Siberian Synchrotron and Terahertz radiation center

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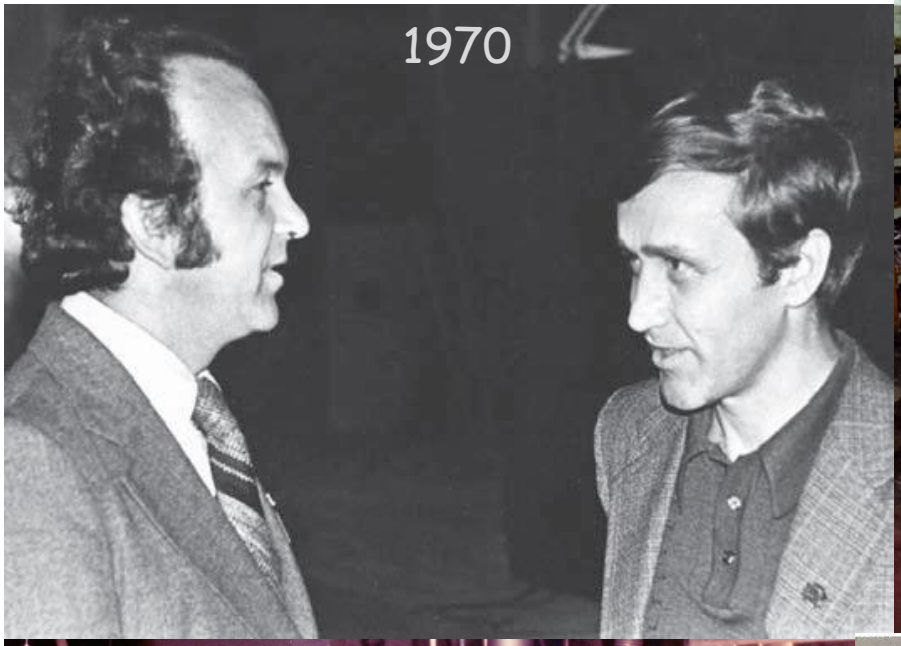
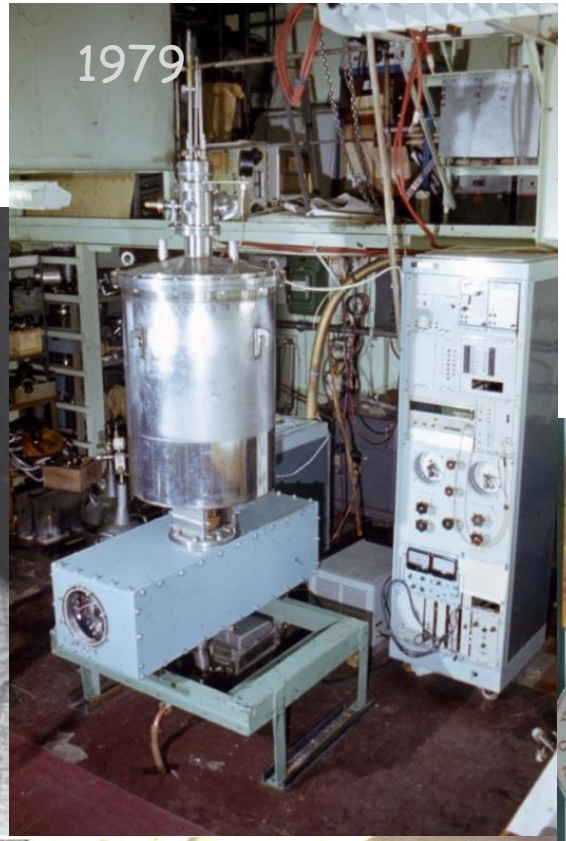
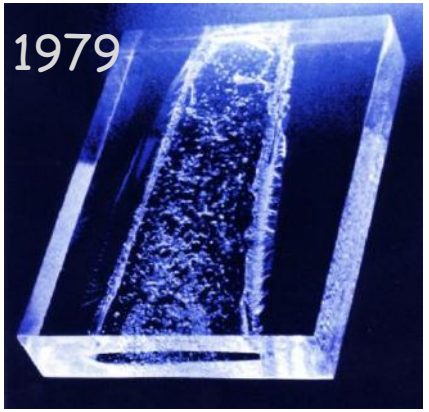
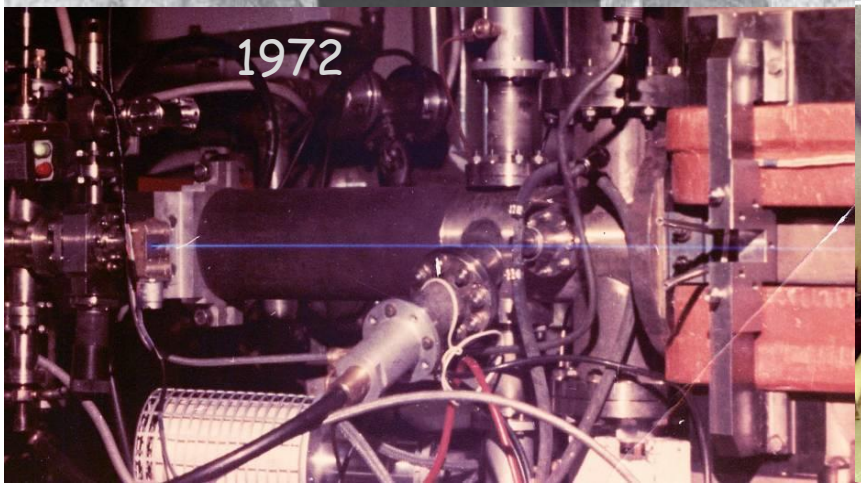
Budker INP
Novosibirsk, Russia

SSTRC History

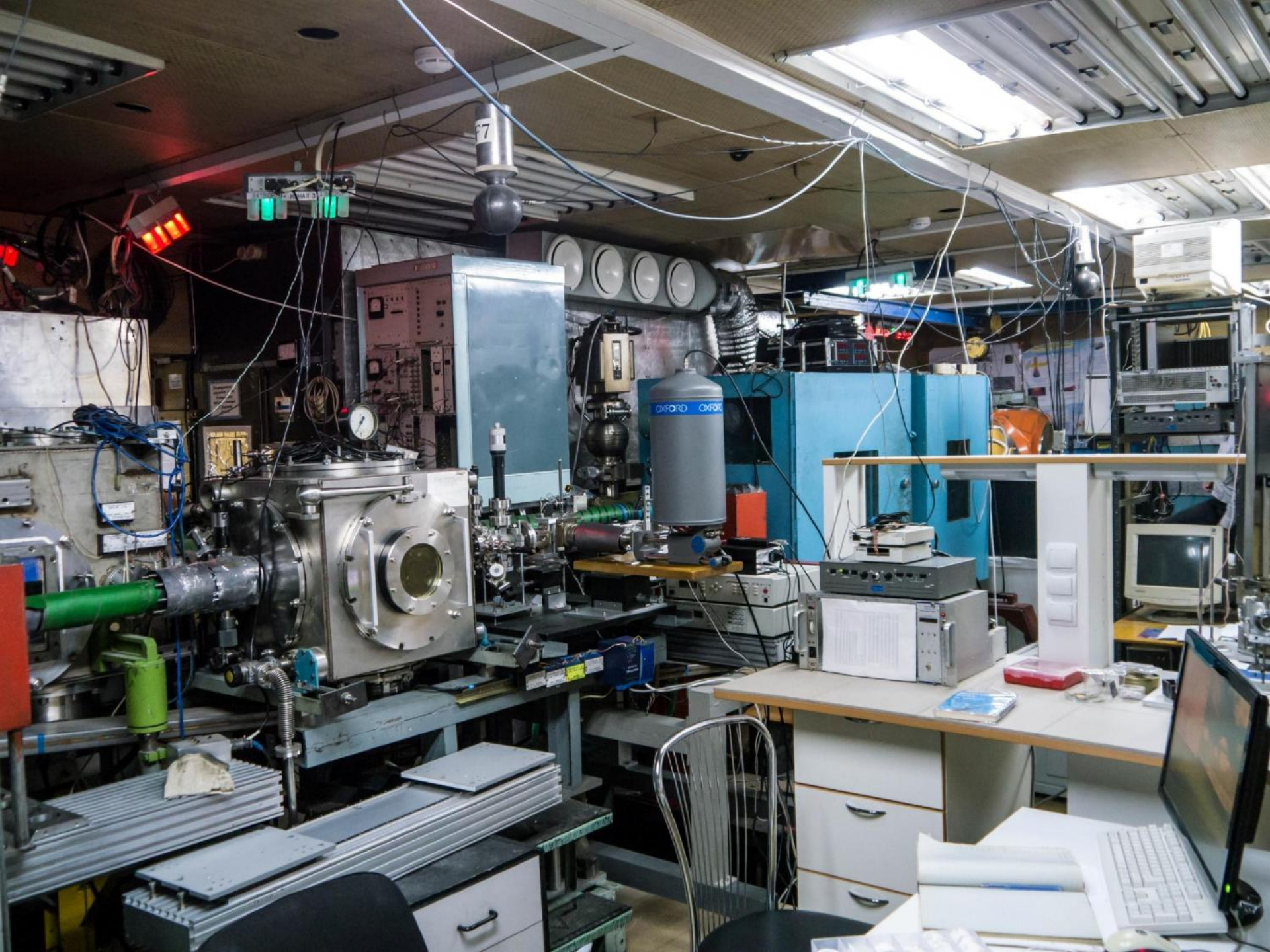








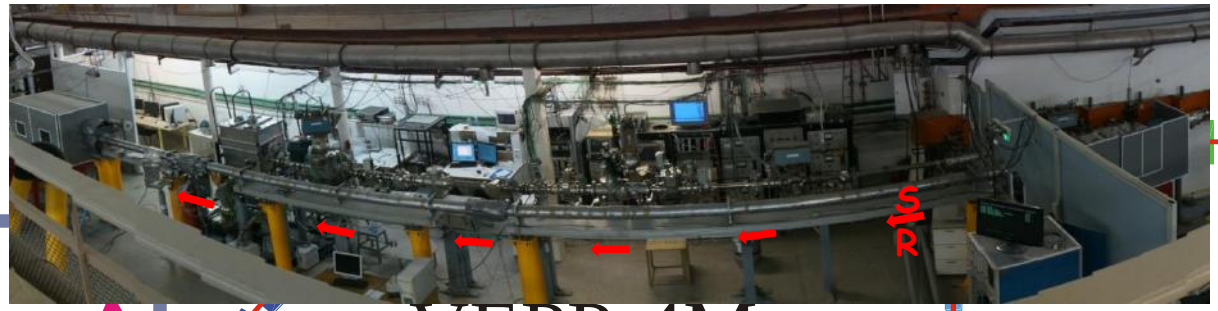

1980


OXFORD

SSTRC
Main directions

- SR applications activity
- FEL developing, building, maintenance and upgrading
- FEL radiation applications in the teraherz rage
- Developing and fabrication superconducting insertion devices
- Developing and fabrication magnetic elements for accelerators
- Developing of the new light source for SSTRC
- SR and FEL conferences organization
- Education activity
- International collaborations

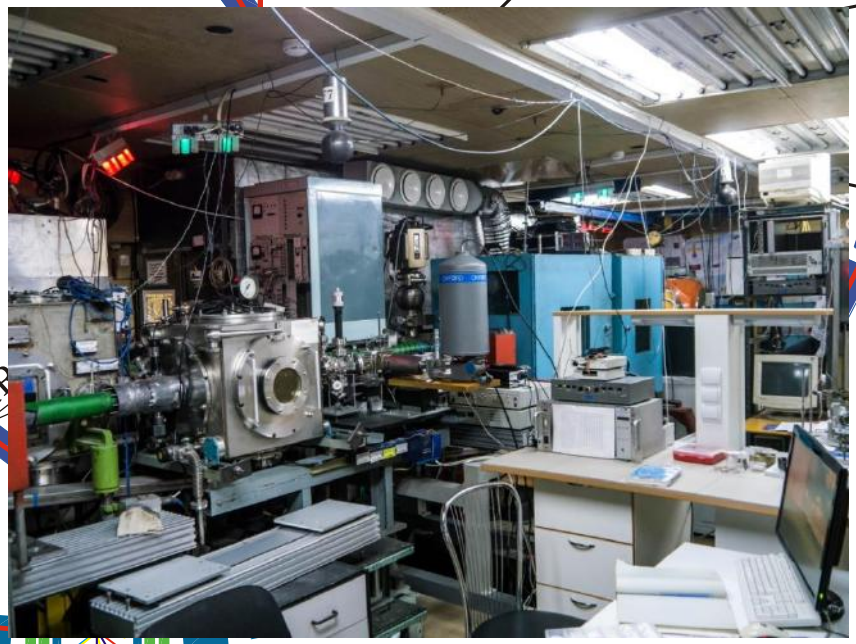
Light sources in the SSRTC



VEPP-4M

SR

R=45.5 m



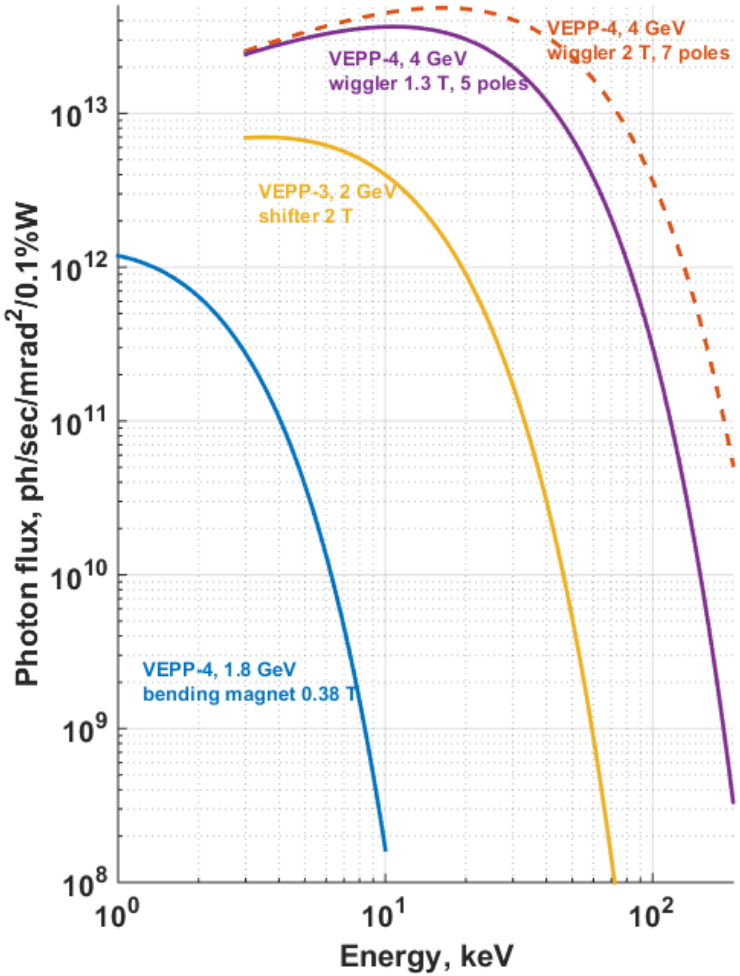
SR

ROKK-1M

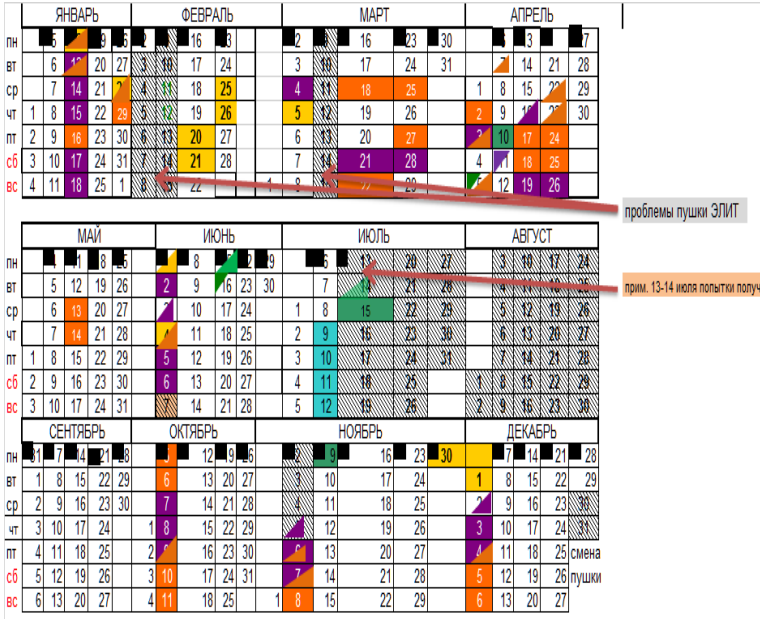
Detector KEDR

SR sources

	VEPP-3	VEPP-4M Low Energy	VEPP-4M High Energy
Energy, GeV	2	1.8	4
Circumference, m	72	366	
Lattice type	FODO	FODO	
Emittance, nm rad	~300	25	120
Max. current, mA	100	20	20
Number of bunches	1 - 2	1, 2, 4, 8	1, 2, 4, 8
SR devises	Wave length shifter (2 T)	Bending magnet (0.38 T)	Multipole wiggler (1.3 T x 5 poles)
Optic function in irradiation point β_x, β_y, η_x, m	2, 4.5, 0.7	9.64, 7.9, 0.9	9.7, 7.9, 1.16
Source size in irradiation point $\sigma_x \times \sigma_y$, mm	0.9 x 0.3	2.3 x 0.1	1.5 x 0.25
Critical energy, keV	5.3	0.8	13.8
Number of beamlines	8	1	1 (3 stations)



Time for SR applications work (hours)



	1-е полугодие	392 смен		2-е полугодие	246 смен		1+2 полугодие	638 смен	
1 работы на другие программы : ВЭПП-4, КЕДР и останов	246 смен	2956 часов	63%	194 смен	2330 часов	79%	441 смен	5286 часов	69%
2 отработанно на СИ ВЭПП-3	27 смен	320 часов	7%	4 смен	44.4 часов	2%	30.4 смен	364 часов	5%
3 СИ ВЭПП-3 + СИ ВЭПП-4 , низкая энергия	33 смен	396 часов	8%	18 смен	212 часов	7%	50.7 смен	608 часов	8%
4 планируется СИ - 3	0 смен	0 часов	0%	0 смен	0 часов	0%	0.0 смен	0 часов	0%
5 СИ ВЭПП-4, 4 ГэВ	29 смен	348 часов	7%	12 смен	144 часов	5%	41.0 смен	492 часов	6%
6 внезапные смены ВЭПП-3	6 смен	72.0 часов	2%	2 смен	20.4 часов	1%	7.7 смен	92 часов	1%
заметные потери на аварийный ремонт	43 смен	512.4 часов	11%	11 смен	128 часов	4%	53.4 смен	641 часов	8%
0 профилактика	8 смен	99.6 часов	2%	6 смен	72 часов	2%	14.3 смен	172 часов	2%
1/4...1/2 смены									
дневная смена									

ИТОГО за 2015 год

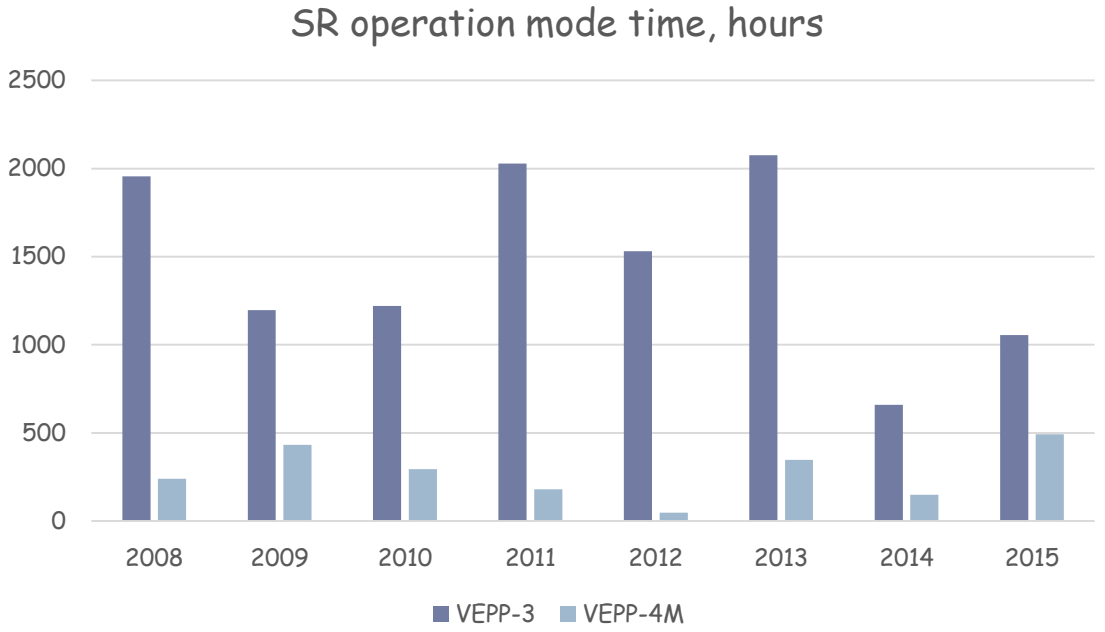
работы кроме СИ	440.5	смен	5286.4 час	69%
ремнот и проф	67.7	смен	812.4 час	11%
работа СИ	129.8	смен	1557.2 час	20%
в том числе				
СИ - 3	88.8	смен	1065.2 час	14%
СИ-4ГэВ	41.0	смен	492 час	6%

7656 час 100%

доля СИ от общ.вр. с учет. рем. и проф. 20%

доля СИ от общ.вр. без учет. рем. и про 23%

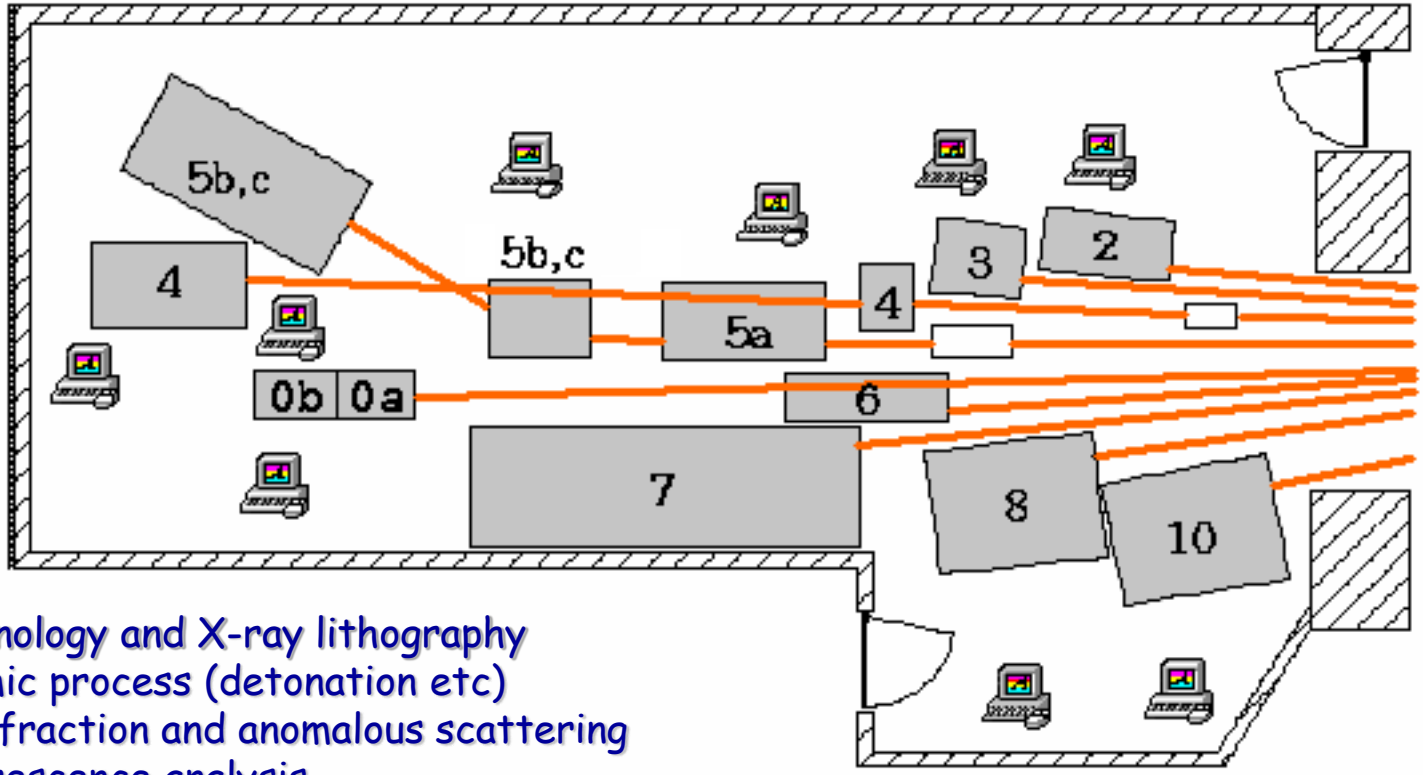
Year / Light source	2008	2009	2010	2011	2012	2013	2014	2015
VEPP-3	1956	1197	1221	2028	1530	2076	660	1056
VEPP-4M	240	432	294	180	48	348	150	492



8

VEPP-3 synchrotron radiation beamlines

VEPP-3 SR experimental hall (14x5 m)



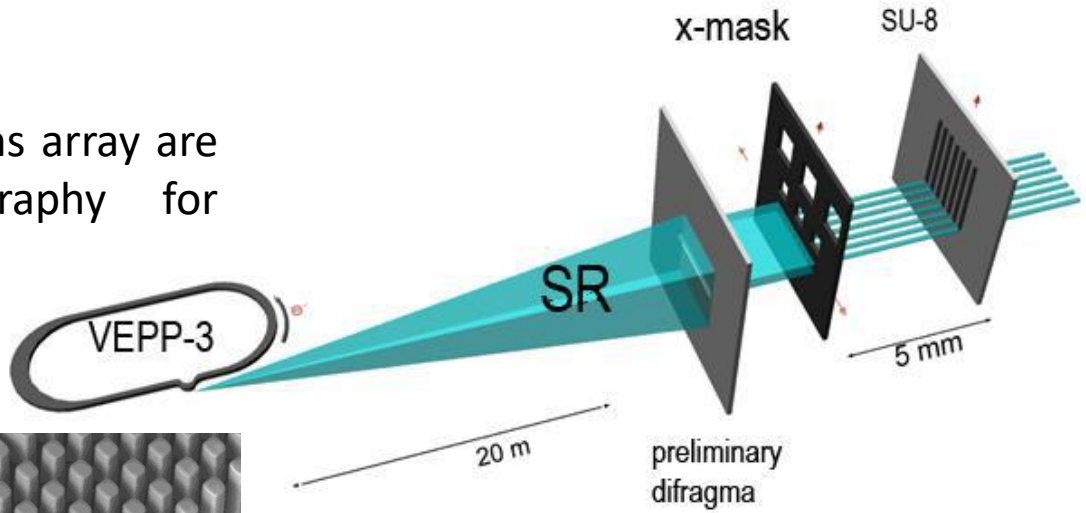
0a - LIGA-technology and X-ray lithography
0b - Fast dynamic process (detonation etc)
2 - Precise diffraction and anomalous scattering
3 - X-ray fluorescence analysis
4 - High pressure diffraction
5a – X-ray microscopy and microtomography
5b – Time resolved diffraction
5c – Small angle scattering
6a - Time resolved luminescence
6b – Precise diffraction-2
7 - SR monitoring station
8 - EXAFS-spectroscopy

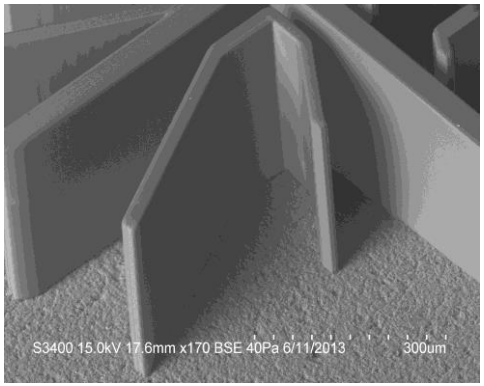
VEPP-4 SR beamlines

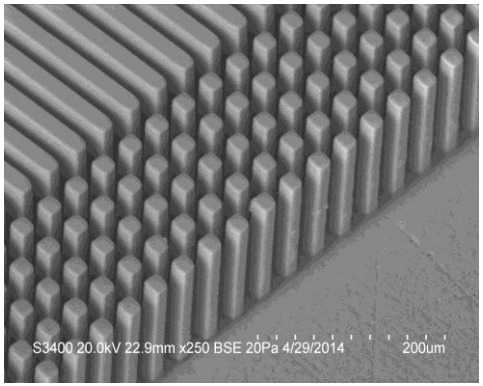
1. «Cosmos» (metrology in VUV and soft X-ray range 10-2000 eV)
2. Phase contrast microscopy, microtomography and hard X-ray fluorescence
3. «Vzryv-2» (nanosecond diagnostics)
4. «High presure» - assembling
5. "Plamya" beamline – developing
6. Precise difractometry (planning)

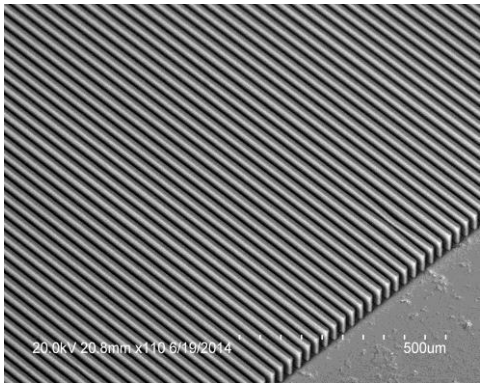
“LIGA” station at VEPP-3

Single microbeam SR or microbeams array are used for Direct X-ray lithography for Fabrication of deep LIGA structures.





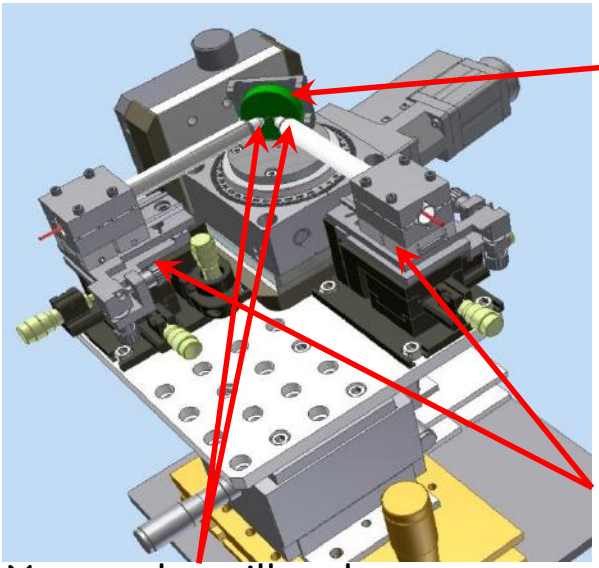




Electron lithography.
SEM Hitachi Type II + Nanomaker for microstructure forming in the thin PMMA layers (2-3 μm) for fabricating intermediate template for the soft X-ray lithography

Samples of high aspect ratio microstructures: micro-lamellae, micro-grid, array columns

Beamline 3, Scanning μSRXRF
Confocal polycapillary X-ray optics

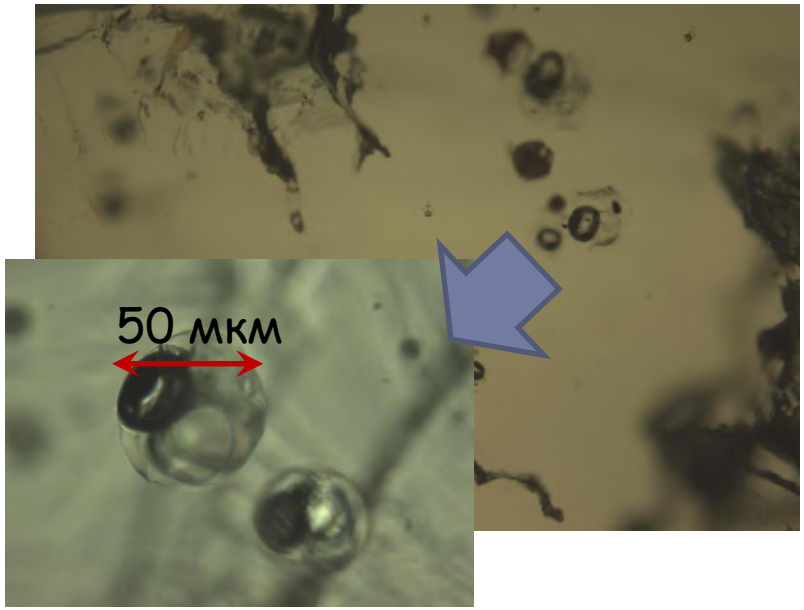


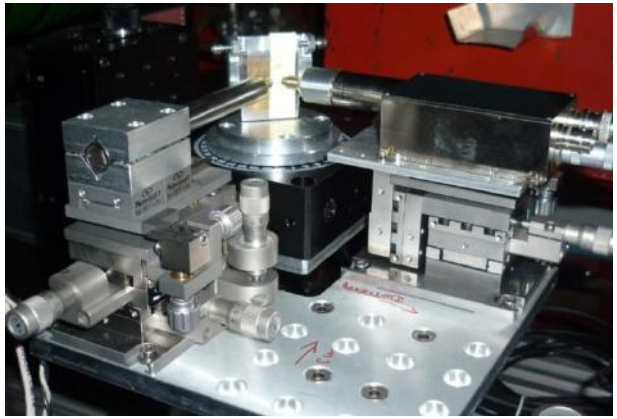
sample

Microfluid insertions

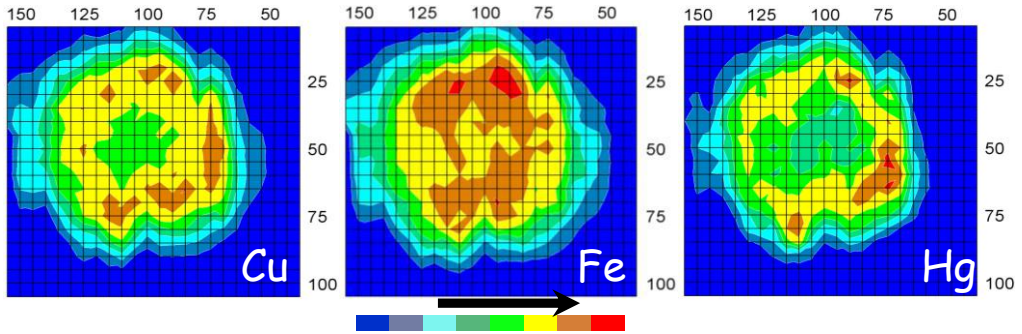
Lenses adjustment stages

X-ray polycapillary lenses



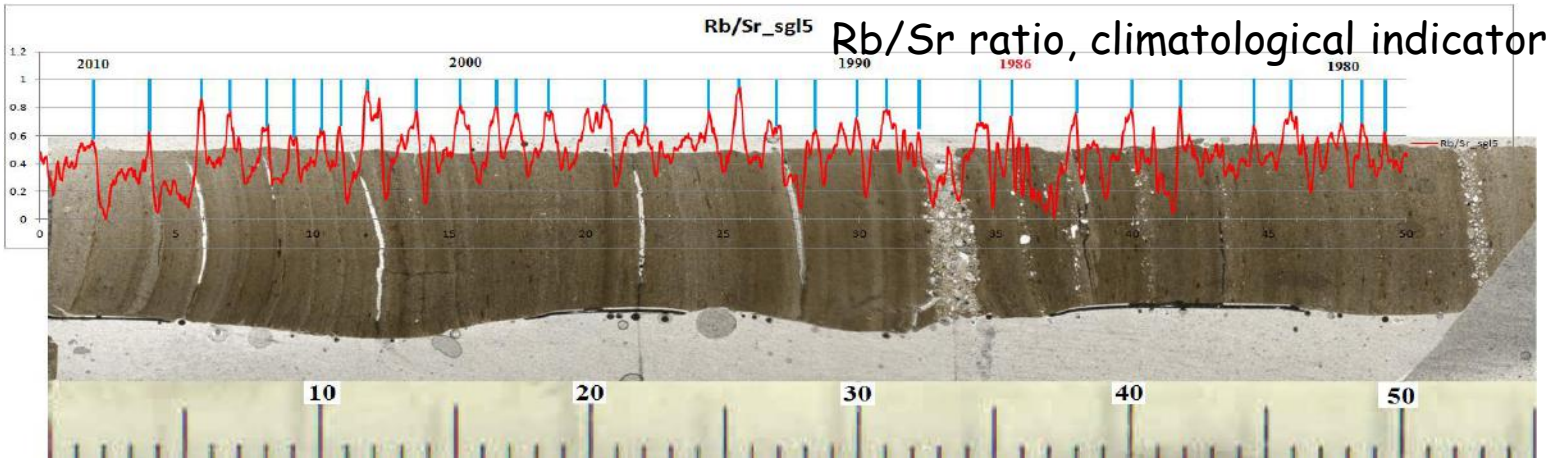


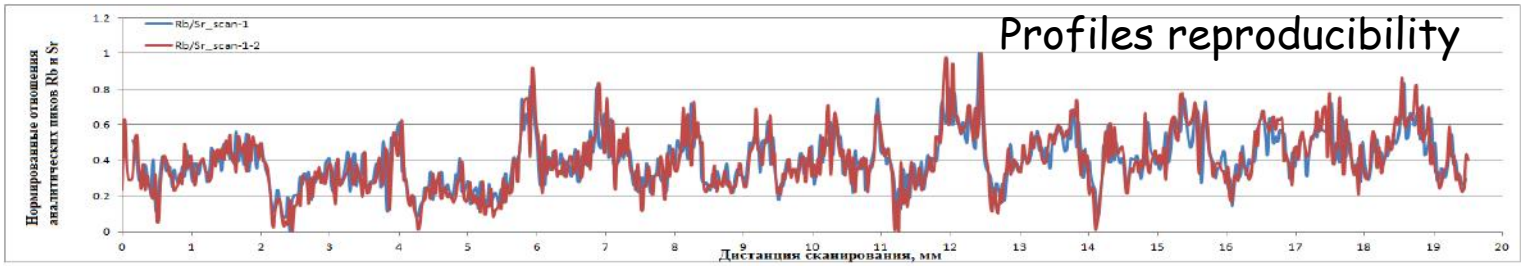
Spatial resolution about 10 μm
3d reconstruction

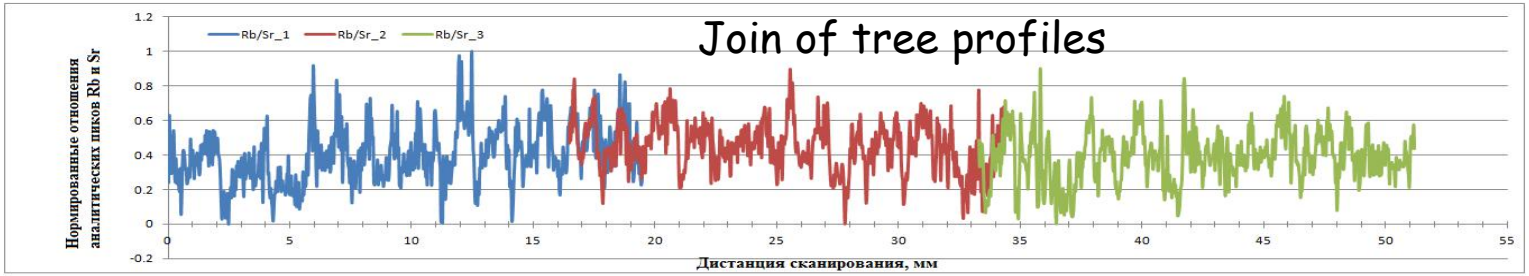


Elements distribution in the coss-section of the human hair

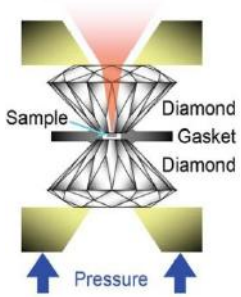
Beamlibe 3. SRXRF. Lake bottom sediments analysis.

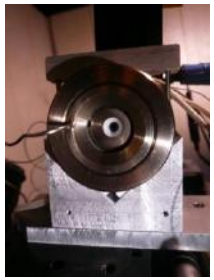


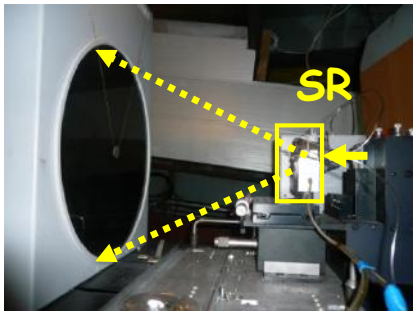


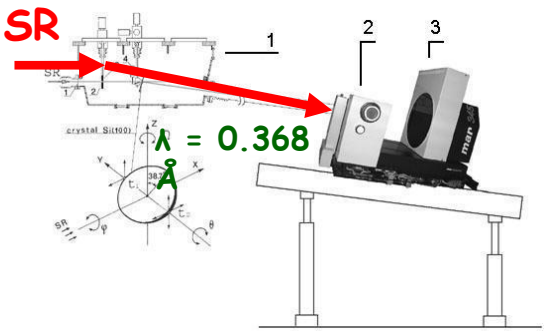


XRD experiments at simultaneously high pressure and high temperature
Beamline 4, VEPP-3

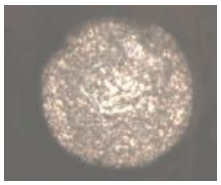


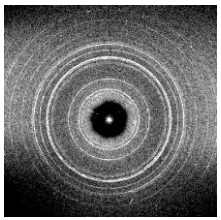






High pressure, resistively heated diamond anvil cell and general view of the diffraction experiment

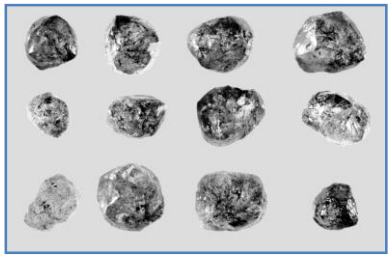




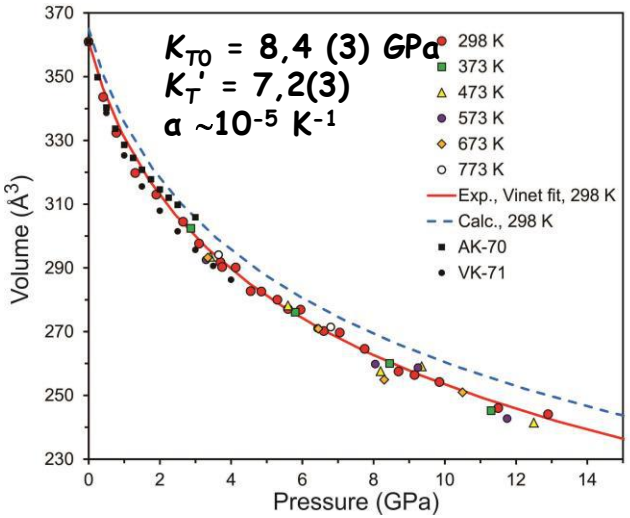
View in the chamber and the XRD pattern of powder sample at P ≈ 3 GPa

Stability of hydrocarbon compounds at high pressure and temperatures and implications for the deep structure of the Earth and planets

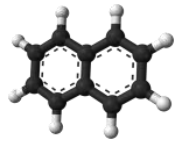
polycyclic aromatic hydrocarbons - important components of inclusions in the deep minerals and meteorites



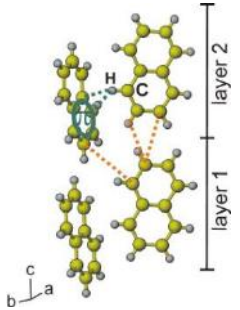
poly-phase inclusions of hydrocarbons in diamonds from deposits of the north-east of Siberian platform (Томиленко и др., 2001, Доклады РАН).



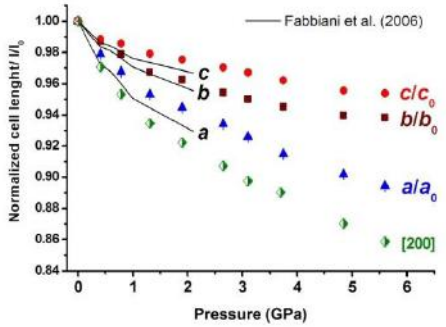
Pressure dependence of the unit cell volume of naphthalene $C_{10}H_8$ at 298-773 K.



naphthalene molecule

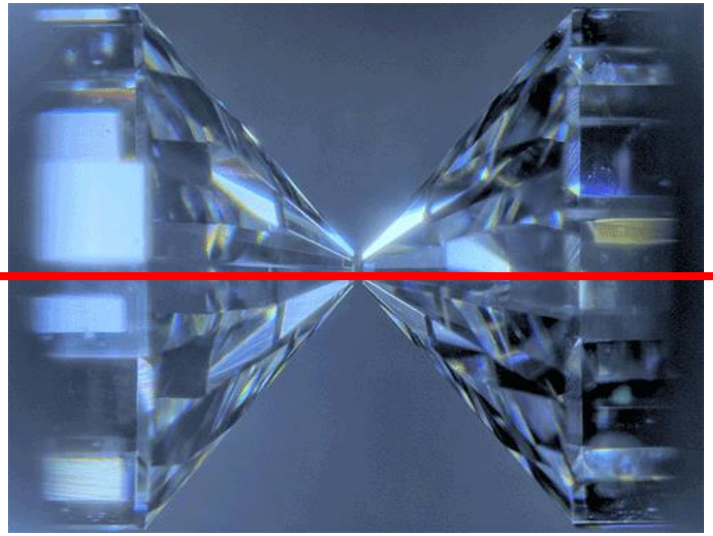


Structure and anisotropic compressibility of naphthalene up to 6 GPa

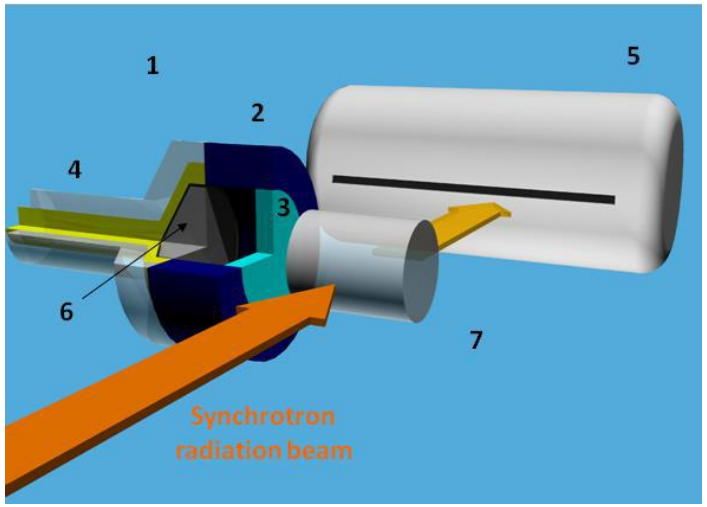


Murchison meteorite
Aromatic hydrocarbons predominate in hydrocarbon matter of meteorites *(Pering, 1971, Science)*

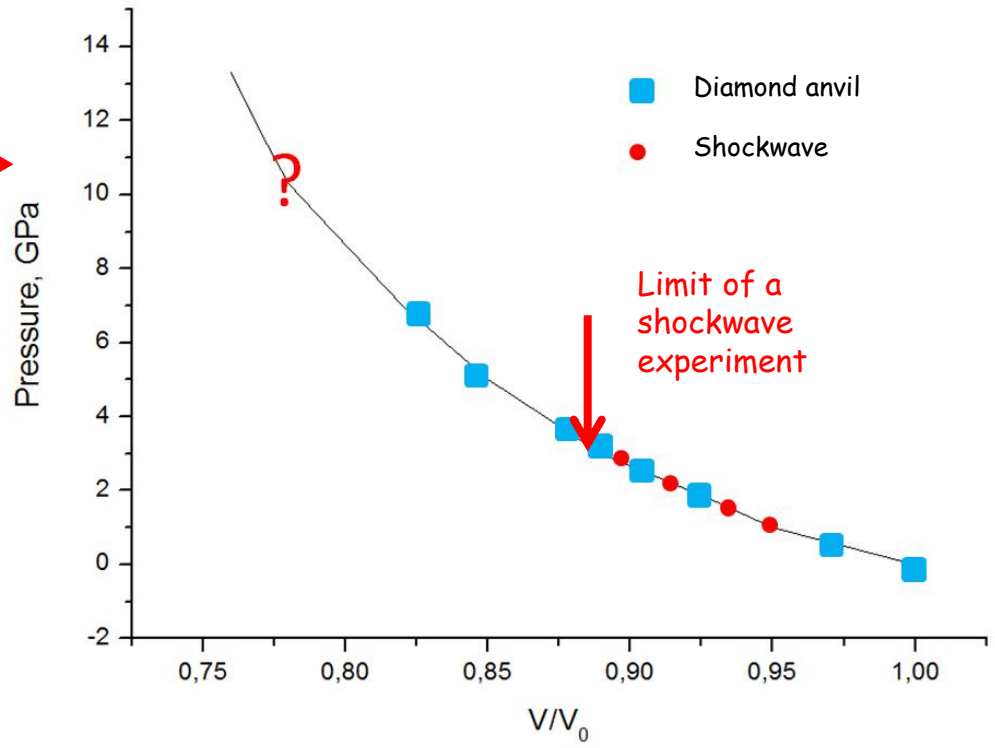
The equation of state of explosives



Diamond anvil



Shockwave experiment



Experimentally obtained curve equation of state of shockwave loading TATB and compression in the diamond anvils

Beamline 5b. Time-resolved XRD

One-coordinate detector OD-3
WAXS mode

One-coordinate detector OD-3
SAXS mode

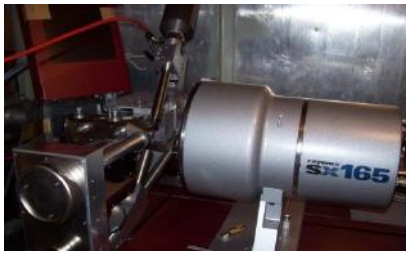
Dedication:
In situ study of the phase and structural transformation during chemical reaction by X-ray diffractometry

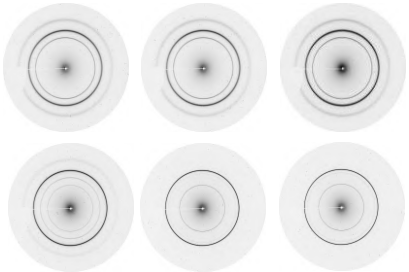
Main parameters:
Monochromator: curved asymetric cut silicon single crystal Si (111)
Energy: ~ 8.2 keV

Equipment:
One-coordinate detector OD-3:
Angle range: ~ 30 degrees (at a distance of up to 350 mm of the sample)
Channel: ~ 0.01 °
The number of channels: 3328
Minimum time frame - 1 mks
Maximum load: 10 MHz

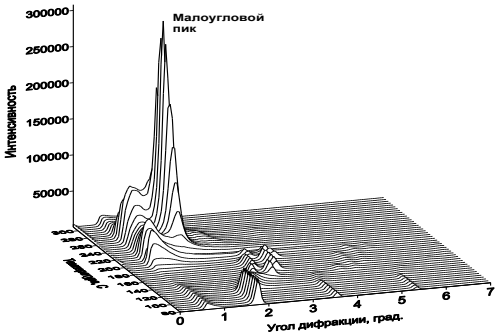
XY detector MarCCD
Pixel Size - 80 * 80 mkm
The diameter of the working area - 165 mm
The minimum reading time – 2 sec

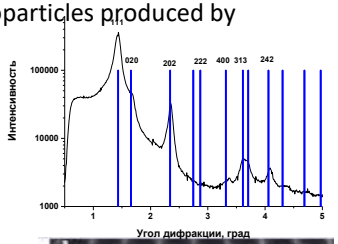
2D-detector MarCCD

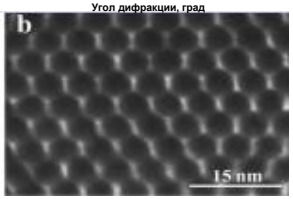




Formation 3D-structure of the silver nanoparticles produced by the decomposition of the carboxylate

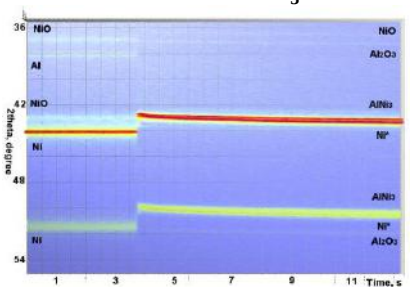




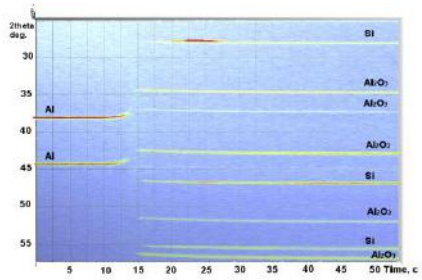


Phase transformation dynamics in the Self-propagating high temperature synthesis (SHS) in the mechanical composite materials….

$NiO + Al + Ni \rightarrow AlNi_3$

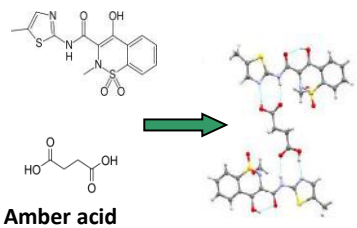


$SiO_2+Al \rightarrow Si + Al_2O_3$

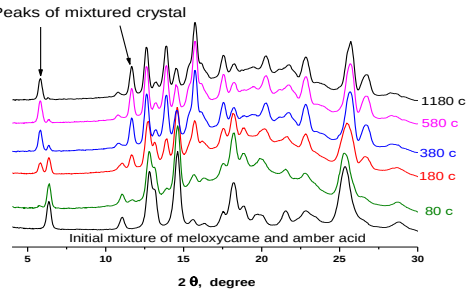


… and during formation mixed organic crystals

Meloxycame

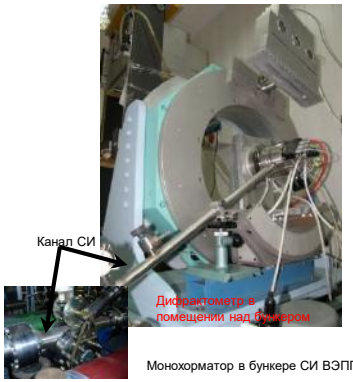


Amber acid

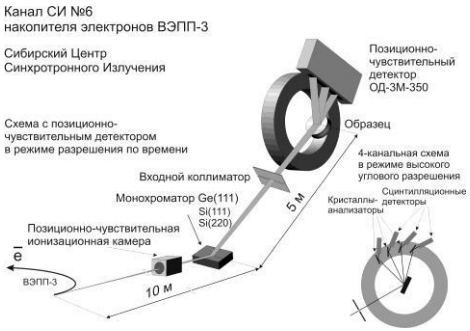


Beamline 6. Precise diffractometry

General view

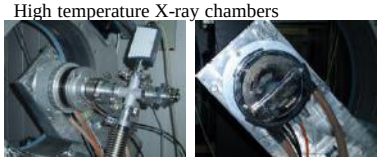


Layout



Equpment

High temperature X-ray chambers

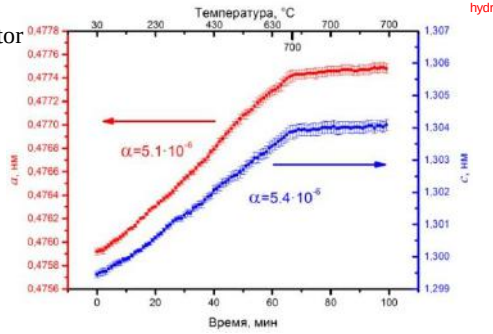


Luggage Anton Paar HTK-2000 experiments at temperatures up to 1400 ° C in air or an inert atmosphere to 2000 ° C in vacuum.

Camera Anton Paar XRK-900 experiments at temperatures up to 900 ° C in an oxidizing or reducing environment, and gas mixture pressure of from 0.1 mbar to 10 bar.

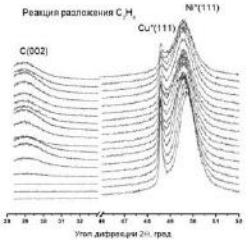
- 3-channel system of preparation of gas mixtures on the basis of mass flow-controllers;
- hydrogen generator
- Gas analyzer based on SRS RGA-100 quadrupole mass spectrometer

Corundum lattice parameter change due to thermal expansion by heating in an inert atmosphere. Camera XRK-900, envinment - He.

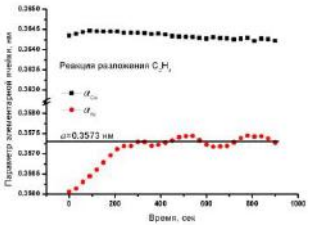


Phase composition of Ni-Cu catalysts for the synthesis of nitrogen-containing carbon nanofibers and its changes in response

Changing the state of the catalyst in a reaction medium. 100% C2H4

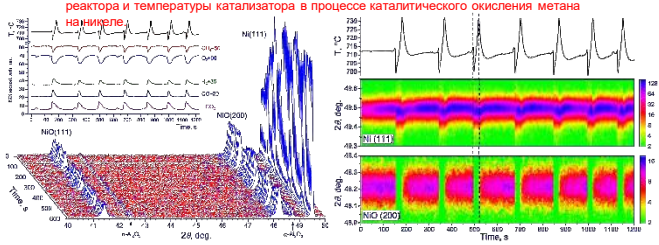


Changes in the catalyst lattice parameter in a reaction medium. 100% C2H4



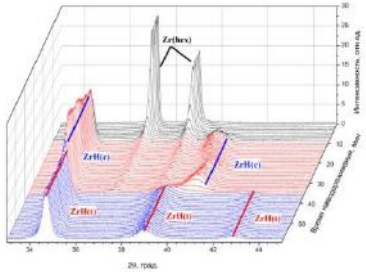
Autooscillations reaction rate in the catalytic oxidation of light hydrocarbons to Ni and Pd

Изменение фазового состава катализатора, состава газовой смеси на выходе из реактора и температуры катализатора в процессе каталитического окисления метана на никеле

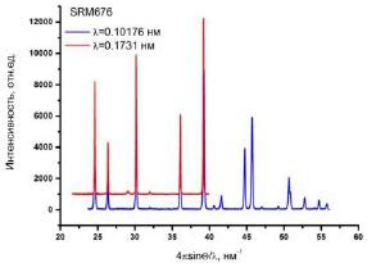


In Situ Investigation of the structure changes alloy based on zirconium with saturated hydrogen from the gas phase

In an atmosphere of hydrogen at 350 ° C is formed of a cubic phase of zirconium hydride, and at 450 ° C there is a transition to the tetragonal phase cubic.



The main parameters of the station
Monochromator:
A single-crystal, with the beam deflection in the vertical plane at an angle ofapproximately 30 °;
Crystals: Ge (111), Si (111), Si (220);
The discrete set-energy radiation: 7.162 keV, 7.460 keV, and 12,183 keV
collimator:
Slits output;
beam on the sample size 0.5 × 5 mm2
detection systems:
One-coordinate detector OD-3M-350;
The range of angles 30 °,
resolution 0.01 °, the time resolution of 1 ms.
Sample Holders:
High-temperature X-ray cameras Anton Paar XRK-900 and HTK-2000



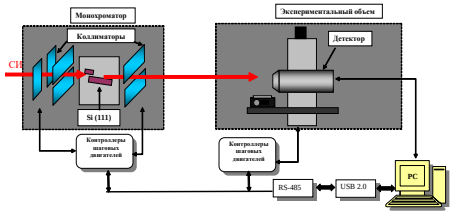
XRD patterns of corundum, obtained at different photon energies in a fixed detector position

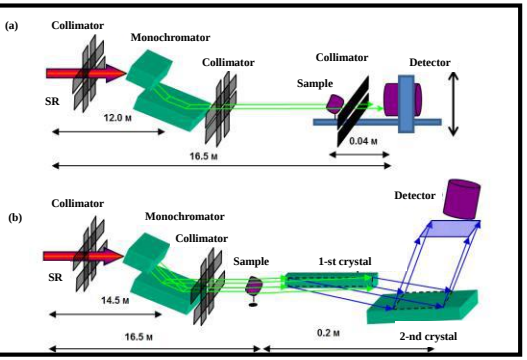
Realized methods

diffractometry with time resolution at high temperatures (up to 1400 ° C in air to 2000 ° C in vacuum);
diffractometry with time resolution in a reaction medium (up to 900 ° C at gas pressures from 0.1 mbar to 10 bar);

Beamline 5a. X-ray microscopy and microtomograpy

Main layout

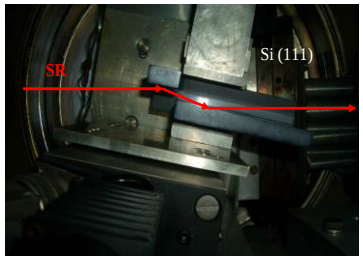




Imaging layout
(a) - without bragg-magnifier, (b) - with bragg-magnifier

The main parameters of the station
Monochromator:
Two crystals, silicon, (+ n, -n) c working crystallographic plane (111)
The range of photon energies of monochromatic radiation: 5-45 keV
Spatial resolution
without bragg-magnifier: 50 µm
with bragg-magnifier 2 µm

Monochromator



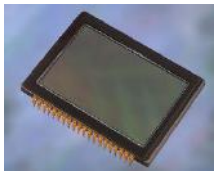
Channel cut monochromator: Si (111)

Experimental hatch

1 - sample 2 - first asymmetrical crystal, 3 - second asymmetric crystal, 4 - Detector

Two dimensions detector"Photonic Science"

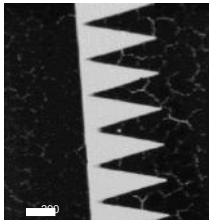
Effective range: 62 x 41 mm2
The scintillator: Gadolinium oxysulfide
Energy range: optimum 5 - 35 keV
Range of registration: 65536 (16-bit)

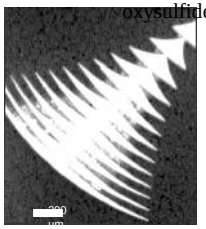


CCD 4008 x 2670
pixel size 9x9 µm²

Fiber optics with magnification 1.73

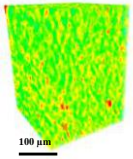
Testing of the X-ray transparent coatings

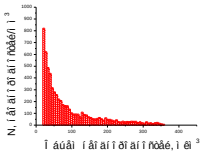


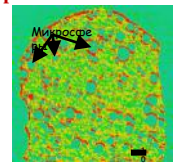


oxysulfide

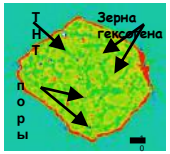
Density distribution in the explosive



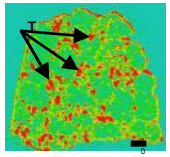




Эмульсионное ВВ

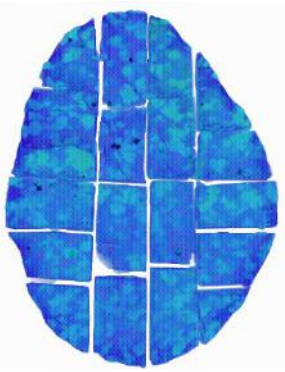


TNT and hexogen mixture

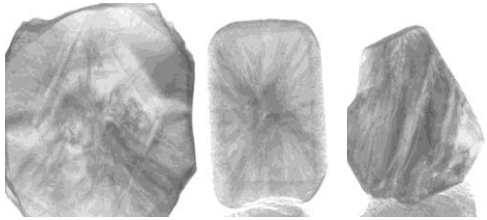


Hexogen with 7% TNT

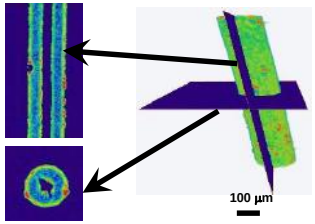
Minerals distribution in geological samples



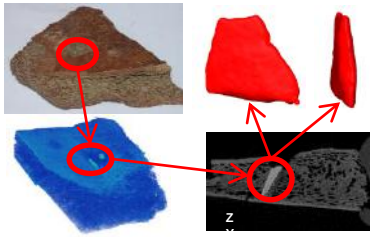
X-ray topography on natural diamonds



Archaeological research

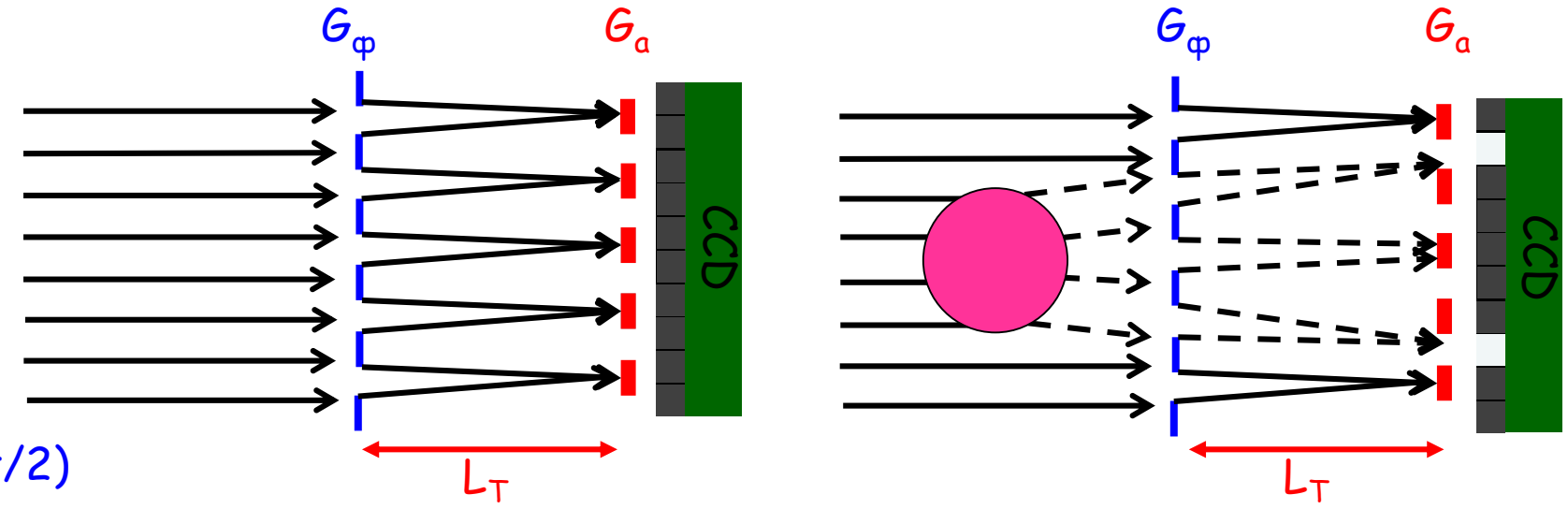


Hair from accent barrows



Detail of the tip in buffalo bones

Phase contrast imaging with using Laue Talbot interferometer

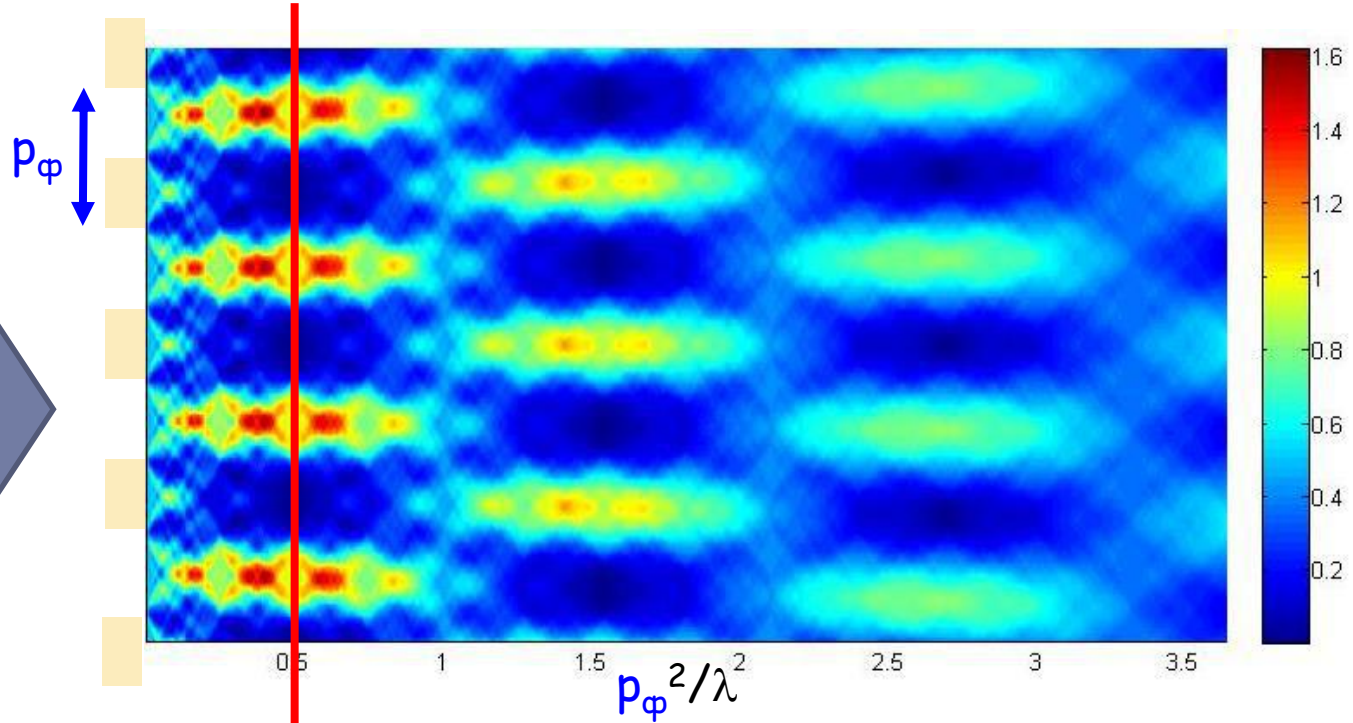


$(\Delta\varphi=\pi/2)$

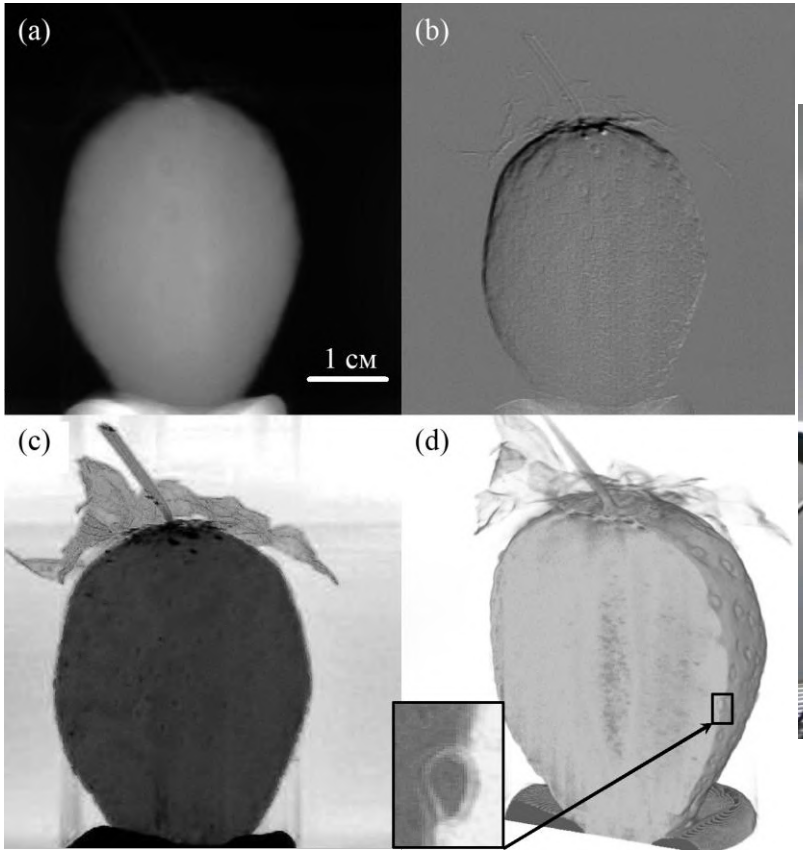
$nL_T=np_\varphi^2/2\lambda$

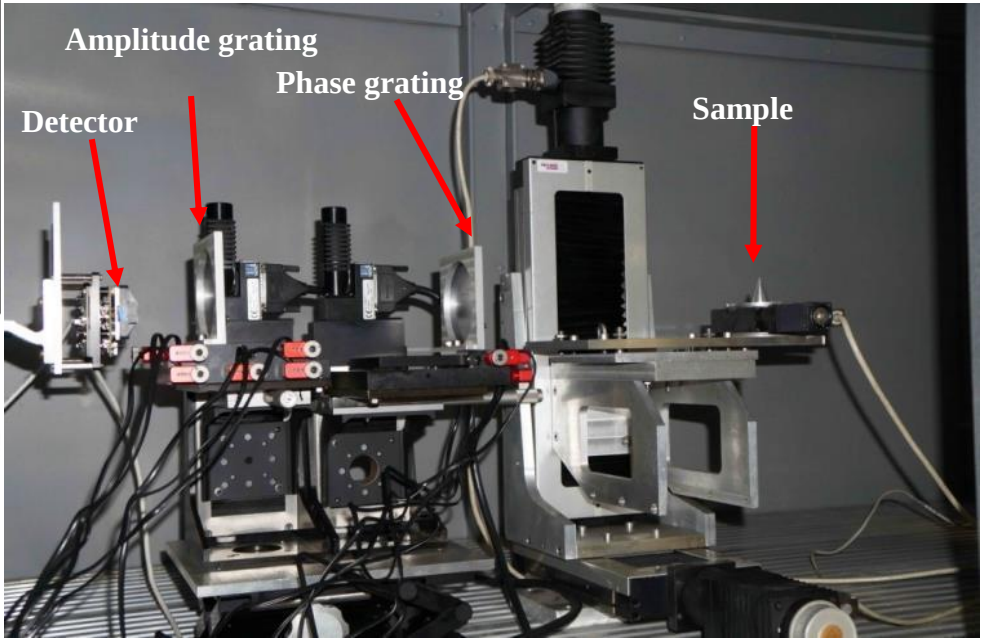
$p_a=p_\varphi$

SR



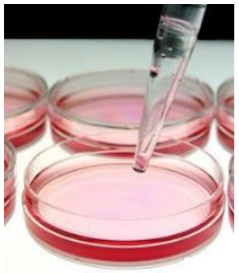
Phase contrast microscopy



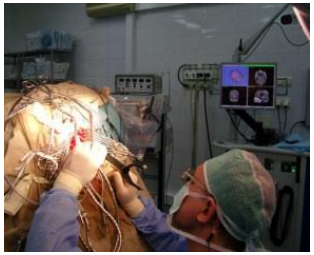


(a) – Absorption contrast, (b) – Differential phase contrast $\partial\Phi(x)/\partial x$, (c) – phase contrast $\Phi(x)$, (d) – Tomographic reconstruction of three-dimensional structure of strawberries set phase projections.



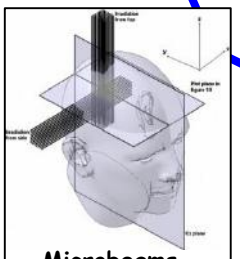


VEPP-4 SR experimental hall

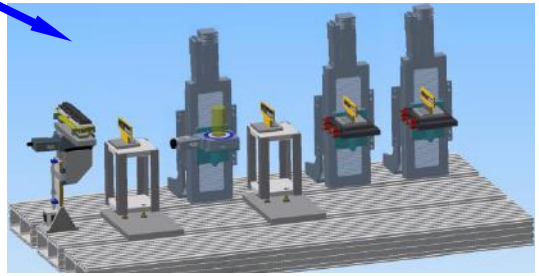


CLINIC
Primary Culture
tumor

CRYOBANK



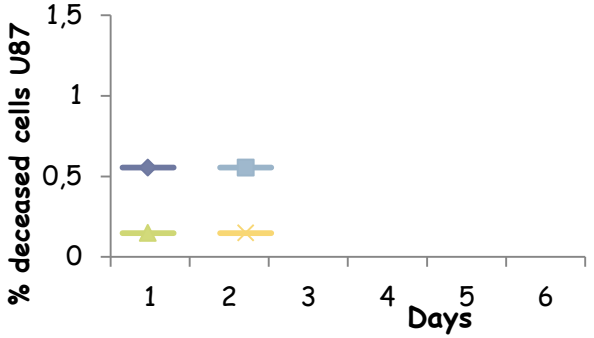
Microbeams
radiation
therapy



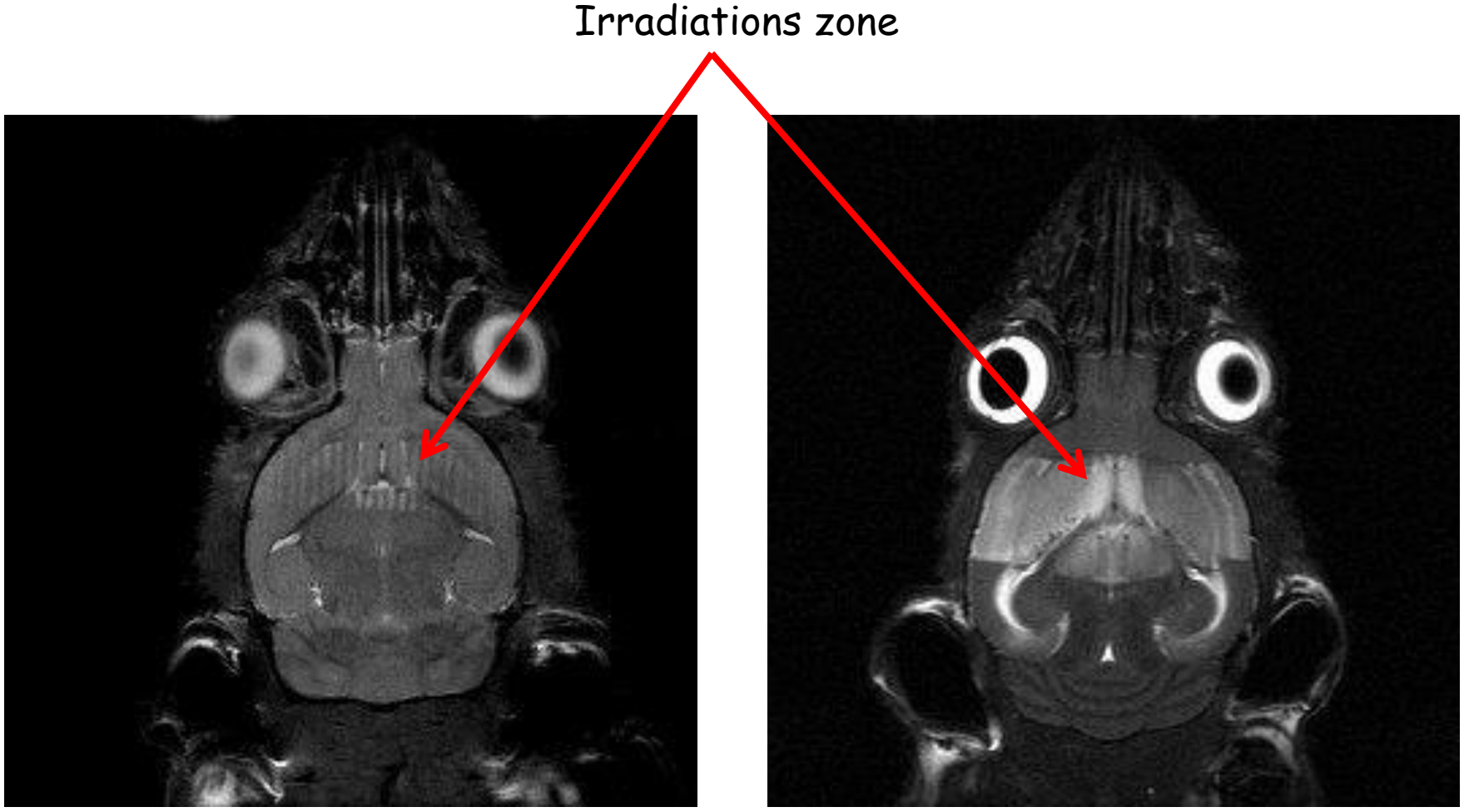
in vitro

in vivo

Cytopathic effects nanoparticles at microbeams irradiated human glioblastoma cell culture



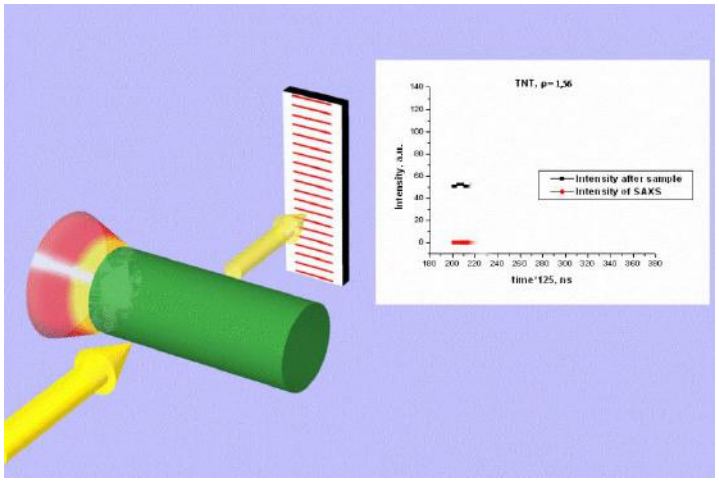
In-vivo experiments on Hairless SCID mouse



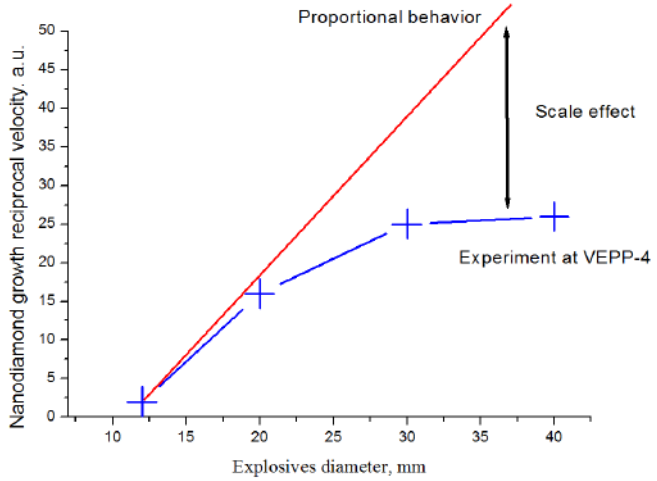
Microbeam irradiation
800 Gy
(mouse survived)

Broad beam irradiation
400 Gy
(mouse died at next day)

Detonation Diamond nucleation : scale effect



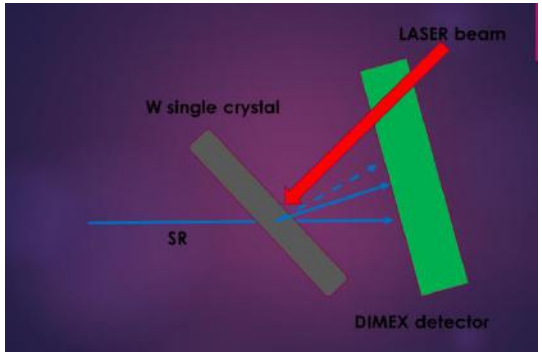
- The scheme of SAXS experiment during detonation of explosive trotyl/hexogen.



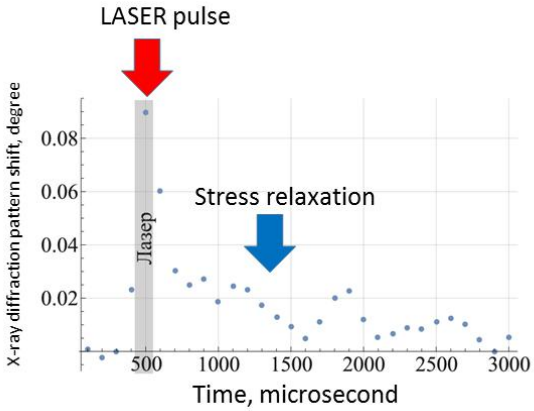
- The scheme of SAXS experiment during detonation of explosive trotyl/hexogen.

- It was found that an increase the mass of explosives leads to increases of produced diamonds mass. Accordingly, increases the rate of formation of diamonds. However, the dependence of the diamonds mass versus the mass of explosive is nonlinear. Also there is non-linear dependence of the formation rate of diamonds versus the weight of the explosives. Thus we observe a scale effect.
- Interpretation: the dependence of chemical reactions from the detonation conditions (diameter), the formation of larger diamonds in the detonation of explosives with large diameters.

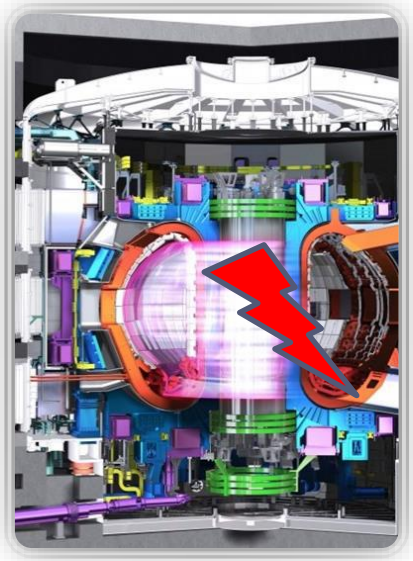
ITER: plasma discharge on the diverter. Material behavior. Model experiment with laser pulse heating



The scheme of model experiment with LASER pulse heating during 100 microseconds.



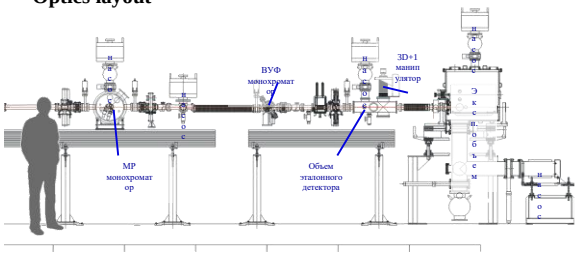
The experimental data of model experiment with LASER pulse heating .



- Now we are preparing an experiment to study the behavior of the crystal lattice of the material of the fusion reactor first wall in a plasma discharge on the diverter

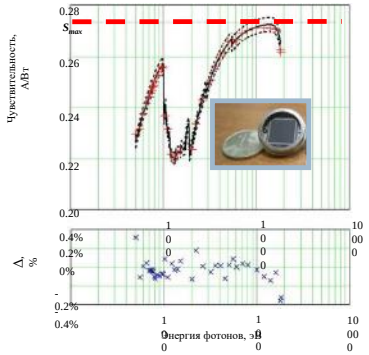
Soft X-ray and VUV metrology station

Optics layout



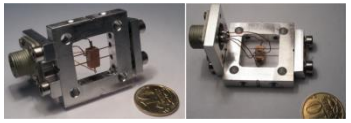
The spectral sensitivity of the reference detector SPD
silicon photodiode development
PTI (St. Petersburg)

The detector is calibrated to the national metrological center German PTB using a cryogenic radiometer. Calibration accuracy - 1%.



The top graph - the calibration data (+) and approximation of data (solid line) of the model function. The lower graph shows the difference between (x).

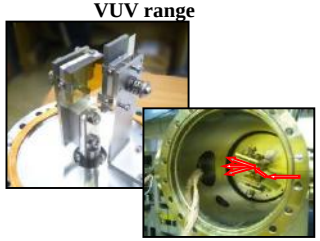
The calorimeter. Absolute detector for absolute measurement of beam powerof 300 mW or more
Measurement accuracy - 2-5%



Two coordinate detector fro Lebedev Institute (Moscow)

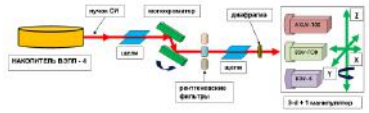
Based on CCD E2V tech. (GB)

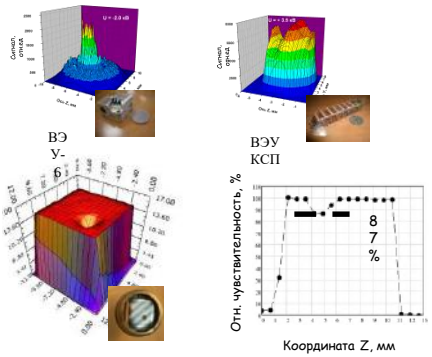
Gratis monochromator for VUV range



Spectral range: 5 - 100 eV
Spectral resolution: 0.3-2%
The angle of incidence: 70º
Scanning angle: ± 10º
The lattice period: 1/300 mm
Plating: Gold
The fixed position of the output beam in the scanning process - 14 mm

Sensitivity map measurements





Map sensitivity photodiode FDUK-100UV after local irradiation dose of 1.8 MGrey (123 J / cm2)

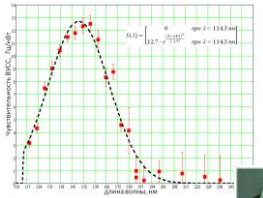
Soft X-ray monochromator

Spectral range: 80-3000 eV
Spectral resolution: 0.1-10%
The range of angles of incidence: 10º- 85º
Mirrors: Y / Mo, Fe / C, W / Si;
Crystals: mica, RbAP, KAP
Adjust the angle of the second mirror: ± 10º
The fixed position of the output beam in the process of scanning the spectrum

Reflectometry system in the experimental volume

It allows to work with mirrors, crystals and diffraction gratings. Investigation of the reflection coefficients, rocking curves, quality focusing systems, etc.

Calibration meter solar activity for a geostationary satellite "Electro-L №3" Customer - Institute of Applied Physics (Moscow)



Absolute spectral sencitivity

certified measurement procedure

Problems

- Currently used storage rings are not dedicated for SR generation, thus the SR parameters are not satisfying for modern requirements
- VEPP-3 and VEPP-4 are intensively used for high energy physics experiments, thus SR experiments have a low priority in operation time sharing rules

Reasons for creation new source in Novosibirsk

- Siberian Synchrotron Radiation Center (SSRC) unifies many SR users from different scientific organizations. Most popular modern scientific techniques are realized on SSRC beamlines.

- Good geographical location of the Novosibirsk Scientific Center provides effective applications of SR methods for institutes and universities from Siberian region.

- BINP stuff has a big experience for development and fabrication of the modern acceleration elements as well as facilities (including light sources), so possibility to make such source for own needs is evident.

- Great experience of BINP in developing and fabrication of superconducting insertion devices for SR centers also gives some additional kicks for SR source project.

Siberian circular photons source (SKIF. СКИФ)

- Project review

National strategy for light sources

1. SKIF project(3 GeV. 480 m)
2. USSR-4 (Kurchatov Institute. Protvino. 6 GeV. 1.3 – 1.5 km)
3. Far East light source (Vladivostok. Russky Island)

- Developing of the optimal scalable cell
- Unification of the straight elements (quadrupoles. sextupoles and correctors)
- Common approach for design of the bending magnets. dipoles chambers and girders
- Similarity of the key systems (RF. power suppliers. IDs. frontends etc)
- Staff education

SKIF can be pilot project for other Russian light sources.

SRF "SKIF"

The order of the President of Russian Federation Vladimir Putin to build two synchrotron radiation facilities:

- 6 GeV Machine in Protvino (Moscow region, Kurchatov Institute – USSR-4)
- 3 GeV Machine in Novosibirsk (BINP and IC SB RAS – SRF "SKIF")

and x-ray radiation facility at Island Russkiy (Vladivostok – type of machine is under discussion)

Light source in the Novosibirsk

- Optimal geographical location
- Unique interdisciplinary scientific infrastructure
- Big number of the regional universities with broad profiles
- Experienced users society from Siberian center of synchrotron and terahertz radiation (collective resources center)
- International cooperation with Kazakhstan. Mongolia. China

User potential

- **About 50 institutes of the Siberian and Ural Branches Russian academy of science**
- **About 10 universities from Novosibirsk. Tomsk. Krasnoyarsk. Irkutsk . Ekaterinburg and other**
- **A number of the industrial enterprises from Siberian region**

BINP capabilities
Accelerator elements and systems manufacturing

Industrial technologies. big workshop
Experience in the manufacturing different accelerators systems:

- Magnetic elements
- Insertion devices (including superconductive)
- Vacuum and cryogenic systems
- RF system (generators. cavities. waveguides etc)
- Electronics for diagnostic and control

Real experience for fabrication and commissioning of the big accelerator facilities









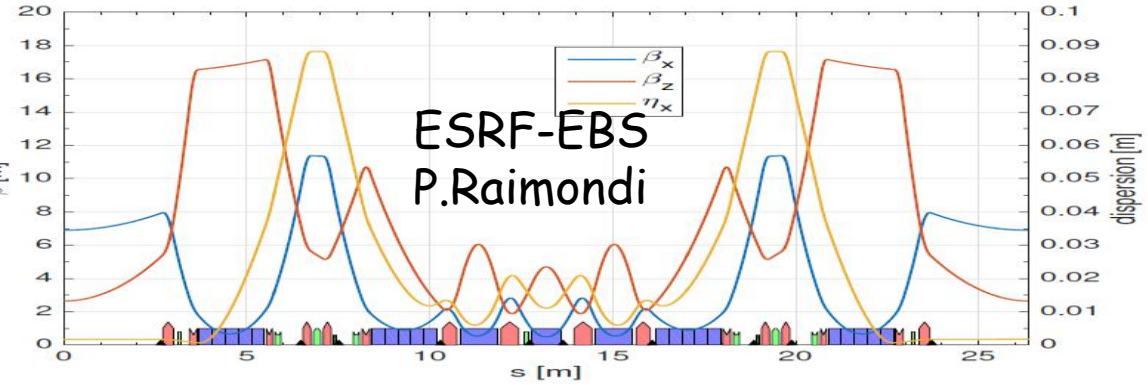

Stages and funding (bln. Rub. In the prices of 2017)

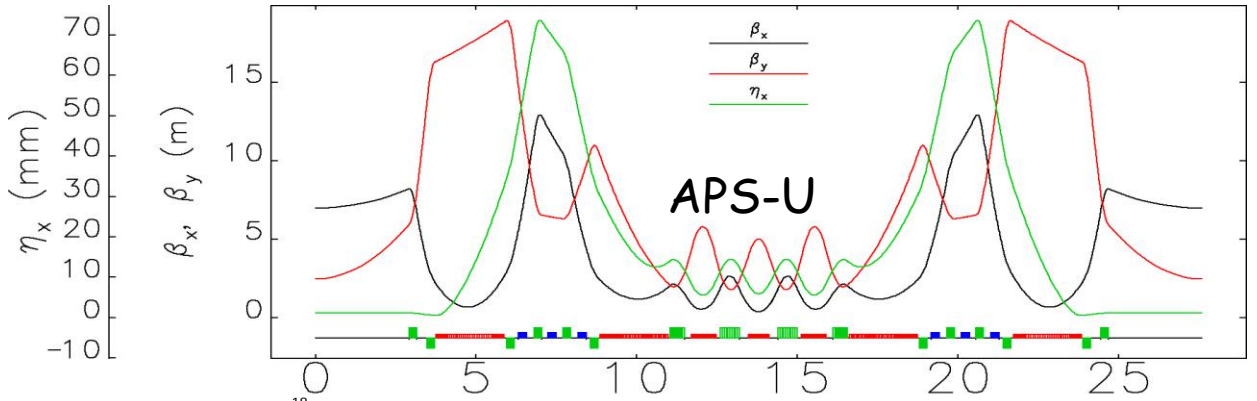
Subsequent operation for up to 30 years.

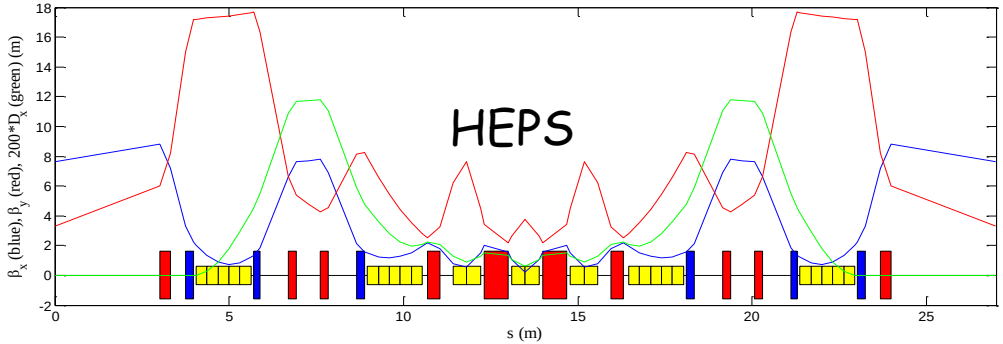
Stages	18	19	20	21	22	23	24	-	33	34
CDR										
TDR		1.0	2.2							
Building construction			0.3	4.1	5.1	2.5				
Accelerator			0.3	4.4	5.0	3.3				
Beamlines			0.6	2.0	2.5	2.5	1.0	1.0	1.0	1.0
Maintenance						1.0	1.7	1.7	1.7	1.7

Starting in 2024. developing beamlines of Stage 2
2034 - reaching the design capacity.

SRF "SKIF"

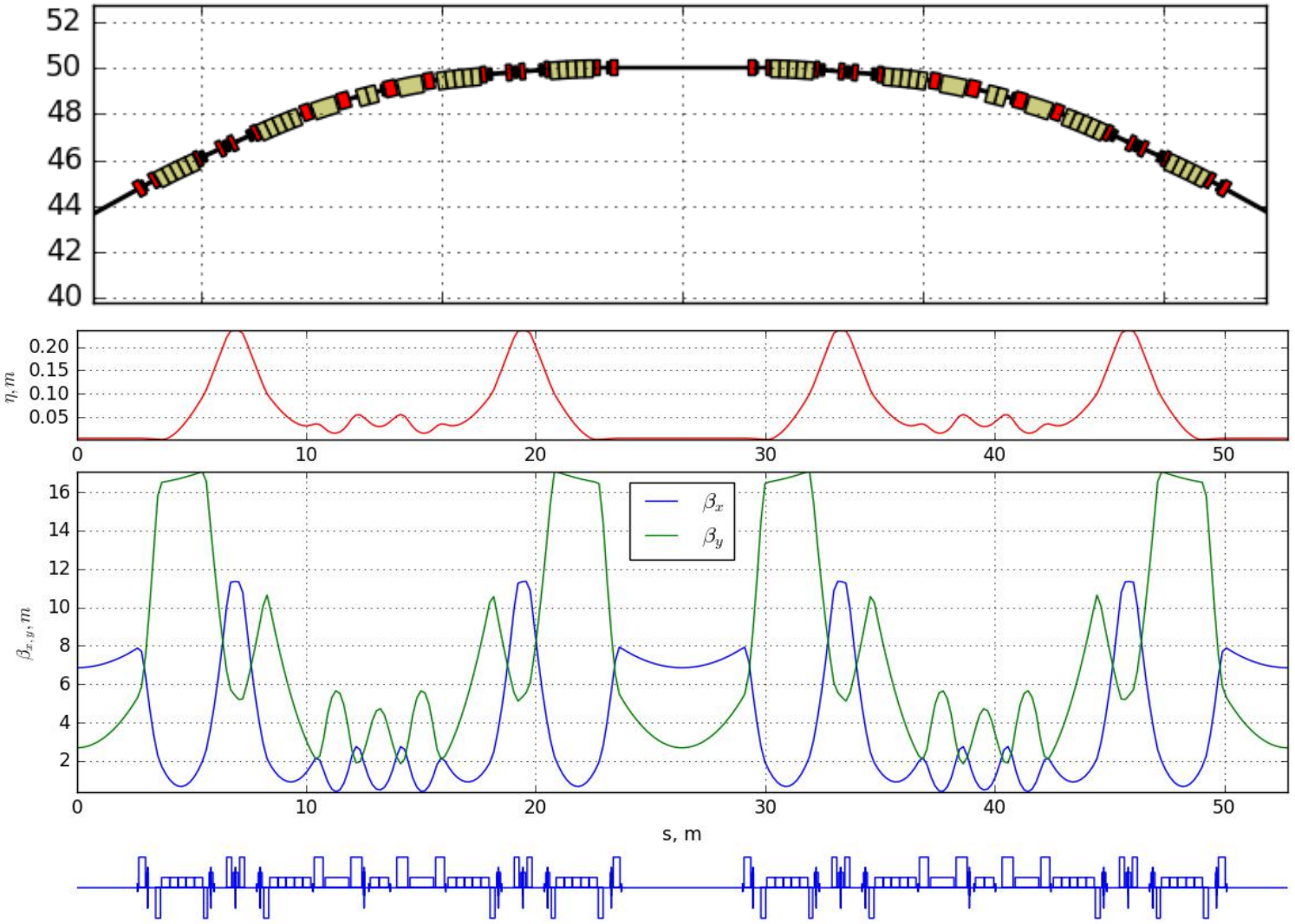






Perspective
MBA
magnetic cell

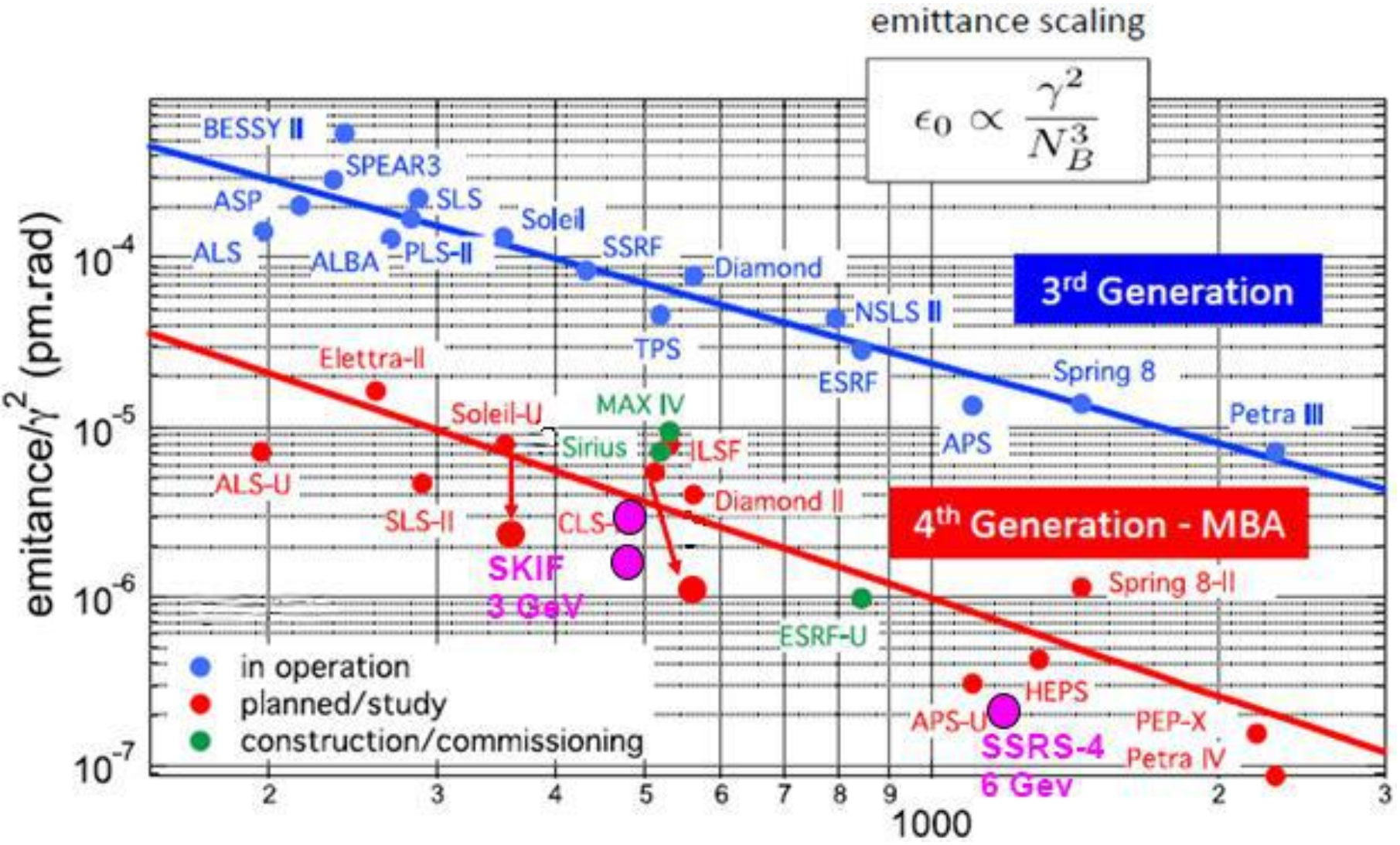
SRF "SKIF"


52
50
48
46
44
42
40
η, m
0.20
0.15
0.10
0.05
0
10
20
30
40
50
$\beta_{x,y}, m$
16
14
12
10
8
6
4
2
β_x
β_y
s, m

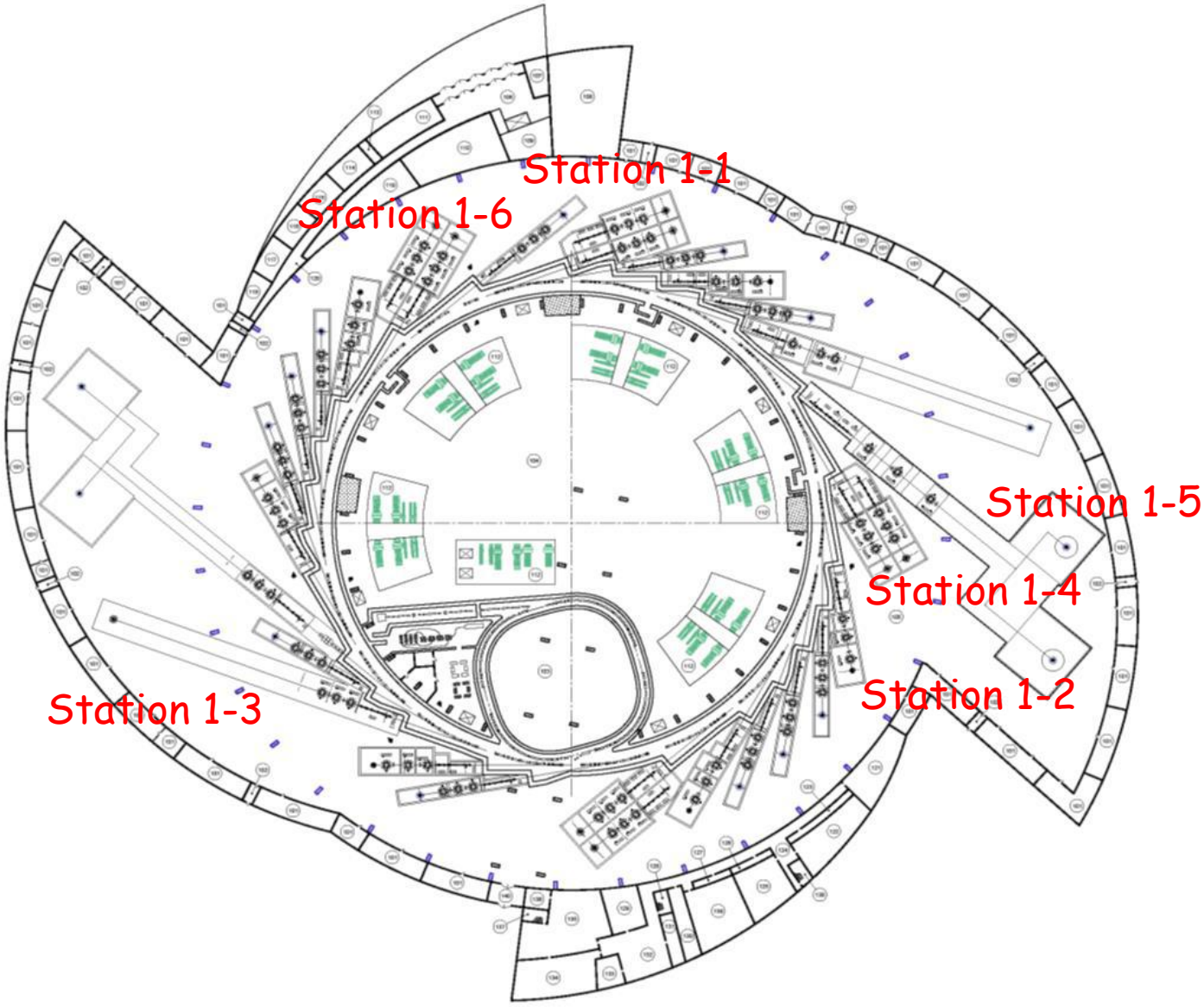
SRF "SKIF"

Parameter	Value
Energy	3 GeV
Current	Up to 400 mA (2 mA in bunch)
Emittance	186 pm·rad (current structure) 61 pm·rad (under investigation)
Injection type	Full injection
Perimeter	480 m
Number of experimental stations	6 (first stage) +24 (second stage)
Number of ID	14

Light sources (emittance-circumference plot)



SRF "SKIF"


Station 1-1
Station 1-6
Station 1-5
Station 1-4
Station 1-2
Station 1-3

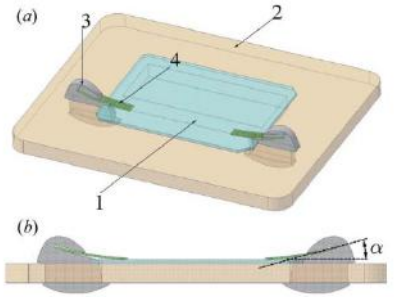
Phase-1 beamlines

- Nanofocus beamline. scanning μXRF
  - **(V.S. Sobolev Institute of Geology and Mineralogy);**
- Structural diagnostic beamline
  - **(Institute of Solid State Chemistry and Mechanochemistry);**
- Fast dynamic processes beamline
  - **(Lavrentyev Institute of Hydrodynamics);**
- XAFS-spectroscopy and MCD beamline
  - **(Boreskov Institute of Catalysis);**
- Phase contrast imaging and microtomography beamline
  - **(Budker Institute of Nuclear Physisc);**
- Soft X-ray spectroscopy and reflectometry beamline
  - **(Nikolaev Institute of Inorganic Chemistry).**

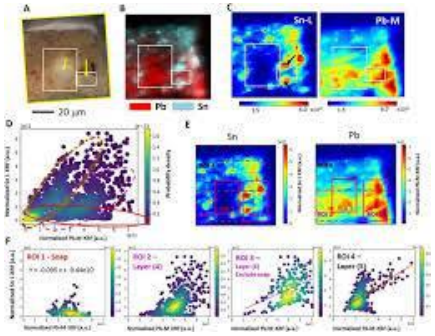
1-1 «MicroFocus» Beamline

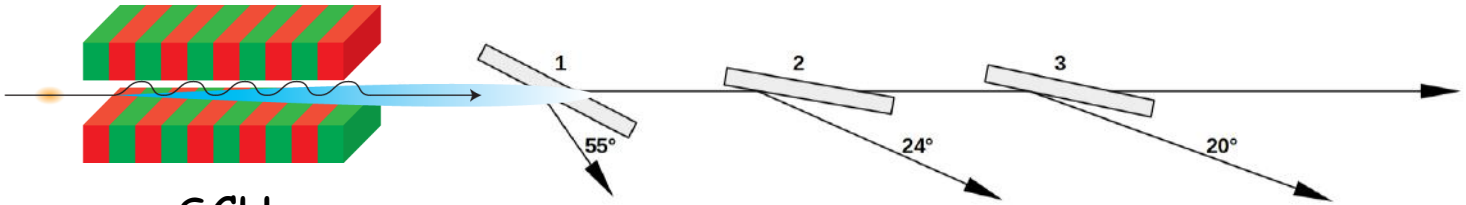
Multi-purpose beamline with diamond 'beam-splitters' (LCLS design)
Four microbeam end-stations for *simultaneous* operation:

- **Macromolecular crystallography**
- **Nuclear resonance**
- **Extreme conditions**
- **Nano XRF&XRD**

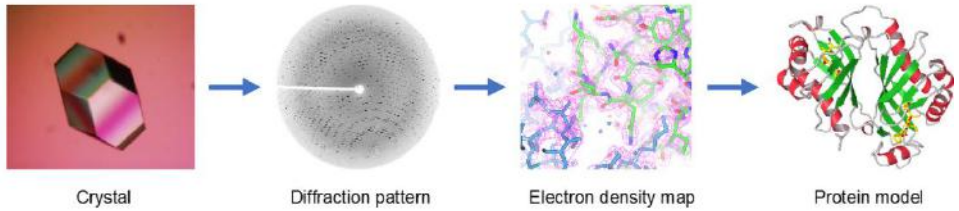


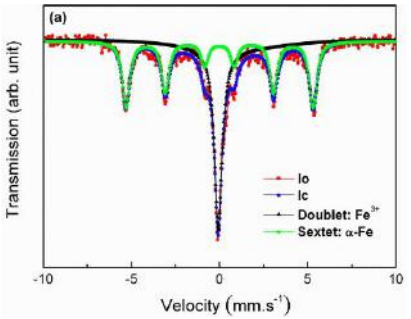
Stoupin *et al.* 2014

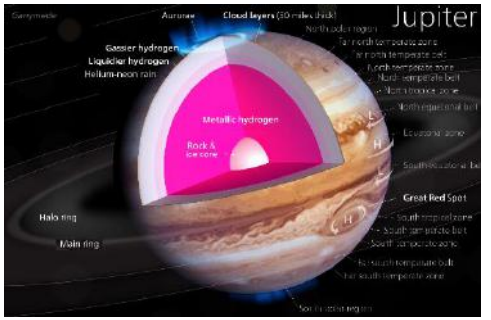




SCU

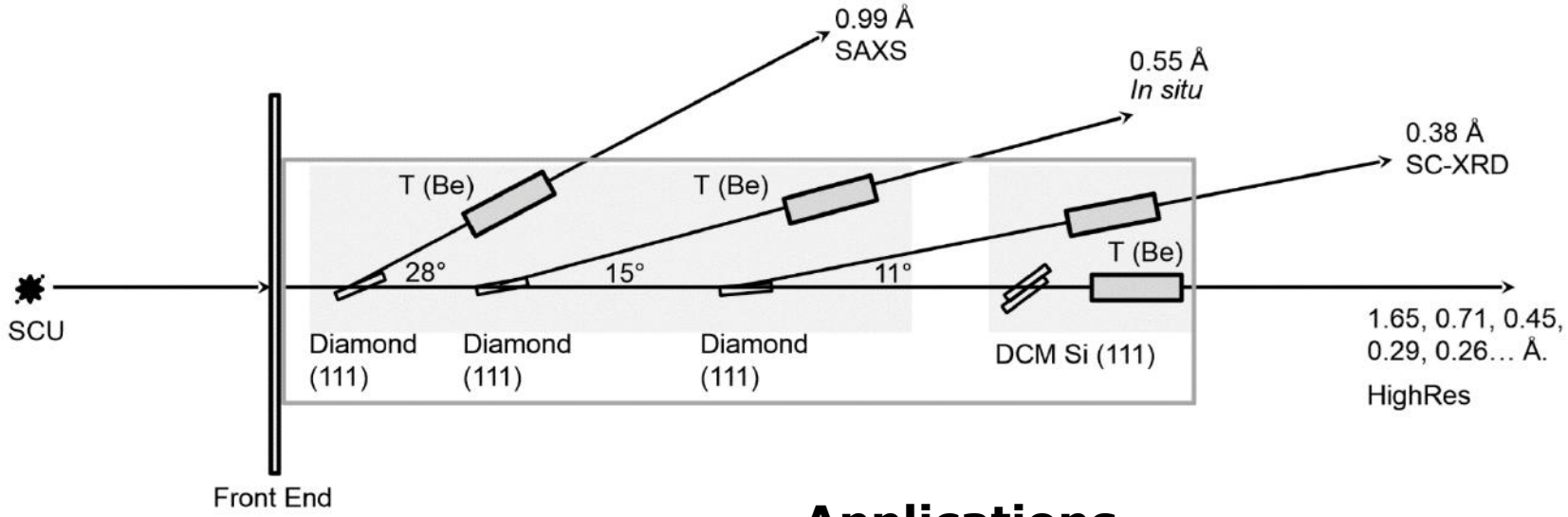






1-2 Structural Diagnostics Beamline

Beamline dedicated to application of diffraction techniques for wide range of research and technology tasks



Features

- Source – SC Undulator
- Simultaneous operation of all sections in main mode (fixed energy)
- Energy variations for HighRes section in extra modes (side sections are out of operation)

Applications

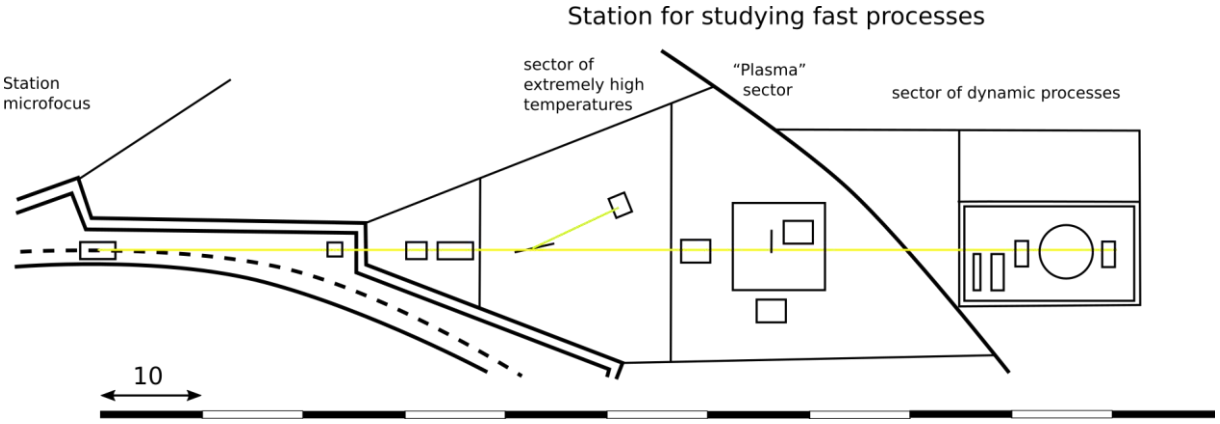
- Hydrogen energy, fuel cells
- Catalysis
- Ceramics and energetic materials
- Films and membranes
- Polymers and carbon materials
- Pharmaceuticals
- Disperse phases
- Nanomaterials

1-3 Fast processes Beamline

The station is designed to study objects with rapidly changing properties and is optimized for measurements with high temporal resolution up to one bunch.

Experimental methods:

- High-speed radiography and tomography (X-Ray Imaging);
- Time resolved small angle X-Ray Scattering;
- Time resolved X-Ray Diffraction.



In the **sector of extremely high temperatures**, the formation of high-temperature materials under pulsed heating will be studied.

- Synthesis of high-temperature materials (oxides, borides, carbides) in the process of electron-beam and laser processing.
- Production of high-temperature composite materials for parts of hypersonic and spacecraft and the needs of nuclear energy.
- Materials science tasks (annealing, recrystallization, texturing) at high temperatures..

In the **"Plasma" sector**, the effect of plasma in a thermonuclear reactor on materials will be investigated:

- the effects of high temperature and plasma on materials in a fusion reactor. It is planned to reproduce: constant and pulsed heat load, plasma flow;
- diffraction measurements of strain and stress.

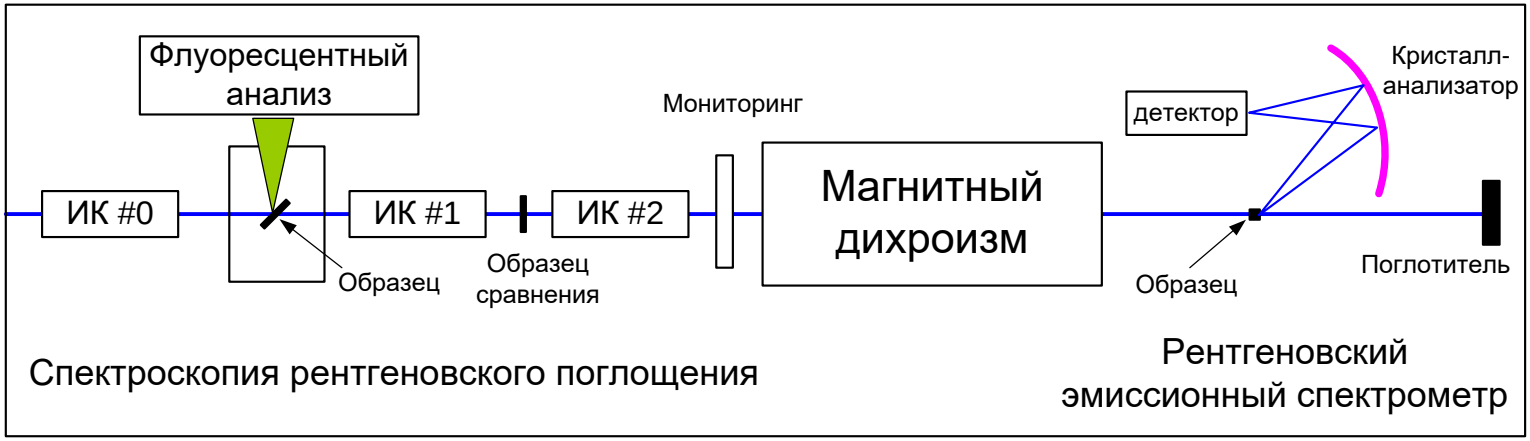
In the **sector of dynamic processes**, the behavior of a substance under extreme conditions will be investigated under intense dynamic effects:

- properties of energetic materials, shock and detonation front structure, equation of state, phase transitions under compression, chemical reactions, dynamic formation of nanostructures;
- high-speed deformation and destruction of materials and structural elements;
- dense plasma behavior for inertial thermonuclear fusion conditions.

1-4 XASF & MCD Beamline

Experimental methods:

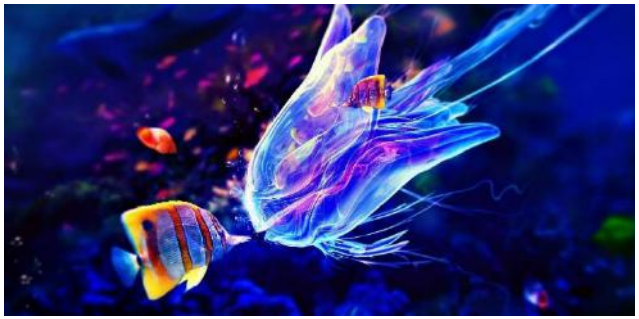
- XAFS-spectroscopy (EXAFS, XANES, NEXAFS);
- MCD.



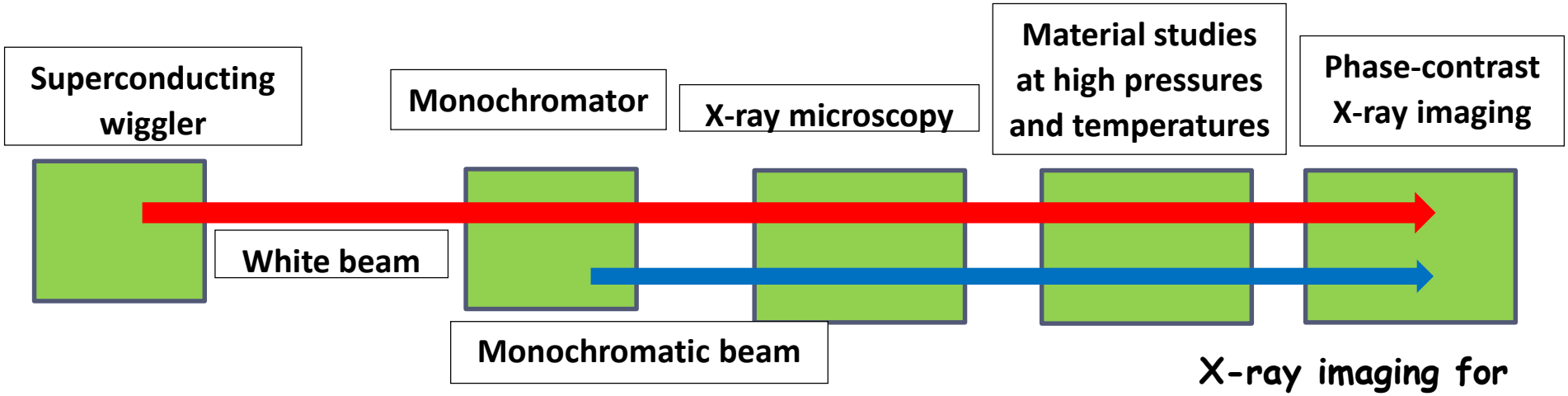
traditional

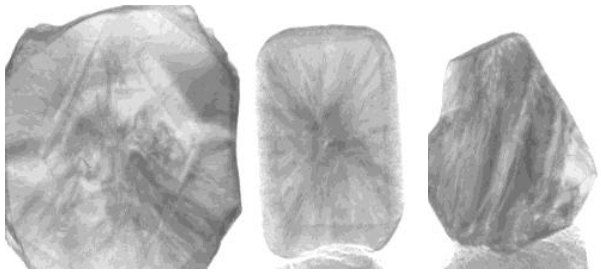
in situ

operando

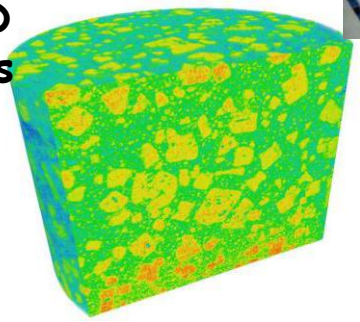


1-5 High-energy X-ray Diagnostics Beamline



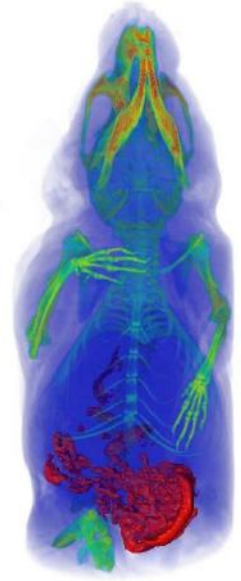


Investigation of 3-D structure of crystals and composite materials

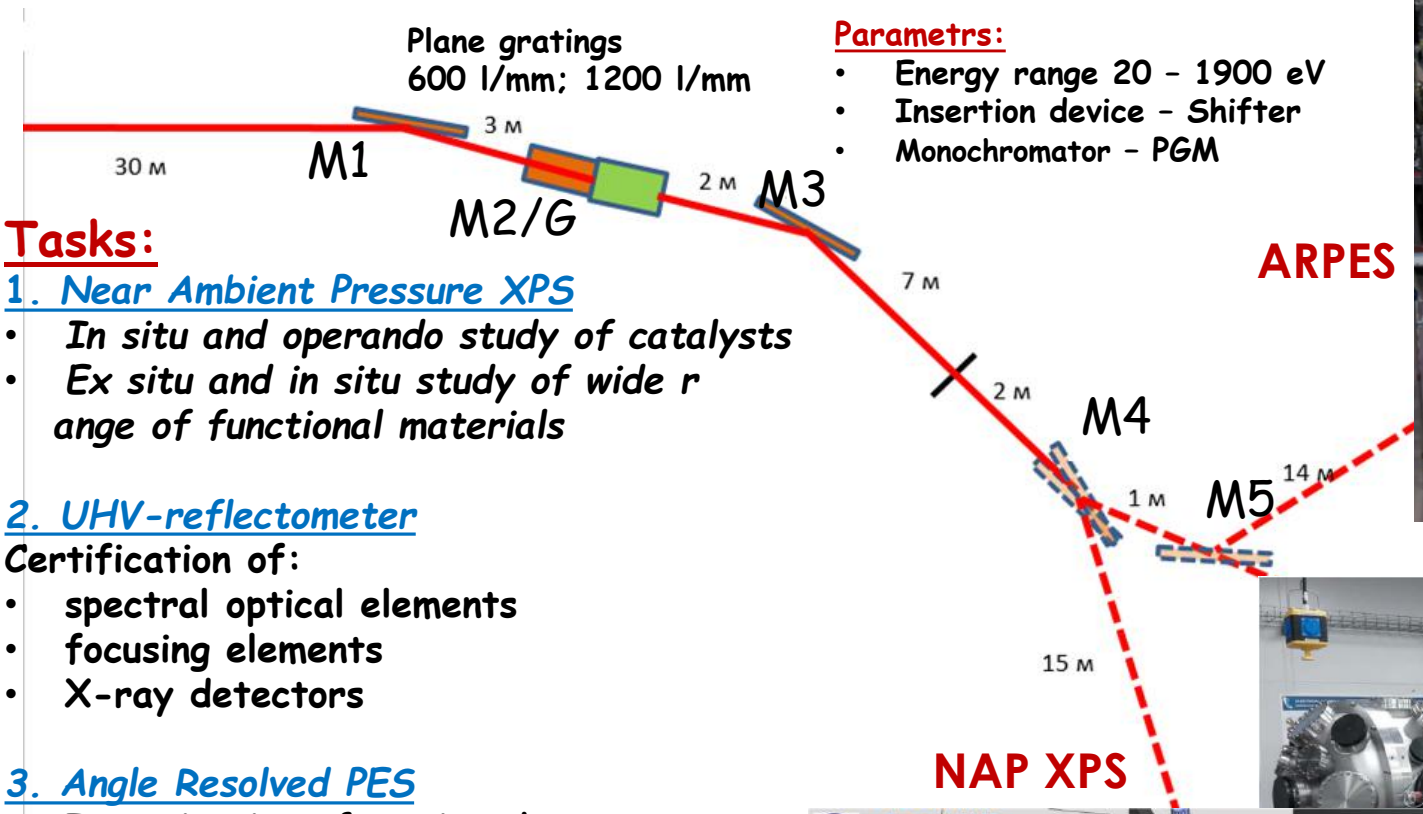


Characterization of materials at pressures ranging to 30 GPa and temperatures up to 2500°C

X-ray imaging for biological and medical application



1-6 Electronic structure Beamline



Parametrs:

- Energy range 20 – 1900 eV
- Insertion device – Shifter
- Monochromator – PGM

Tasks:

1. *Near Ambient Pressure XPS*
   - *In situ and operando study of catalysts*
   - *Ex situ and in situ study of wide r ange of functional materials*

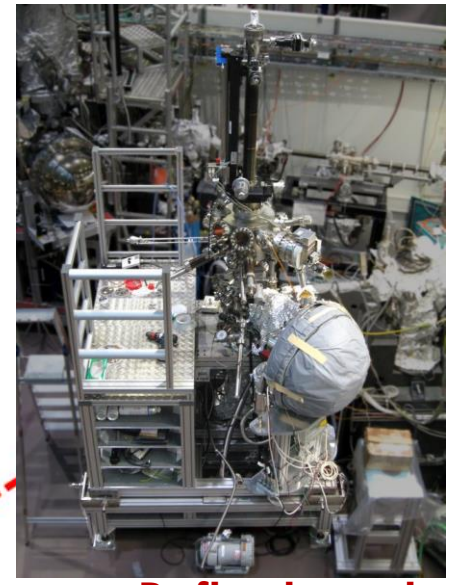
2. *UHV-reflectometer*

Certification of:

- spectral optical elements
- focusing elements
- X-ray detectors

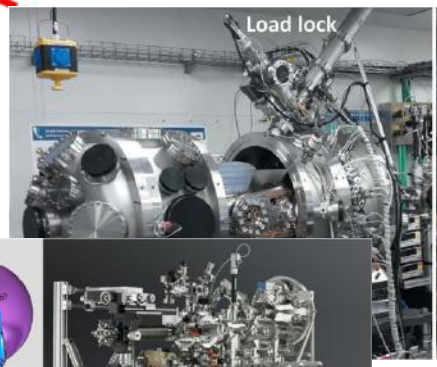
3. *Angle Resolved PES*
   - Investigation of semicunductor materials
   - Investigation of multilayer materials and interfaces

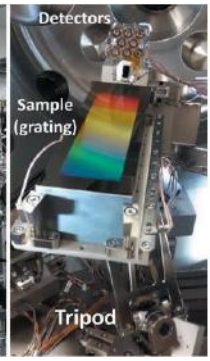
ARPES

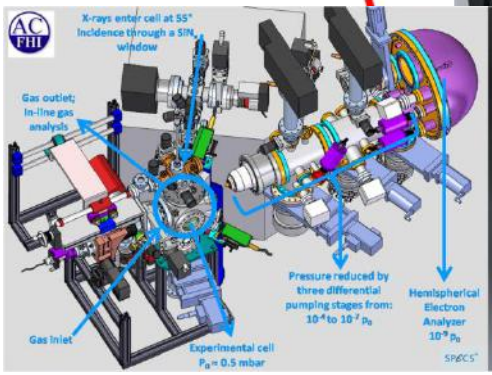


Reflectometer

NAP XPS







Todays questions:

1. Interest to our project from worldwide synchrotron researchers community in two way:
   - experimental tasks and activity;
   - experimental station proposals.

2. Future collaboration on facility construction/building and using of the new machine SRF "SKIF".

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Thank you for attention