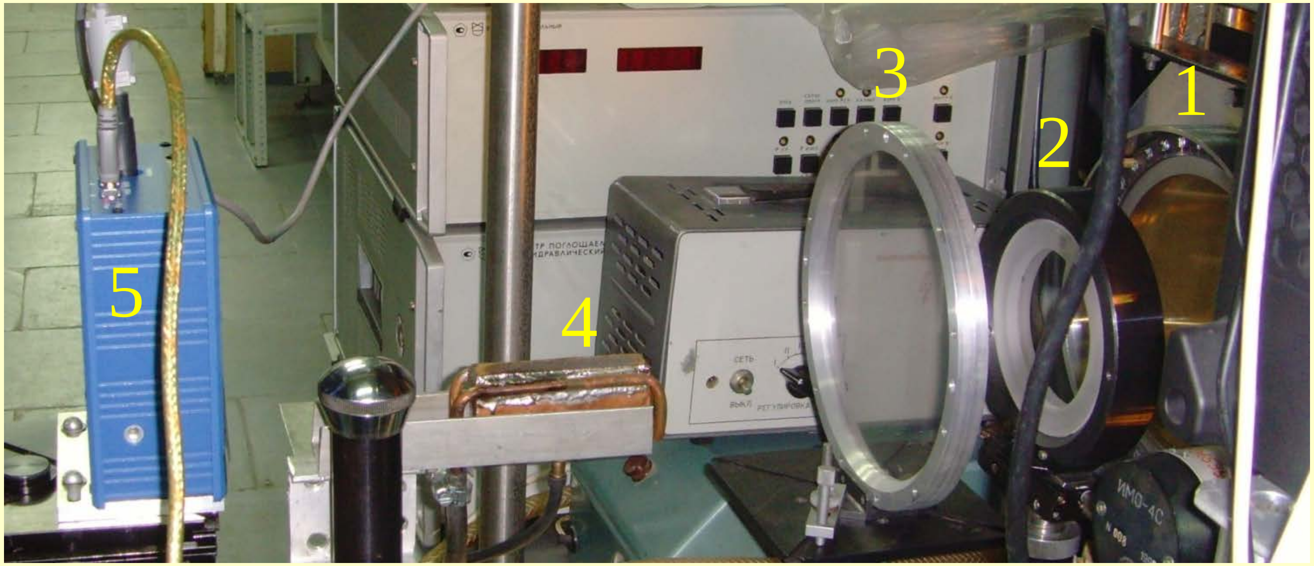


V. Kubarev. Wednesday 12:30, THz section

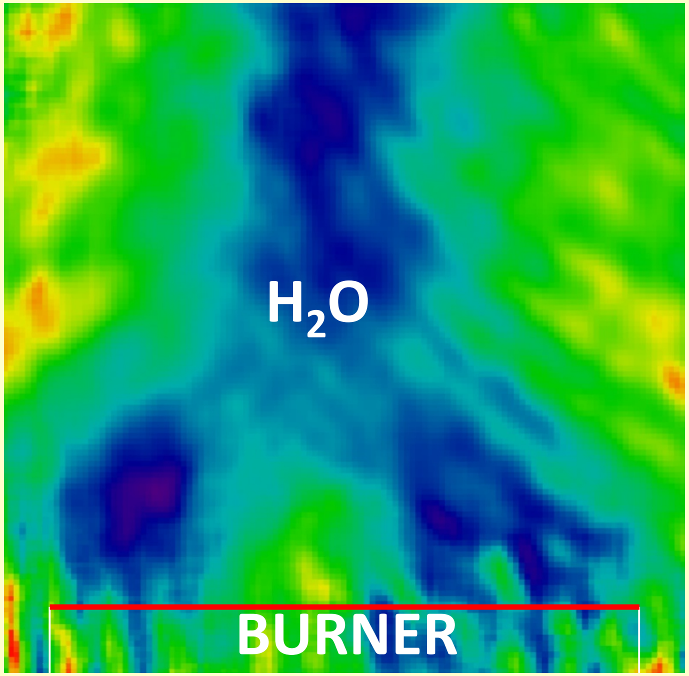
Workstation-5: Molecular spectroscopy

The station is equipped with grating monochromator, various optical gas cells and optical elements, elecromagnet and solenoids for Zeeman and Faraday experiments. There are also pulsed CO_2 and N_2 – lasers, synchronized with FEL.

Measurements of water vapor concentration in flame



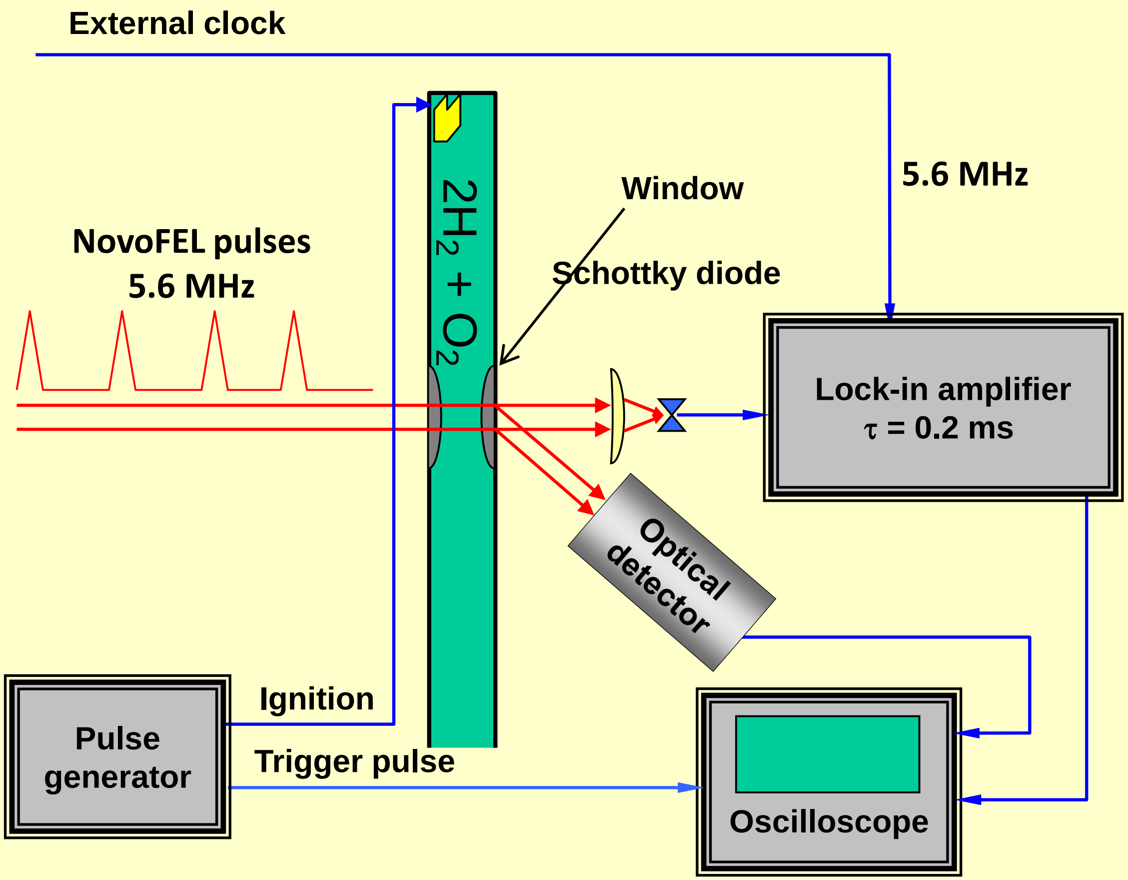
1 – Polarizer attenuator
2 – Lens
3 – Protection film
4 – Burner
5 – Pyroelectric camera Pyrocam II

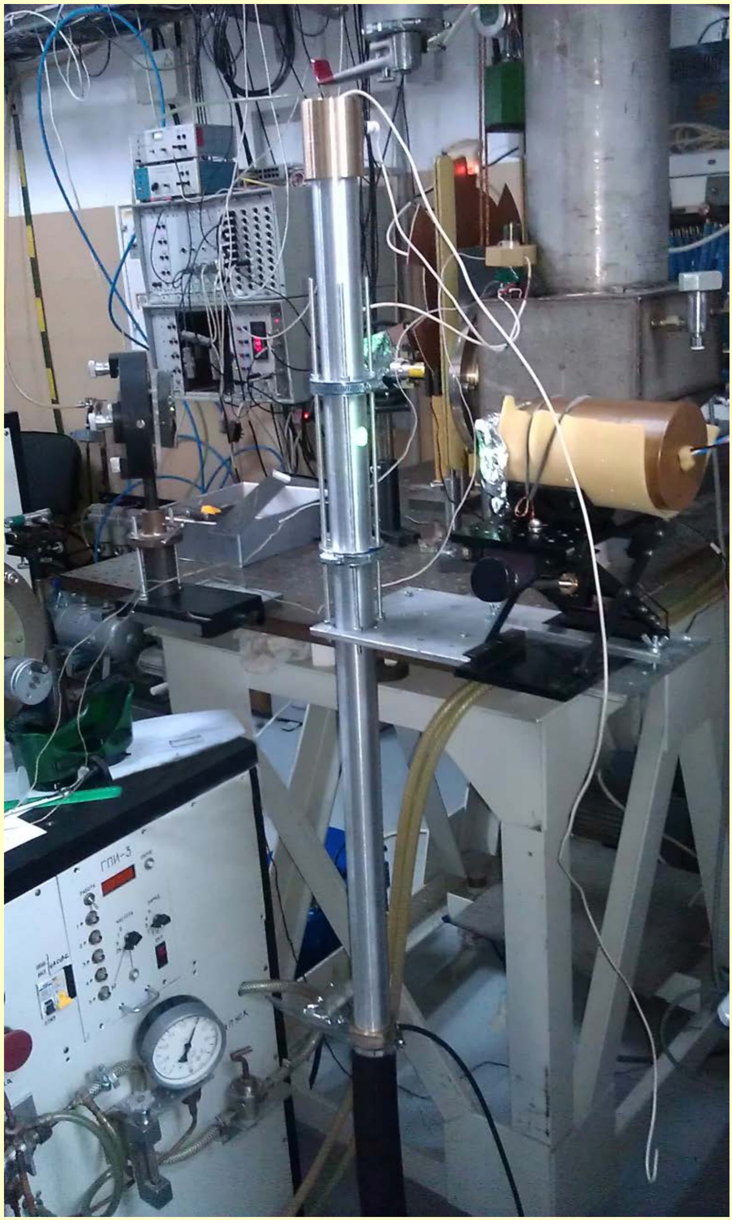


NovoFEL wavelength 167 mm (water line absorption)
Flame of stoichiometric mixture $2H_2 + O_2$
Thickness of burning layer is 80 mm, width 20 mm

A. A. Vasiliev, E. I. Palchikov, V. V. Kubarev, E. N. Chesnokov, P. V. Koshlyakov, A. V. Dolgikh, I. Yu. Krasnikov, K. A. Ten "About Works on Research of Stationary and NonStationary Waves of Burning in the Hydrogen–Oxygen Mix on the Novosibirsk Free Electron Laser“ Bulletin of the Russian Academy of Sciences. Physics, 2013, Vol. 77, No. 9, pp. 1175–1177.

Dynamics of burning and detonation in hydrogen-oxygen mixture



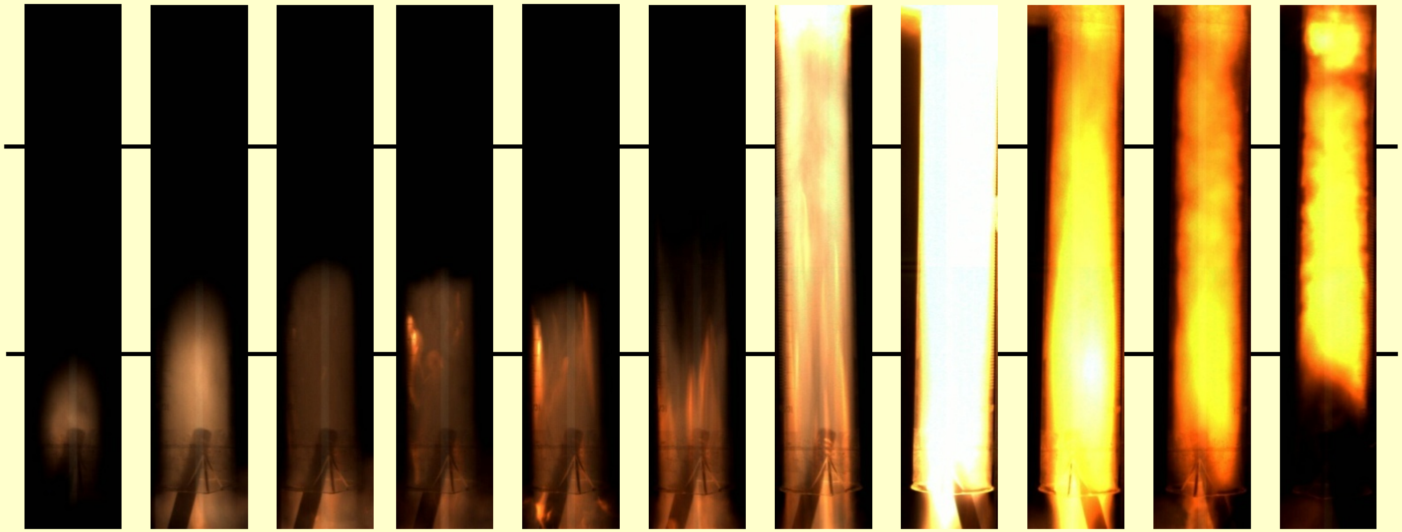


Wavelength of NovoFEL is tuned to a determined absorption line of H_2O or OH radical

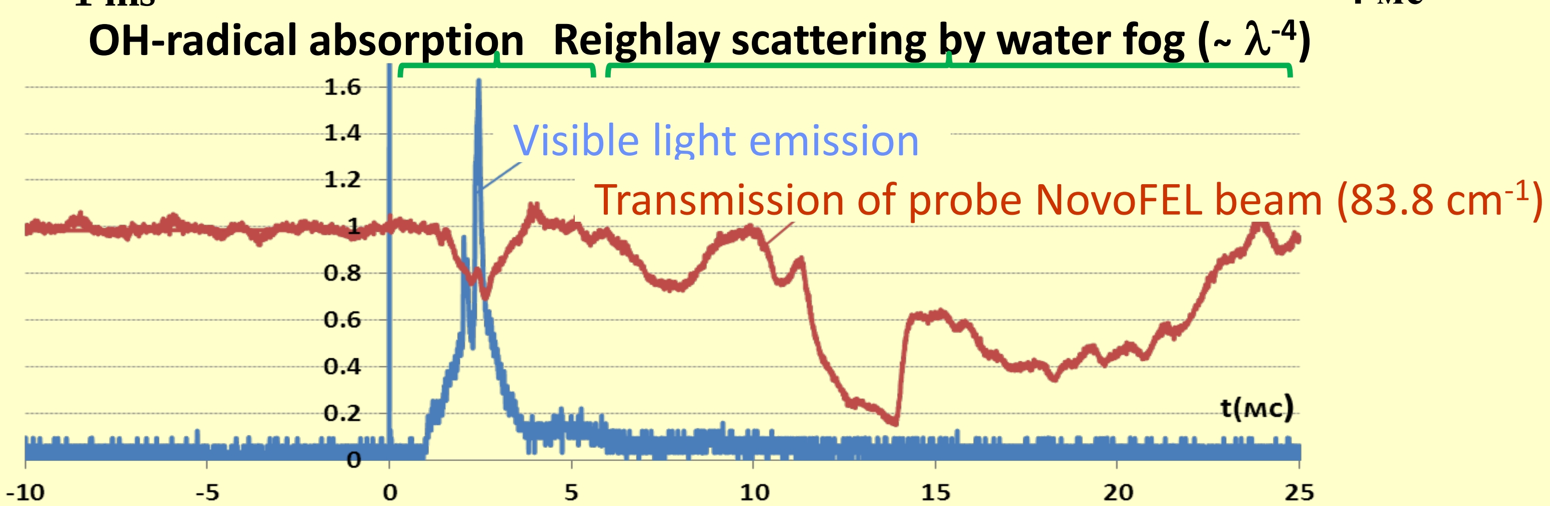
A. A. Vasiliev, E. I. Palchikov, V. V. Kubarev, E. N. Chesnokov, P. V. Koshlyakov, A. V. Dolgikh, and I. Yu. Krasnikov. "Investigating Nonstationary Waves from the Combustion and Detonation of a Hydrogen–Oxygen Mixture in the Optical and Terahertz Ranges", Bulletin of the Russian Academy of Sciences. Physics, 2015, Vol. 79, No. 9, pp. 1202–1207.

Dynamics of burning and detonation in hydrogen-oxygen mixture

High-speed image acquisition of detonation in transparent pipe

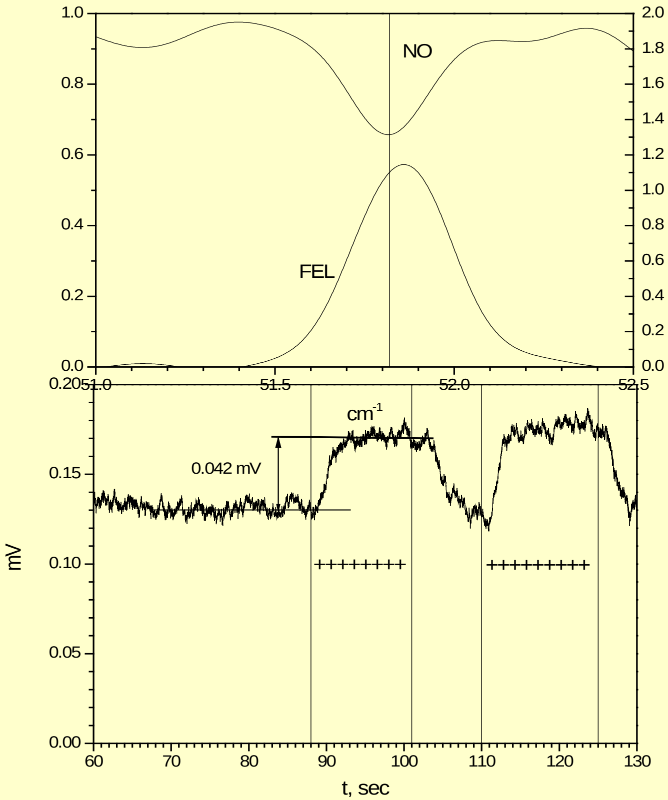


1 ms **4 мс**

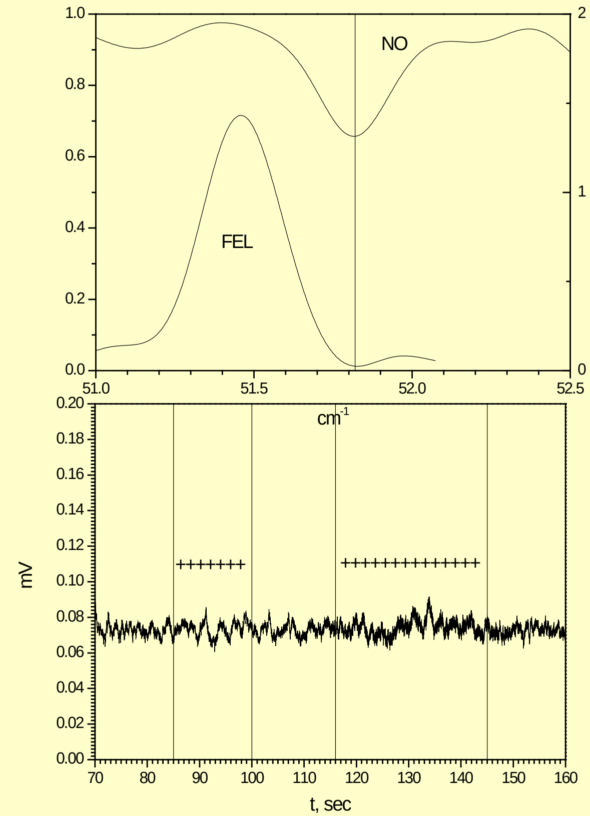


A. A. Vasiliev, E. I. Palchikov, V. V. Kubarev, E. N. Chesnokov, P. V. Koshlyakov, A. V. Dolgikh, and I. Yu. Krasnikov "Investigating Nonstationary Waves from the Combustion and Detonation of a Hydrogen–Oxygen Mixture in the Optical and Terahertz Ranges" Bulletin of the Russian Academy of Sciences. Physics, 2015, Vol. 79, No. 9, pp. 1202–1207

Faraday rotation at NO absorption lines



FEL is tuned to NO absorption line

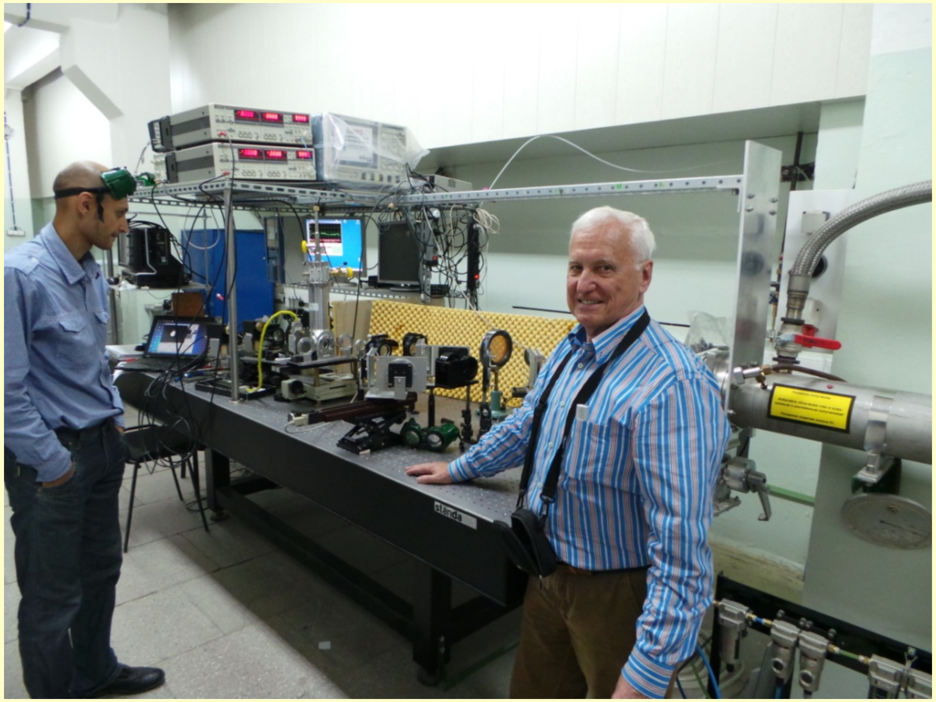


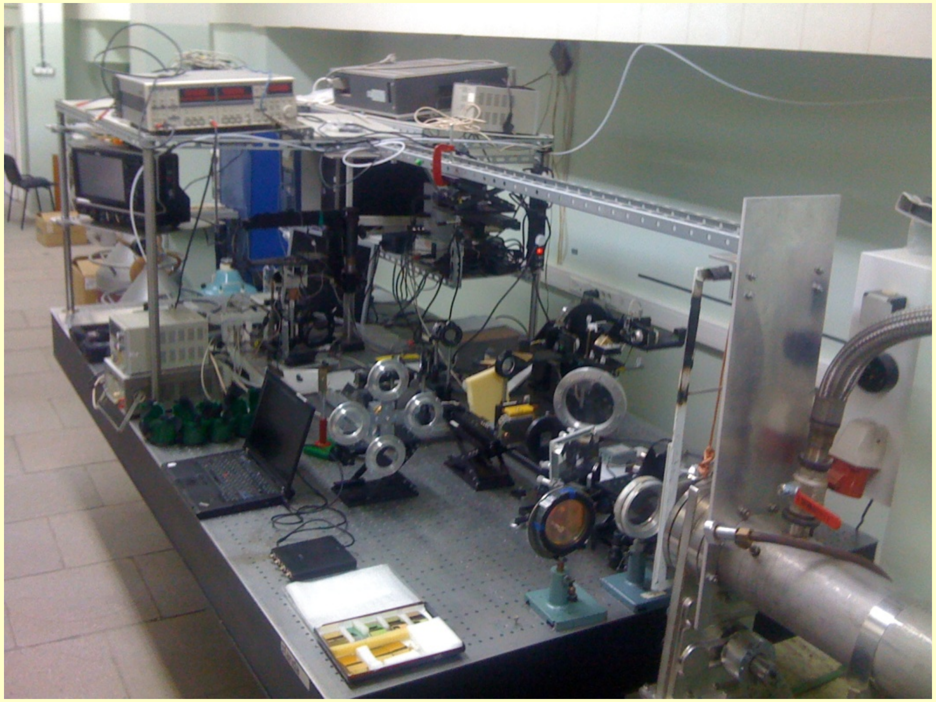
FEL is detuned

Chesnokov, E. N.; Aseev, O. S.; Korobeinichev, O. P. Yakimov, S. A. Knyaz'kov, D. A.Shmakov, A. G.
Using terahertz radiation to detect OH radicals and NO molecules in flames.
COMBUSTION EXPLOSION AND SHOCK WAVES **46,** p. 149-153 (2010)

E. Chesnokov. Wednesday 15:00, THz section

Workstation-6: Spectroscopy and imaging

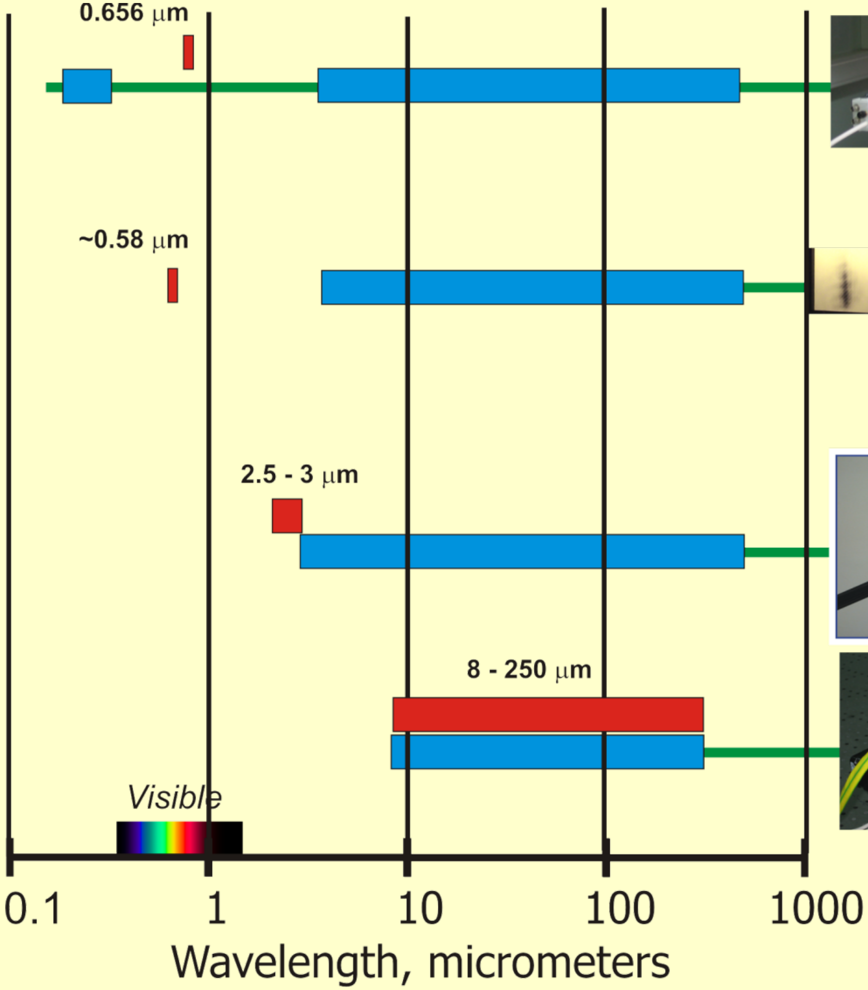


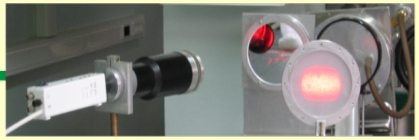


Multifunctional station equipped with an optical table (3x1.5 m), large variety of optical elements, one-channel and imaging sensors, helium cryostat, high-speed oscilloscopes, lock-in amplifiers, home-made THz ellipsometer, THz interferometers, *etc*.

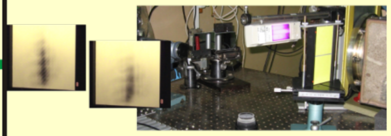
2D sensors

Three fingerprint sensors

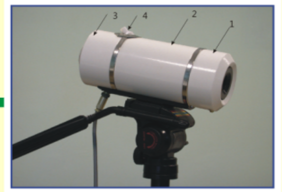




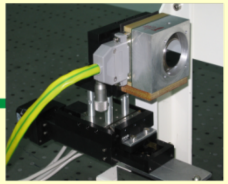
Thermal sensitive interferometer
(0.2 - 0.35 & 3 - 250 μm)
BINP SB RAS



Thermal sensitive phosphor screen
"thermal image plate" (3 - 250 μm)
Macken Instr., Inc.



128x128 Thermal recorder
(2.5 - 250 μm)
ISP SB RAS



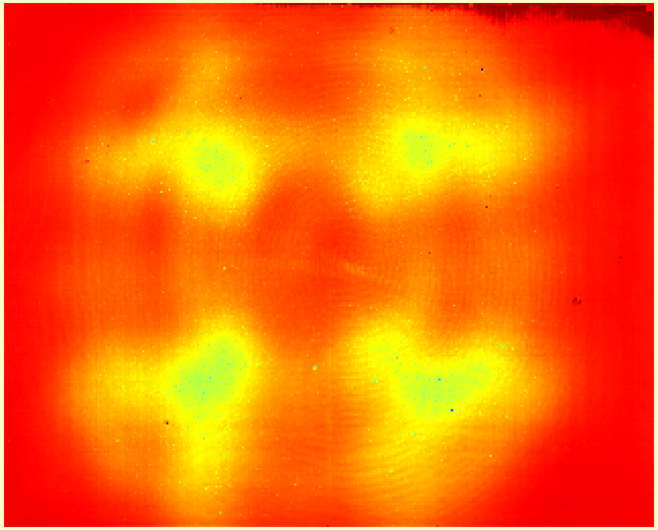
320x240 Microbolometer FPA
(8 - 250 μm - direct imaging)
ISP SB RAS

THz sensor

Real-time THz video recorded with microbolometer matrix

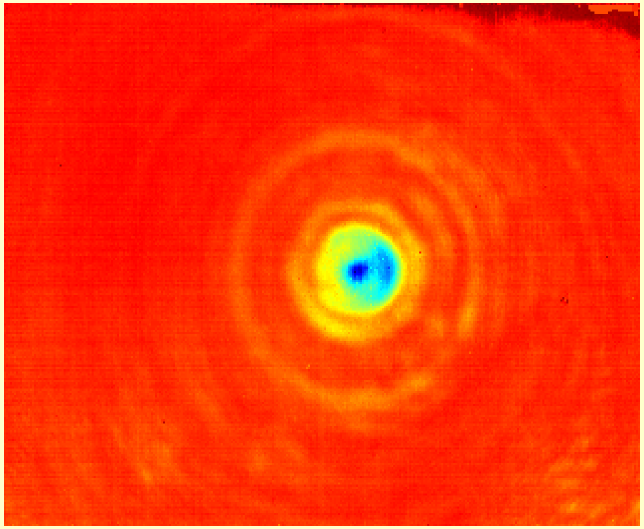
(Shaping of FEL beam with binary silicon DOE)

Scanning from 298 to 411 mm

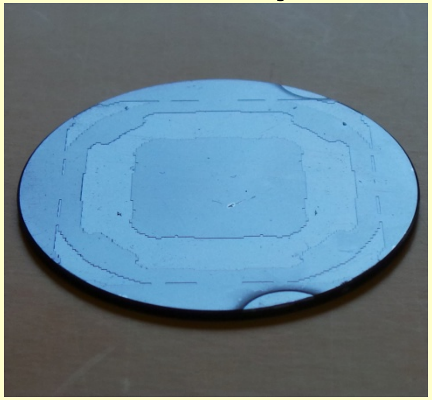


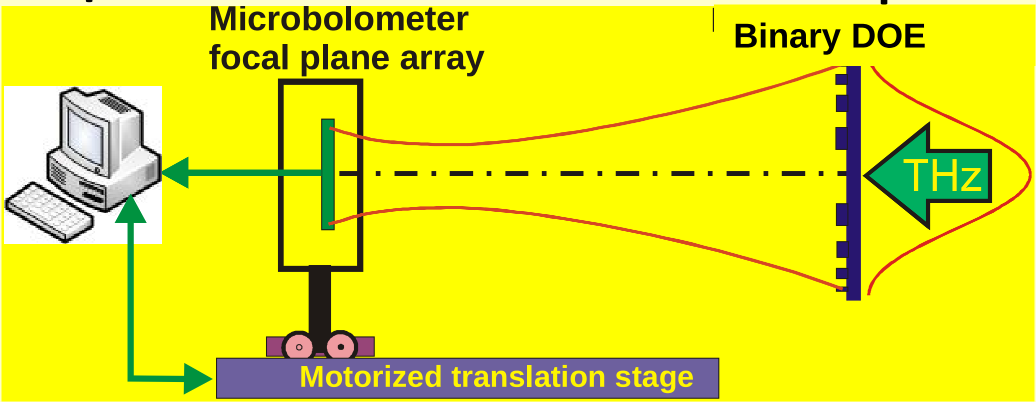
Shaper in a "square"

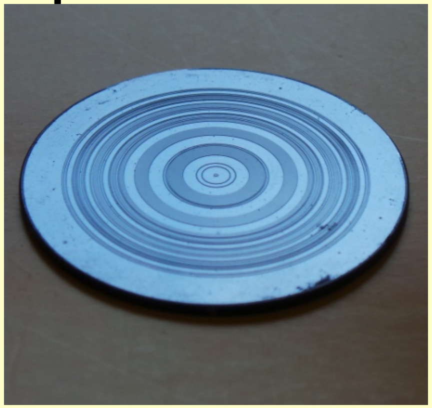
Scanning from 90 to 160 mm



Shaper in a "pencil"



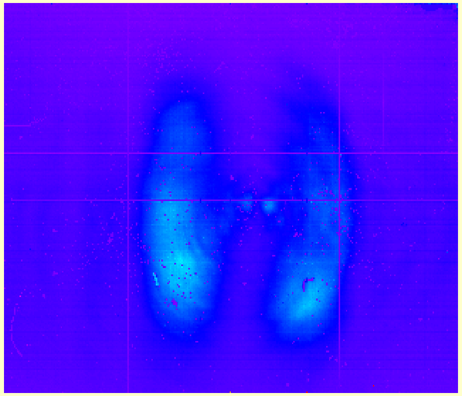
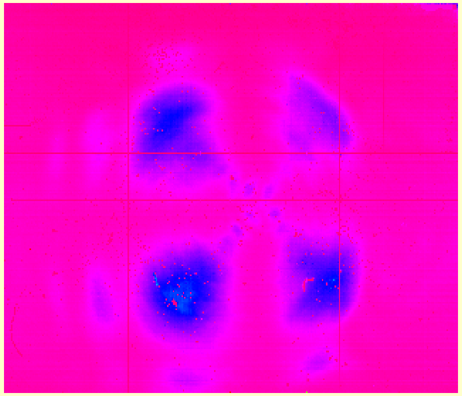
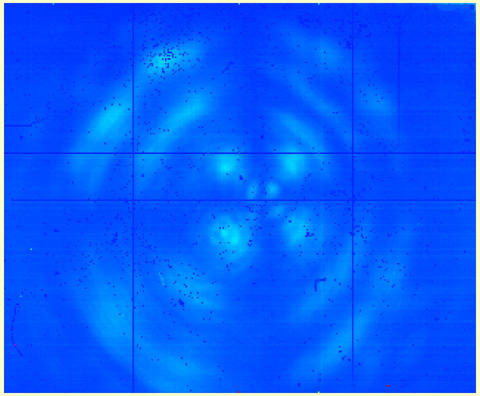


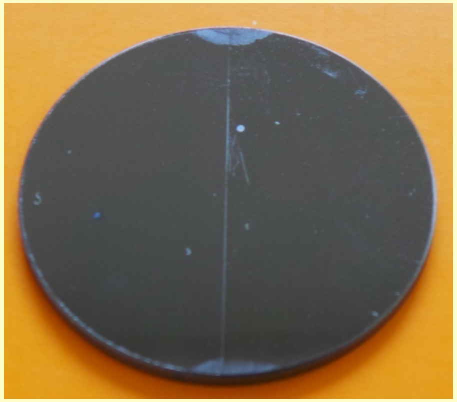
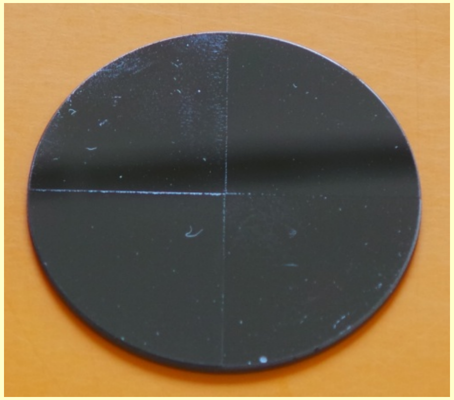
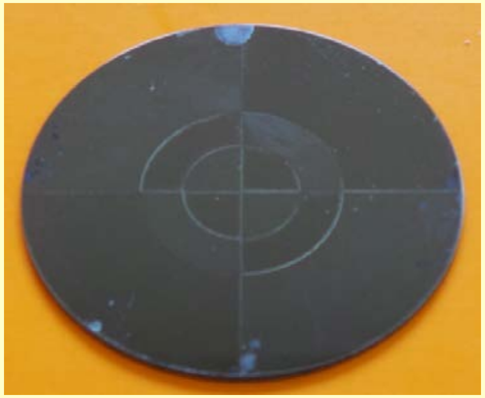


Binary silicon DOE: mode transforming ("modans")

Transformation of NovoFEL beam in the Laguerre-Gaussian beams

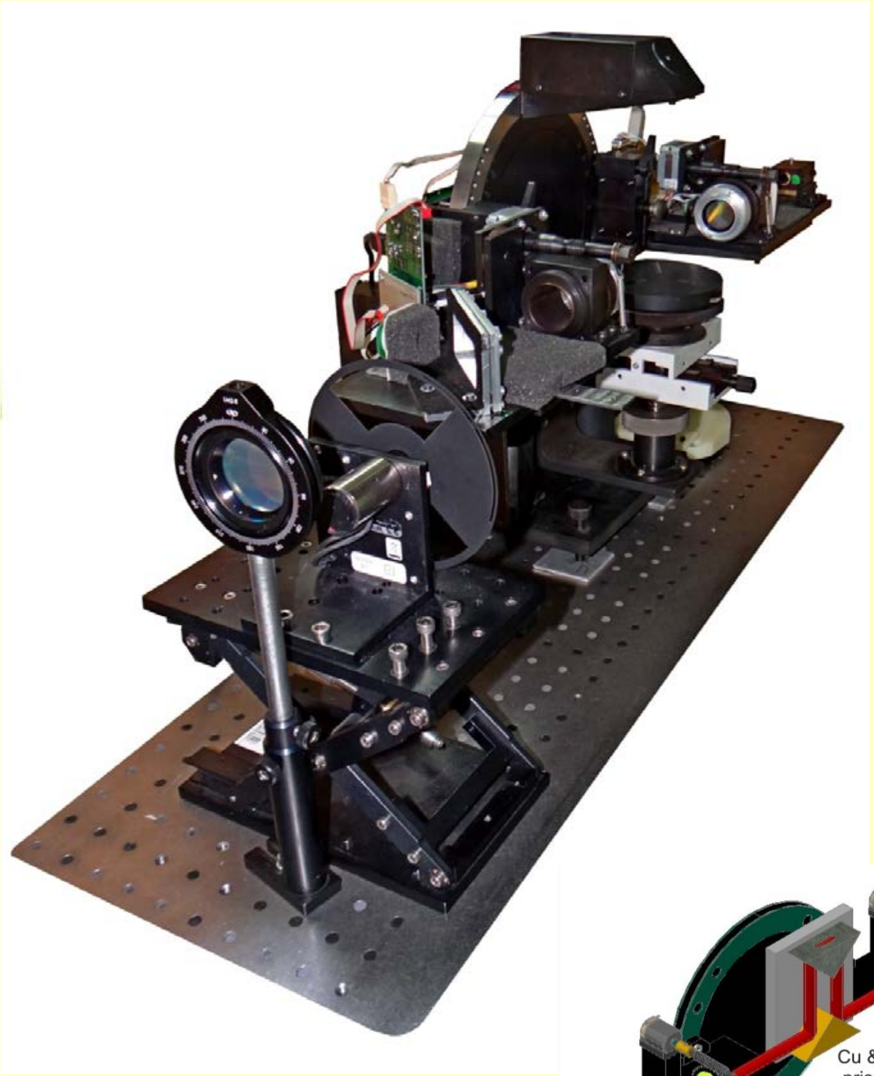
1,0 1,1 2,2

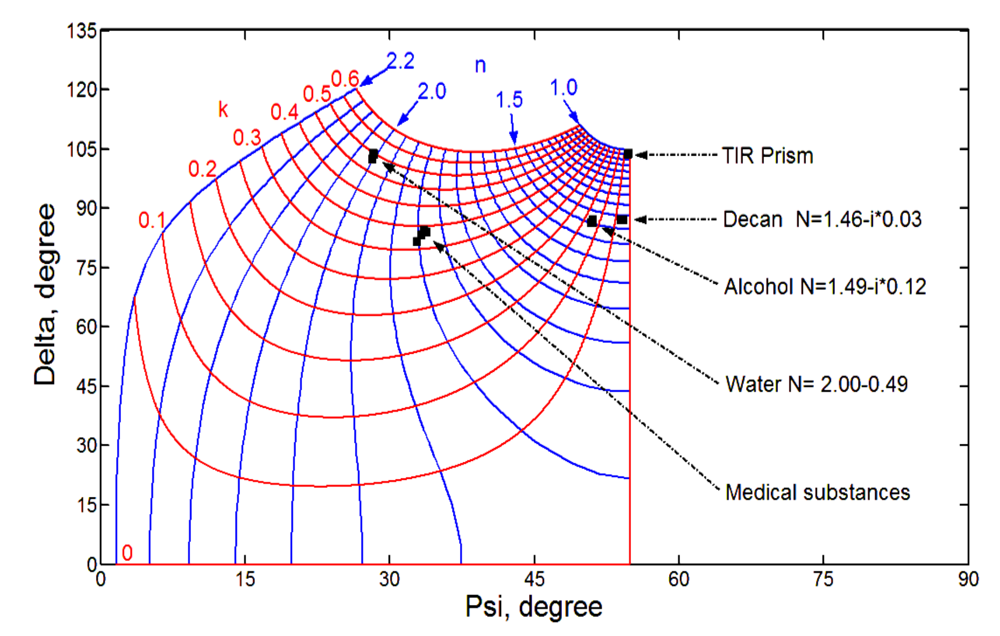




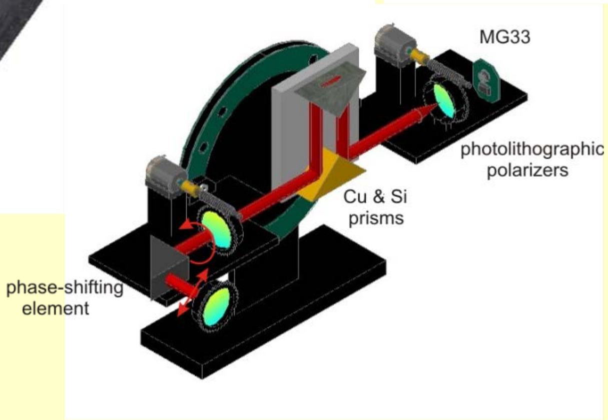
V. Pavelyev. Monday 17:00

THz ellipsometer



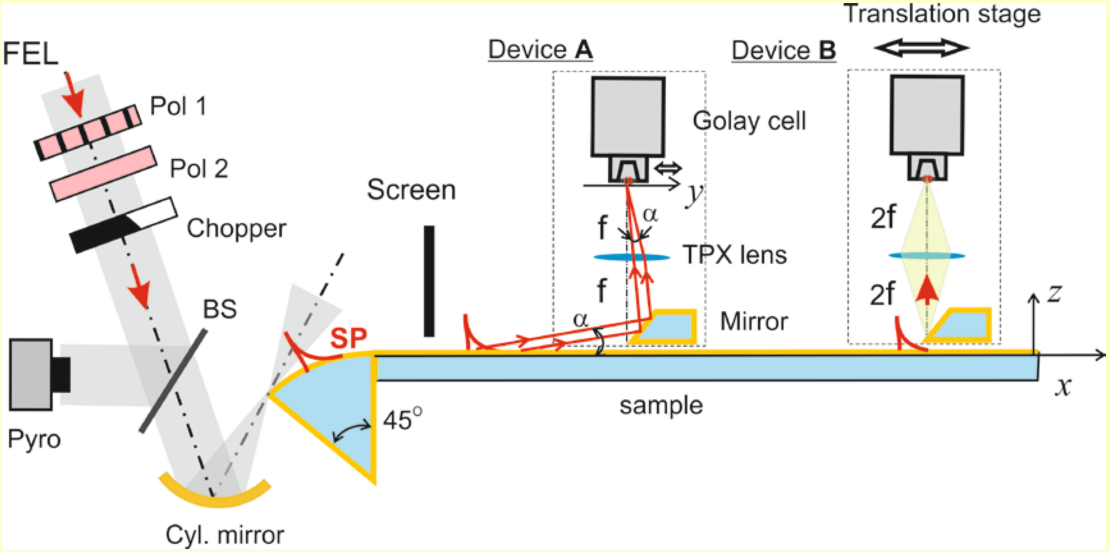
Accuracy of measurements of ellipsometric parameters is 0.5° for ψ and 0.03 for cos(Δ)



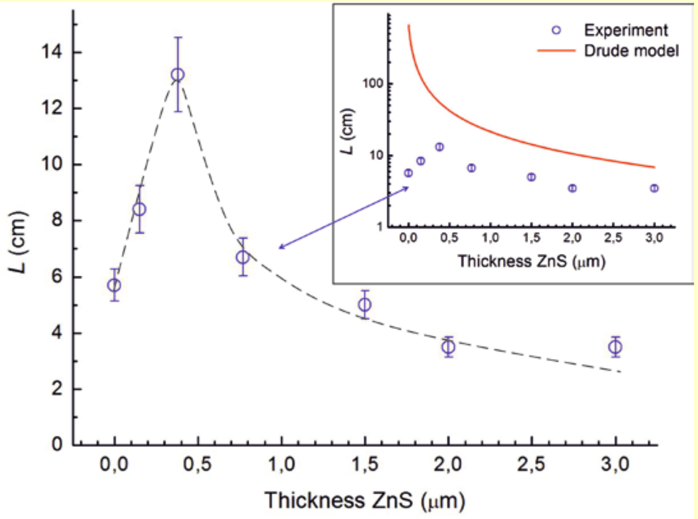


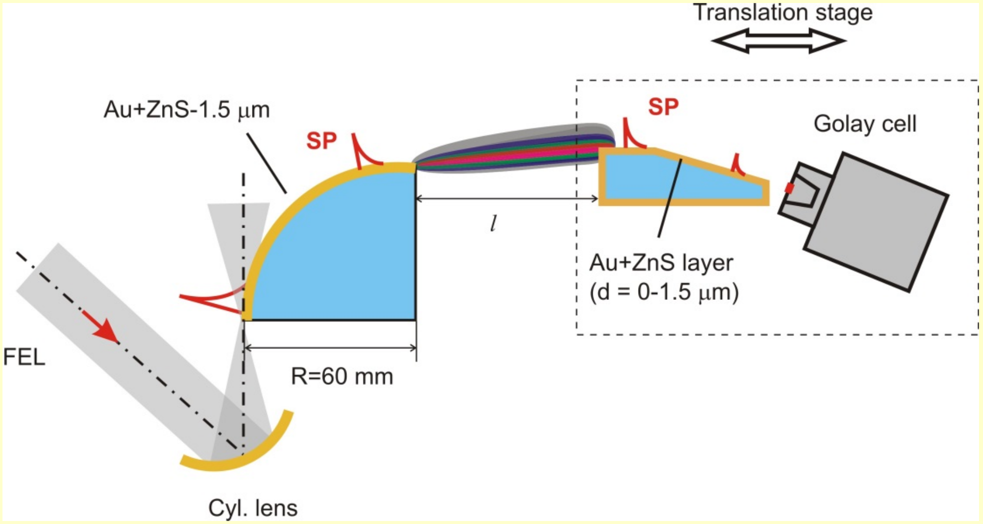
I. Azarov. Tuesday 16:00, Poster session

Surface plasmon polaritons (SPPs) in the terahertz range



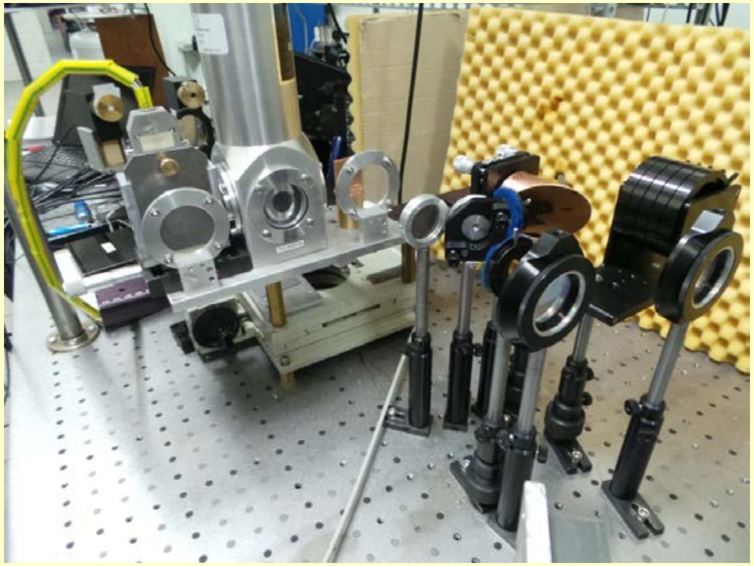
- Techniques for study SPP in the terahertz range have been developed
- Peculiarity of SPP propagation along metal-dielectric in THz

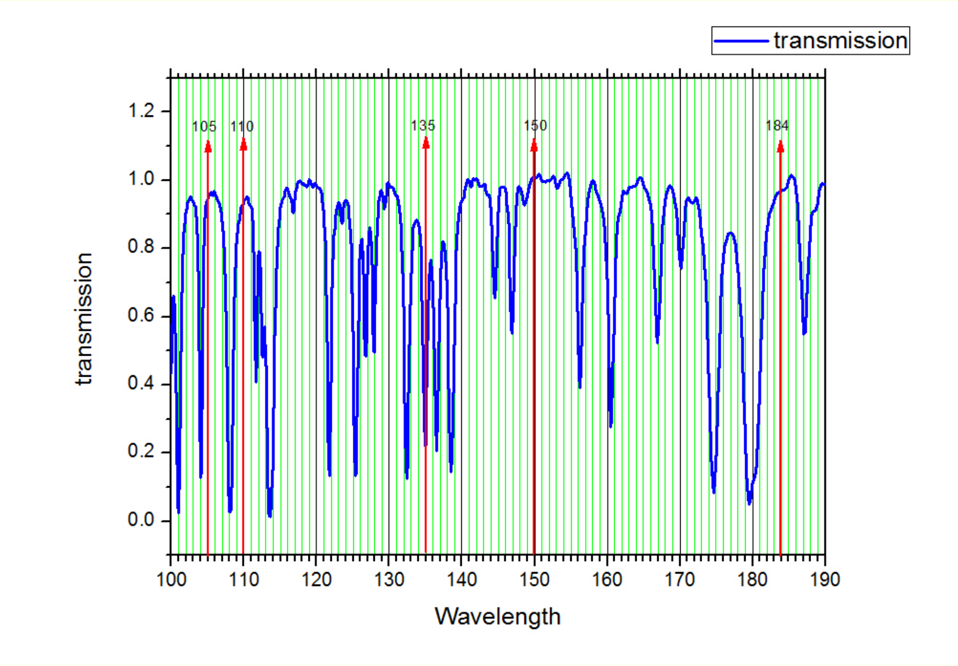


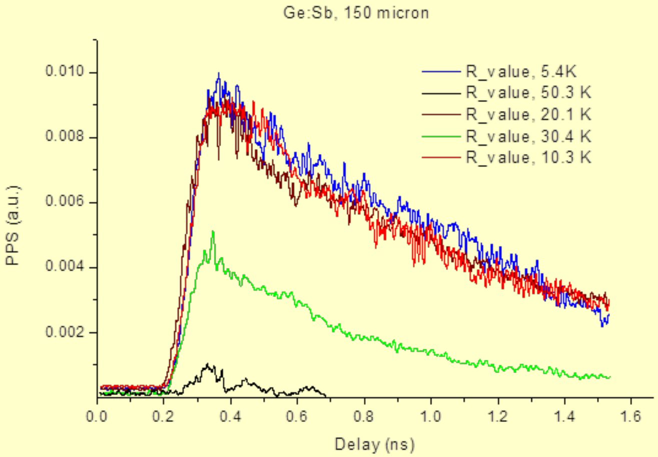


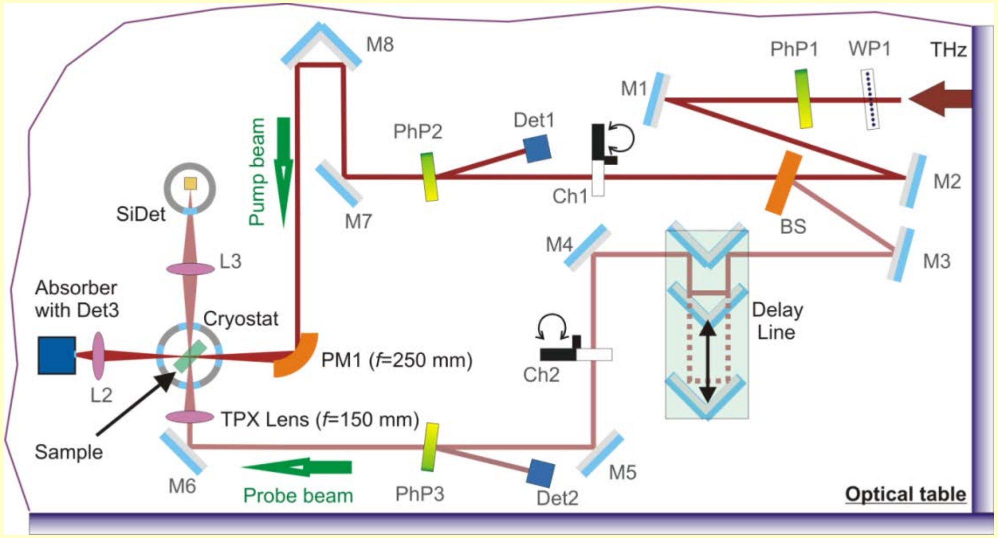
V. Gerasimov. Thursday 14:20, THz section

One-color THz pump-probe spectroscopy





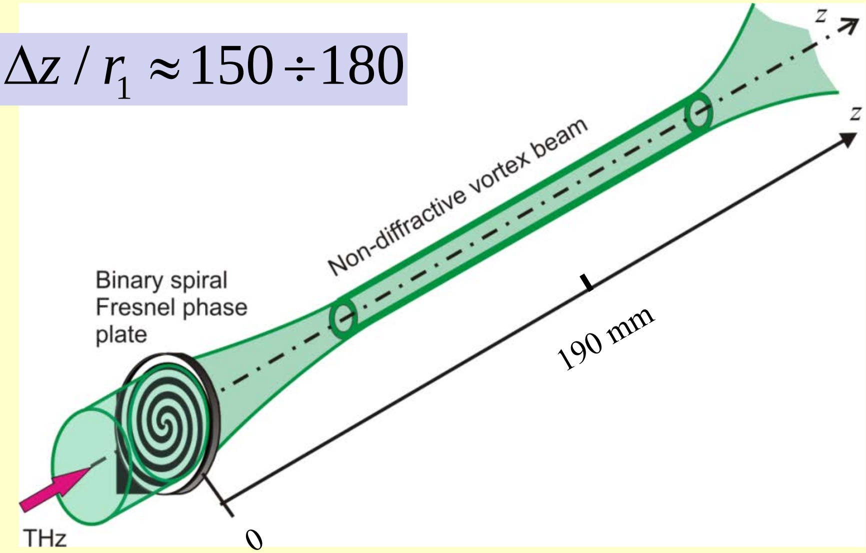


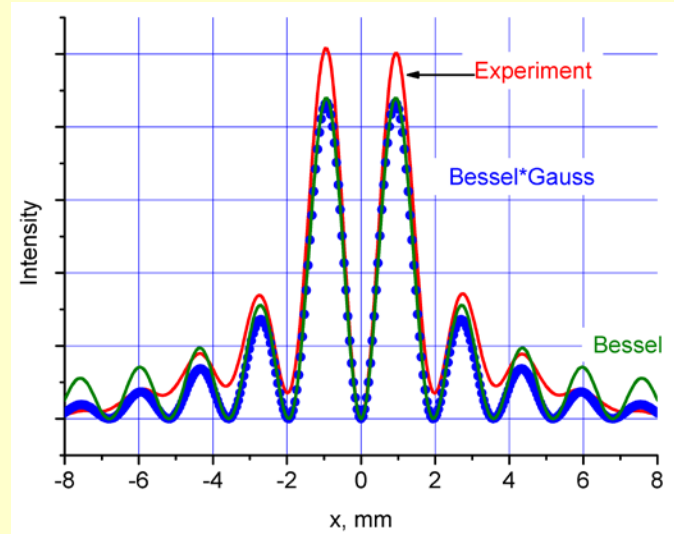


Yu. Choporova. Thursday 14:00, THz session

THz Bessel beams with angular orbital momentum

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





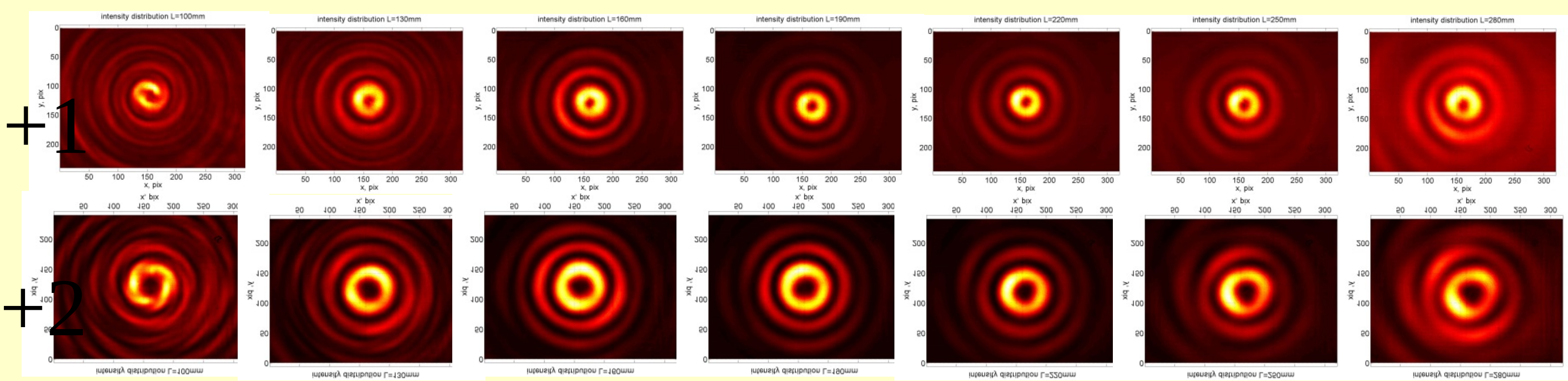
$$BG_{|l|}(r,\varphi,z=0) = J_{|l|}(\alpha_l r)\,\mathrm{e}^{-\frac{r^2}{\omega_0^2}+il\varphi}$$

Experiment

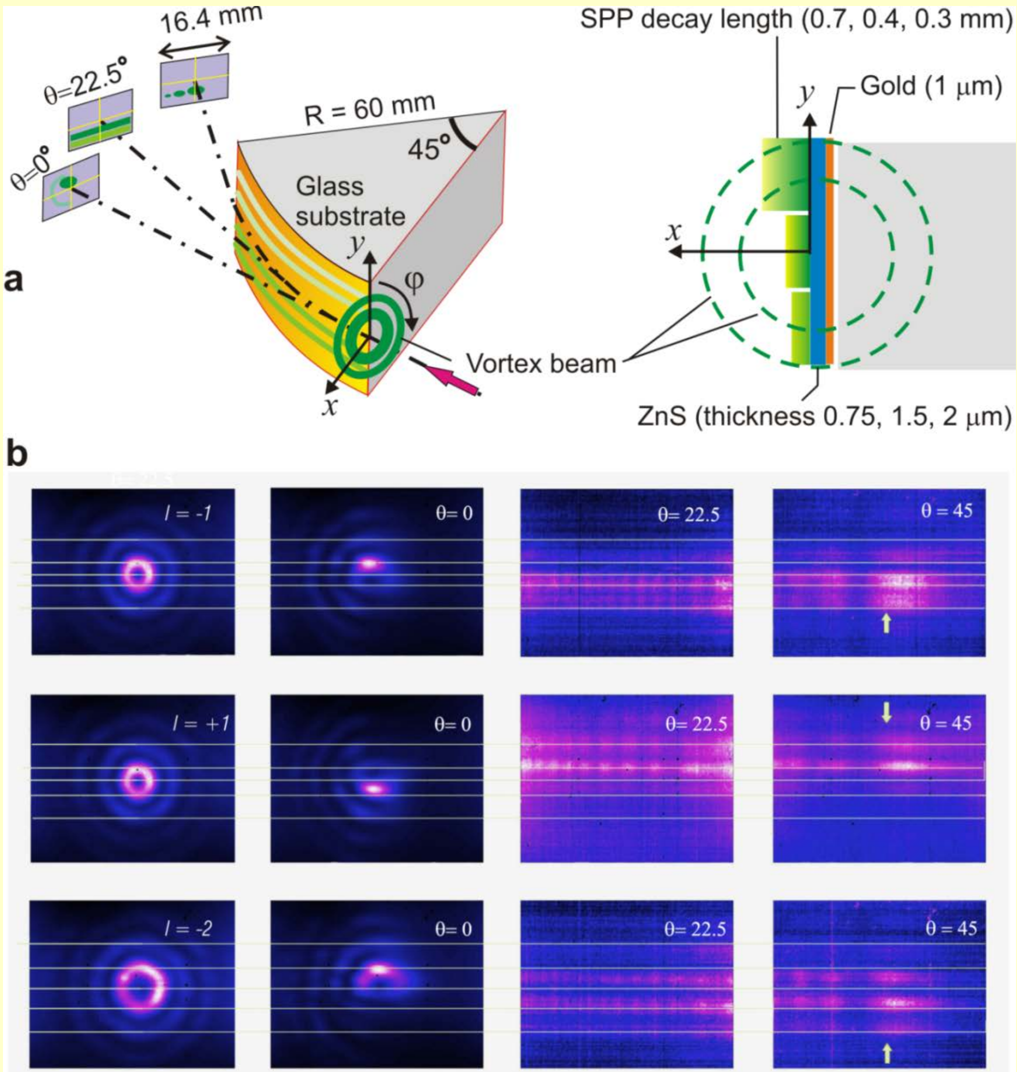
z = 100 130 160 190 220 250 280 mm

$l = +1$

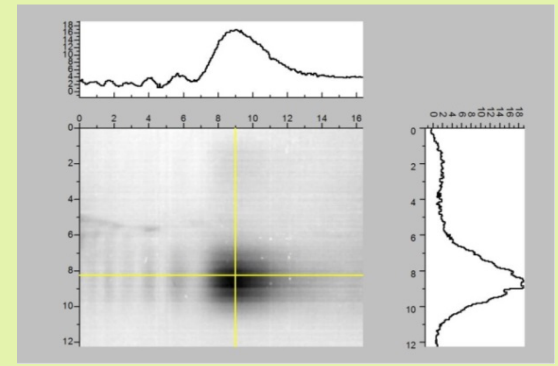
$l = +2$

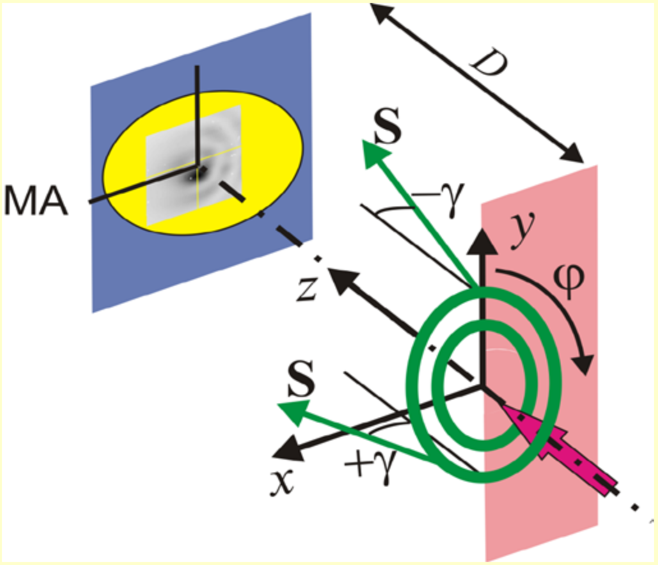


Efficiency of the generation of SPPs depends on direction of beam rotation



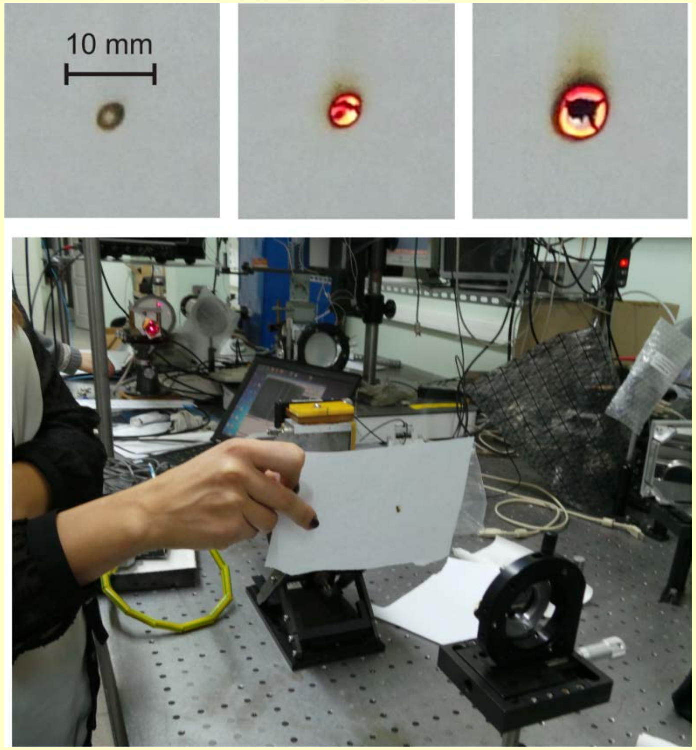
Diffraction of conventional beam,
θ = 45 degrees

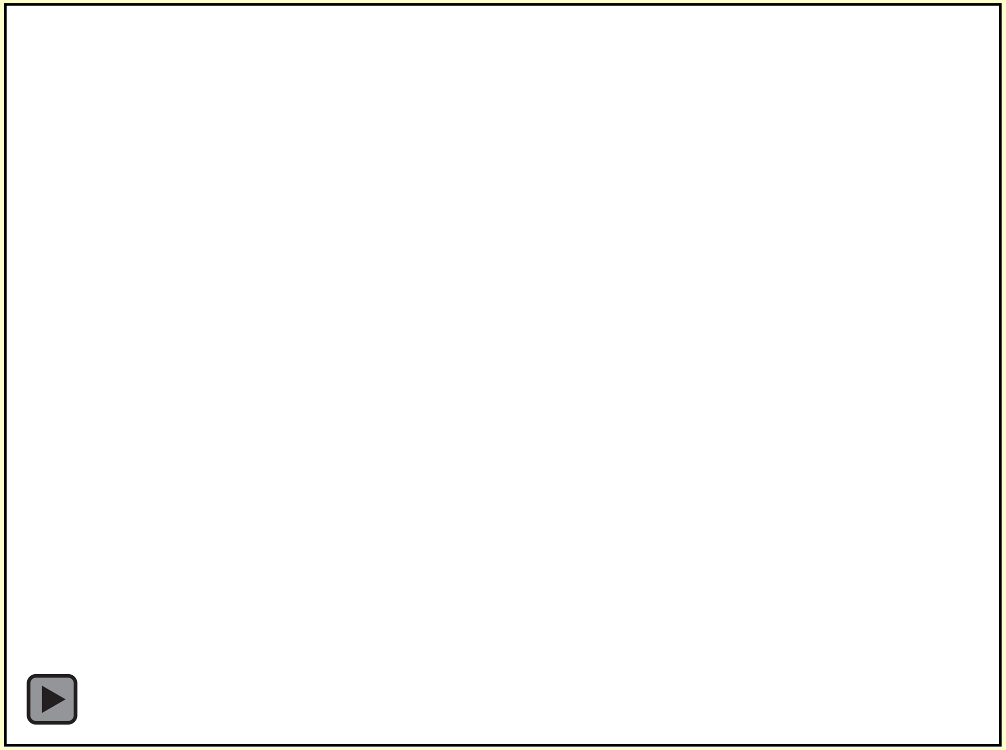




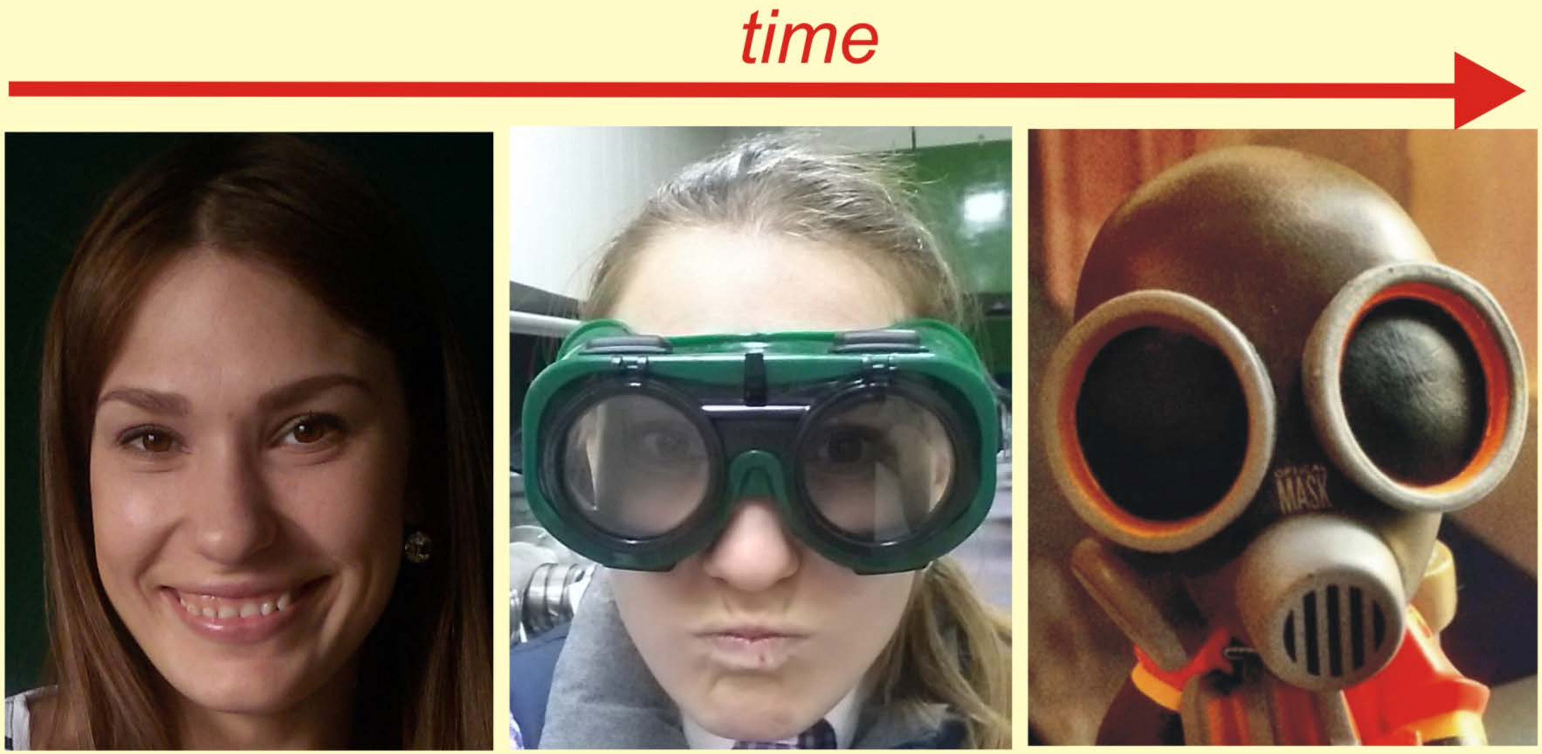
B. A. Knyazev, Yu. Yu. Choporova, M. S. Mitkov, V. S. Pavelyev, B. O. Volodkin, Phys. Rev. Letters, V. 115, 163901, 2015, 5p.

An original technique for detection of THz beams with phase singularity





Does THz radiation effect on the organisms?



My version of the biological effect of terahertz radiation

Summary

- All three laser systems of the NovoFEL facility are now in operation
- The workstations are well equipped with instrumentation which is available to users
- Many experimental methods and techniques have developed at the stations
- Unique features of NovoFEL radiation enable performing unique experiments
- We invite all researchers to suggest high-level experiments at NovoFEL