NATIONAL RESEARCH CENTER "KURCHATOV INSTITUTE"

Kurchatov complex of synchrotron and neutron research: current status and prospects

10.10.2020

Meeting of the President council for science and education

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«Dramatic technological change is underway in the world. In terms of scale, it is comparable to the periods of industrial revolutions and scientific discoveries that have changed people's lives drastically.»

Speech by the President of the Russian Federation Vladimir Putin

Meting of the Council for Science and Education February 8, 2018, Novosibirsk

Nature-like technologies as a Grand Challenge

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We are on the threshold of a new stage in the development of civilization –
we move on to the development of new, bio-and nature-like technologies

Antagonism of technosphere and nature

Nature-like technologies

Development of science

Ideas — **Scientist**

Research infrastructure

Highly developed research infrastructure

- ✓ **Breakthrough results**
- ✓ **Scientific discovery**
- ✓ **New scientific school**

Synchrotron and neutron research in Russia

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In accordance with the decree, **the "Kurchatov Institute" is the leading scientific organization** for the implementation of the Synchrotron and Neutron Research Development Program

УКАЗ

ПРЕЗИДЕНТА РОССИЙСКОЙ ФЕДЕРАЦИИ

О мерах по развитию синхротронных и нейтронных исследований и исследовательской инфраструктуры в Российской Федерации

В целях комплексного решения задач ускоренного развития синхротронных и нейтронных исследований, необходимых для создания прорывных технологий, а также обеспечения создания и развития исследовательской инфраструктуры в Российской Федерации п о с т а н о в л я ю:

1. Правительству Российской Федерации:

а) в 3-месячный срок разработать и утвердить Федеральную научно-техническую программу развития синхротронных и нейтронных исследований и исследовательской инфраструктуры на 2019 - 2027 годы (далее - Программа);

б) обеспечить при разработке и реализации Программы:

определение основных направлений исследований, касающихся решения принципиально новых фундаментальных и крупных прикладных задач в целях реализации приоритетных направлений научно-технологического развития и достижения национальных

Decree on the development of synchrotron-neutron research (25.07.2019)

УТВЕРЖДЕНА
постановлением Правительства
Российской Федерации
от 16 марта 2020 г. № 287

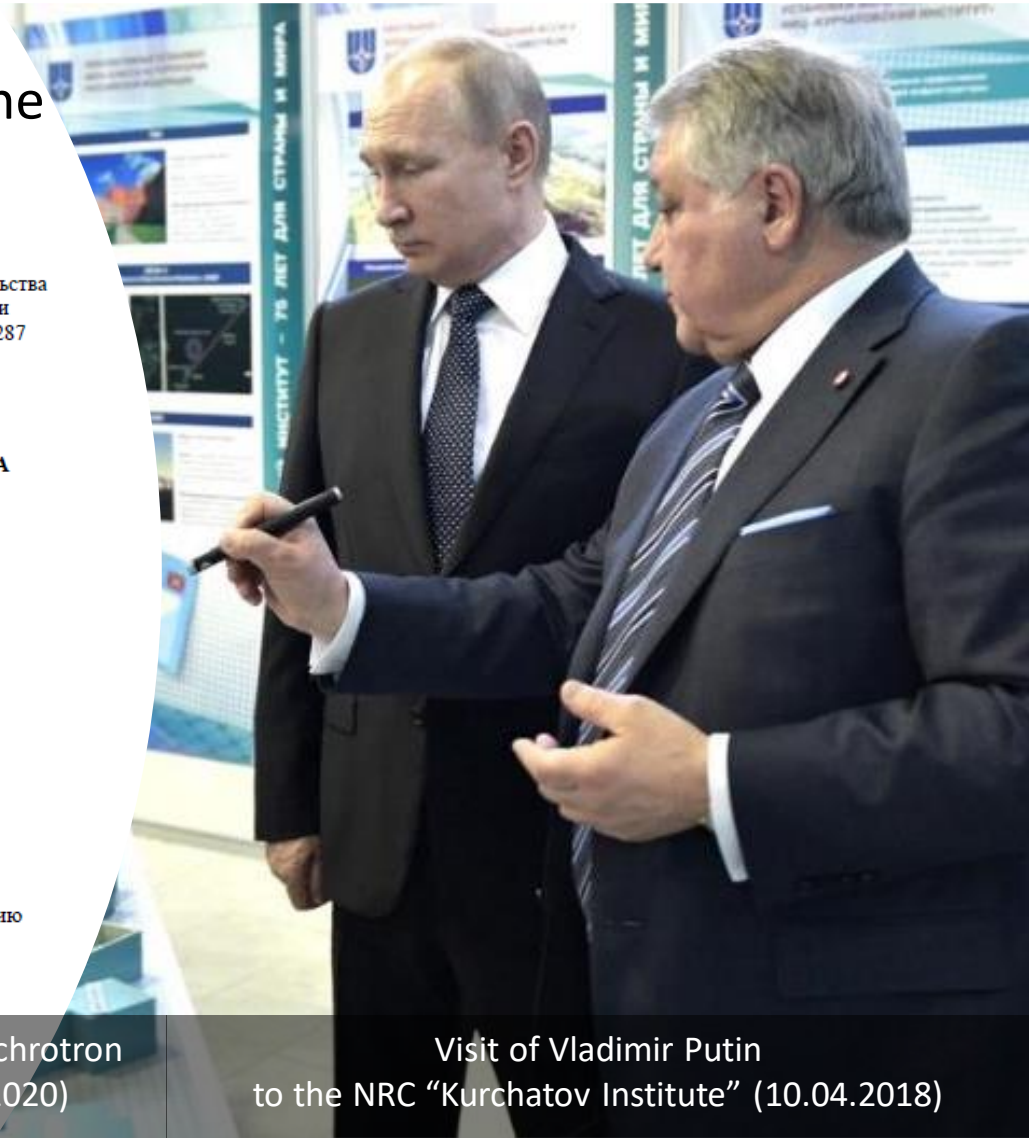
ФЕДЕРАЛЬНАЯ НАУЧНО-ТЕХНИЧЕСКАЯ ПРОГРАММА
развития синхротронных и нейтронных исследований и исследовательской инфраструктуры на 2019 - 2027 годы

П А С П О Р Т

Федеральной научно-технической программы
развития синхротронных и нейтронных исследований
и исследовательской инфраструктуры на 2019 - 2027 годы

Наименование Программы	-	Федеральная научно-техническая программа развития синхротронных и нейтронных исследований и исследовательской инфраструктуры на 2019 - 2027 годы
Основание для разработки Программы	-	Указ Президента Российской Федерации от 25 июля 2019 г. № 356 "О мерах по развитию синхротронных и нейтронных исследований и исследовательской инфраструктуры в Российской Федерации"

Federal program for the development of synchrotron and neutron research until 2027 (16.03.2020)



Visit of Vladimir Putin to the NRC "Kurchatov Institute" (10.04.2018)

Constructive interference between synchrotron radiation and neutrons

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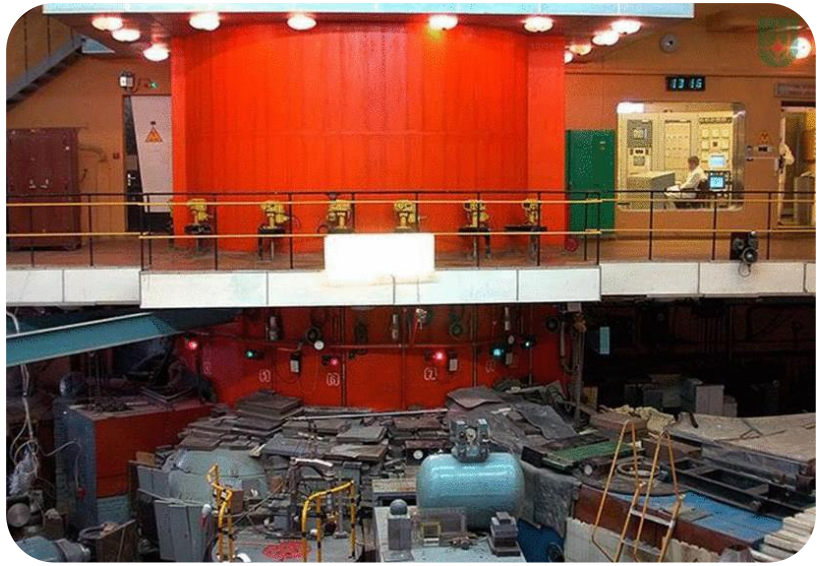
Kurchatov complex of synchrotron and neutron research is of the few places in the world where a neutron source is placed on the same ground as a synchrotron.



Convergence of sciences and technologies

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Large-scale facilities surrounded by scientific laboratories of NBICS center makes Kurchatov institute a really unique place in the whole world for fundamental and applied interdisciplinary researches

Kurchatov source of synchrotron radiation

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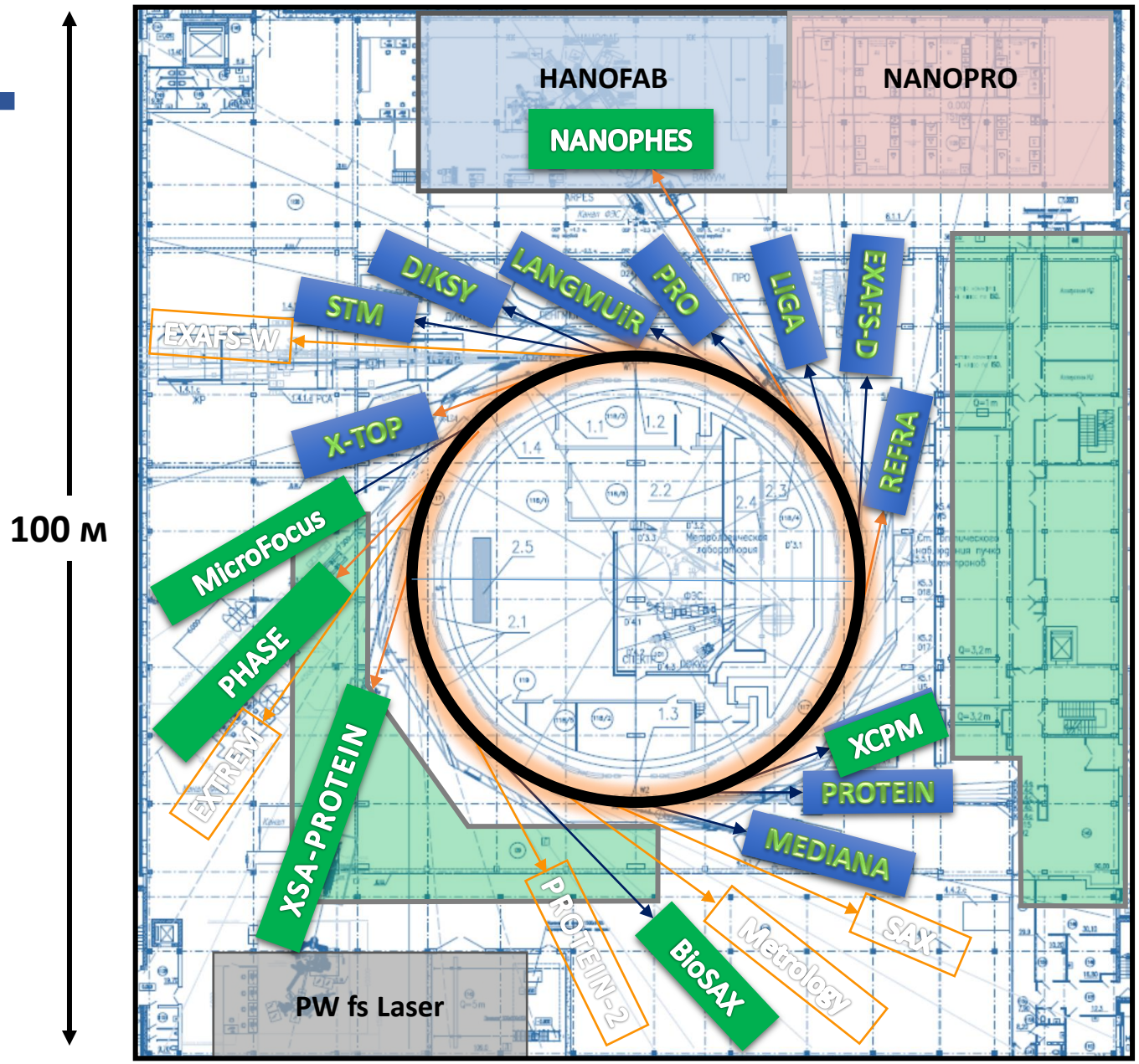
The area of 17 000 m^2

Experimental hall



Experimental hall

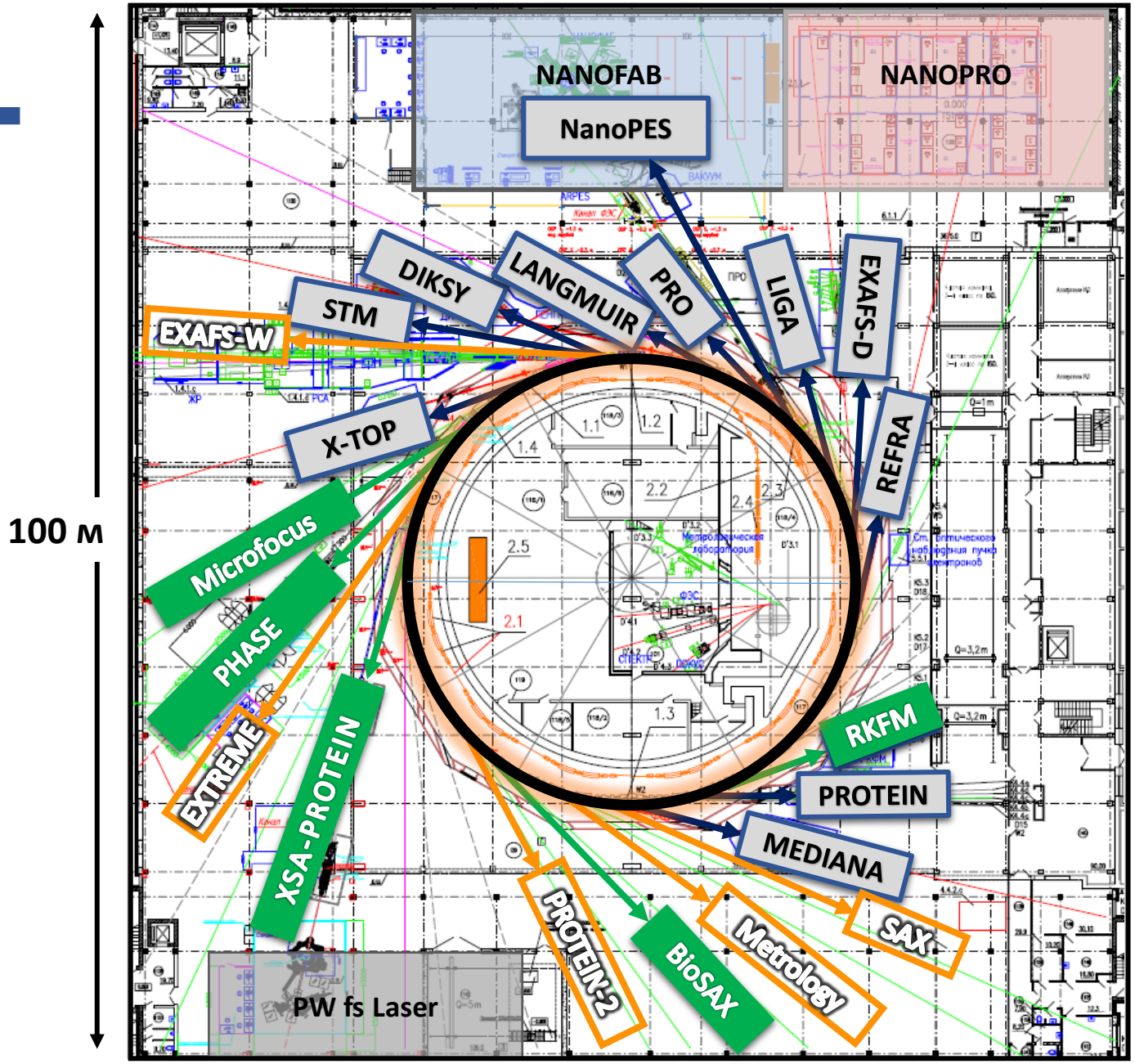
Beamlines:

Operating (16)

incl.

New 2015-19г (5)

Under constructing (5)



New beamlines

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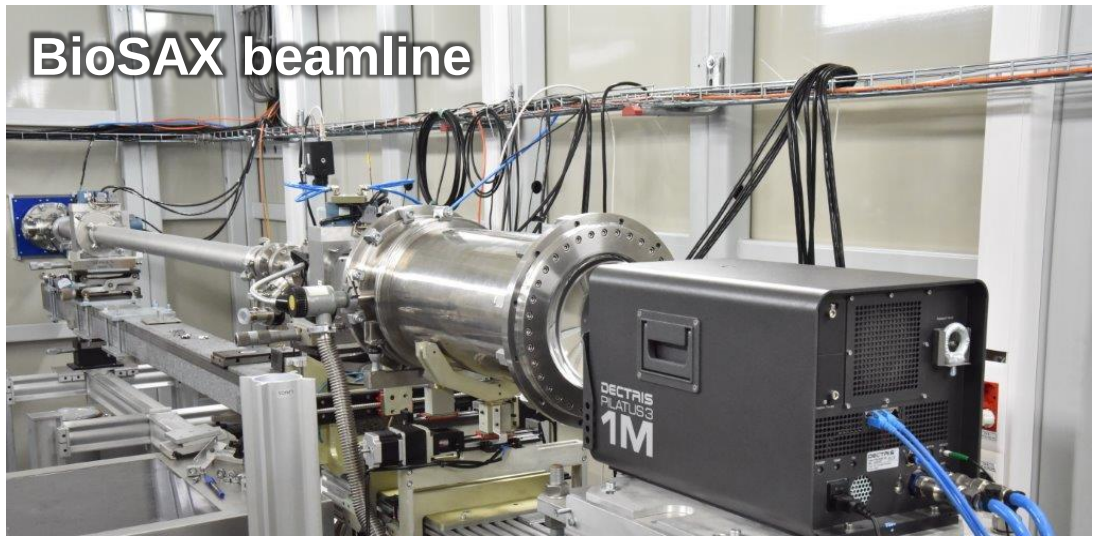

Beamlines, methods and research directions

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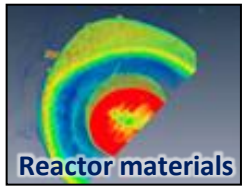
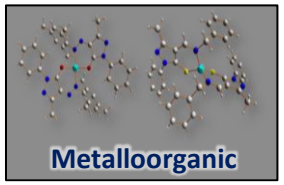
Crystallography, material science, structural chemistry

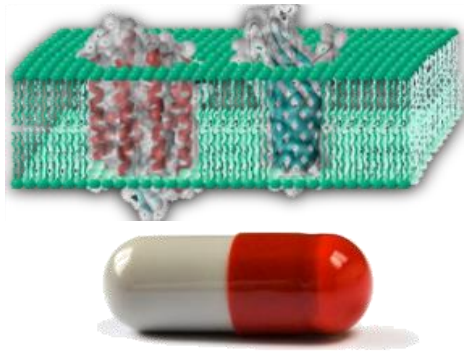
- STM
- DIKSY
- XSA
- X-TOP

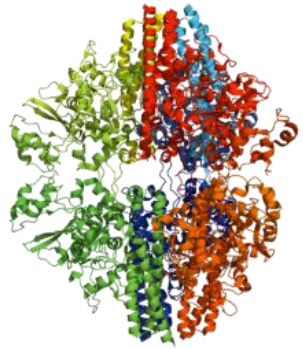




Protein crystallography, molecular biology, medicine

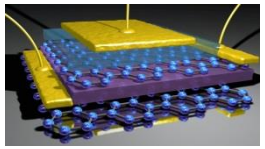
- PROTEIN
- DIKSY
- Langmuir
- Mediana

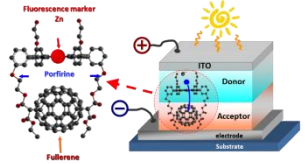




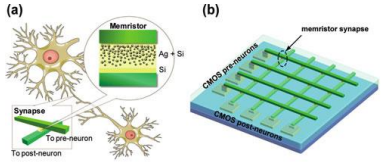
Micro- and Nanoelectronics, hybrid materials

- PHASE
- RKFM
- NanoPES
- Langmuir



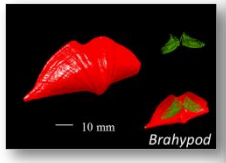


Organic and hybrid multilayer systems

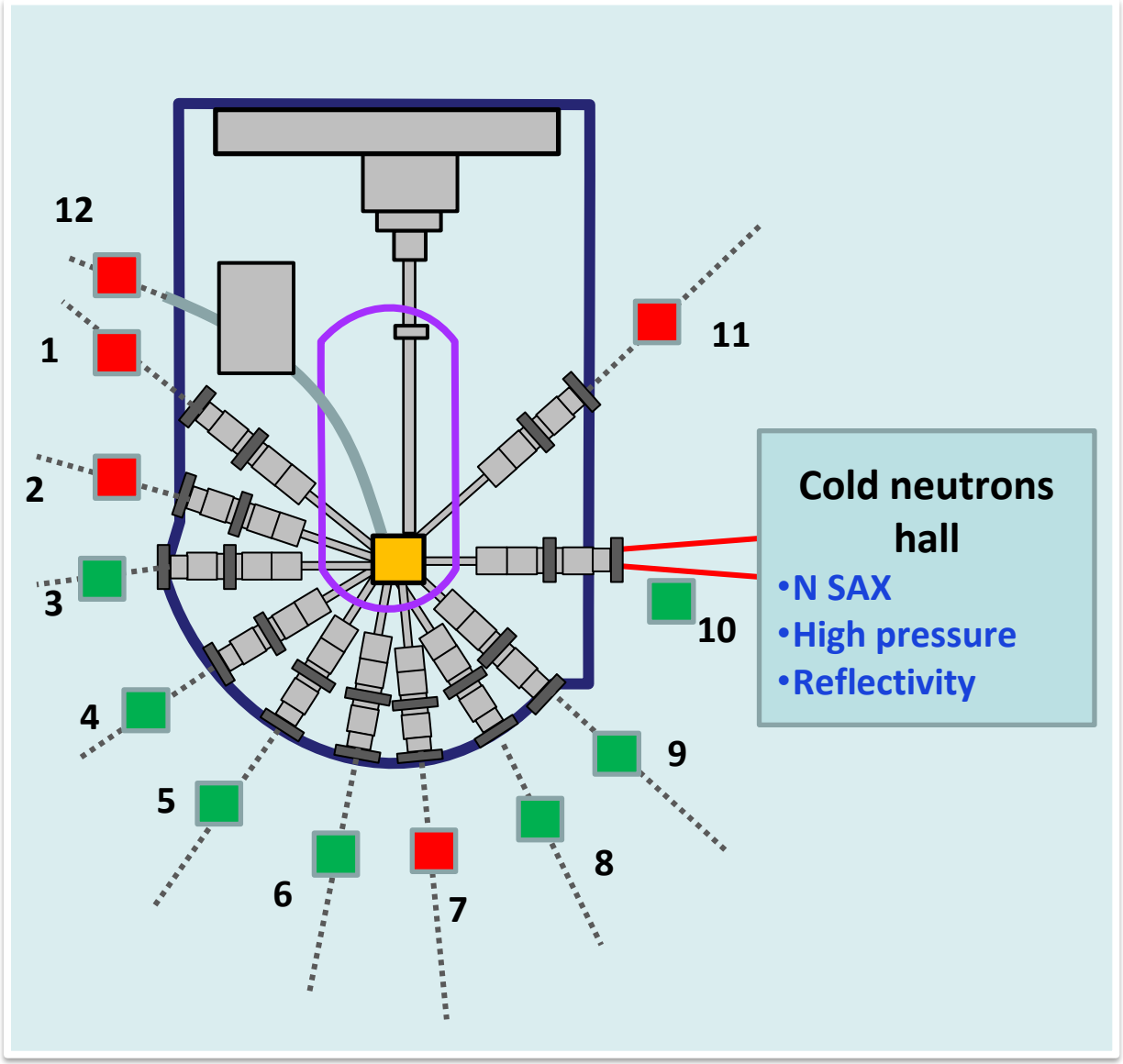


Cultural heritage

- REFRA
- STM
- DIKSY
- RKFM
- Mediana



Neutron reactor IR-8



Nuclear-physics channels

Experimental channels

1 – Ultra cold neutrons

2 – Nuclear spectroscopy

3 – Stress analysis

4 – Single crystals

5 – Inelastic scattering

6 – High pressure

7 – Capillary optics

8 – n, ϒ –radiography

9 – Small angular scattering

10 – Cold neutrons source

Megascience – metrology for modern technologies

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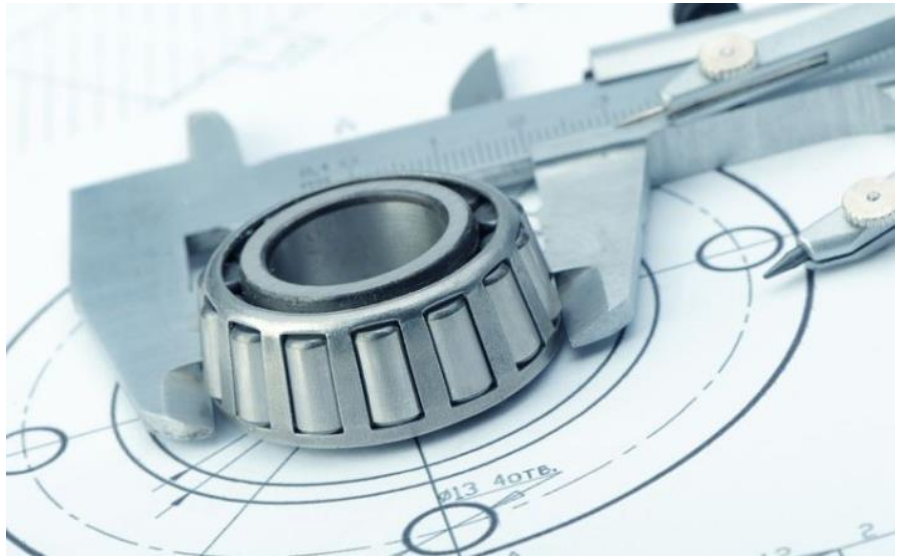

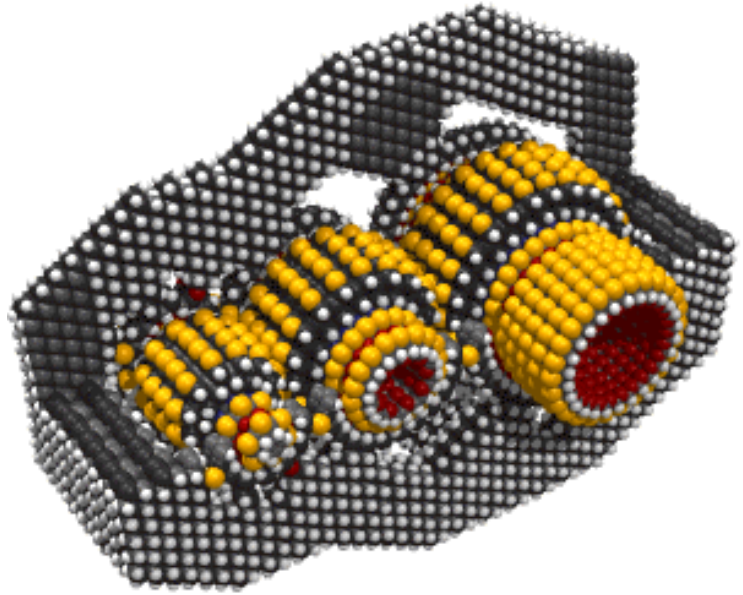

New generation of catalysts

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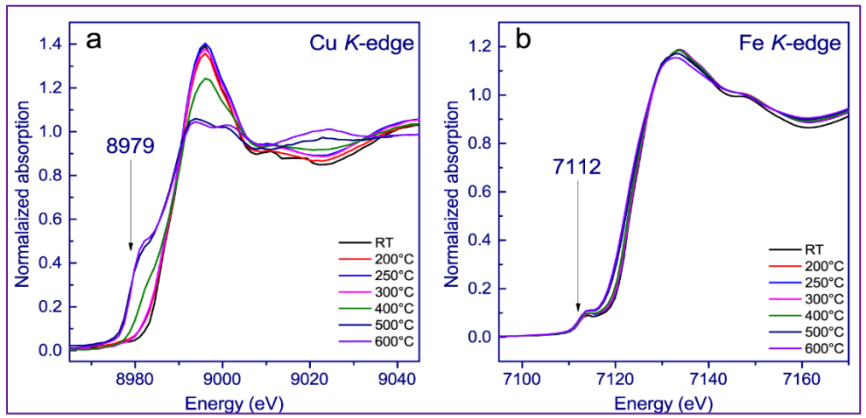
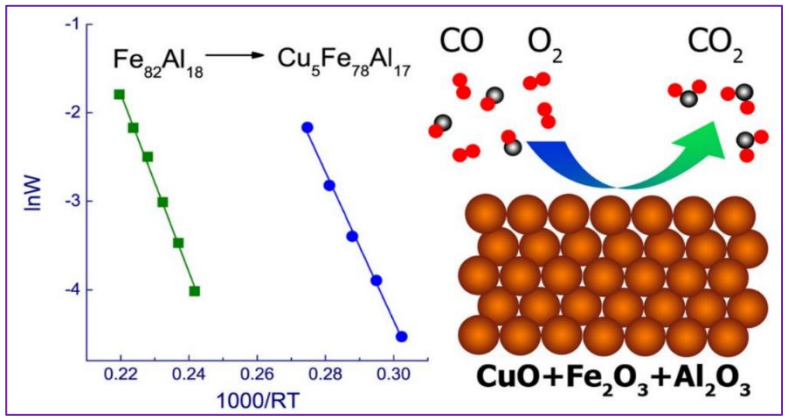
Design of oxidation catalysts based on Cu-Fe-Al (without adding expensive precious metals Pd, Pt)

Structural of materials beamline

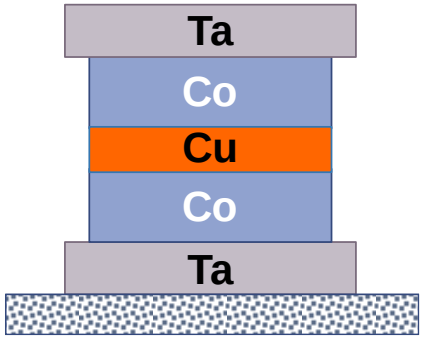
In-situ EXAFS experiment: the mechanism of catalytic activity of a new type of catalysts is determined

Waste incineration using CO catalysts

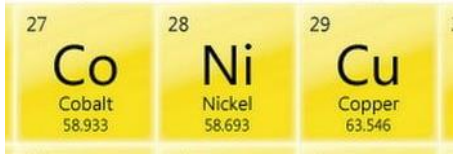




Research of Co/ Cu / Co structures using X-ray standing waves



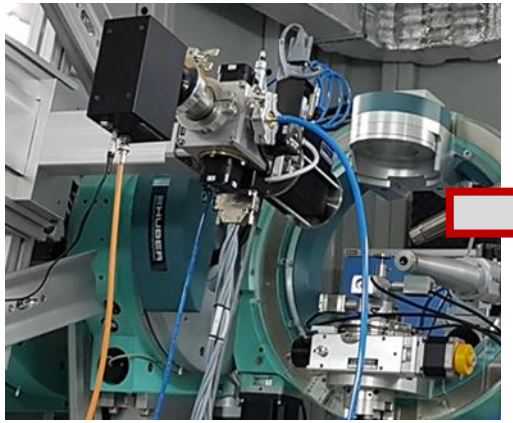
Magnetic structure on the effect of giant magnetoresistance

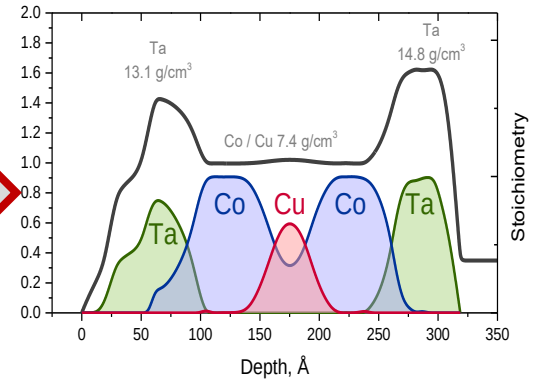


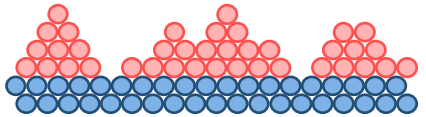
8.9 g/cm³ 8.92 g/cm³

Standard methods (reflectivity) are not sensitive to the structure of the layers of Co and Cu!

Standing x-ray waves method







The task of research:

How does the nonmagnetic Cu layer behave?

How are the Co layers separated?

RESULT: The island mechanism of Cu growth, the formation of an alloy of CuCo

Material science

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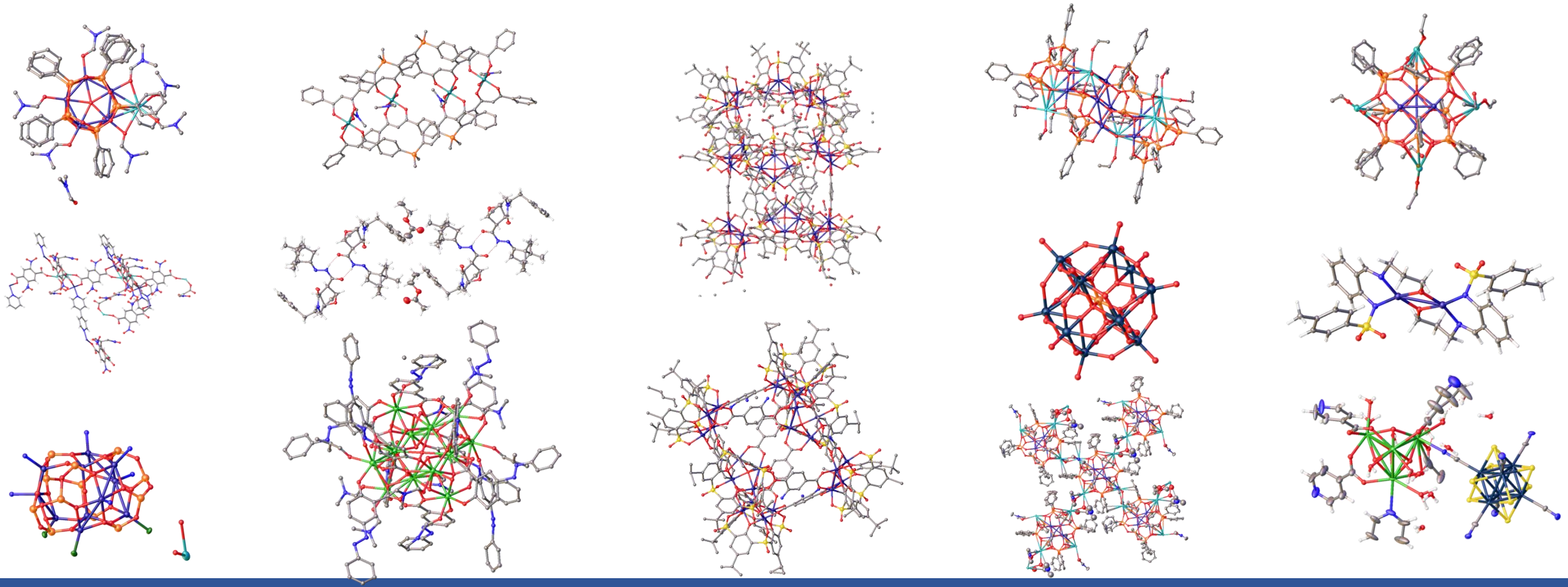
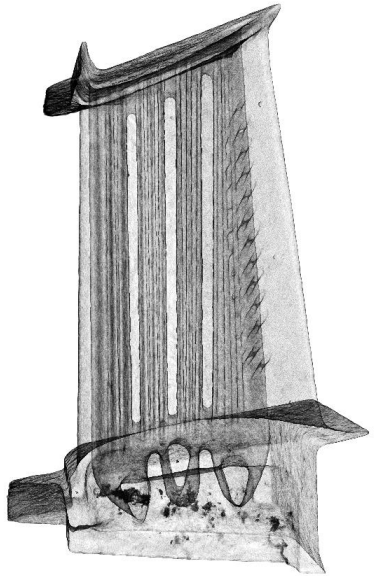
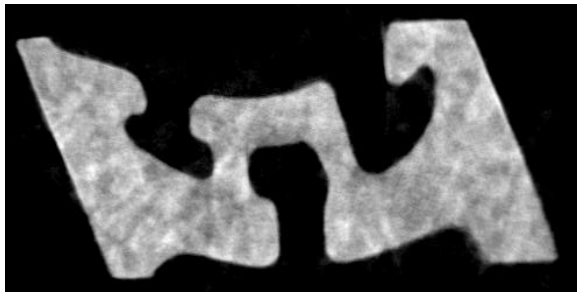
Structural analysis of low-molecule compounds on the BELOK beamline

On the PROTEIN beamline **more than 650 experiments** on small molecules structure refinement have been carried out, **more than 300 structures** have been refined, published **more than 30 papers**.

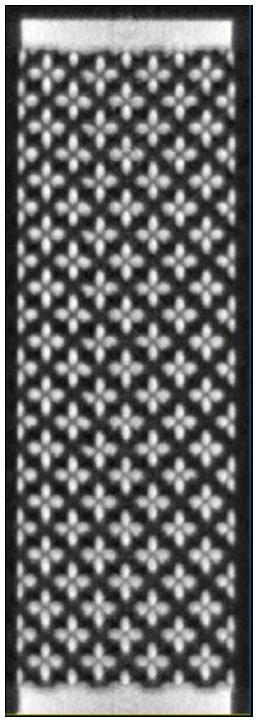


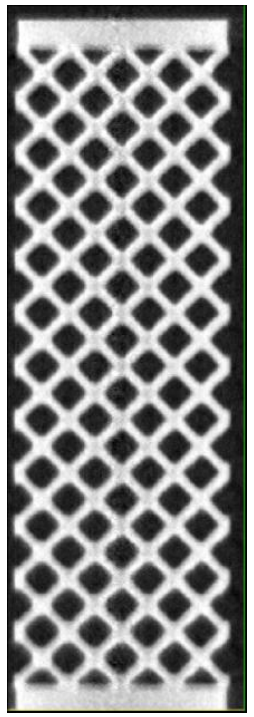
Material science



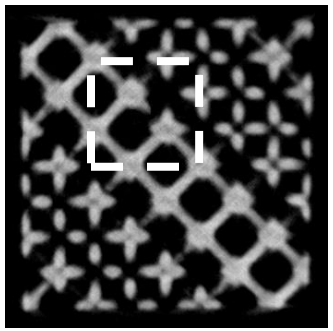


Neutron visualization of the parts of gas-turbine engine

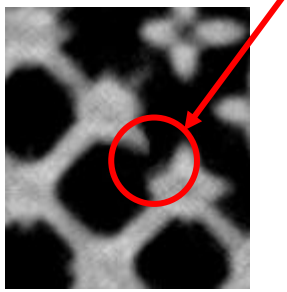




Tomographic projections of the object made using additive technologies



Defect of printing



Material science

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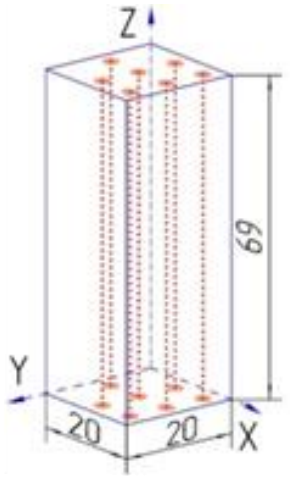
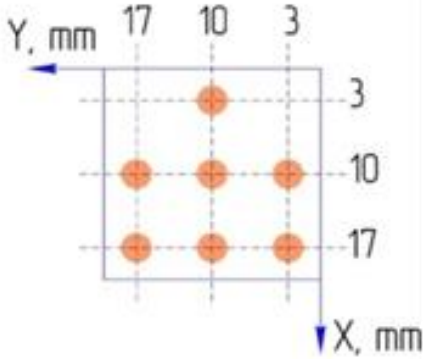
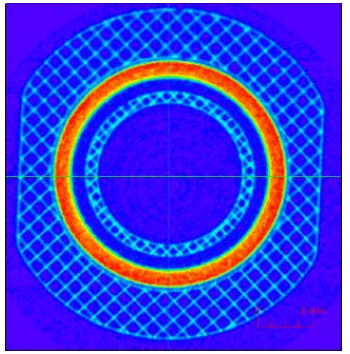
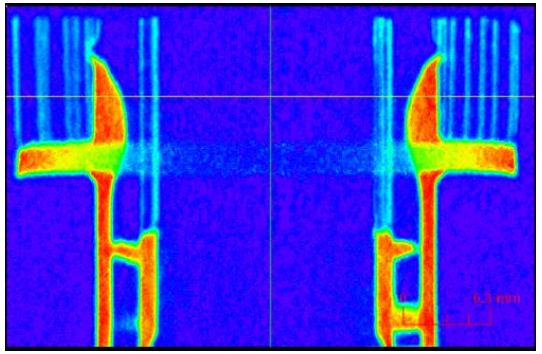
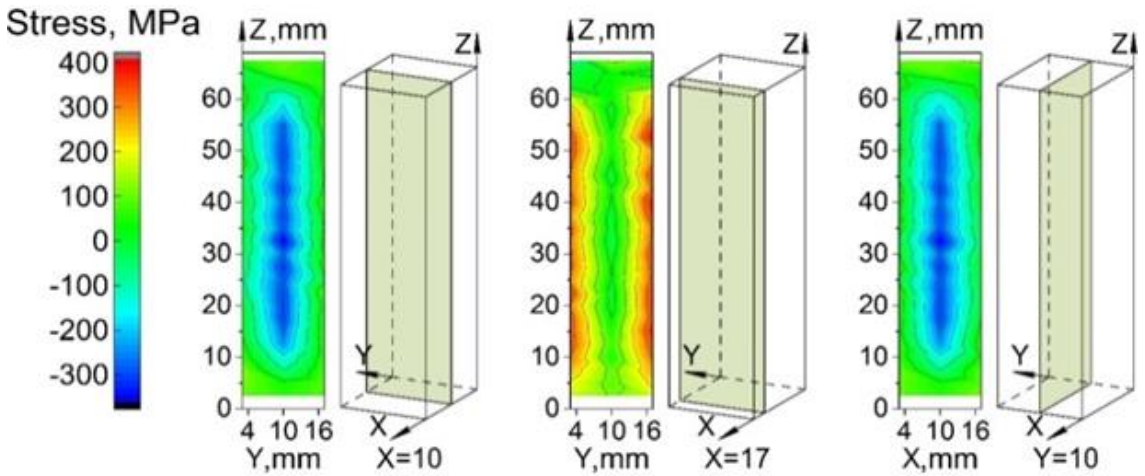
Neutron tomography and strain analysis for additive technologies

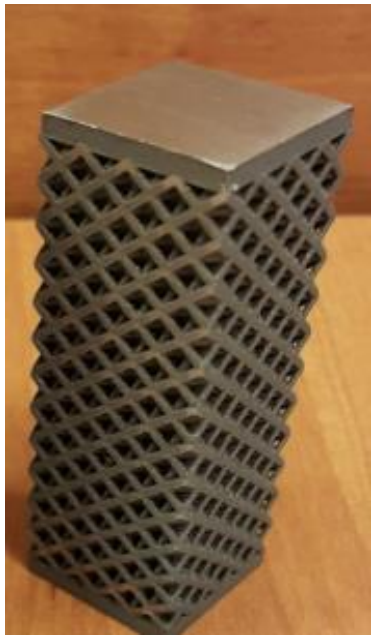


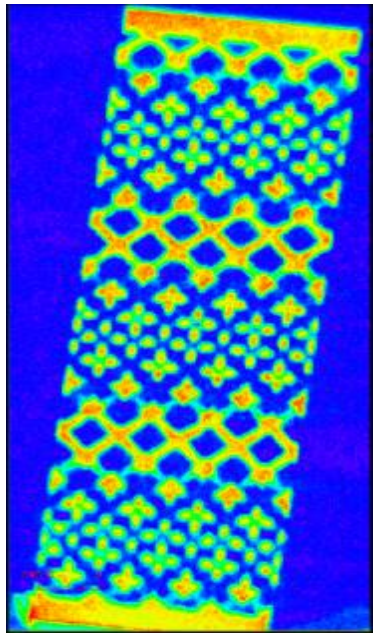






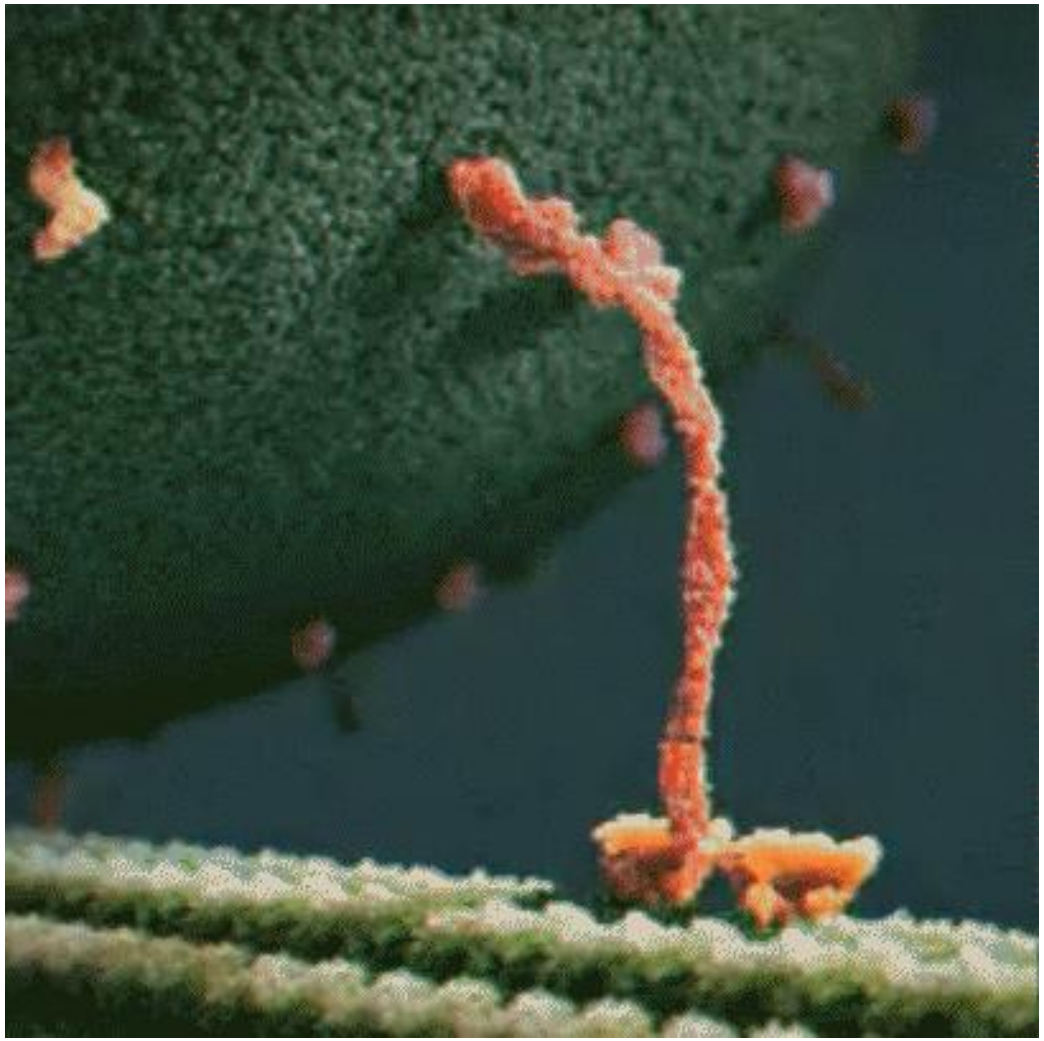


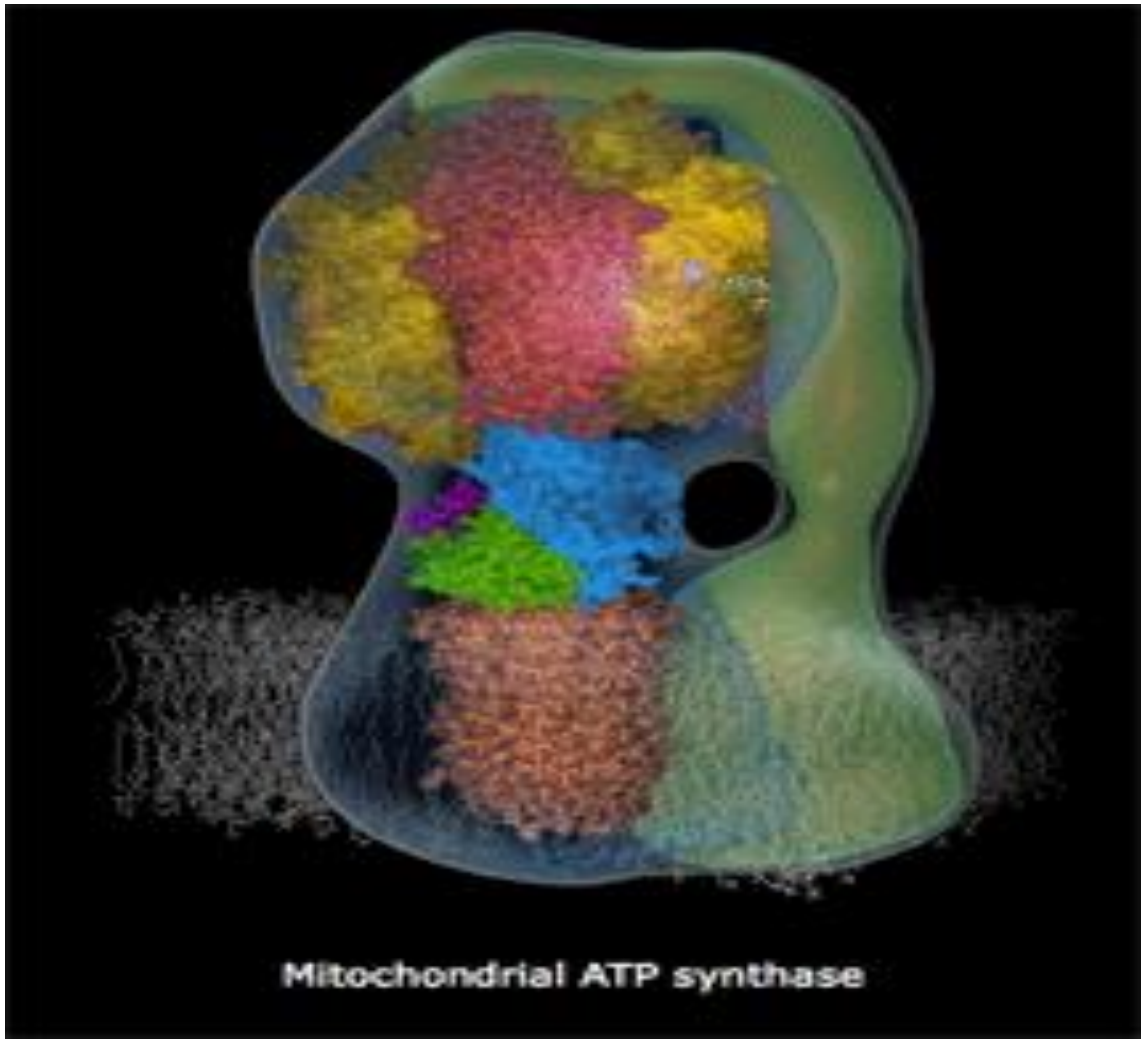




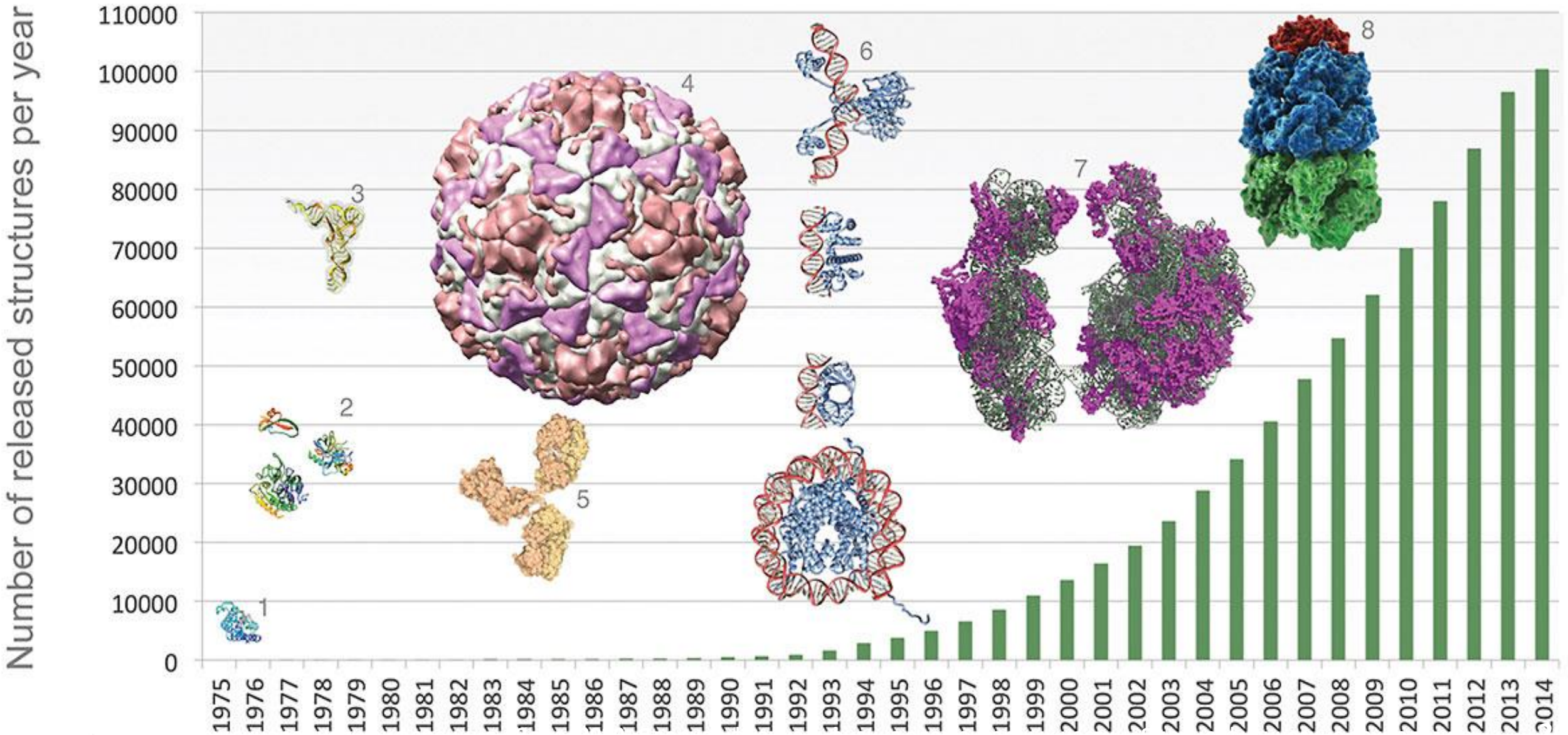
На пути к природоподобию

Смещение направленности исследований от объектов неживой к объектам живой природы

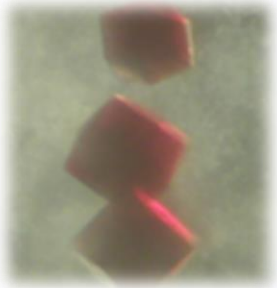




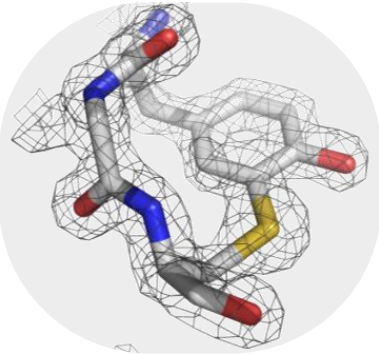
От простого к сложному



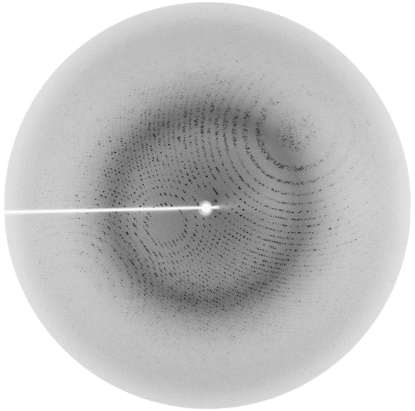
Protein crystallography

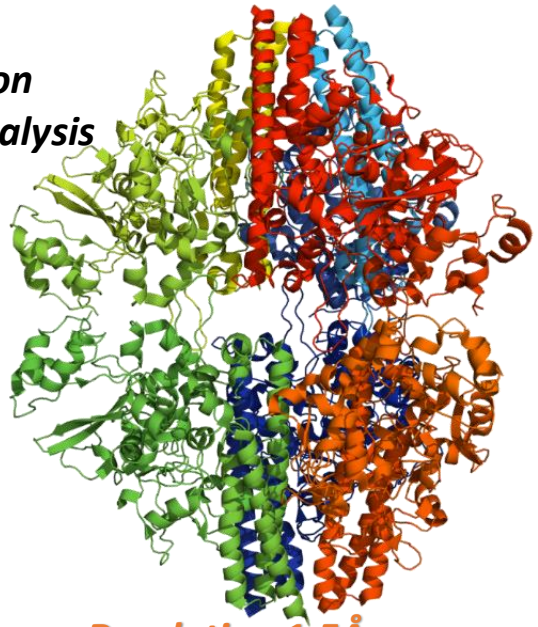


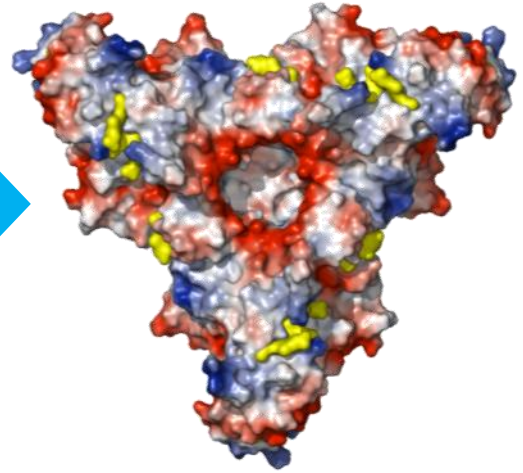
~300μm



Extracting
Purification
Crystallization
Structure analysis

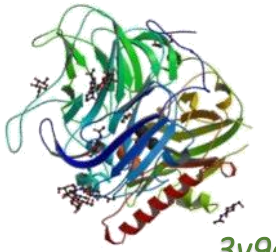






Cytochrome with nitritereductase (TvNiR) from the extremophilic bacterium Thioalkalivibrio nitratireducens. Resolution 1.5Å

Protein Structures - PDB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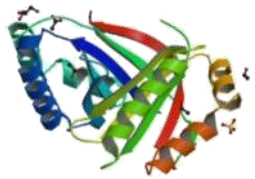
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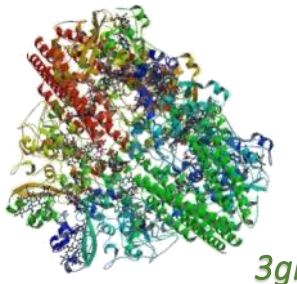
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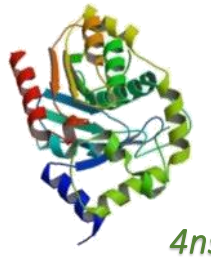
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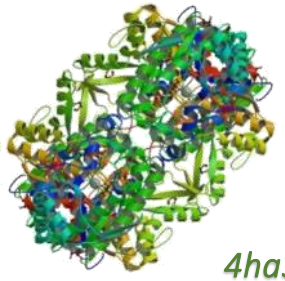
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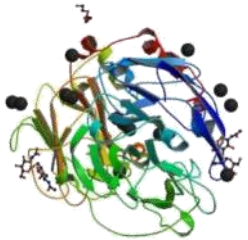
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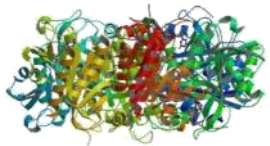
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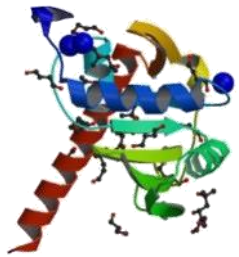
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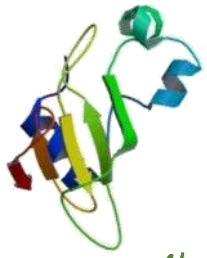
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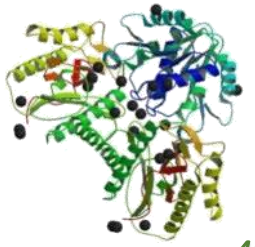
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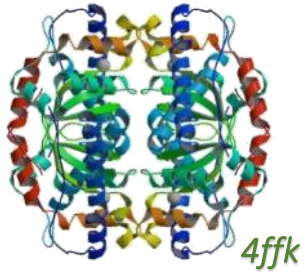
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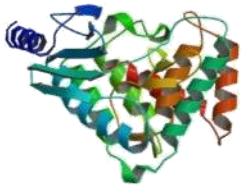
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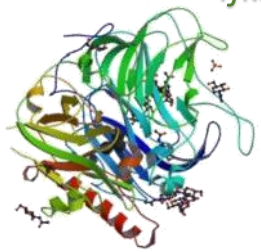
4n1v


4f8x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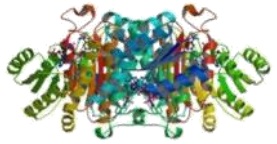
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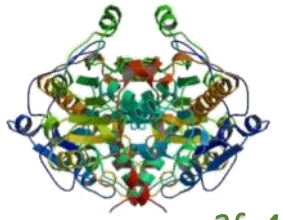
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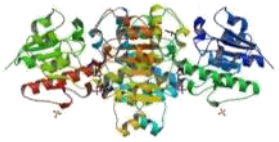
4hgx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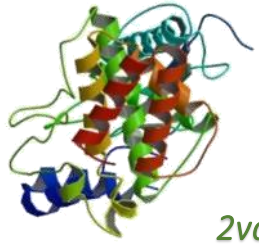
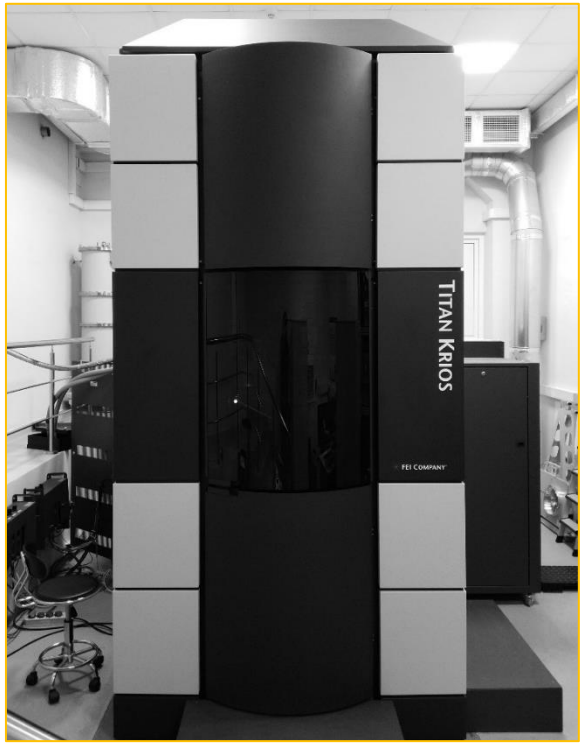
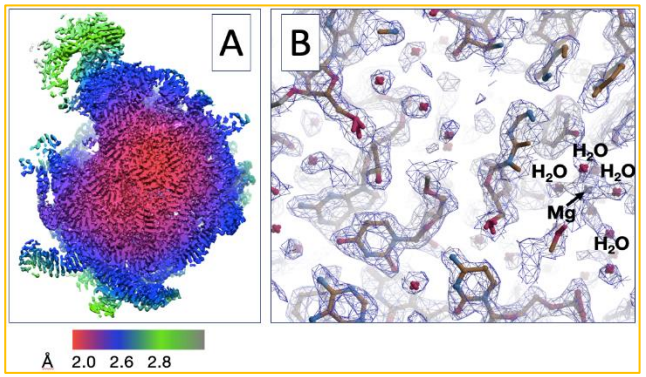
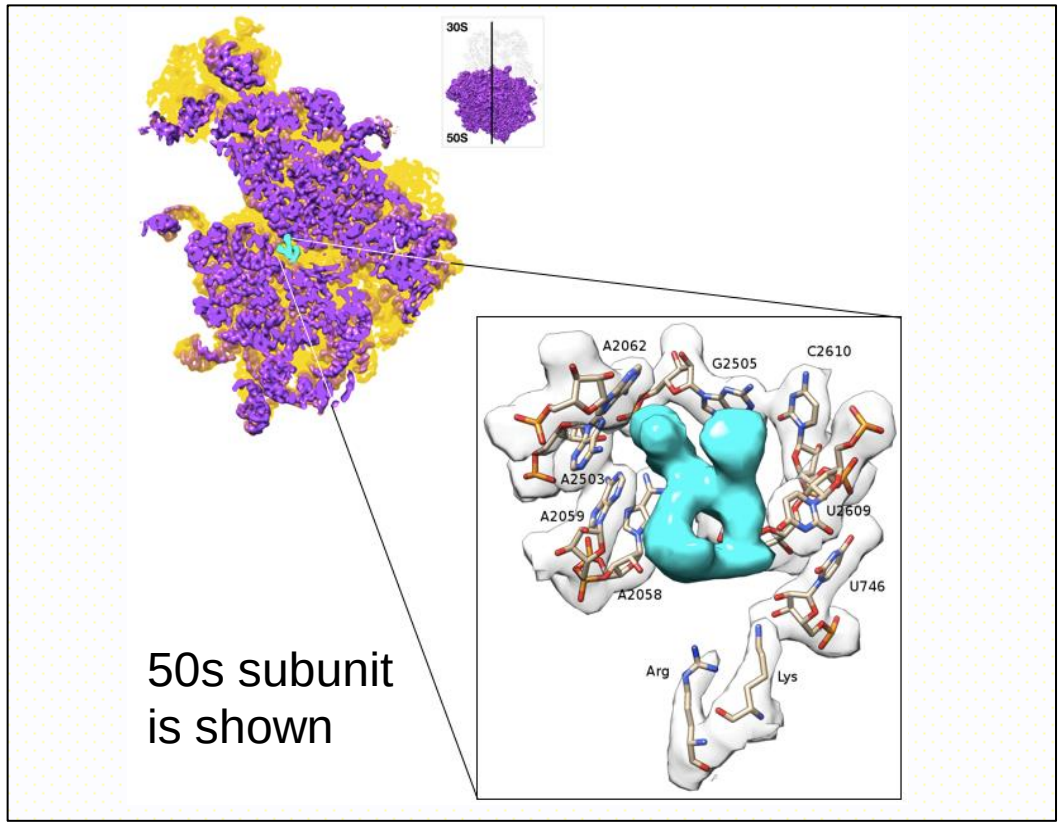

2vqx

Cryo-EM structure of the e. coli 70s ribosome in complex with an antibiotic

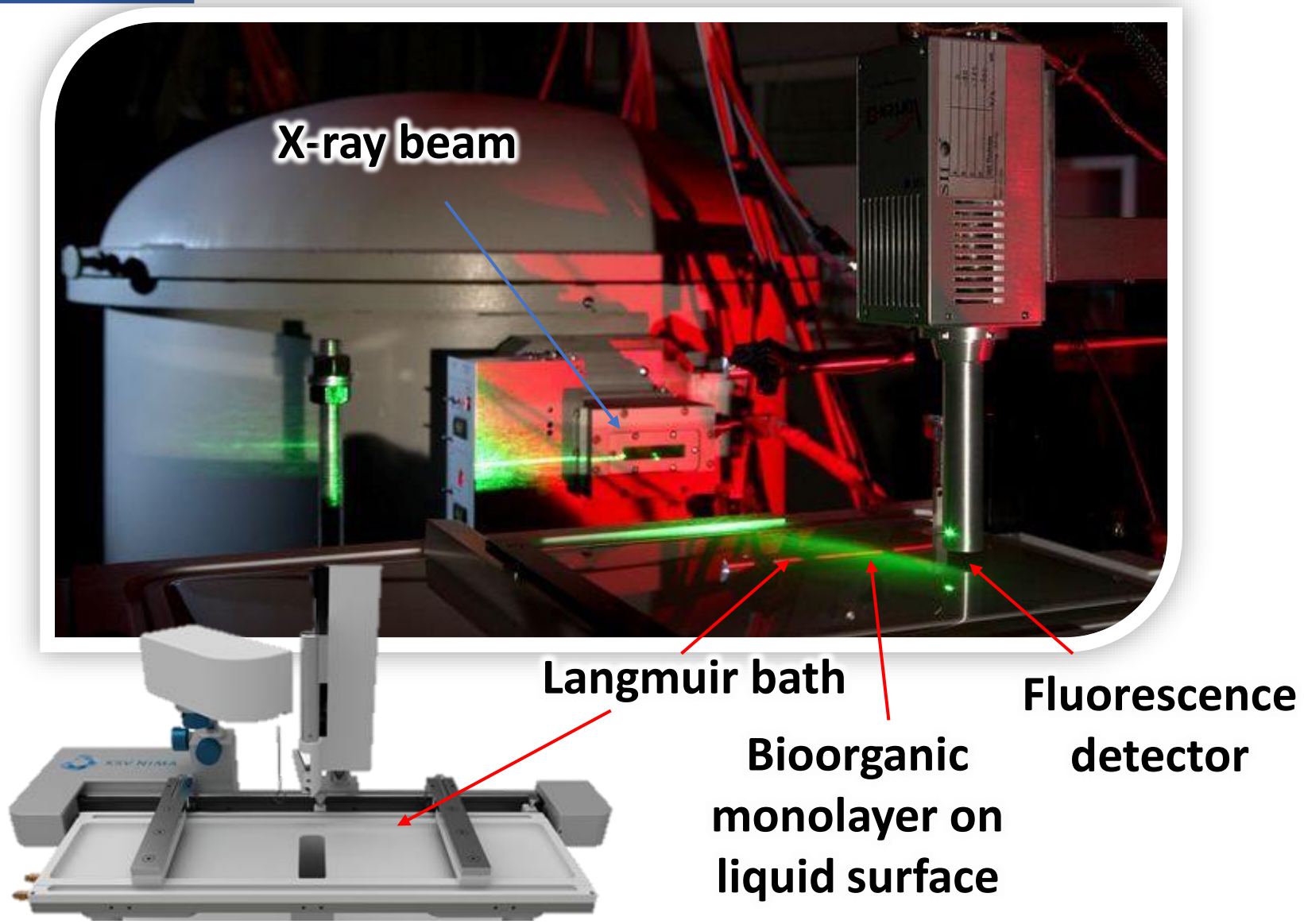






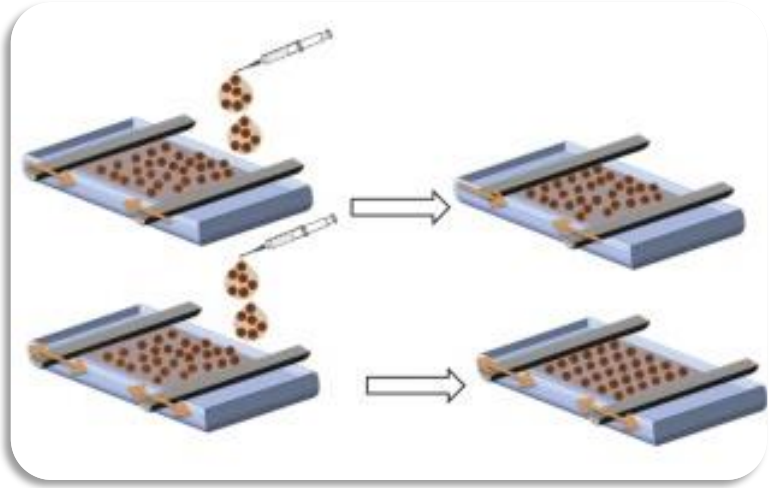
A. Local resolution variations of the structure.
B. An example of high-resolution features of the cryo-EM density: H_20 molecules, Mg, holes in aromatic pyrimidine ring. Mg^{2+} and H_2O positions are taken from PDB 4YBB.

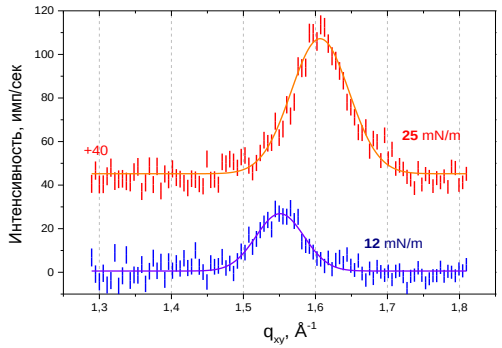
Langmuir beamline



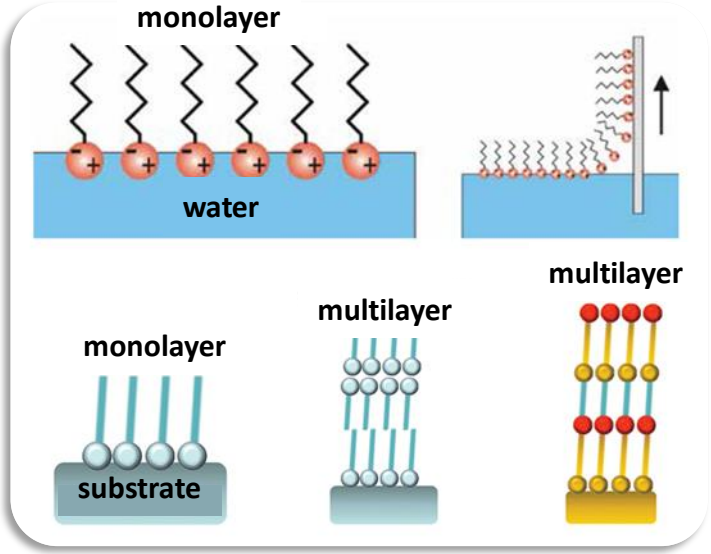
Langmuir beamline: Experimental results

Structural organization - the formation of a two-dimensional crystal

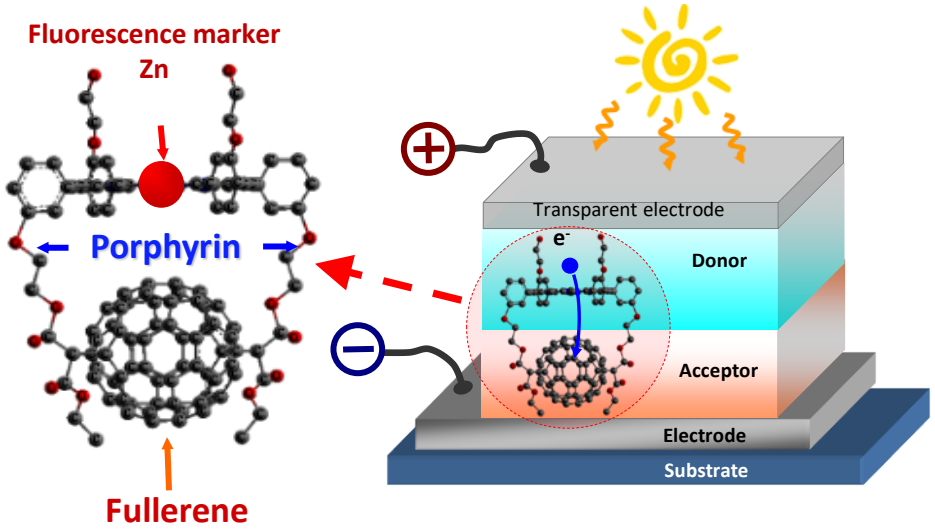


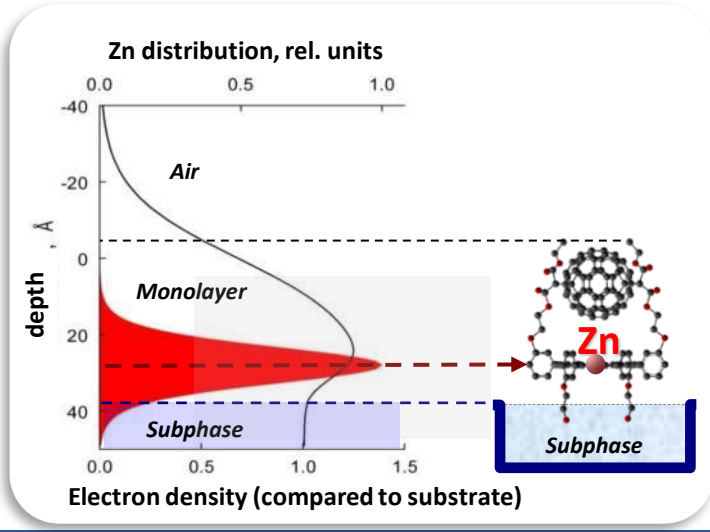


Transfer to solid substrate, Creating a multi-layer structure

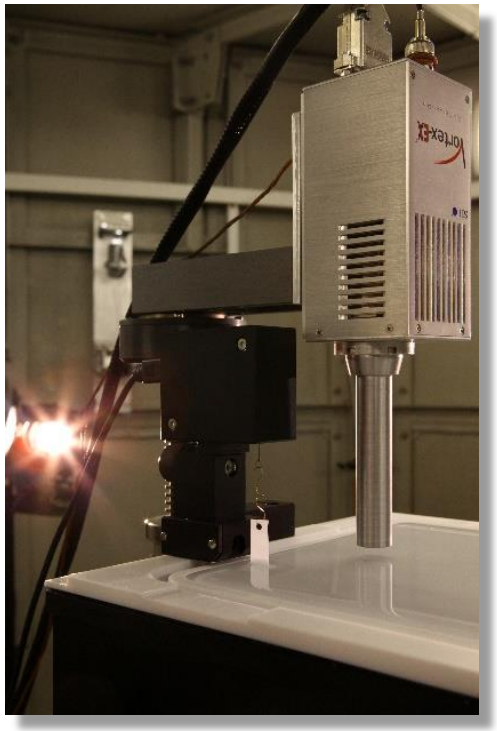


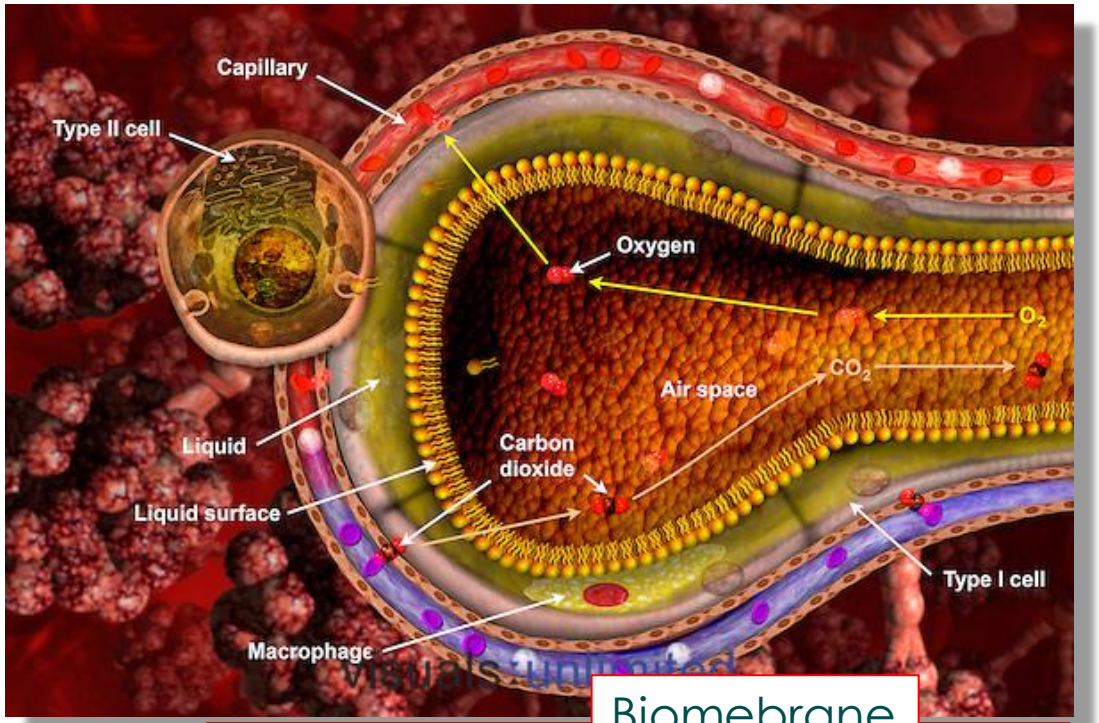
Determination of the orientation of the fullerene-porphyrin dyad on the surface of the subphase

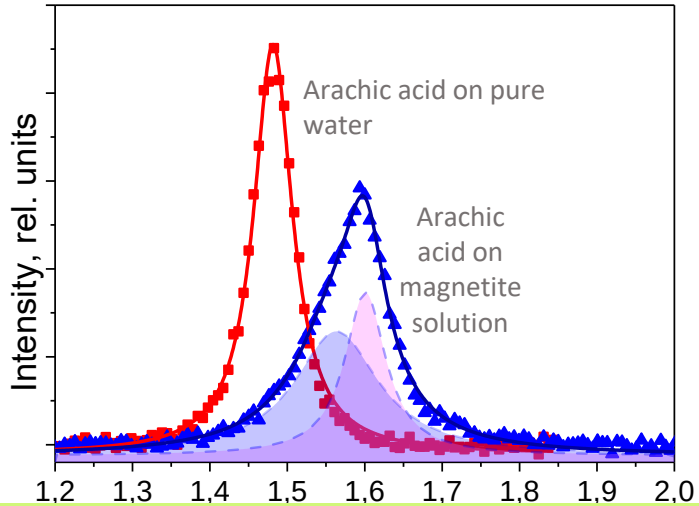




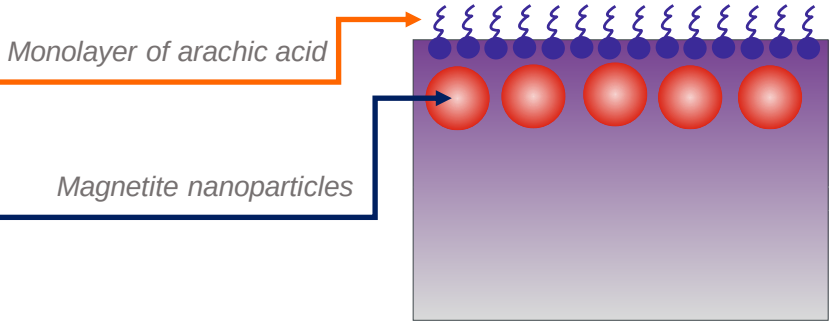
Biology and medicine



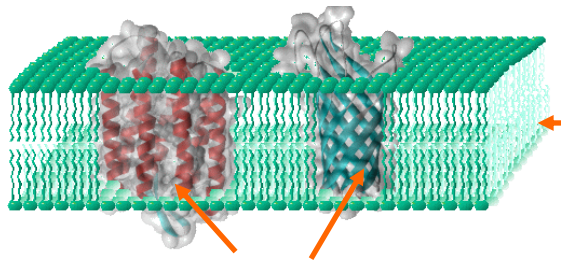


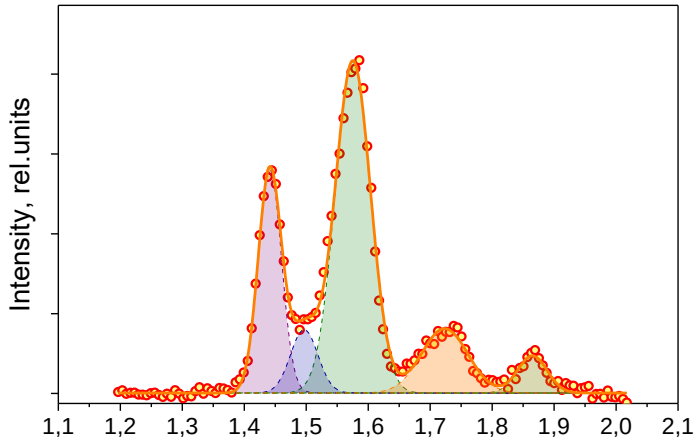


Nanoparticles of magnetite, stabilized by citric acid, core size is 6 nm



Biomebrane

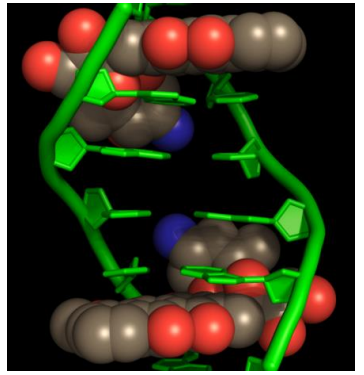




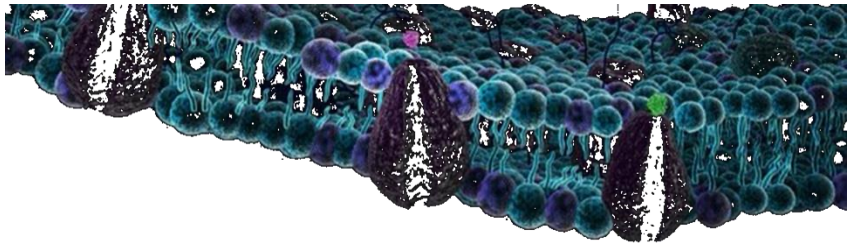
Nanoparticles of **cerium dioxide** , stabilized by citric acid, **core size is 6 nm**

Studies of the antitumor drugs action

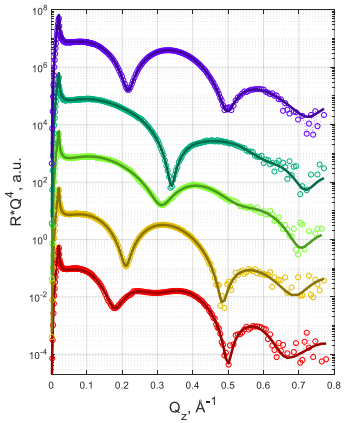
Doxorubicin – an anticancer drug

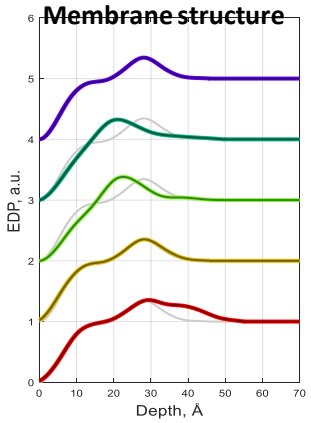


Cell membrane



X-ray reflectivity

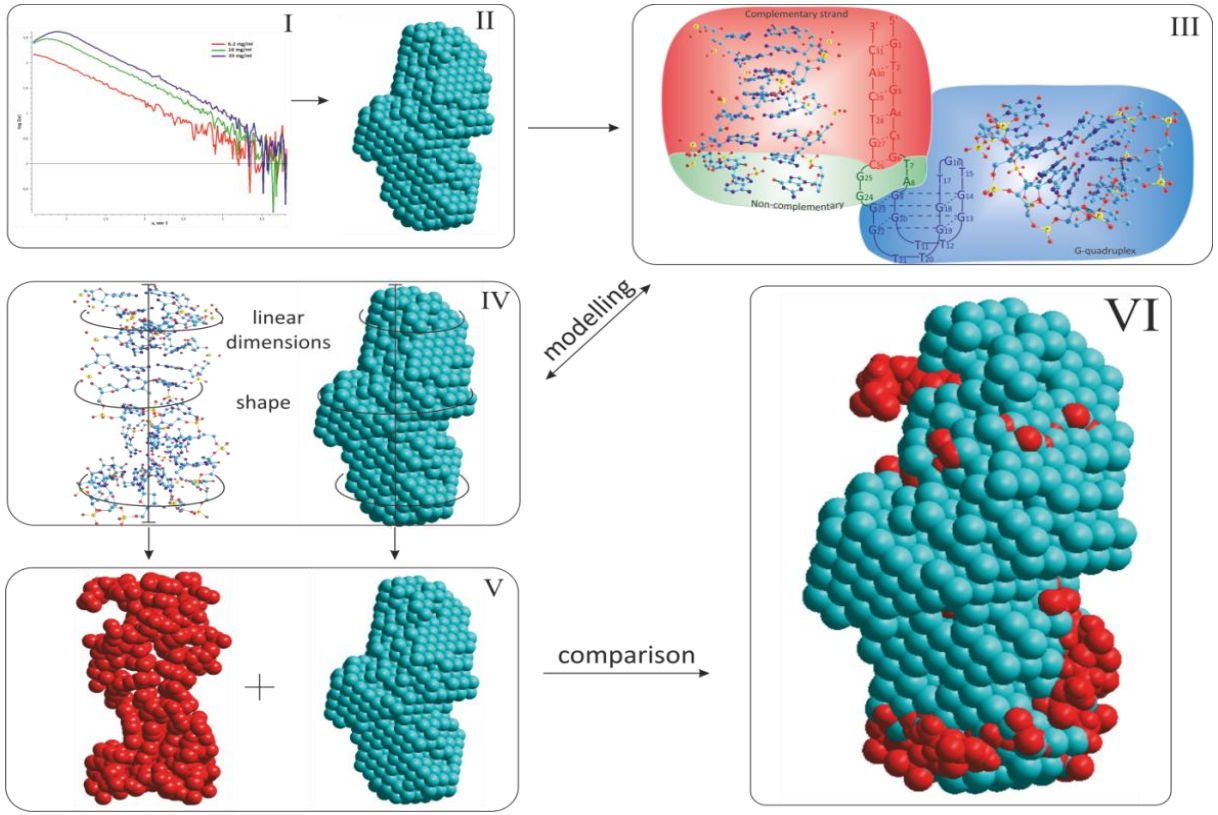




New data on the molecular mechanisms of cell damage under the action of Doxorubicin have been obtained

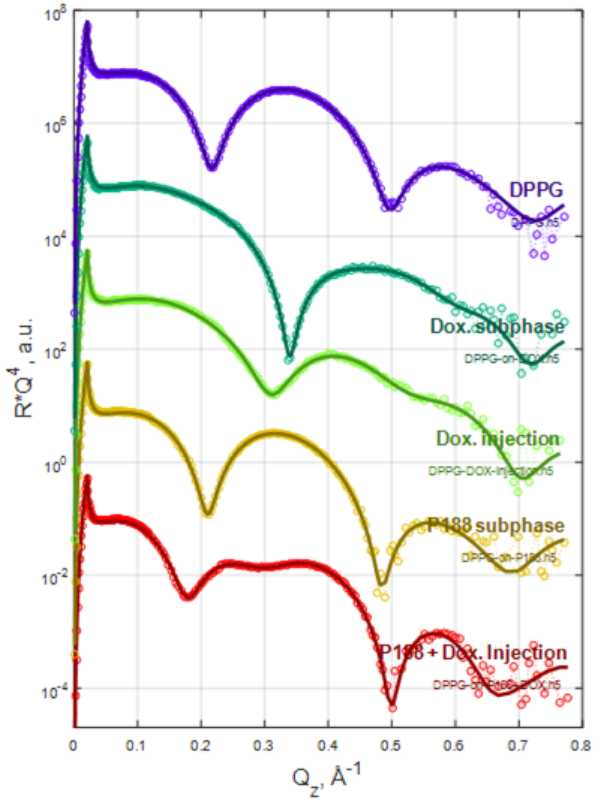
Biology and medicine

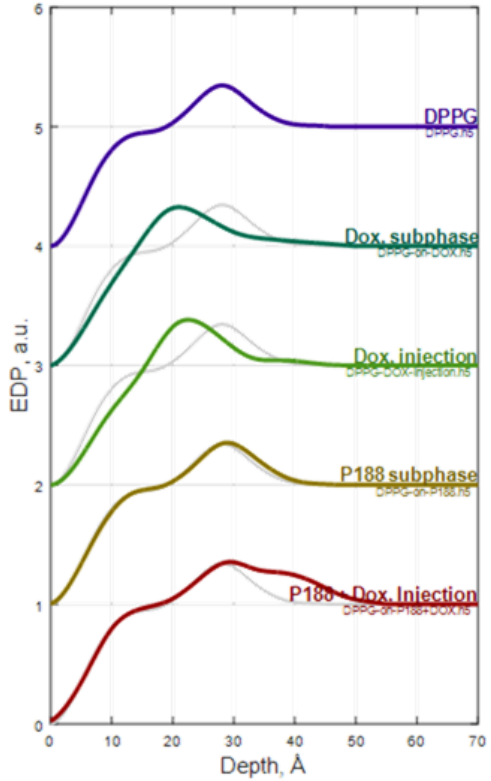
The optimal structure of the aptamer has been established by **SAX, CryoTEM and molecular simulation**, suitable for introduction into medical preparations used in neurosurgery and the most effective diagnosis of glioblastoma.



Anna S. Kichkailo, Tatiana N. Zamay, Andrey A. Narodov et.al. Tumor Specific Aptamers Navigate Intraoperative Margin Assessment in Glioblastoma Neurosurgery. 2018. **Nature BME.**

Experimental measurements by **X-ray reflectometry and surface diffraction** made it possible to obtain new data on the molecular mechanisms of cell damage under the action of antibiotics.





X-TOP beamline: Experimental results

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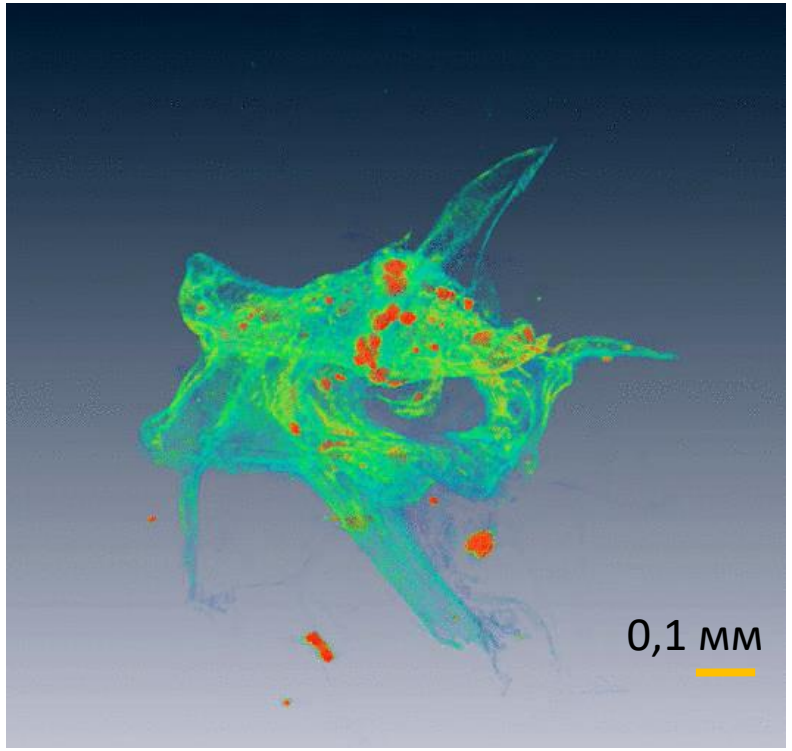
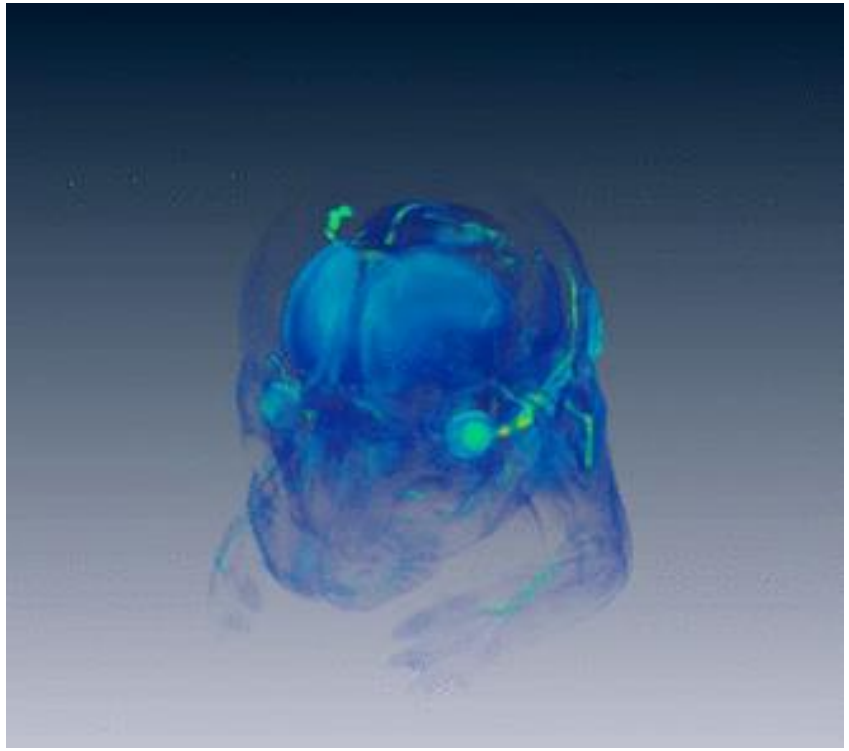
Decalcification studies of bones in a long stay in space



Gecko vertebra after space flight

Learning cognitive processes using x-ray tomography



Active centers in the brain of a newborn mouse visualization

Cultural heritage

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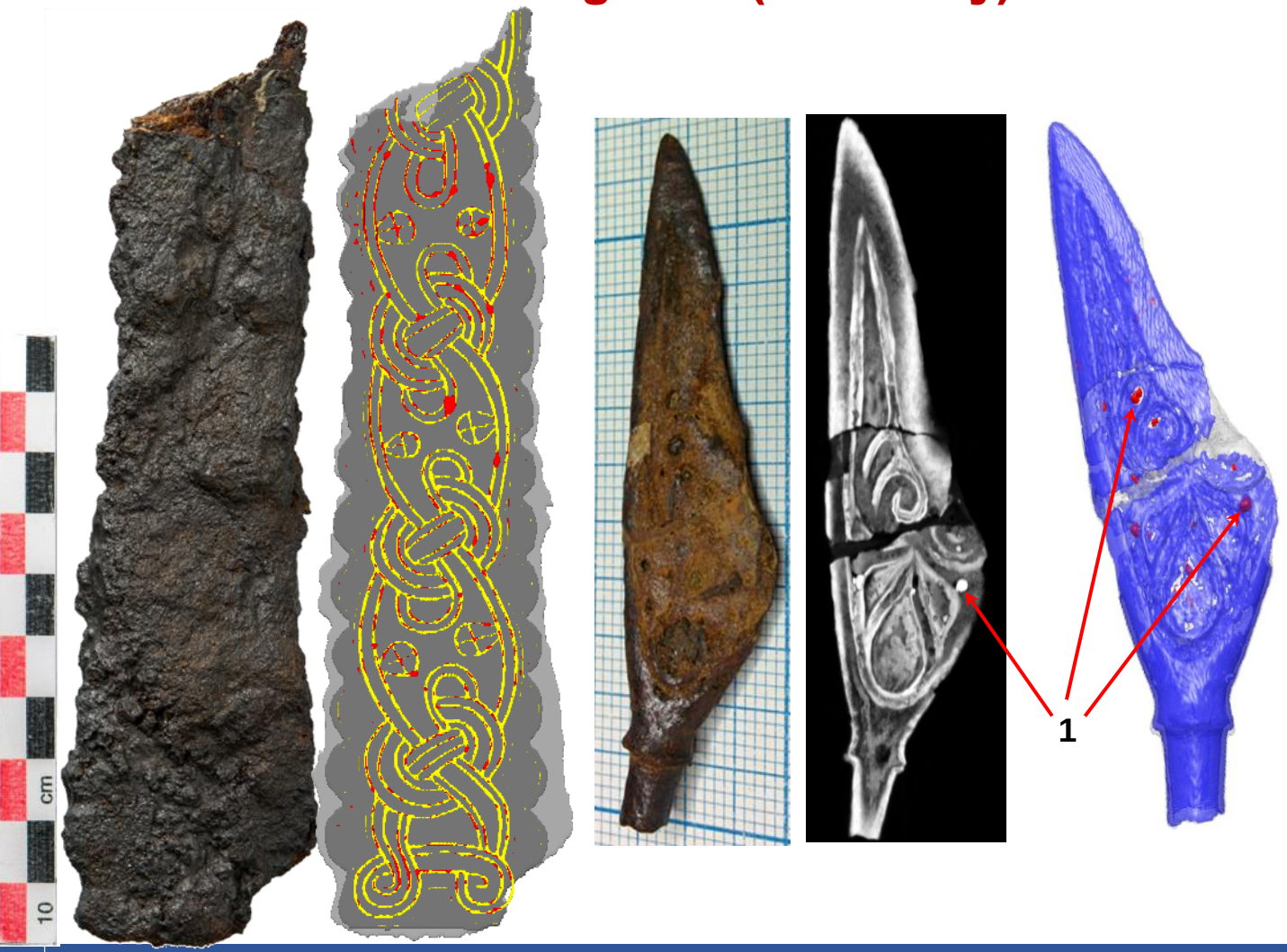
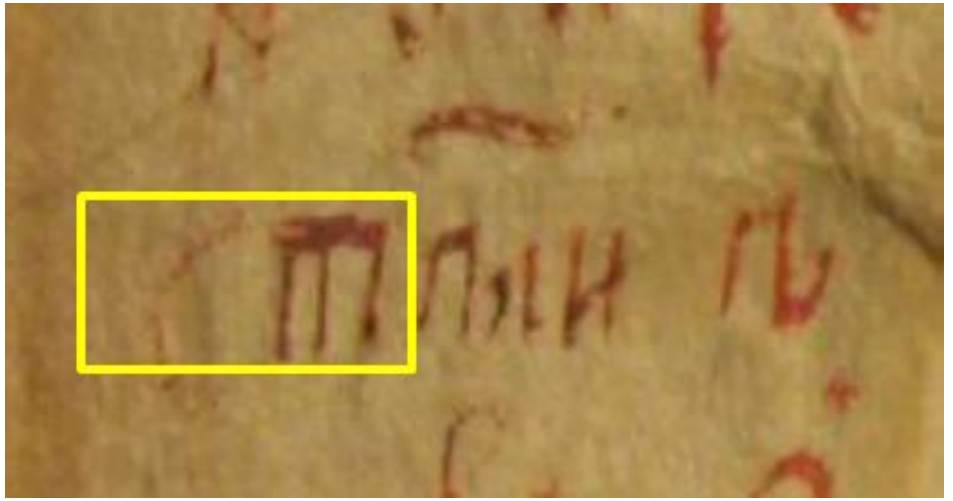
Objects with an ornament from the mound “Black grave” (X century)



Slavic medieval parchments

X-Ray fluorescence 2D mapping



Cultural heritage

Encolpion cross
~ 12th century

X-RAY TOMOGRAPHY



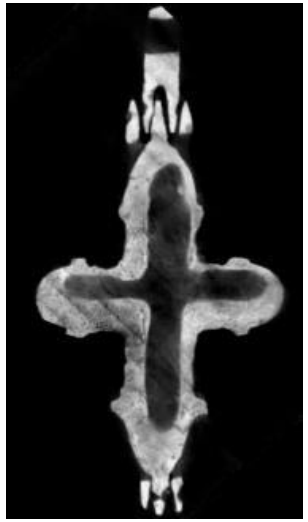
NEUTRON TOMOGRAPHY

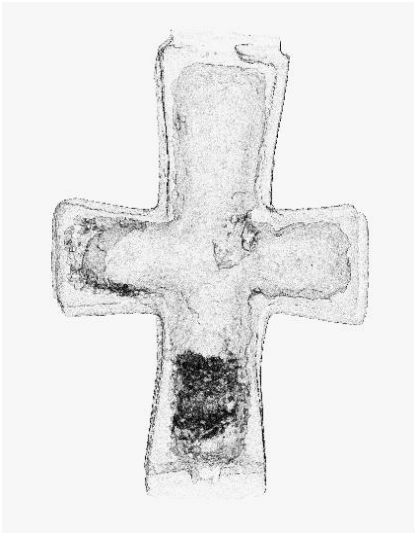


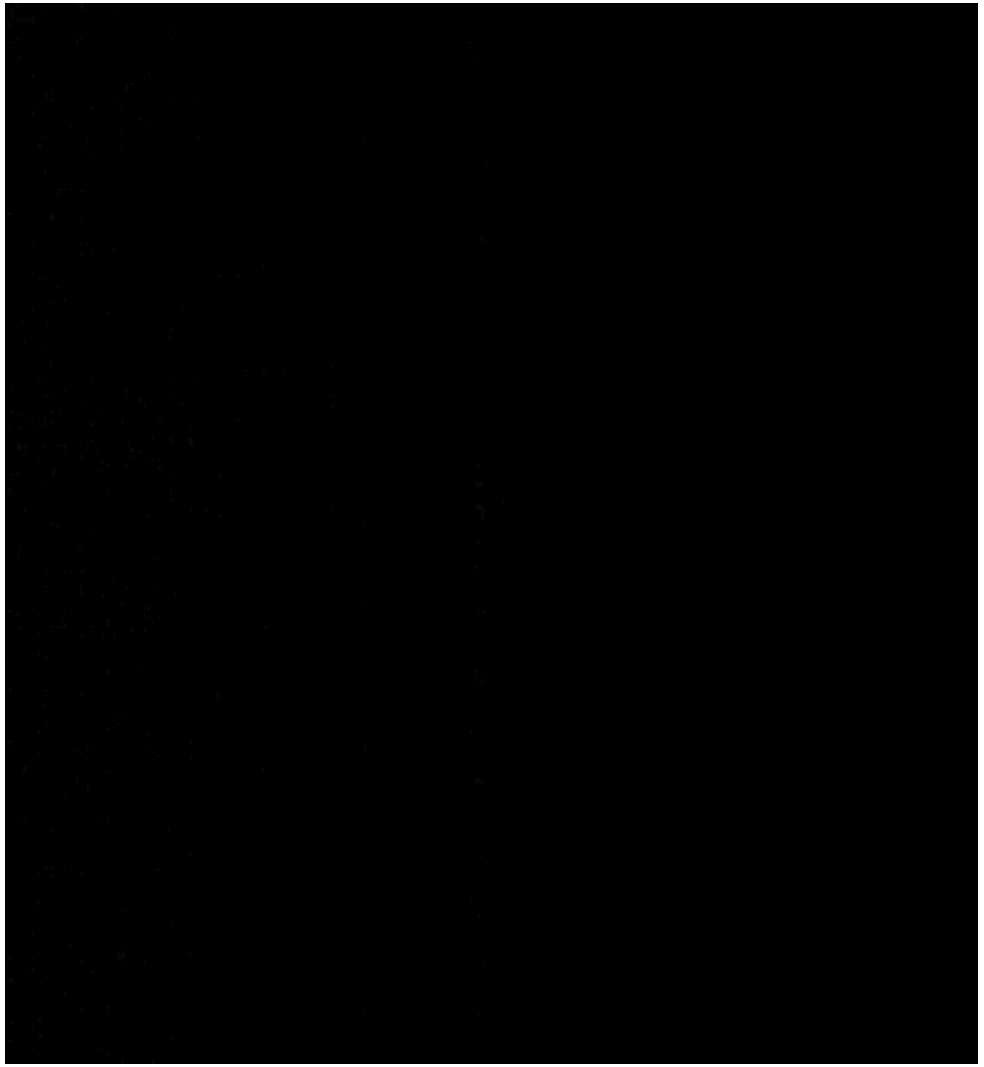

Investigation of cultural heritage

SR

Neutrons





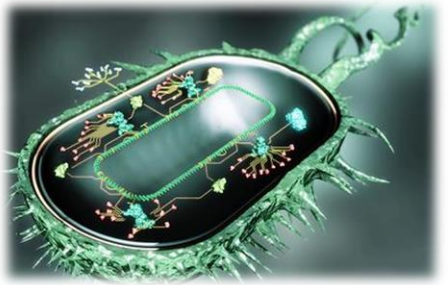


Scientific applications: from crystallography to nature-like technologies

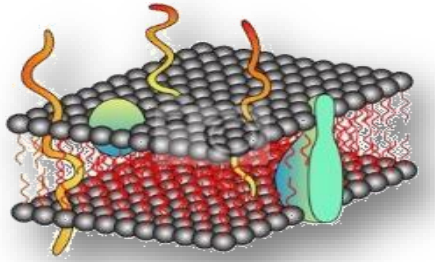
NATIONAL RESEARCH CENTER "KURCHATOV INSTITUTE"

Cognitive studies

Cultural Heritage

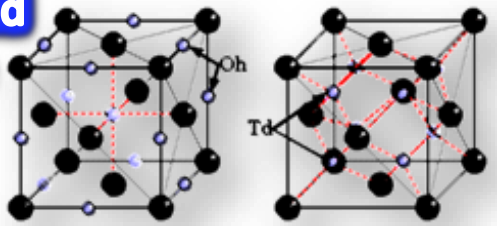


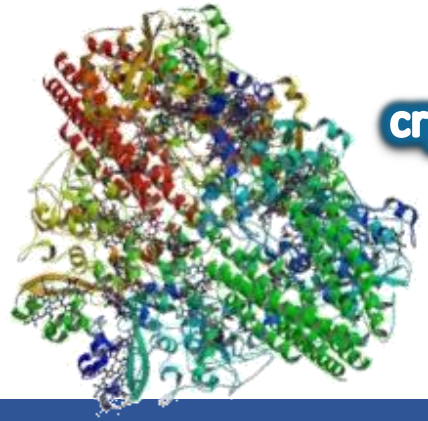
Nature - like technologies



Molecular biology

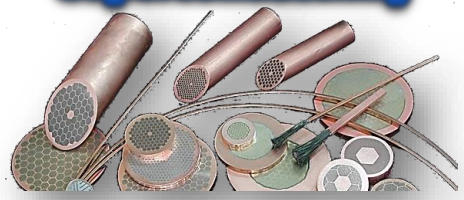
Crystallography and material science



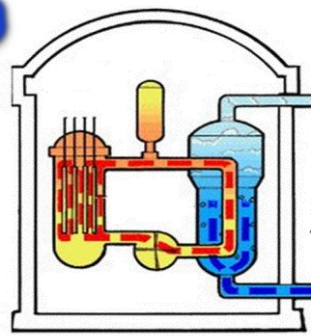


Protein crystallography

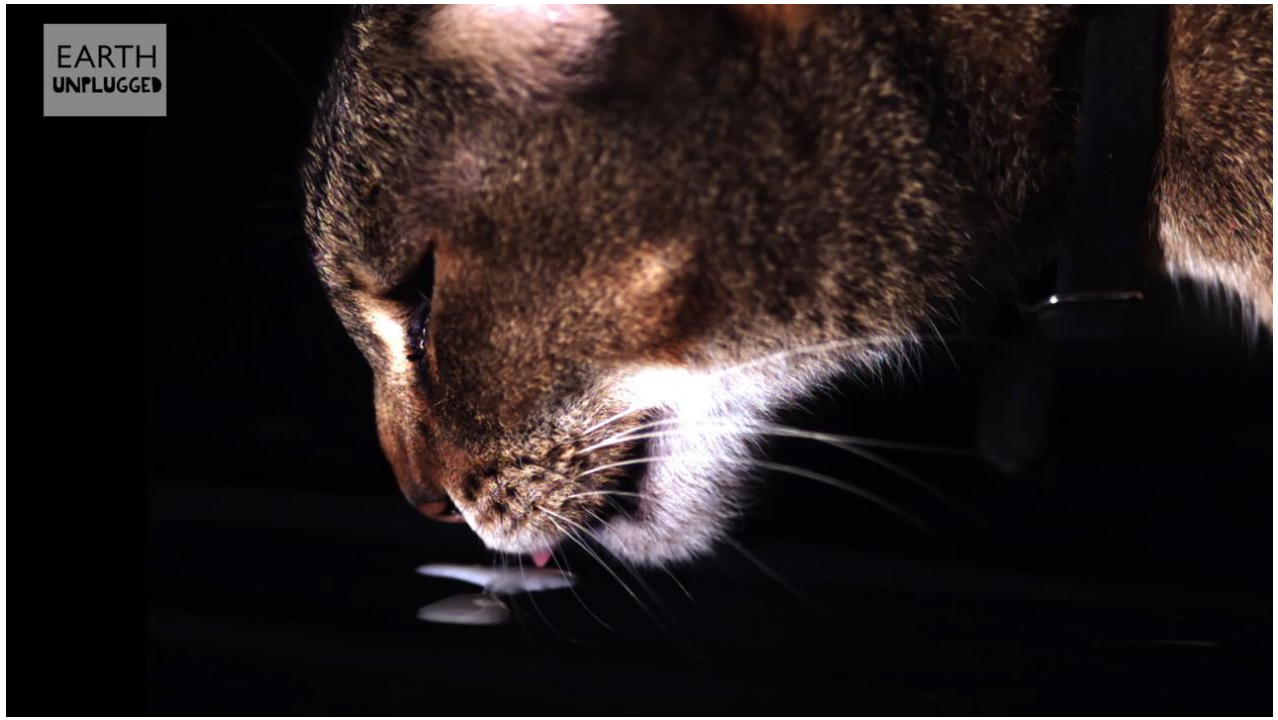
Supercondactivity



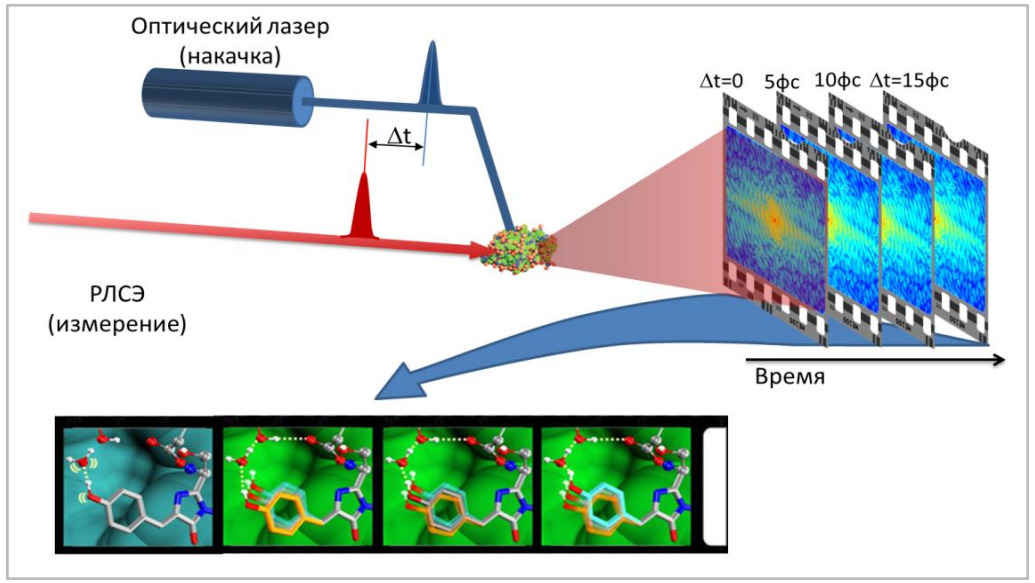
Materials for reactors



Time-resolved experiments



Laser-Synchrotron complex



Synchrotron and Reactor IR-8 modernization

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Synchrotron and reactor IR-8 systems modernization

2.5 GeV current 150 мА

Energy:

25 eV– 150 keV

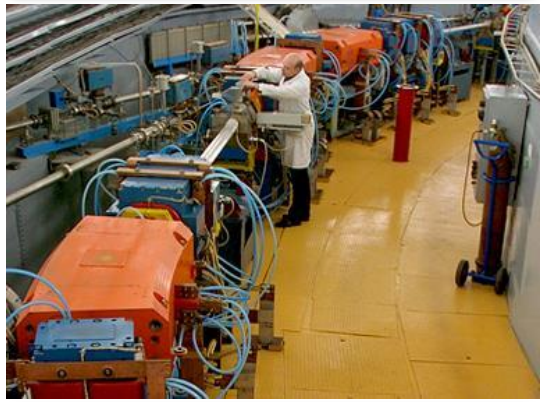
Phonon fluence:

10^{14}-10^{12} ph/c · mm^2

The neutron flux at the end of the horizontal channel

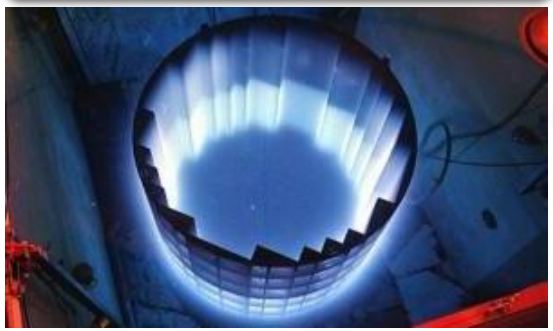
10^{10} n/s · cm^2

Engineering systems



Vacuum system

Active zone



Beryllium reflectors

Magnetic and HF systems

SC wigglers

Protection system

Control system

Modernization of Kurchatov synchrotron (2019-2022)

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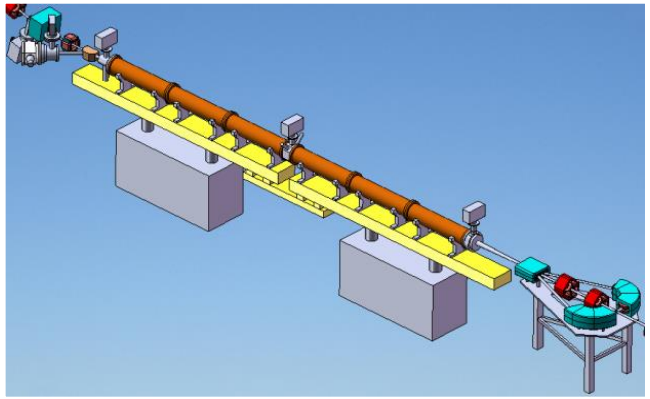
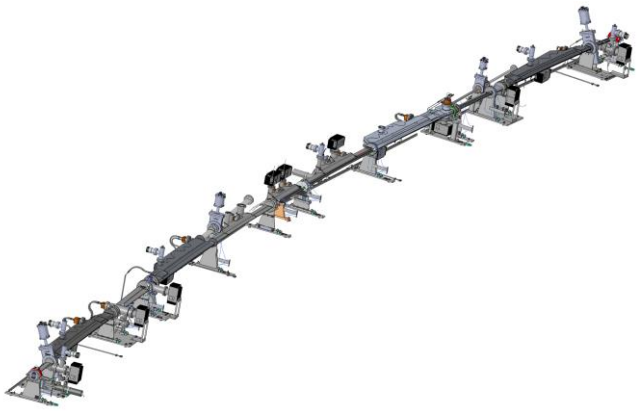
- Storage ring
- Magnet system (MBA structure)
- Vacuum system
- HF system
- Cooling system
- Insertion devices
- Booster Ring
- Linac

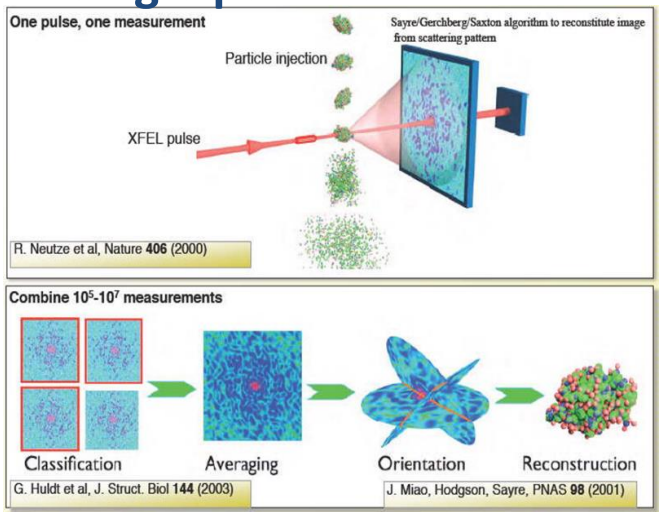
Injection in KSRS-2:
Linac 80 MeV
Magnetic mirror - Linac-160 MeV;
Booster Synchrotron:
E=160-2500 MeV
StorrKSRS-2: 2500 MeV
Emittance = ~ 10 nm-rad



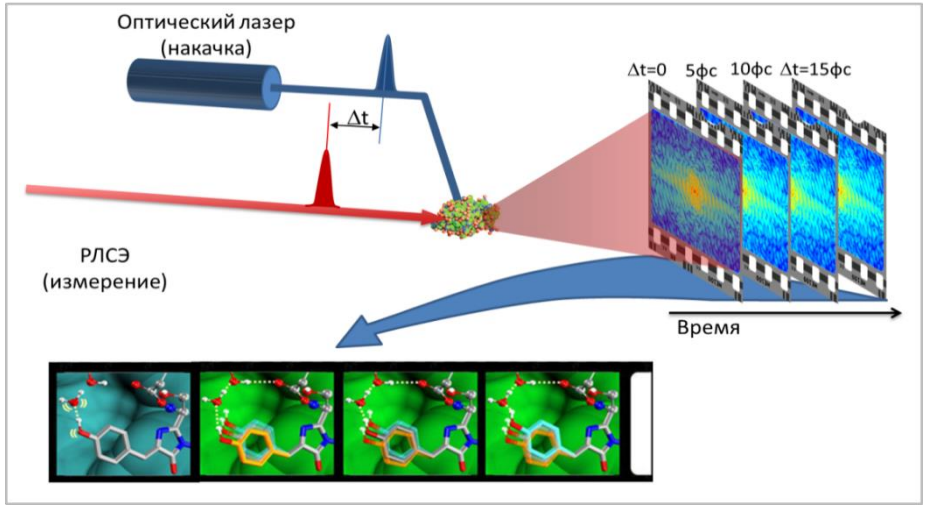


New experimental opportunities

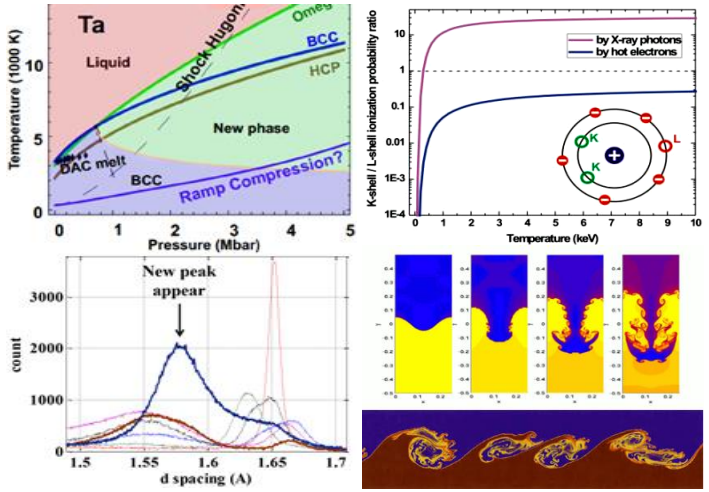
Single partials structure



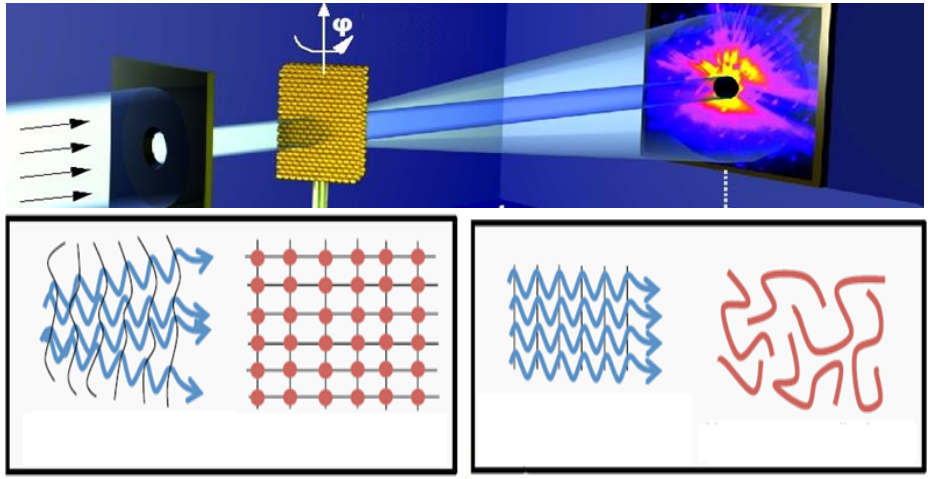
Chemical reactions “movies”



Exotic state of the matter



Coherent applications



New experimental opportunities

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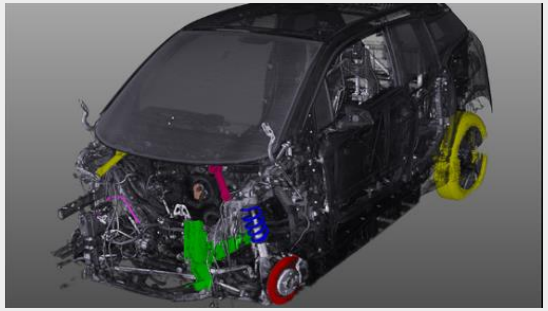
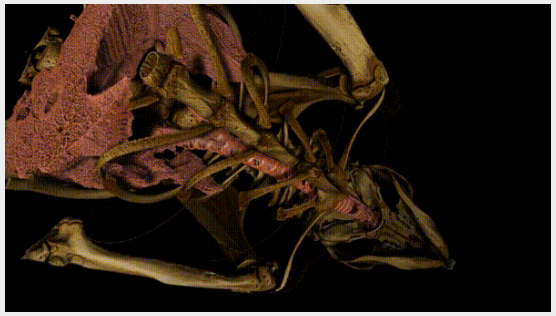
Phase-contrast visualization

High penetration depth of hard X-Rays



Constructive materials

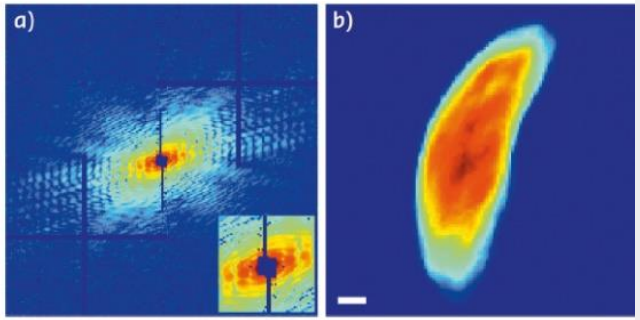


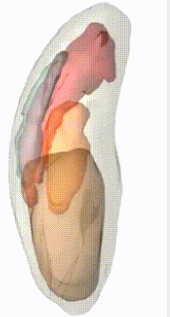
Hierarchical tomography

Coherent imaging

High coherent flux at wavelenght ~1Å

Nanostructures

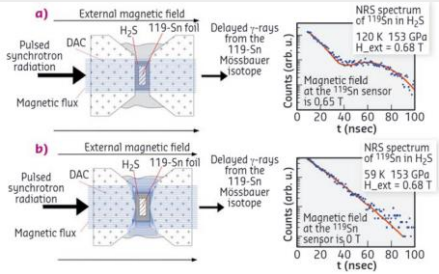




Cells, viruses

Mössbauer spectroscopy

Using the resonance effect of isotopic nuclei

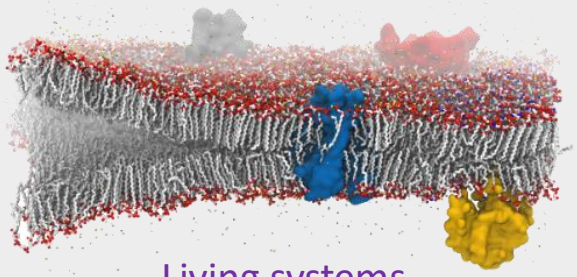


^{57}Fe - 14.412 КэВ
^{151}Eu - 21.541 КэВ
^{149}Sm - 22.494 КэВ
^{119}Sn - 23.879
^{161}Dy - 25.651 КэВ
^{129}I - 27.890 КэВ

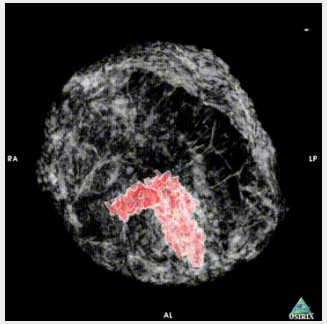
Magnetic phenomena, earth science, superconductivity

Biological Systems Research, Medicine

Radiation Exposure Reduction



Living systems, Biotechnology Structural biology



Radiology

Statistics (average per year)

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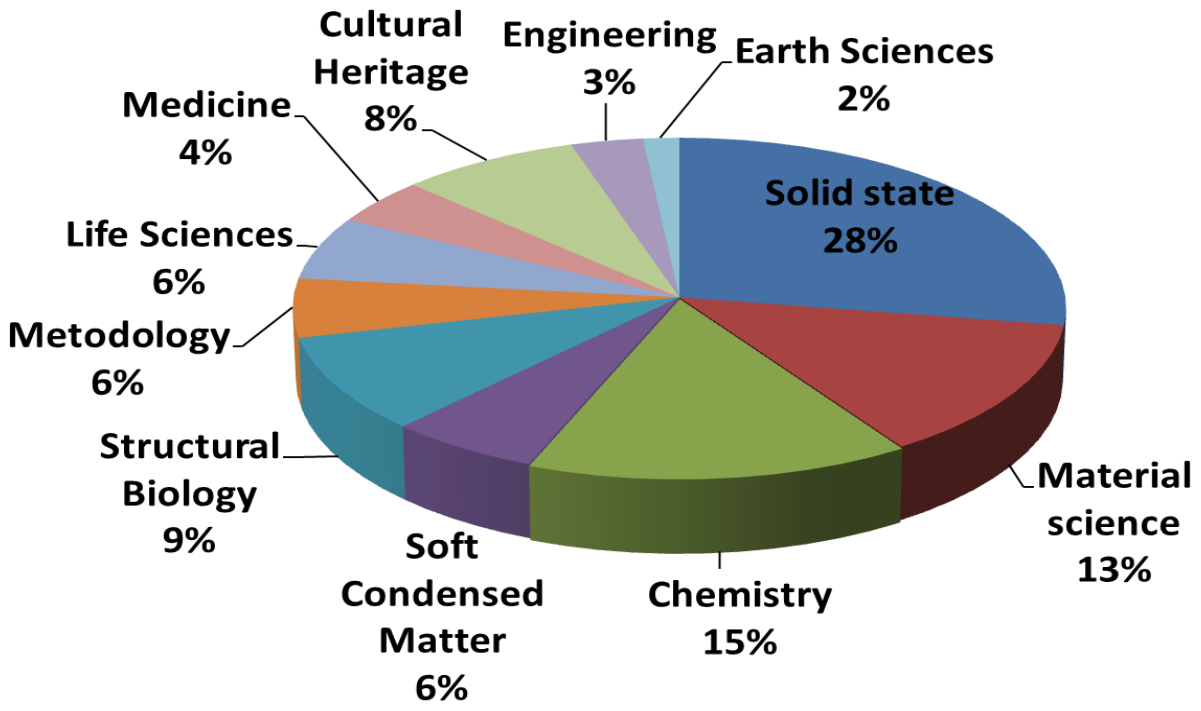
- > 300 accepted proposals (~ 60 organizations)
- > 120 user groups
- > 3 500 hours of experimental time
- > 25 000 hours total time of beamlines operation
- > 150 publications Web of Science



The Grand challenges

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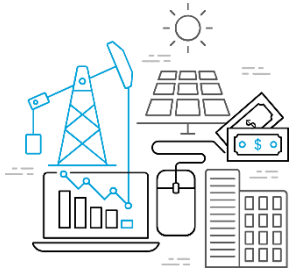


NEW MATERIALS AND DIGITAL ECONOMY

- Structure and properties of functional materials;
- Additive technologies;
- Materials for microelectronics, spintronics, straintronics.

DEMOGRAPHY AND MEDICINE

- Protein crystallography;
- Structure of membranes, viruses;
- Molecular mechanisms of drug action;
- Structure of polymers;
- Development of systems for targeted drug delivery.

NATIONAL SECURITY

- Materials for sensors and detectors;
- Fast processes of combustion;
- Cultural heritage.

FOOD

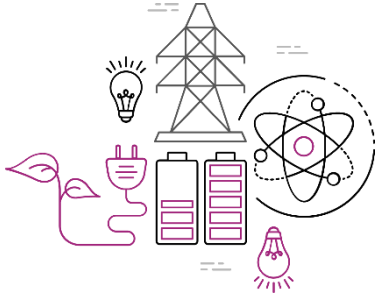
- Molecular and supramolecular structure of foodstuffs
- Denaturation of plant and animal proteins;
- Visualization of seeds of various crops.

TERRITORY CONNECTIVITY AND SPACE EXPLORATION

- Construction materials for extreme conditions;
- Non-destructive weld inspection.

HUMAN, NATURE AND TECHNOLOGIES

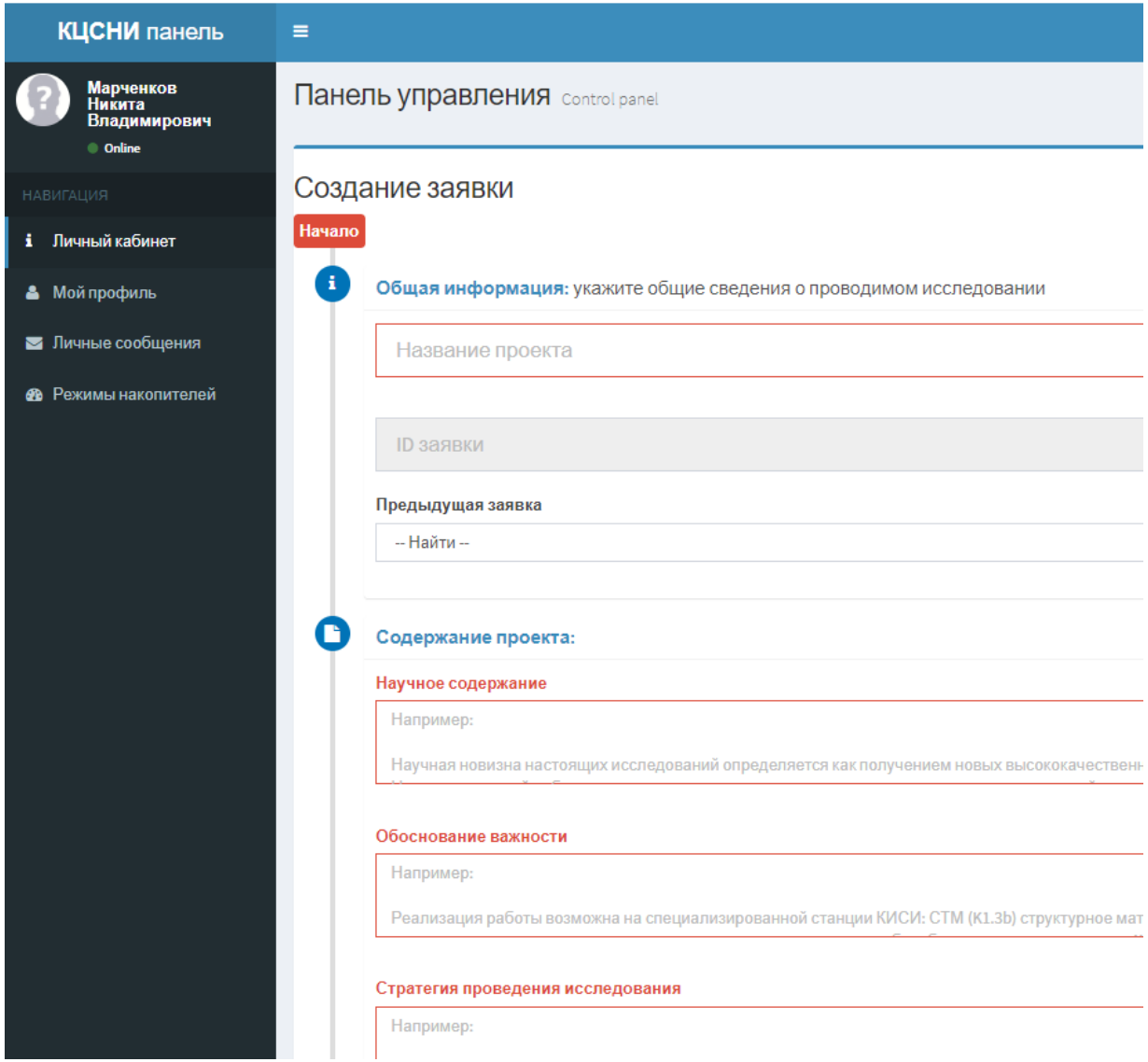
- Metrology for nature-like technologies;
- Diagnostics of components of adaptive neuromorphic systems and memristic materials;
- Micro- and mesoporous systems and materials;
- Structure diagnostics of biotechnologies;
- Ecological monitoring.

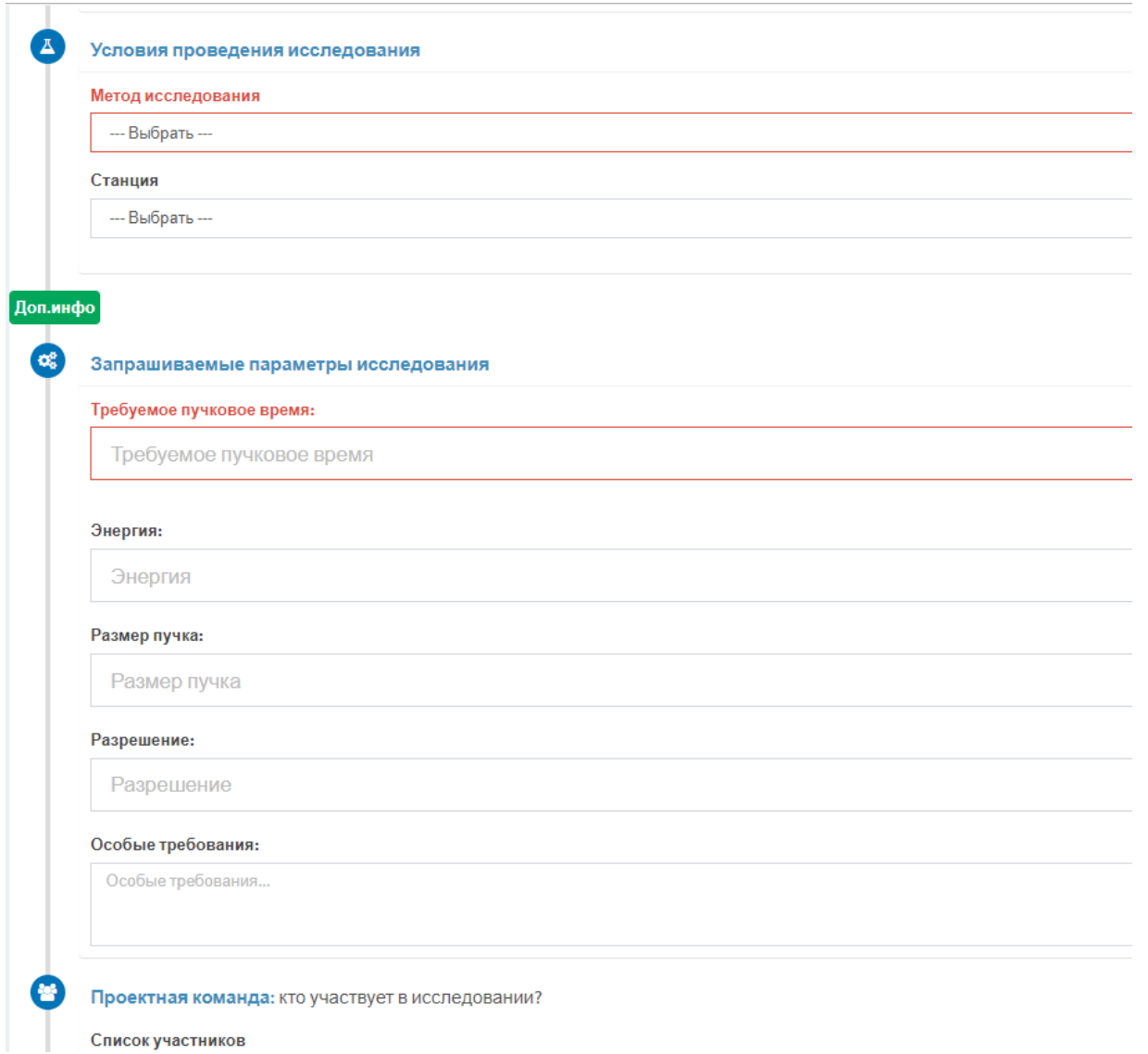


ENERGETICS

- Superconductors and thermoelectric materials;
- Catalysis and chemical processes of energy generating;
- Materials for nuclear energy.

Proposal portal





Contacts

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Thank you for attention!

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