JAGIELLONIAN UNIVERSITY IN KRAKÓW

SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

# SOLARIS National Synchrotron Radiation Centre: Photon Science Directions in Poland at the Large Scale Accelerator's Based Infrastructure

*Jakub Szlachetko*
*on behalf of the SOLARIS Team*
*IBIC 2022, Kraków.*

# Introduction to SOLARIS

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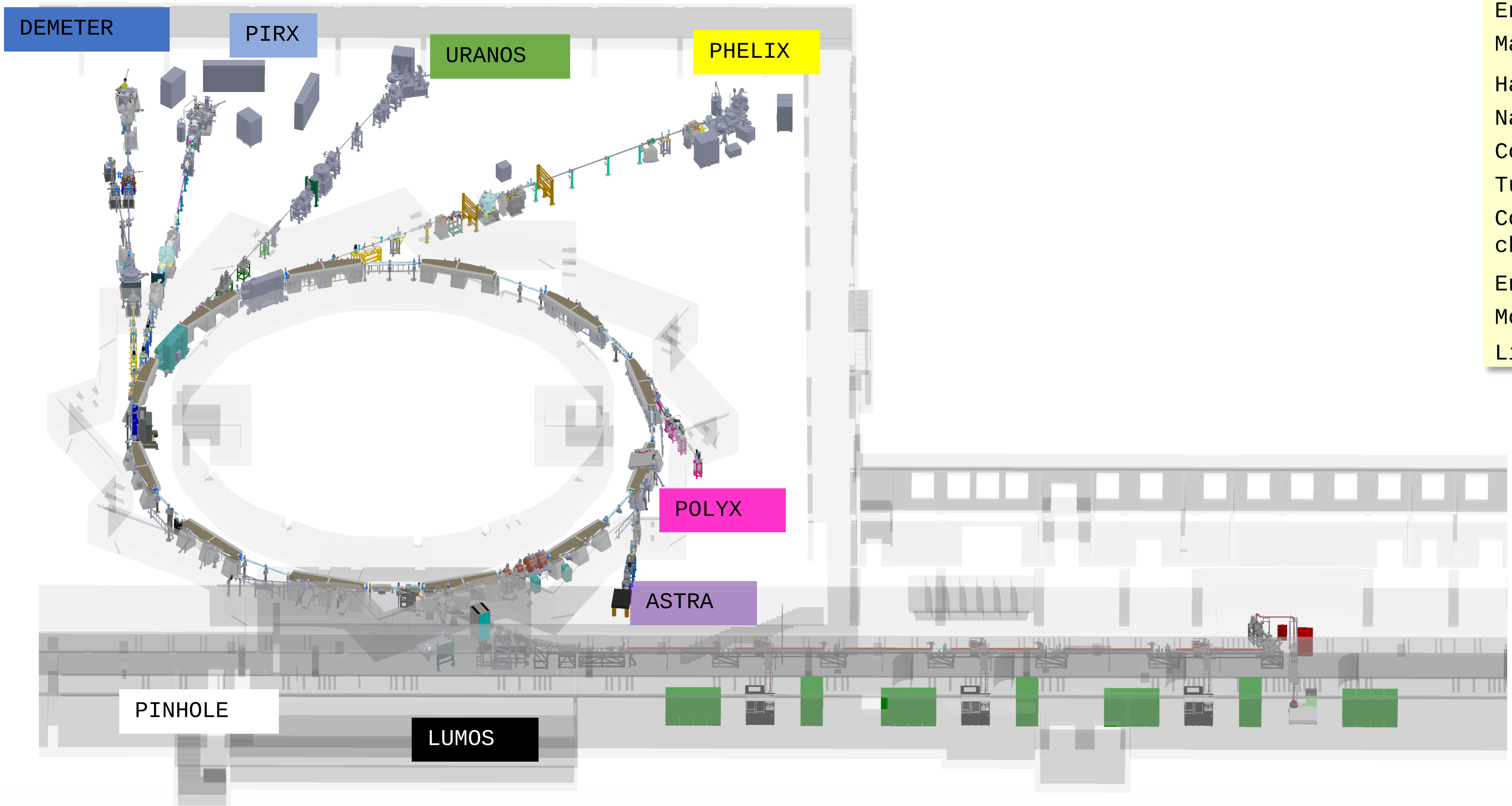
- Solaris is a third generation light source, designed by MAX-lab team (Mikael Eriksson), constructed 2010 - 2015 in Krakow, Poland.
- Between 2015 and 2018 the synchrotron as well as two beamlines (PIRX and URANOS) were commissioned.
- Since October 2018 Solaris has been in the user operation mode.

# *SOLARIS accelerators*

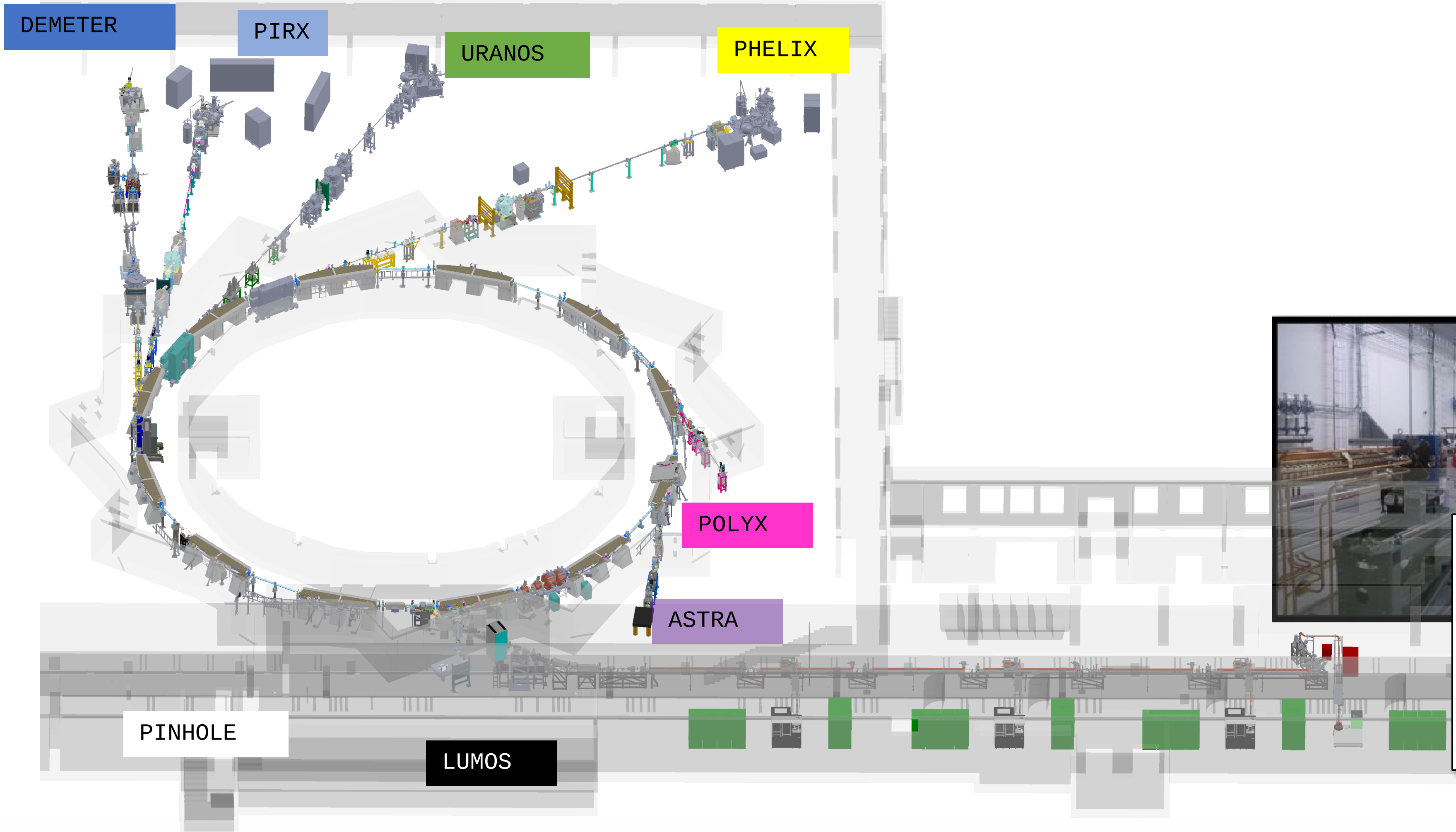
# SOLARIS accelerators




| Parameter | Value |
|---|---|
| Energy | 1.5 GeV |
| Max. current | 500 mA |
| Harmonic number | 32 |
| Natural emittance | 6 nmrad |
| Coupling | 1 % |
| Tune $\nu_x$, $\nu_y$ | 11.22, 3.15 |
| Corrected chromaticity $\xi_x, \xi_y$ | +2,+2 |
| Energy loss/turn | 114.1 keV |
| Momentum acceptance | 4% |
| Lifetime | 13h |

Accelerator Department Manager: dr. Adrianna Wawrzyniak,
adrianna.wawrzyniak@uj.edu.pl

# SOLARIS accelerators

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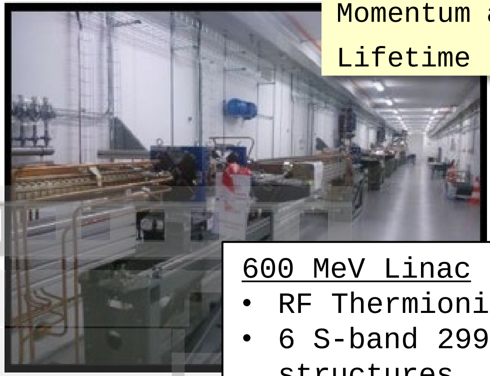

600 MeV Linac

- RF Thermionic Gun
- 6 S-band 2998.5 MHz accelerating structures
- Accelerating gradient 20 MeV/m
- 3 RF Units & SLED cavities
- Dog-leg vertical transfer line
- In operation since Dec. 2014

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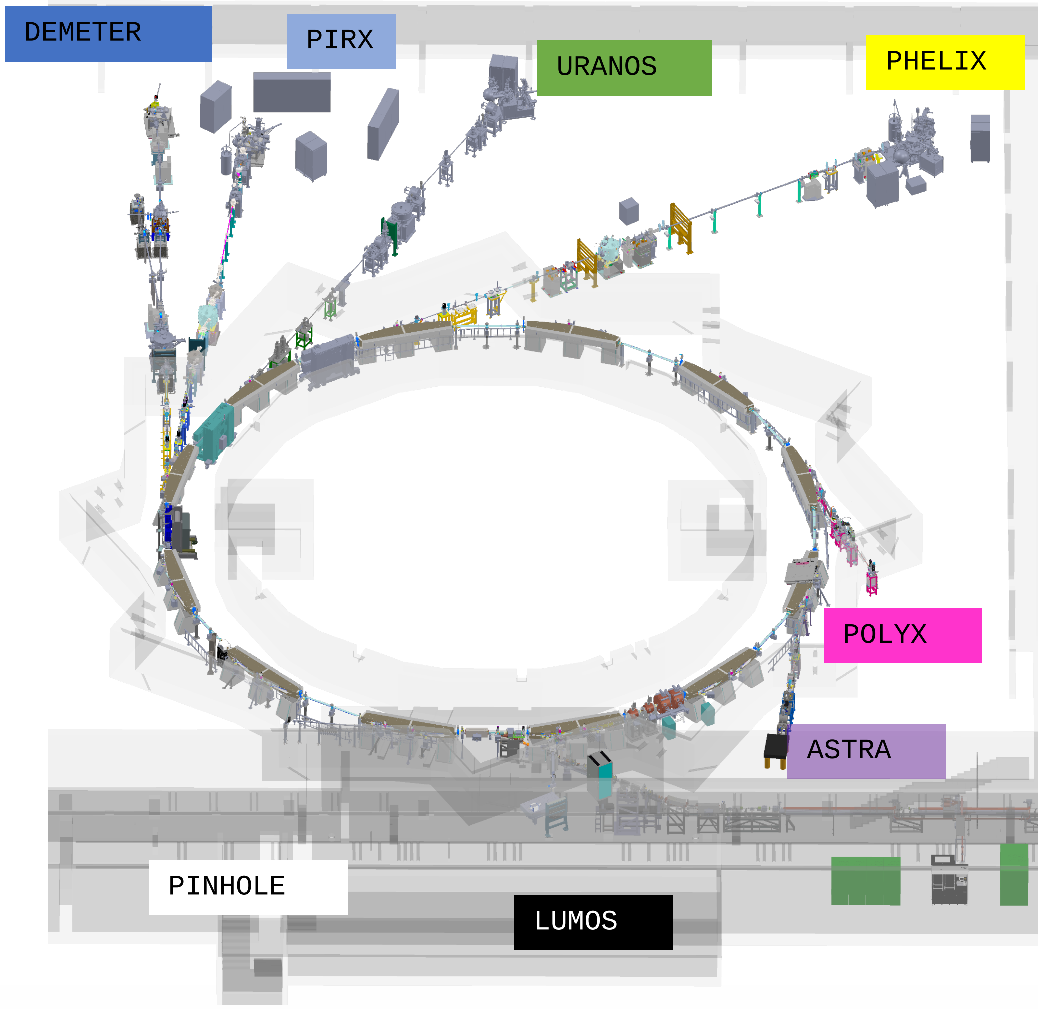
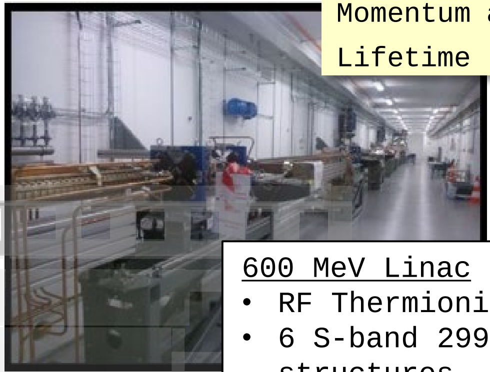
# SOLARIS accelerators




1.5GeV Storage ring

- 12 DBA Cells – 96 m circumference
- Space for ID's (10 sections) ~ 3.5 m
- 10 straight sections for IDs
- 100 MHz RF system
- 300 MHz Landau Cavities
- Injection dipole kicker
- Ramping
- In operation since May 2015



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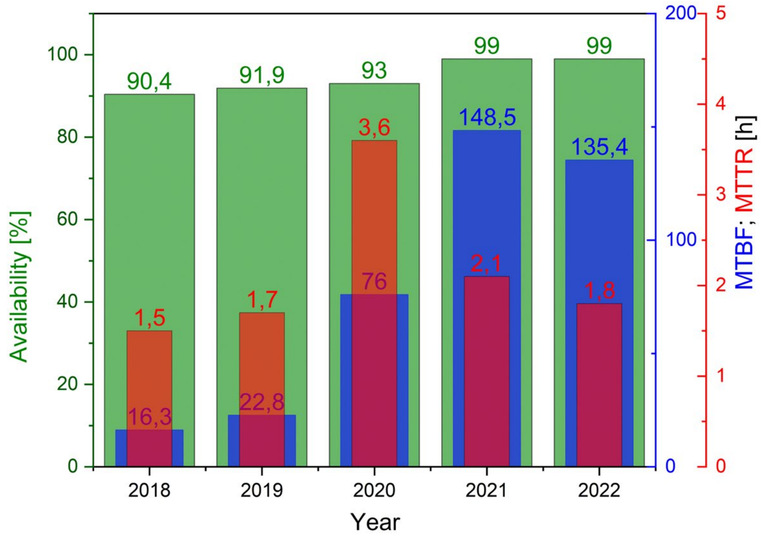
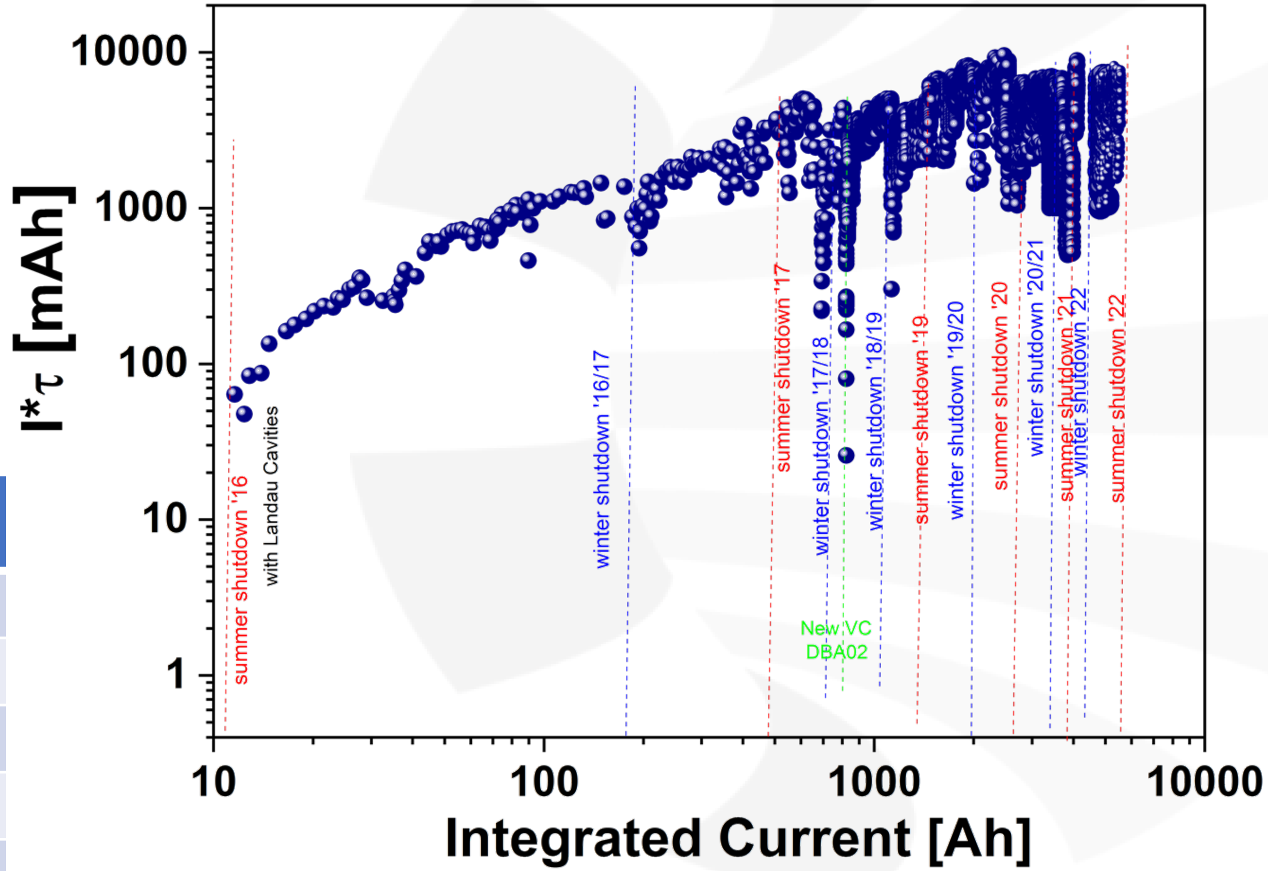
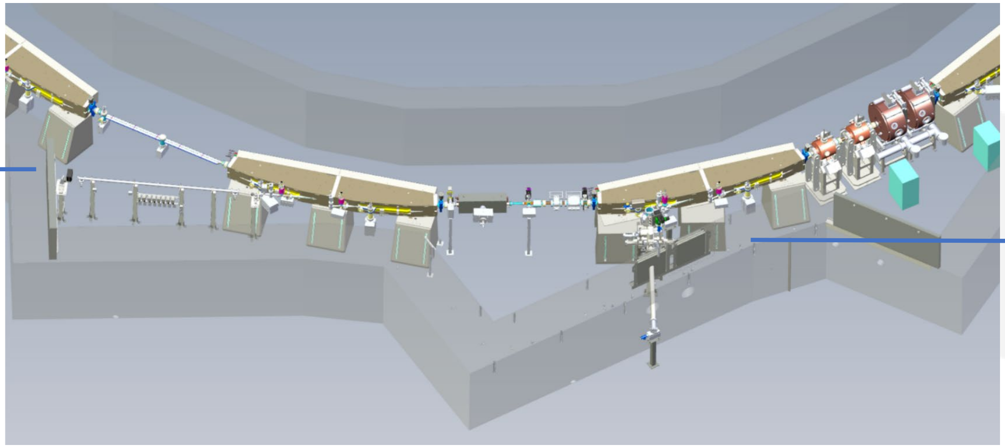
# Beam availability




| Year | Total Beamtime | Availability | MTBF | MTTR | Average current |
|---|---|---|---|---|---|
| 2018 | 1704 h | 90.4 % | 16.3 h | 1.5 h | 270 mA |
| 2019 | 2530 h | 91.9 % | 22.8 h | 1.7 h | 284 mA |
| 2020 | 3868 h | 93.0 % | 76.0 h | 3.6 h | 385 mA |
| 2021 | 4654 h | 99.0 % | 168.7 h | 2.2 h | 302 mA |
| 2022 | 3278 h | 99.0% | 135.4 h | 1.8 h | 393 mA |

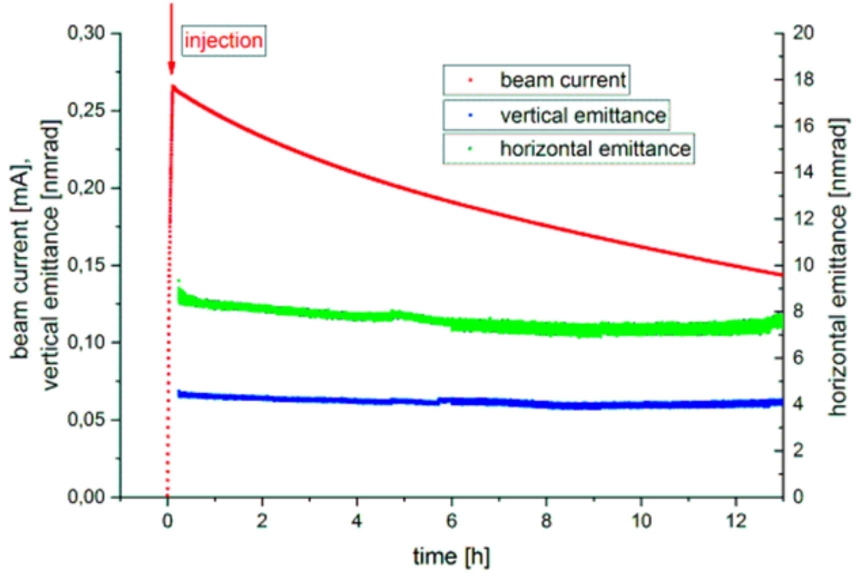


# SOLARIS: Beam diagnostics beamlines



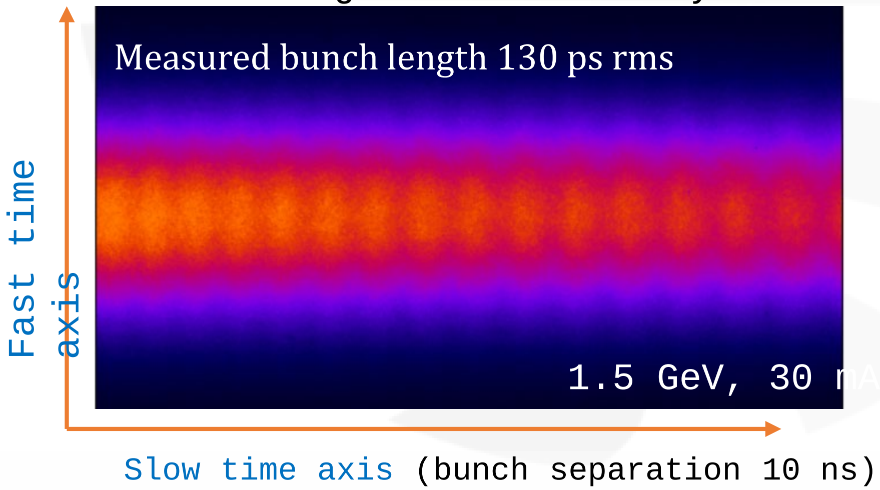
## **PINHOLE** DIAGNOSTIC BEAMLINE

The PINHOLE, depicts the electron beam by analyzing the emitted **X-rays**. The beamline available to monitor transversal beam and vertical/horizontal emitance during operation.




## **LUMOS** DIAGNOSTIC BEAMLINE

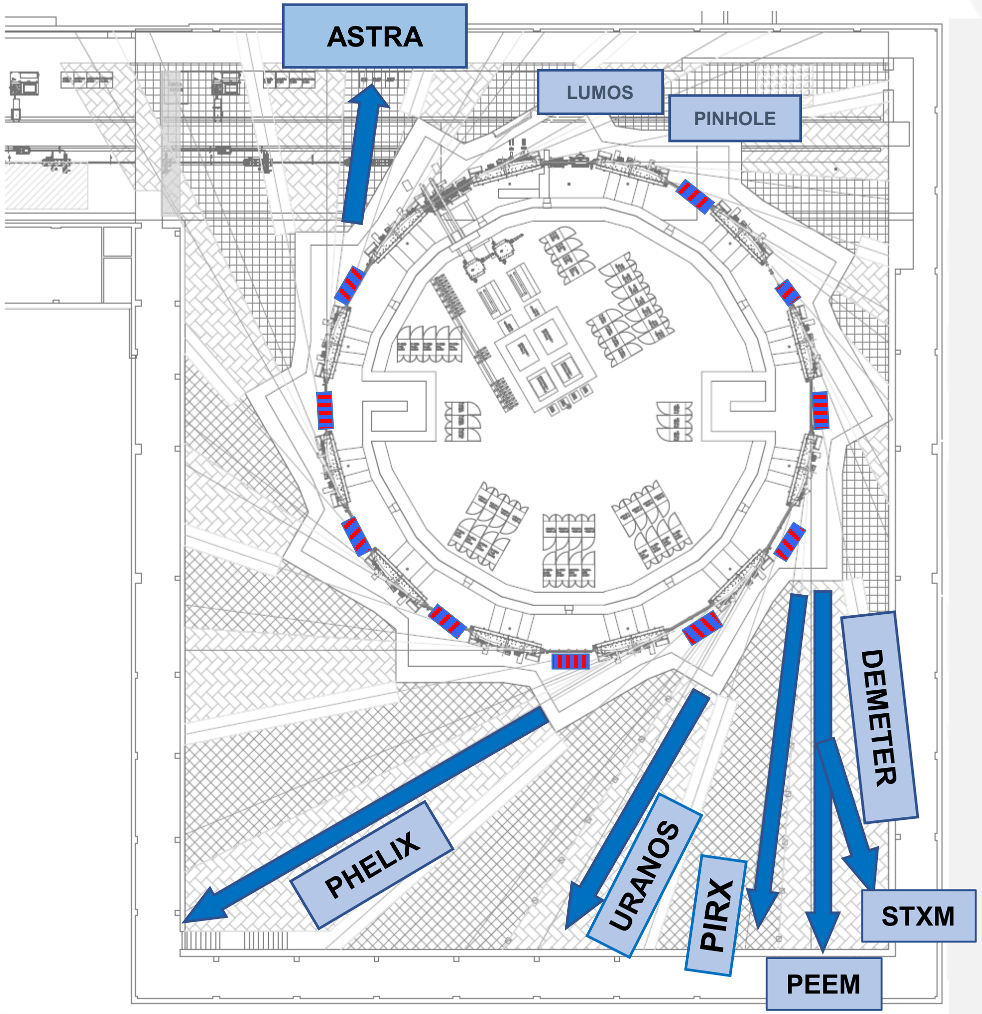
The LUMOS will be operated in **the visible and IR region**. The beamline is used for transverse beam profile and longitudinal bunch length measurements as well as to study the longitudinal beam dynamics..



# *SOLARIS Beamlines & Infrastructure*

# SOLARIS research infrastructure

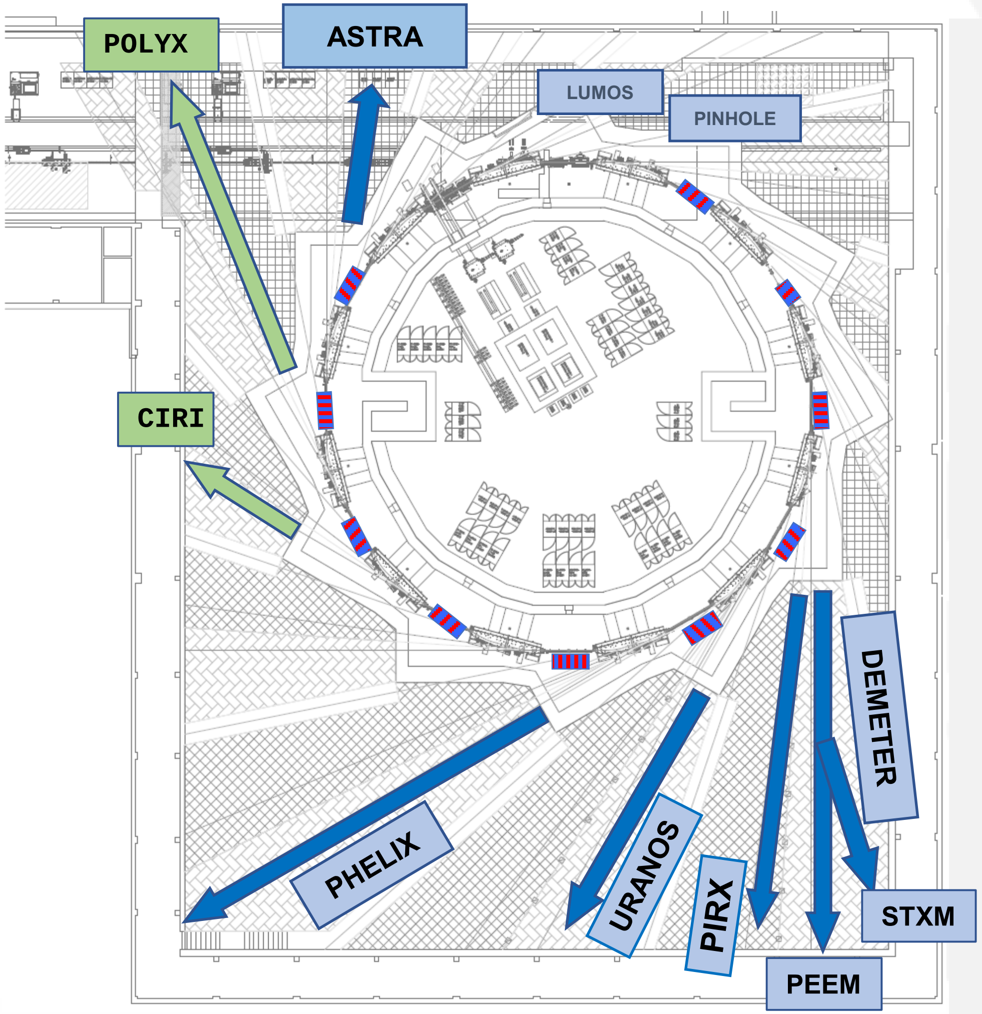
In operation



# SOLARIS research infrastructure

In operation

Under construction, available 2023

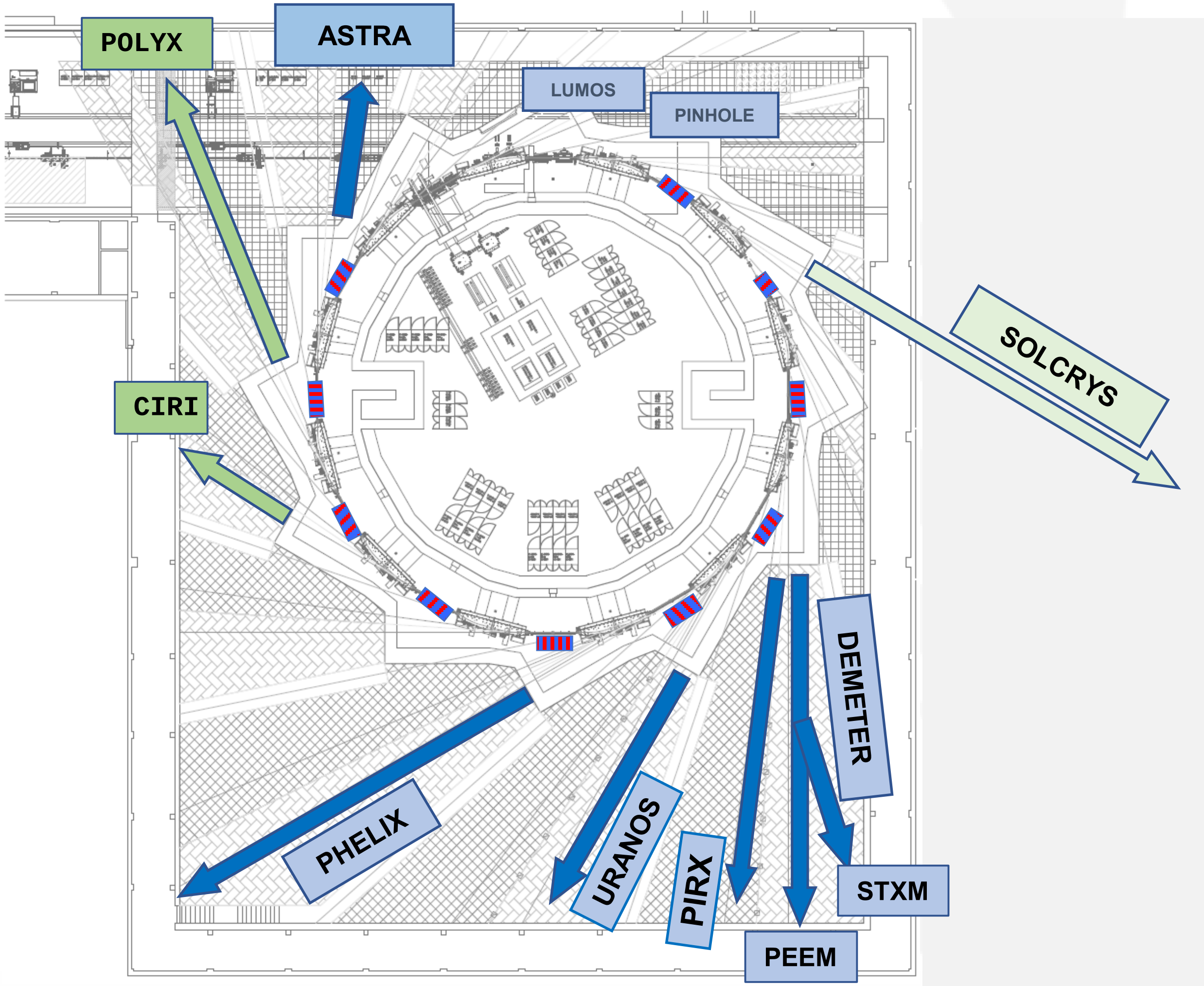


# SOLARIS research infrastructure

In operation

Under construction, available 2023

Under construction, available 2024/2025



# SOLARIS research infrastructure

| |
|---|
| In operation |
| Under construction, available 2023 |
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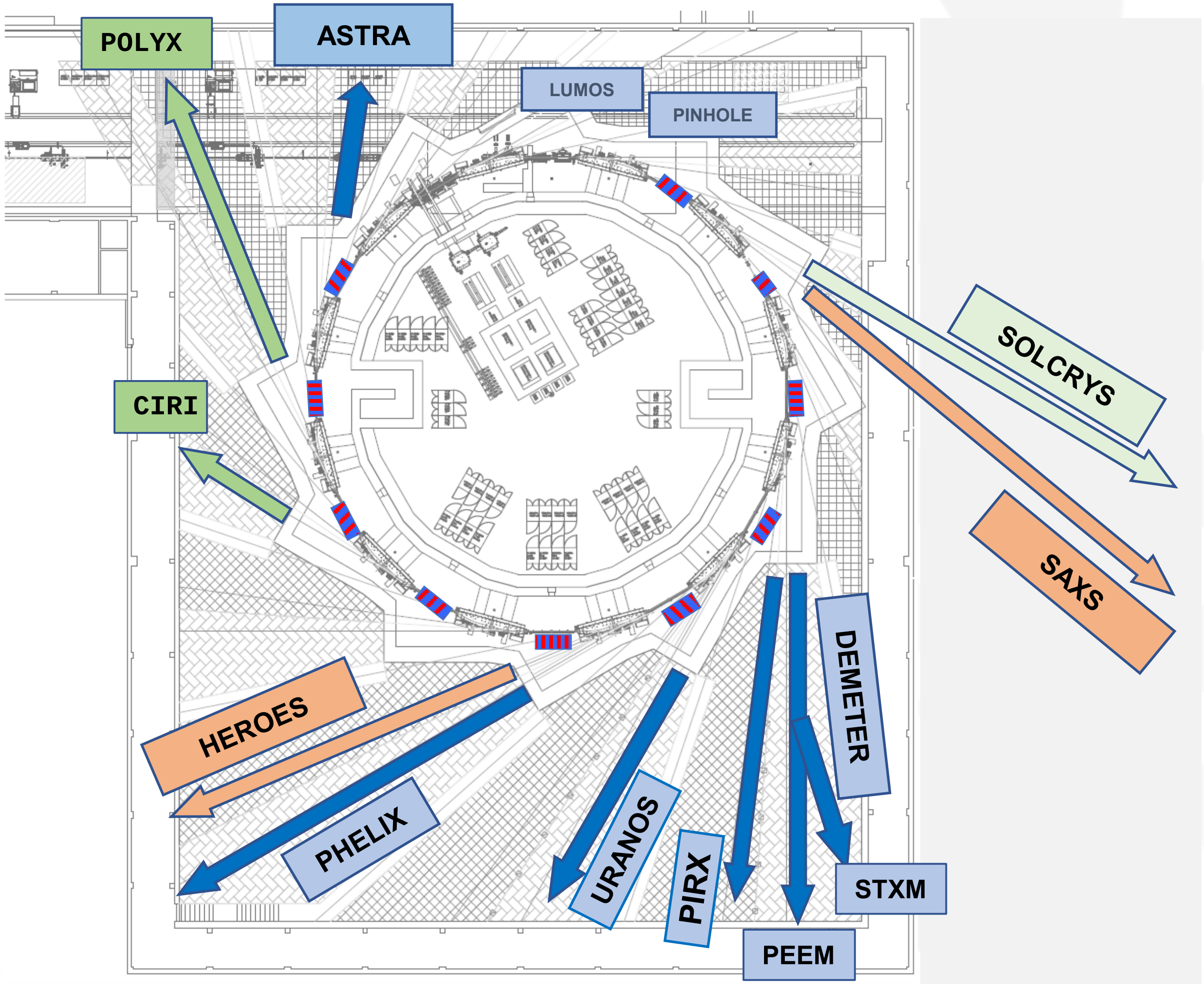
| Project application (decision 2023) |



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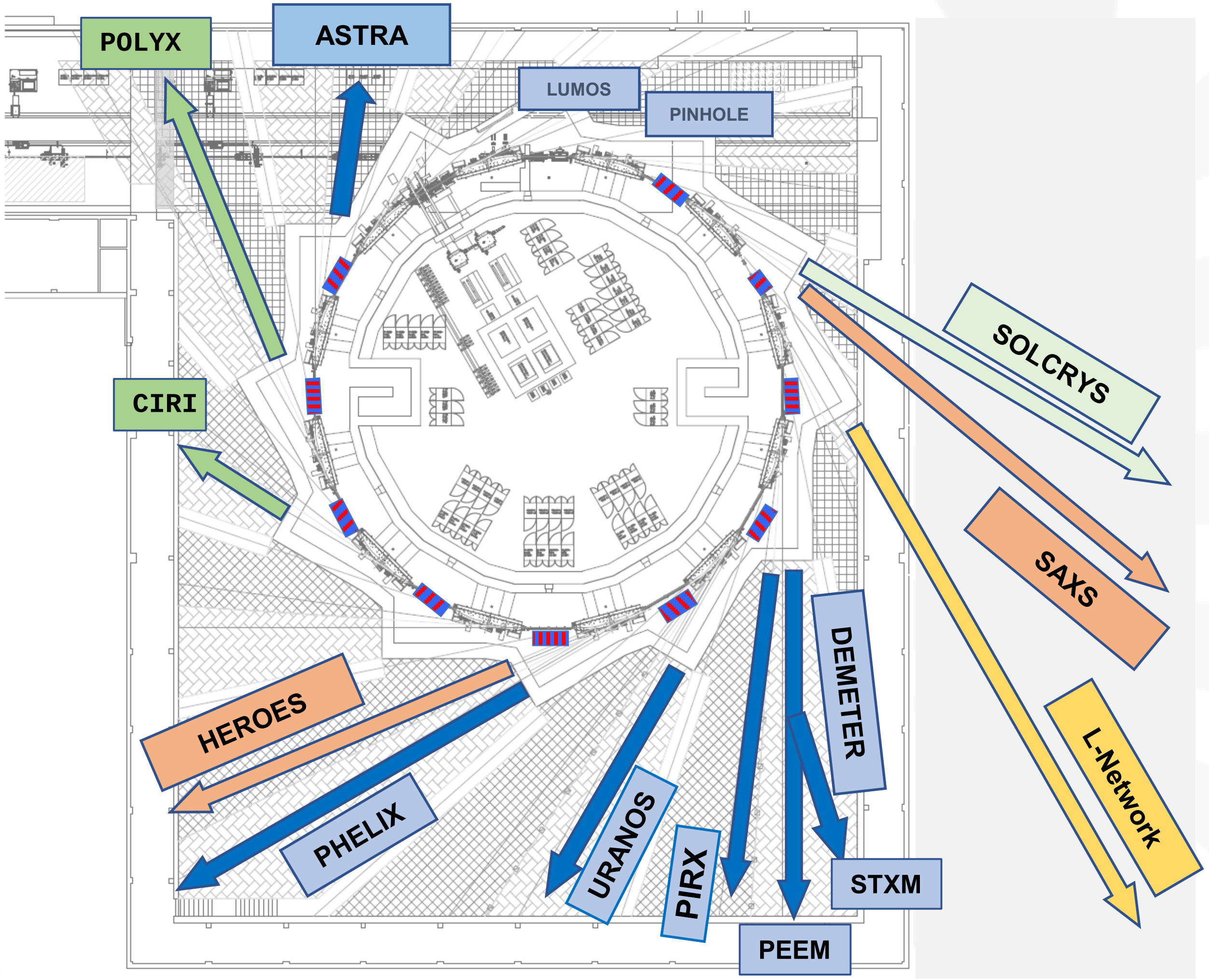

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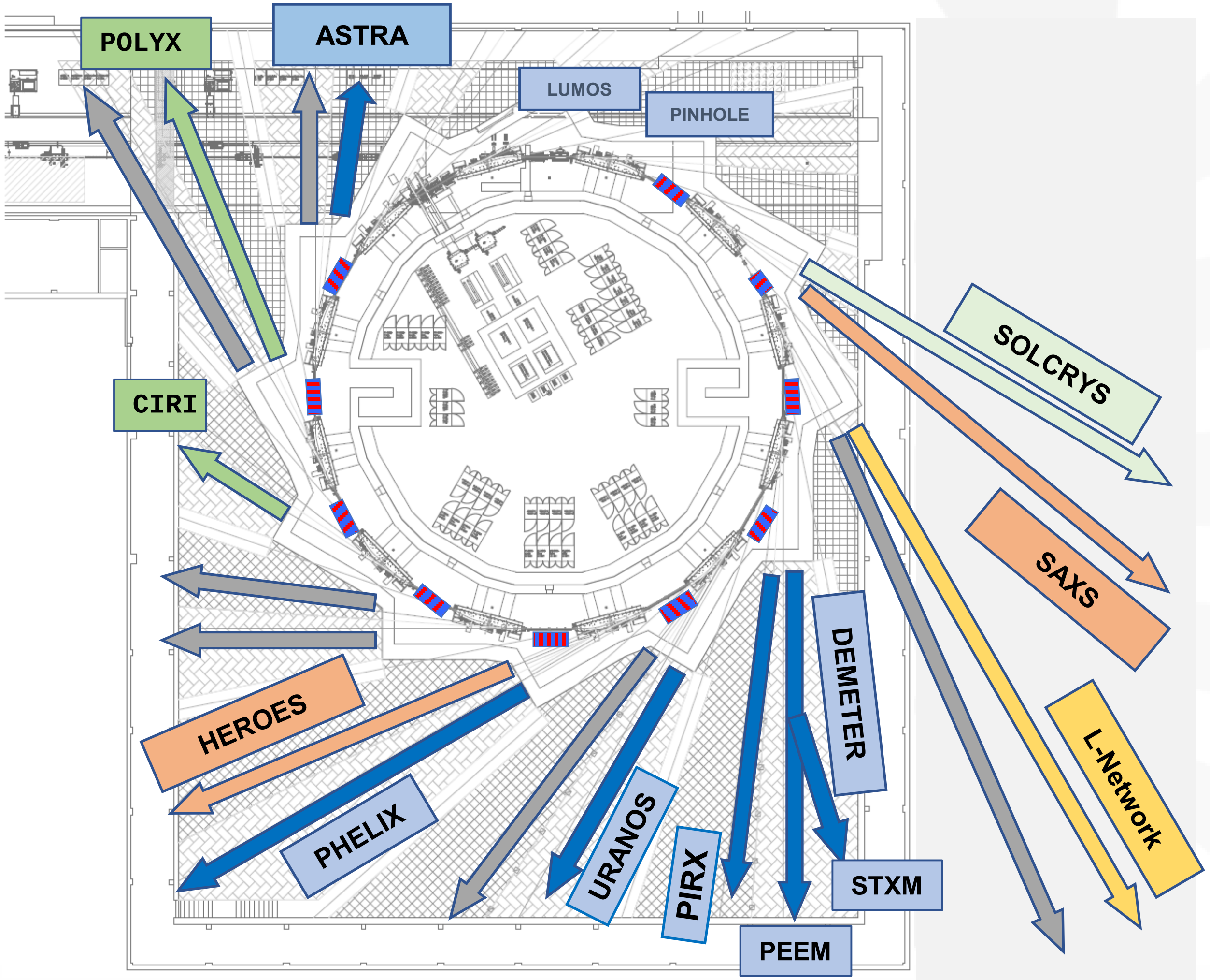
| Slots available for 6 new beamlines |



# SOLARIS research infrastructure

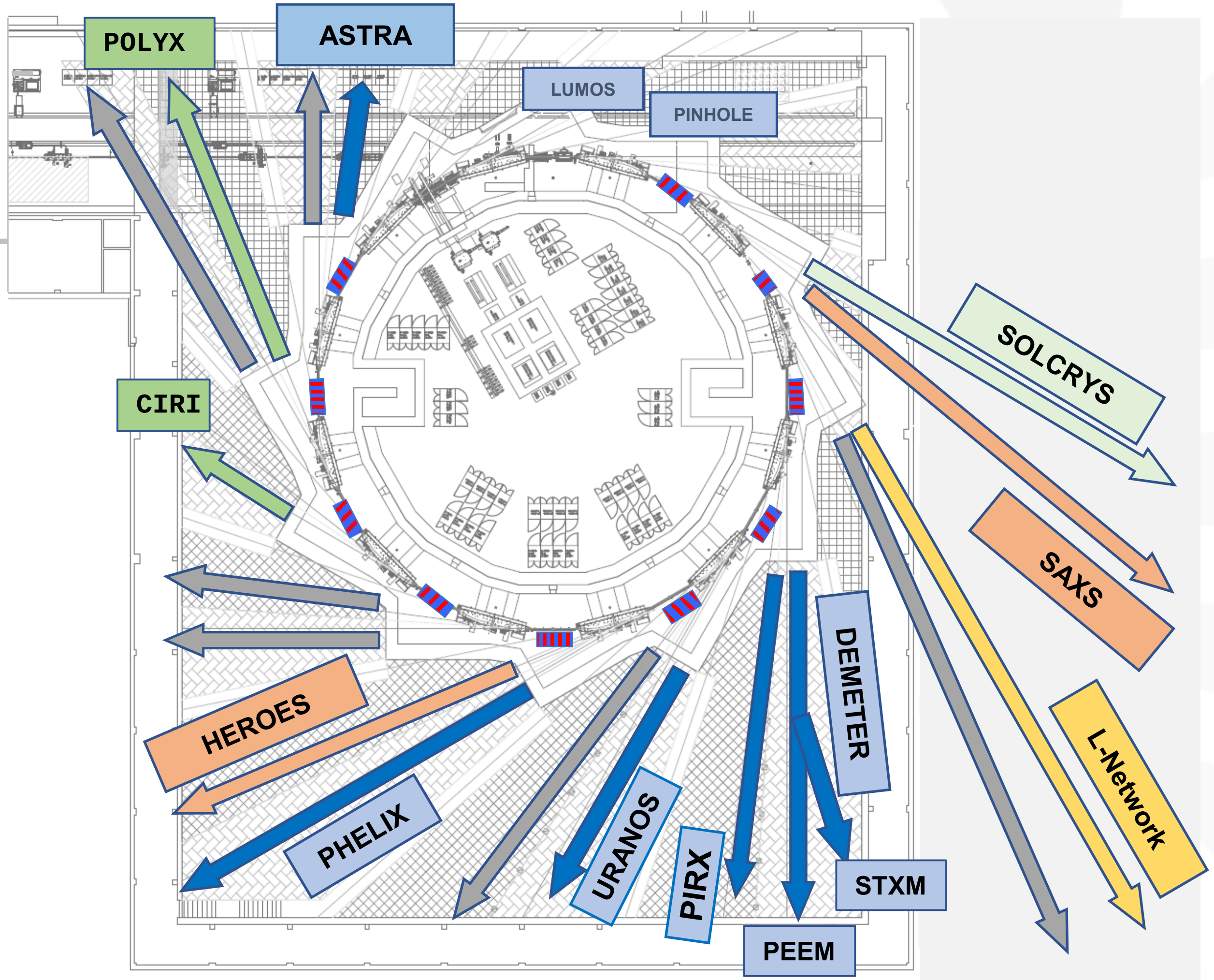
CryoEm centre

Structural Biology Core Facility

Krios

Glacios

- In operation
- Under construction, available 2023
- Under construction, available 2024/2025
- Project application (decision 2023)
- Conceptual phase
- Slots available for 6 new beamlines



# Available beamlines at Solaris

## *Soft X-ray beamlines*

| Beamline | Technical specification | Experimental methods |
| --- | --- | --- |
| **PIRX** | Photon spot size (horizontal x vertical) – 200 x 50 μm$^2$<br>Environment - UHV, HV<br>Photon Energy - **100–1500 eV** | • X-ray absorption spectroscopy (XANES region)<br>• Circular and linear X-ray magnetic dichroism (XMCD and XMLD) |
| **DEMETER** | Photon spot size for STXM – 0.02 x 0.02 μm$^2$<br>Photon spot size for PEEM – 40 x 30 μm$^2$<br>Environment - STXM: gas atmosphere (He, Ar, $O_2$, $N_2$, $CO_2$)<br>PEEM - UVH<br>Photon Energy - **100–1500 eV** | • Photoelectron microscopy PEEM with magnetic dichroism<br>• Scanning transmission X-ray microscopy STXM<br>• Photoelectron spectroscopy(XPS)<br>• Photoelectron diffraction (XPD) |
| **URANOS** | Photon spot size: NIM mode: 350 x 60 μm$^2$ PGM : 270 x 30 μm$^2$<br>Environment - UHV<br>Photon Energy - **8-100** (600) **eV** | • Angle resolved photoelectron spectroscopy (ARPES)<br>• Spin-resolved photoelectron spectroscopy (sXPS) |
| **PHELIX** | Photon spot size – 100 × 100 μm$^2$<br>Environment - UHV<br>Photon energy - **50–1800 eV** for linear polarization<br>Photon Energy - **70-1800 eV** for linear and circular/elliptical polarization | • X-ray absorption spectroscopy (XANES region)<br>• Photoelectron spectroscopy in different modes (angular and spin dependent) |

# Available beamlines at Solaris

## *Hard X-ray beamlines*

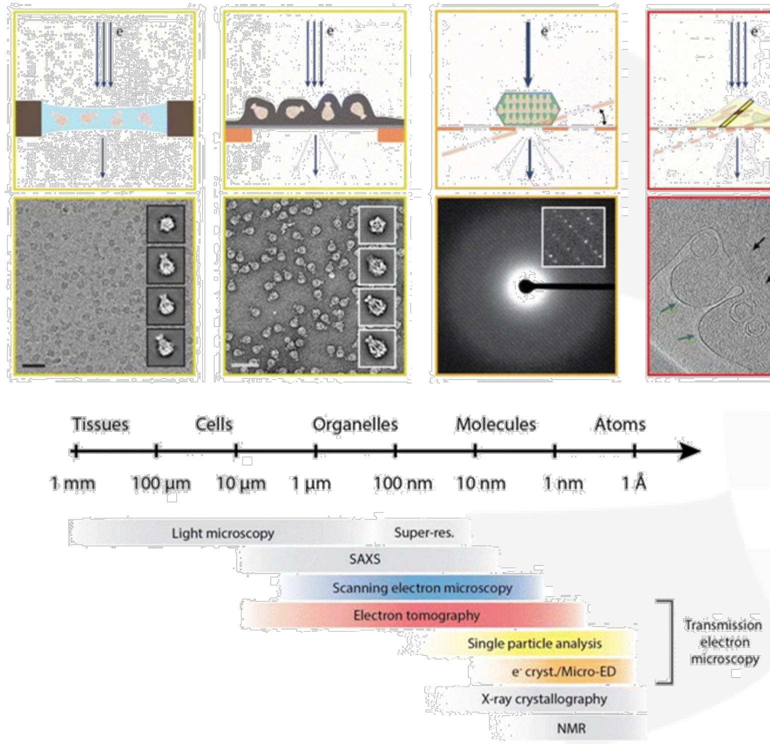
| Beamline | Technical specification | Experimental methods |
|---|---|---|
| **ASTRA** | Photon spot size: 10 x 1 $mm^2$<br>Environment: atmospheric pressure<br>Photon energy: **1000-15000 eV** | • X-ray absorption spectroscopy XAS (EXAFS and XANES) |
| **POLYX**<br>**end of 2023r.** | Photon spot size: od 40 x 40 $\mu m^2$ do 1 x 1 $\mu m^2$<br>Environment: atmospheric pressure<br>Photon energy: **4000-16000 eV** | • X-ray microfluorescence imaging (µXRF)<br>• X-ray absorption imaging (µXAS)<br>• X-ray micro-diffraction(u-XRD)<br>• Microtomography (µCT) |
| **SOLCRYS**<br>**end of 2024r.** | Spot size: 800 x 60 $um^2$<br>Environment: atmospheric pressure<br>Photon energy: **5000-20000 eV** | • X-ray diffraction on monocrystals(XRD)<br>• Small angle X-ray Scattering(SAXS)<br>• Powder diffraction |

## *IR beamline*

| Beamline | Technical specification | Experimental methods |
|---|---|---|
| **CIRI**<br>**end of 2023r.** | Photon spot size: 2.5-10 µm<br>Environment: low pressure or atmospheric environment<br>Photon energy: **0.0125 - 0.500 eV** | • FTIR microscopy (4000 – 100 $cm^{-1}$)<br>• Nano-spectroscopy IR with atomic force microscopy (AFM-SNOM-FTIR imaging) |

# Cryo-Em infrastructure

The Center is an initiative of a consortium consisting of 18 Polish scientific institutions that conduct research in the field of structural biology.




Quentin, D., Raunser, S., *J Mol Med* **96**, 483–493 (2018)

Cryo-Em Project Leader: dr. hab. Sebastian Glatt, Sebastian.Glatt@uj.edu.pl

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SOLARIS

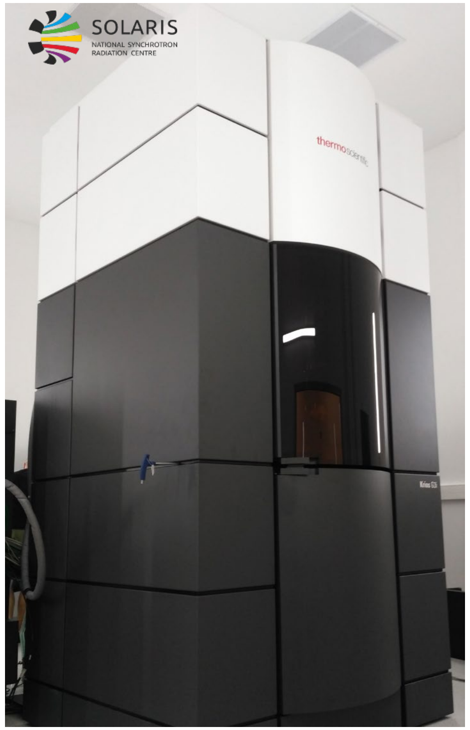
# SOLARIS infrastructure for structural studies

## Cryo-Em facility

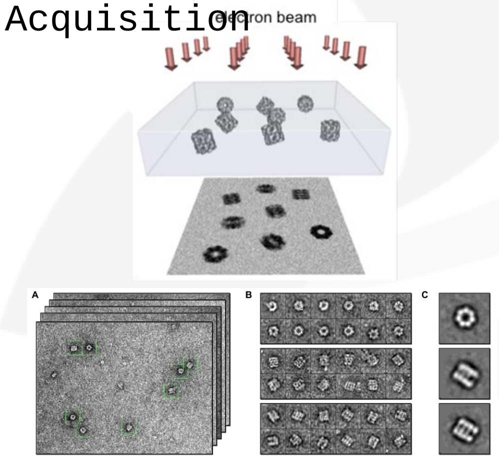

**Glacios Cryo-TEM**
- 200 kV
- Grid AutoLoader
- Double-condenser lens system
- Falcon 4EC
- Ceta-D ThermoScientific CMOS

**Krios G3i Cryo-TEM**

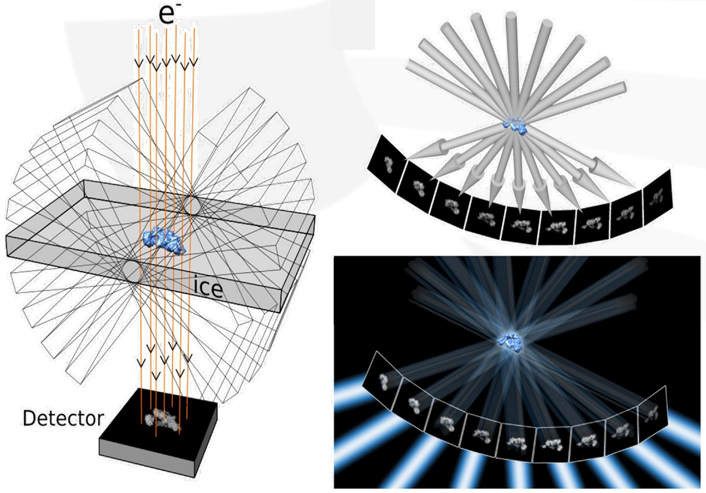
300 kV
Grid AutoLoader
Three-condenser lens system
K3 BioQuantum Gatan
Energy Filter BioQuantum
Falcon 3EC ThermoScientific
Ceta 16M ThermoScientific
CMOS
Phaseplate




Single Particle Acquisition




Tomography




I. Koning et al. / Annals of Anatomy 217 (2018) 82–96

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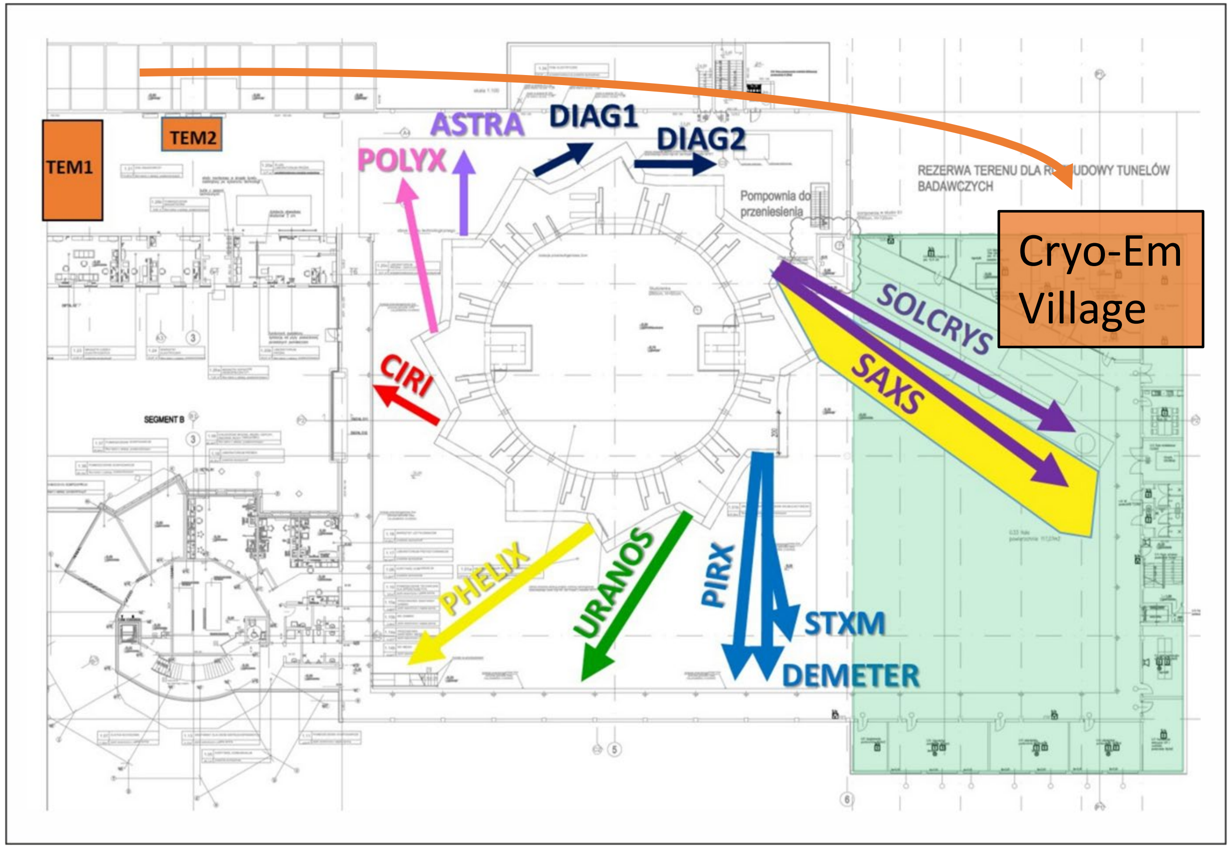
SOLARIS NARODOWE CENTRUM PROMIENIOWANIA SYNCHROTRONOWEGO

# SOLARIS Summary of experimental methods

| Spectroscopy | Microscopy | Diffraction |
|---|---|---|
| Materials composition<br>Chemical charcterisation<br>Oxidation and spin state | Samples imaging down to sub-nm range<br>Chemical sensitivity<br>Molecular interactions | Structure of matter down to atomic scale<br>Research on ordered and disordered system<br>Phase transitions |
| X-ray absorption<br>X-ray fluorescence<br>Nano-spectroscopy IR<br>Photoelectron spectroscopy<br>Magnetic dichroism | Scanning Transmission X-ray Microscopy<br>AFM/SNOM/IR Microscopy<br>Photoelectron emission microscope<br>Cryo-Em | X-ray tomography<br>SAXS/WAXS<br>X-ray crystallography<br>Powder diffraction |

# SOLARIS experimental hall extension




# *SOLARIS Users community*

# Development and operation pillars at SOLARIS

1. **Synergy** between SOLARIS & research centers
    a. Addressing expectations of research groups
    b. Addressing new research ideas and challenges

2. **Integration** of research groups

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3. **User driven** development:
    1. users + SAC => ROAD to new research infrastructure
    2. “beamline consortia” – development of new beamlines - result of initiatives of external groups

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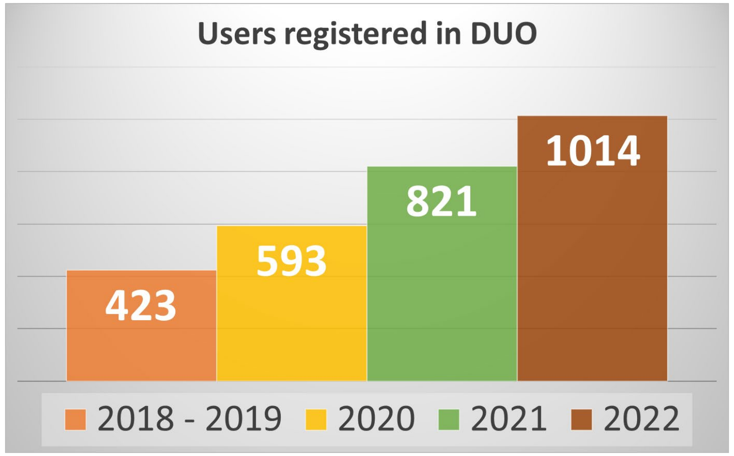
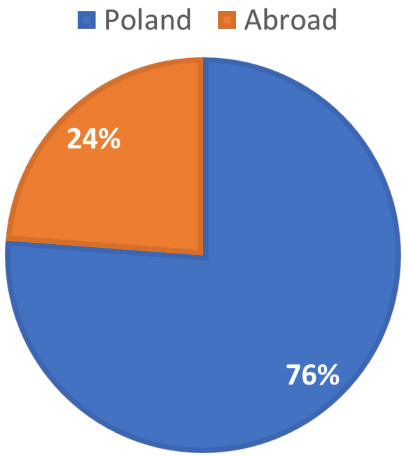
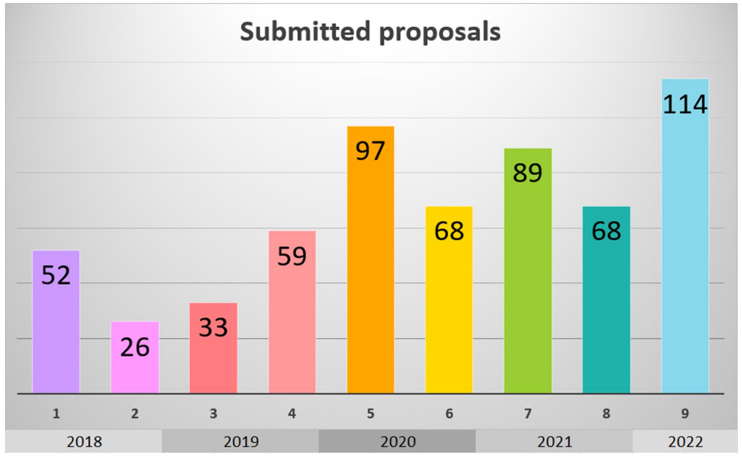
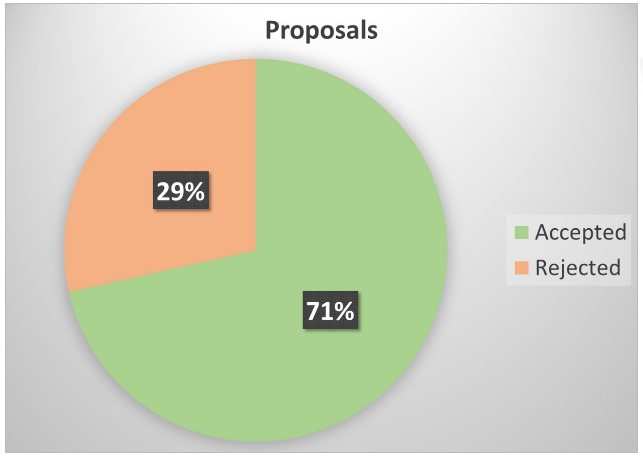
4. **User-driven** operation: operation of each beamline is backed up by “beamline consortia”

# Users' community and proposals




SOLARIS User Office: mgr Alicja Górkiewicz, alicja.gorkiewicz@uj.edu.pl

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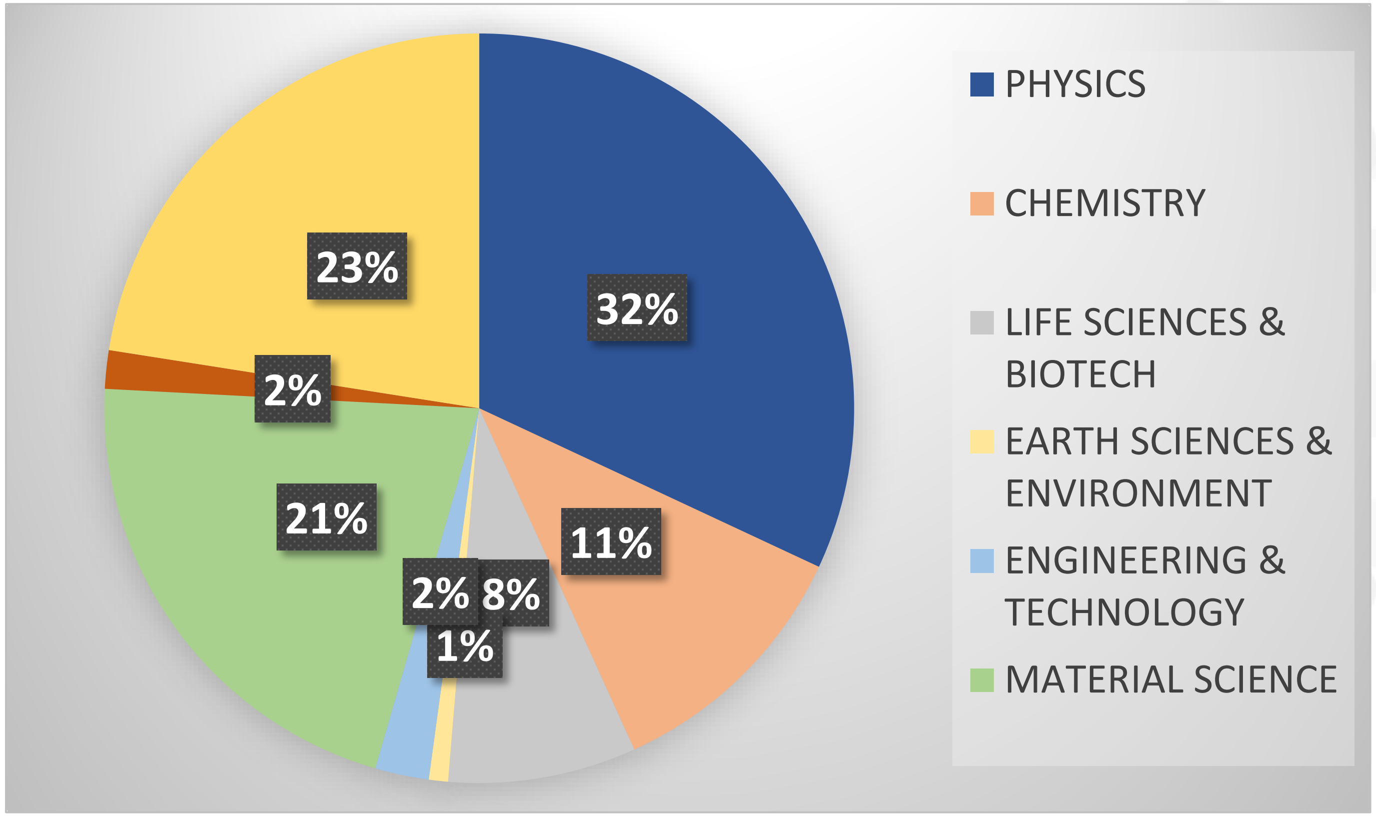
SOLARIS NARODOWE CENTRUM PROMIENIOWANIA SYNCHROTRONOWEGO

# Research areas



# Users' community development

Number of users: 423 (2019) → **1000+ (2022)**

Access time applications: 92 (2019) → **157 (2021)**

International users: 15% (2019) → **36% (2021)**

Accelerator avilability: 2530h/105dni (2019) → **4654h/193days (2021)**

# *SOLARIS Research highlights*

# SOLARIS research areas

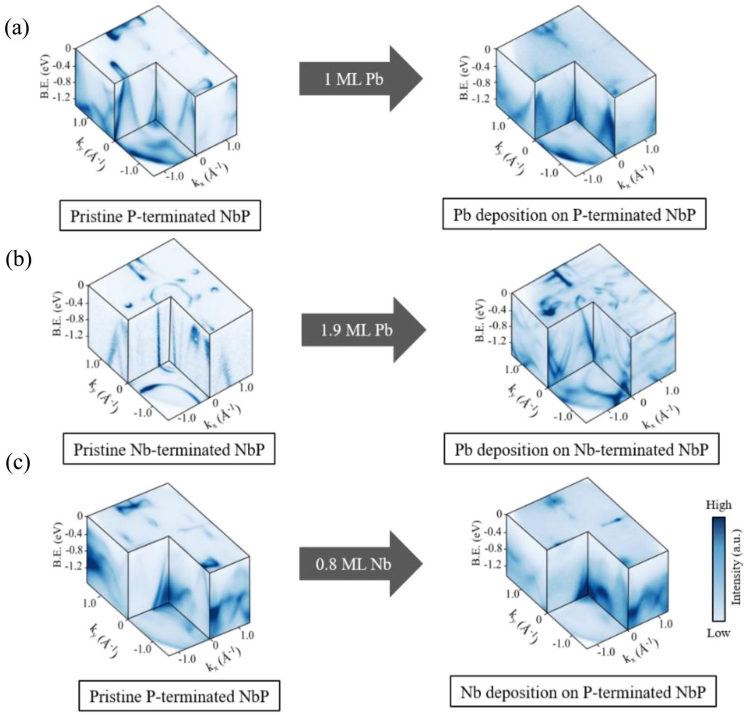
- Research areas:
  - ✓ testing and researching materials in the field of renewable sources and energy storage
  - ✓ material research important for new computing technologies and data storage
  - ✓ research at the molecular and structural level, which are crucial for new drugs, diagnostic methods, and for civilization diseases
  - ✓ exploration of machine learning
- Development of experimental methods/techniques and construction of new beamlines/infrastructure

………………and many more.

# URANOS beamline

URANOS - Ultra Resolved Angular photoelectron spectroscopy beamline - allows for measurements of fundamental quantities, i.e. the energy and the momentum, describing a photoelectron state in the space.

Topological Lifshitz transition in Weyl semimetal NbP decorated with heavy elements




**Topological materials** applications:

- energy-efficient microelectronic components
- catalysts materials
- improved thermoelectric converters,
- magnetic storage media

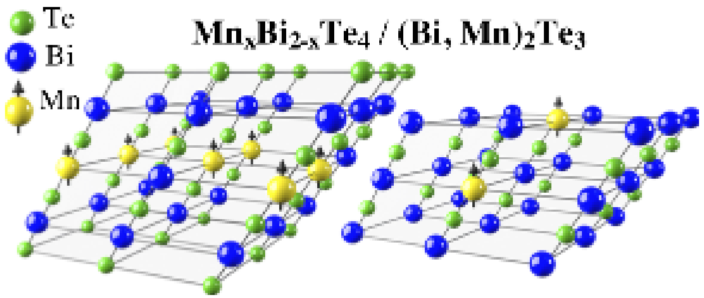
Figure present the surface electronic properties of the P-terminated and Nb-terminated surfaces of NbP with Pb or Nb deposition. An unexpected Fermi surface modification has been observed and attributed to a topological Lifshitz transition (change in the topology of a Fermi surface) with preserved topological characteristics even after surface perturbation.

A. S. Wadge et al., Topological Lifshitz transition in Weyl semimetal NbP decorated with heavy elements; Phys. Rev. B 105, 235304 (2022).

URANOS project leader: dr. Natalia Olszowska, natalia.olszowska@uj.edu.pl

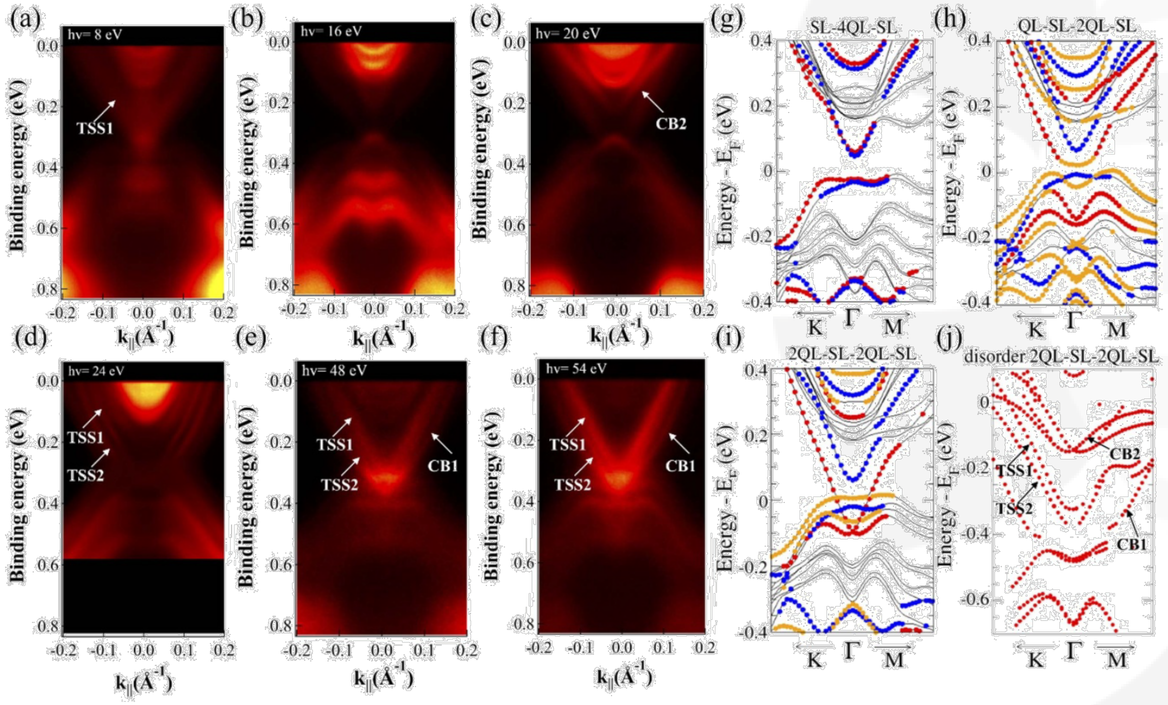
# Disorder in magnetically self-organized topological $MnBi_2Te_4/(Bi_2Te_3)_n$ superlattices

The structural analysis revealed disorder effects in a form of Mn substituting Bi in Bi2Te3 five-layers (QLs) and Mn missing in MnBi2Te4 seven-layers (SLs), which significantly affects the band structure of the system.




Disorder of Mn atoms induces ferromagnetic coupling of Mn-depleted SLs with Mn-doped QLs, which is seen in FMR as an acoustic and optical resonance mode of the two coupled spin subsystems.

Surface electronic band structure

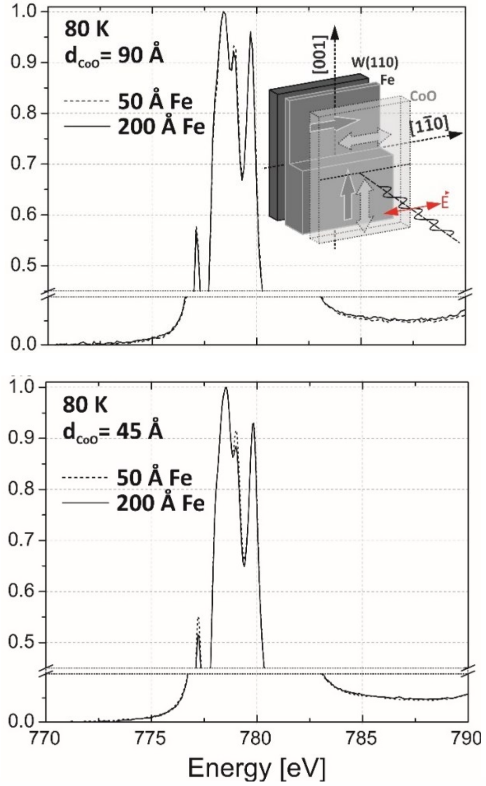



J. Sitnicka et al., Systemic consequences of disorder in magnetically self-organized topological MnBi2Te4/(Bi2Te3)n superlattices 2D Mater. 9 (2022) 015026.

# PIRX beamline

The PIRX is a bending magnet beamline dedicated to spectroscopy in the soft X-ray energy range. The beamline is designed to study chemical and electronic, structural and magnetic properties with XAS, XMCD/XMLD methods.

**Ferromagnet drives the antiferromagnet:** storage materials related to Li- or Na-based batteries , superconductors , and magnetism of the multilayer systems




M.Ślęzak et al.; Scientific Reports 9, Article number: 889 (2019)

FM layer with strong uniaxial magnetic anisotropy determines the interfacial spin orientations of the neighboring AFM layer

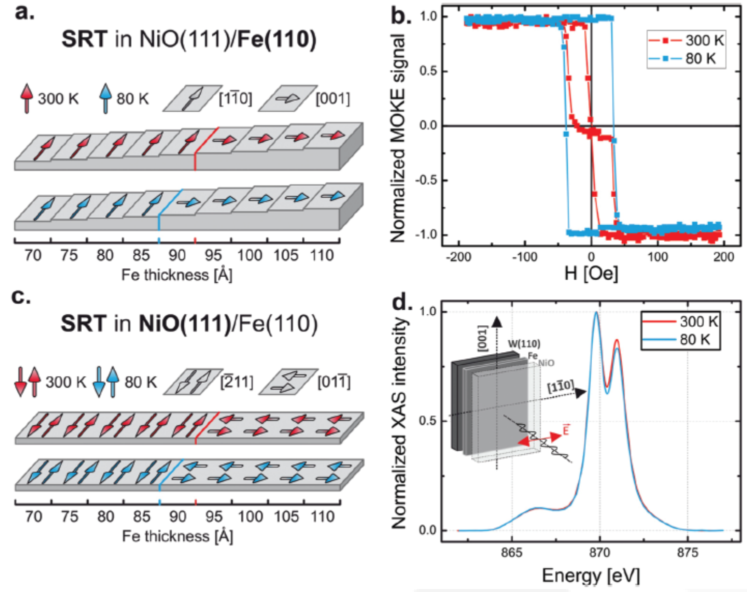
The presented master-slave relation for AFM-FM is unique the same effects were then confirmed for the other epitaxial system

→ rotation of CoO spins from Fe[1-10] to Fe[001]

→ Fe imprints magnetic anisotropy in CoO

Direct evidence of spin reorientation transition in CoO: XMLD

Dependence of Fe spin orientation vs. film thickness




M.Ślęzak et al.; Nanoscale **12** (2020) 18091

PIRX project leader: dr. Marcin Zając, mar.zajac@uj.edu.pl

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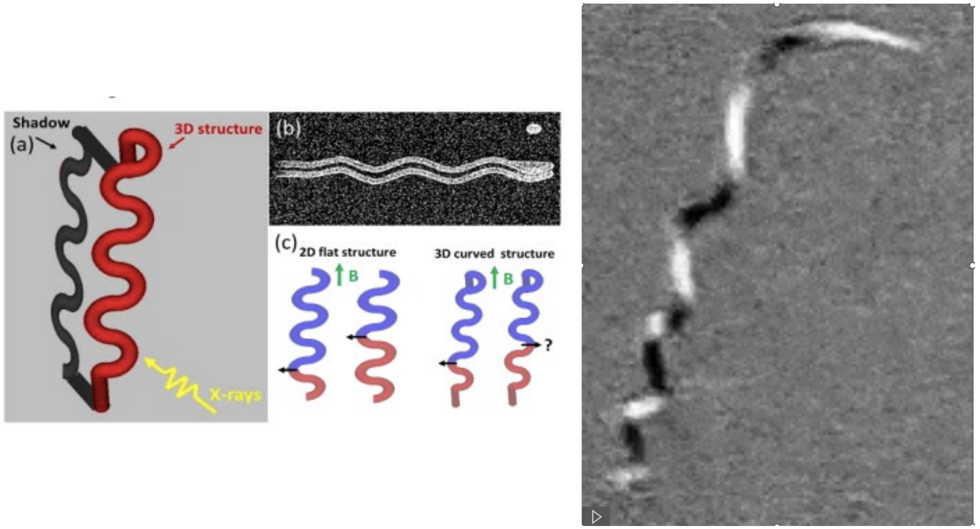
SOLARIS NARODOWE CENTRUM PROMIENIOWANIA SYNCHROTRONOWEGO

# DEMETER beamline - PEEM & STXM stations

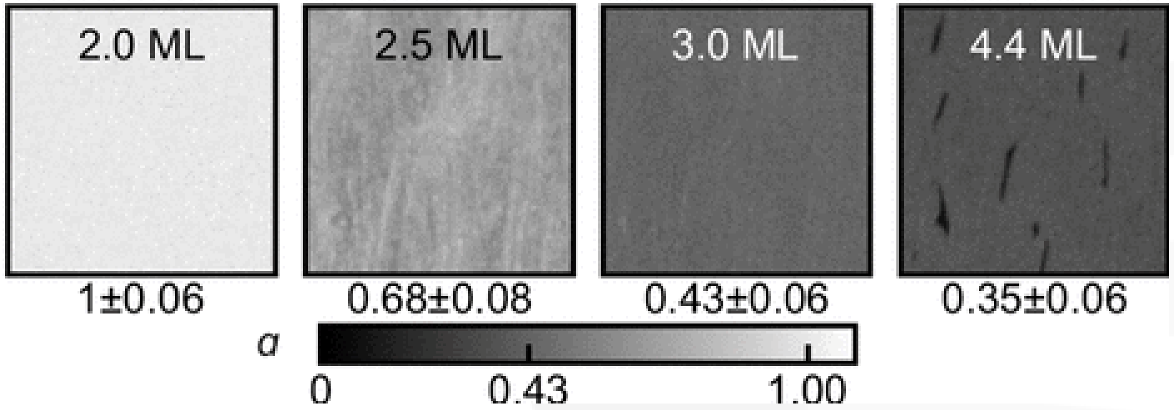
DEMETER (Dual Microscopy and Electron Spectroscopy Beamline) beamline is specialized research installation using variable polarization radiation, and explores coexistence of two branches: the photoemission electron microscope and scanning transmission X-ray microscope.

**Spintronics**




Shadow of a cobalt nanowire that is subjected to a magnetic field. As a result of the magnetic field, the domain structure changes depending on the number of twists. S. Ruiz-Gomez (Max Planck Institute Dresden)

**Organic molecules**



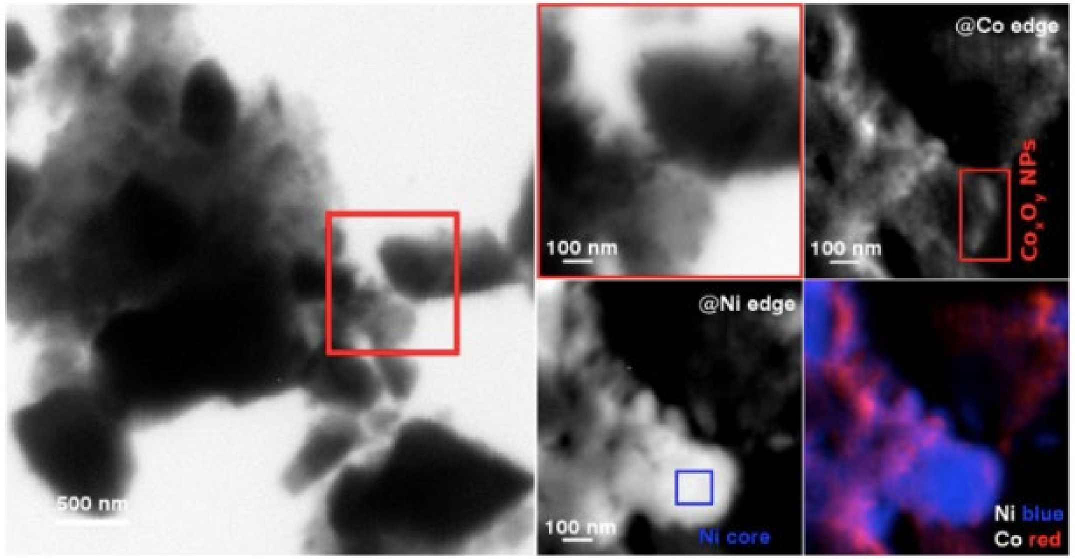

Observation of the growth of organic molecules on the metal surface. Understanding the growth mechanism and its control will allow the use of molecule / metal systems in many areas such as batteries and the electronics industry. T. Wagner (Johanes Kepler University Linz)

DEMETER project leader: dr. Anna Mandziak, anna.mandziak@uj.edu.pl

# DEMETER beamline - PEEM & STXM stations

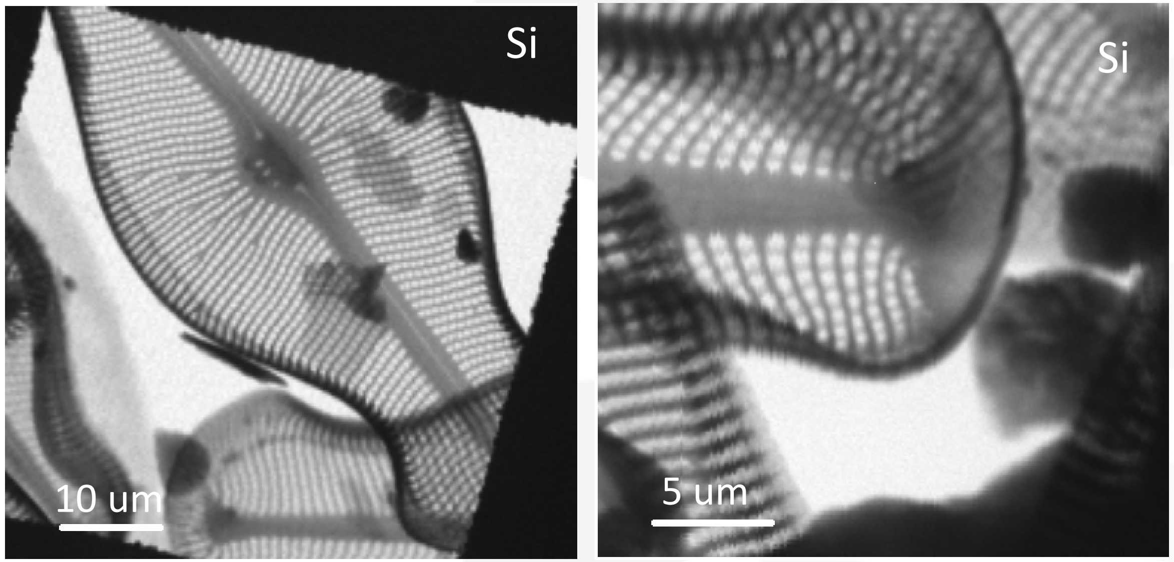
DEMETER (Dual Microscopy and Electron Spectroscopy Beamline) beamline is specialized research installation using variable polarization radiation, and explores coexistence of two branches: the photoemission electron microscope and scanning transmission X-ray microscope.

Catalysis




Solid Oxide Electrolysis Cells (SOECs) devices that are able to convert water into hydrogen and oxygen P. Błaszczak et al. Int. J. Hydrog. Energy (in press).

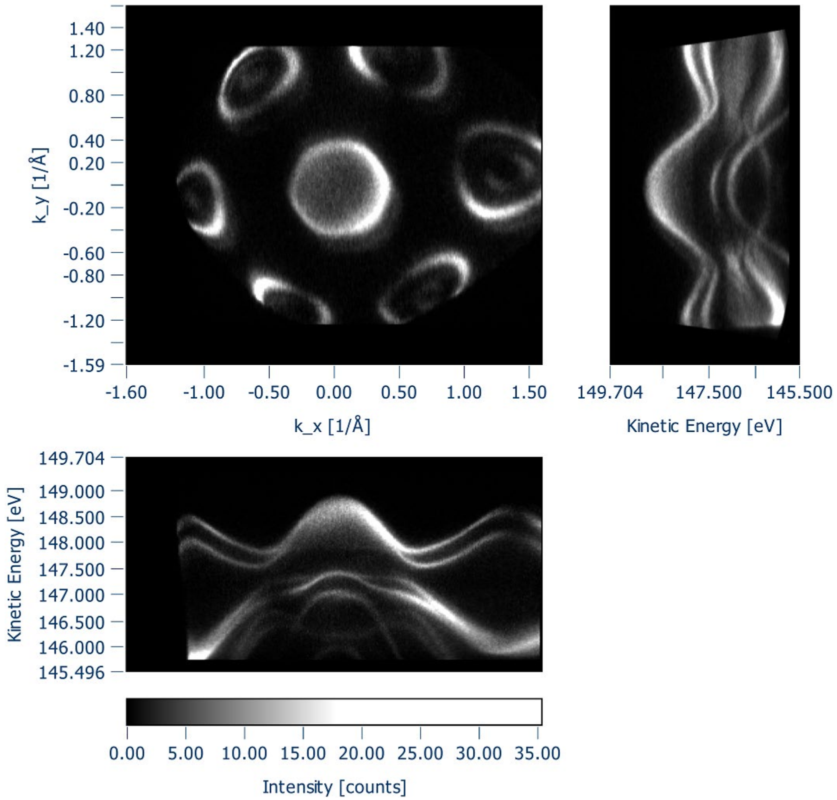
Life science




Diatom (Neo-Latin diatoma) member of a large group of algae, specifically microalgae, found in the oceans, waterways and soils of the world. Diatom images taken at Si edge. Diatom taken from Szczecin Lagoon I. Zgłobicka (Technical University Białystok)

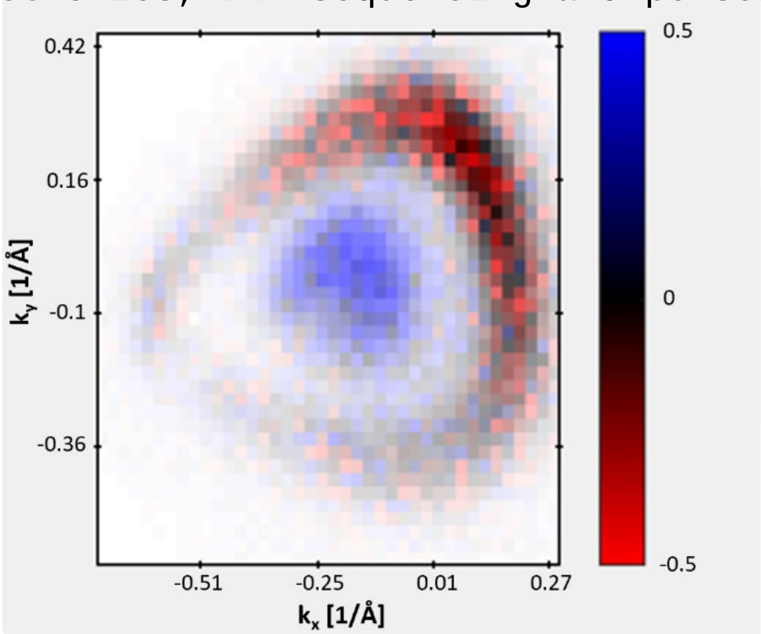
# PHELIX beamline

PHELIX is a beamline using soft X-rays to obtain a variable polarization of light: linear polarization at any angle as well as circular and elliptical polarization.




APRES measurements for WSe2 sample in ($k_x$, $k_y$, E) space for excitation energy $E_{hv}$ = 150 eV.

Transition metal dichalcogenides (TMDC) exhibiting a unique combination of atomic-scale thickness, direct bandgap, strong spin–orbit coupling and favorable electronic and mechanical properties, which make them interesting for fundamental studies and for applications in high-end electronics, spintronics, optoelectronics, energy harvesting, flexible electronics, DNA sequencing and personalized medicine.

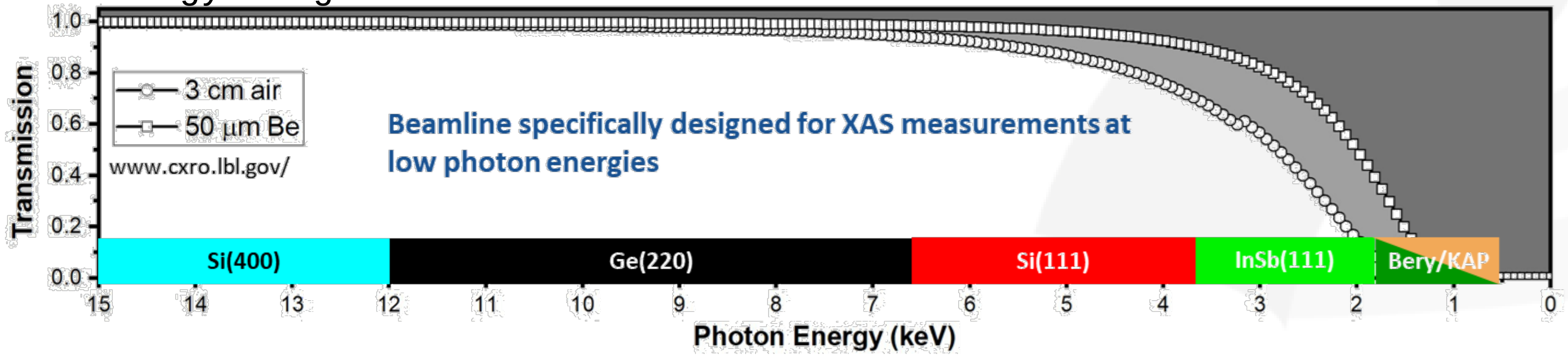



Spin-ARPES of $WSe_2$ collected for the excitation energy of 70 eV and sample rotated by 45°. The colormap shows the spin information. Red and blue indicate the opposite spin direction, black is for spin integrated spectra.

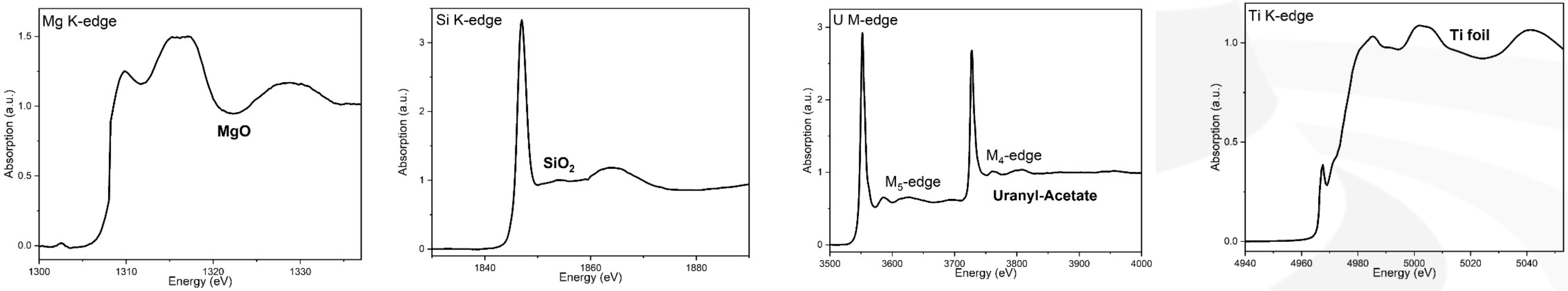
PHELIX project leader: dr. Magdalena Szczepanik, m.m.szczepanik@uj.edu.pl

# ASTRA beamline

The bending magnet beamline ASTRA (former SOLABS beamline) - Absorption Spectroscopy beamline for Tender energy Range and Above - will be dedicated to X-ray absorption spectroscopy (XAS) and related techniques in the energy range from 1 keV to 15 keV



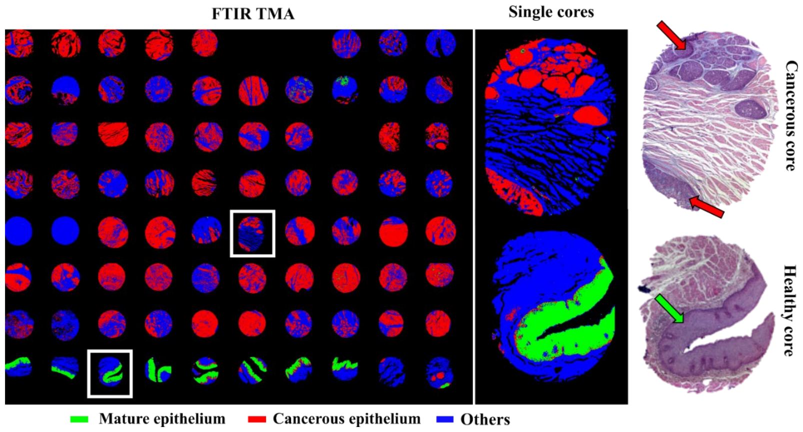

Recorded transmission XAS spectra of reference compounds over broad energy range

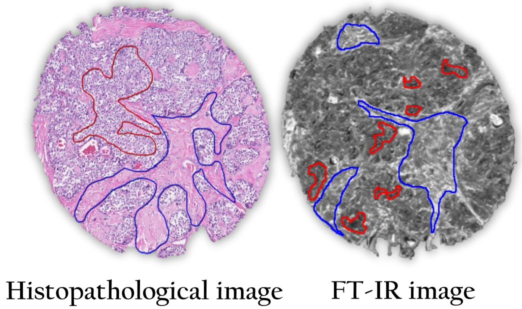



ASTRA project leader: dr. Alexey Maximenko, alexey.maximenko@uj.edu.pl

# CIRI beamline

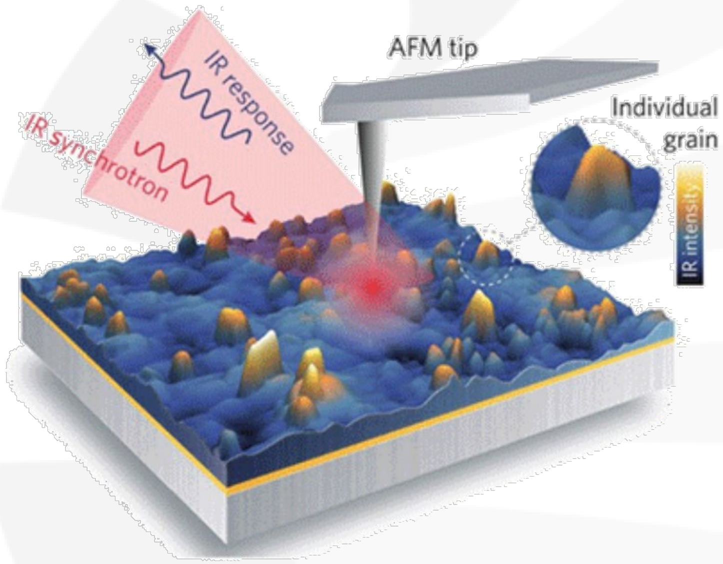
Chemical InfraRed Imaging beamline - CIRI (former SOLAIR) will allow radiation extraction in a very wide wavelength range (0.2 - 500 µm), including far (FIR) to near infrared (NIR).




D Liberda, M Hermes, P Koziol, N Stone, TP Wrobel, *Journal of Biophotonics*, 8, 2020

FT-IR imaging offers a high sensitivity, high throughput and label-free measurement platform, that allows creation of cancer (or other pathology) classification models using machine learning. Micrometer spatial resolution is adequate for tissue imaging and enables measurements of dozens of patient biopsies and screening of suspect tissue areas.




*Broadband infrared radiation from Synchrotron focuses on a metal tip that strictly restricts the fields at its apex to further interact with the sample surface in standard AFM mode.*

CIRI project leader: dr. hab. Tomasz Wróbel, tomek.wrobel@uj.edu.pl

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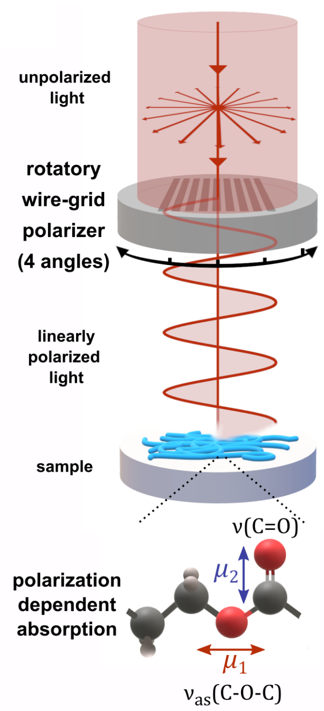
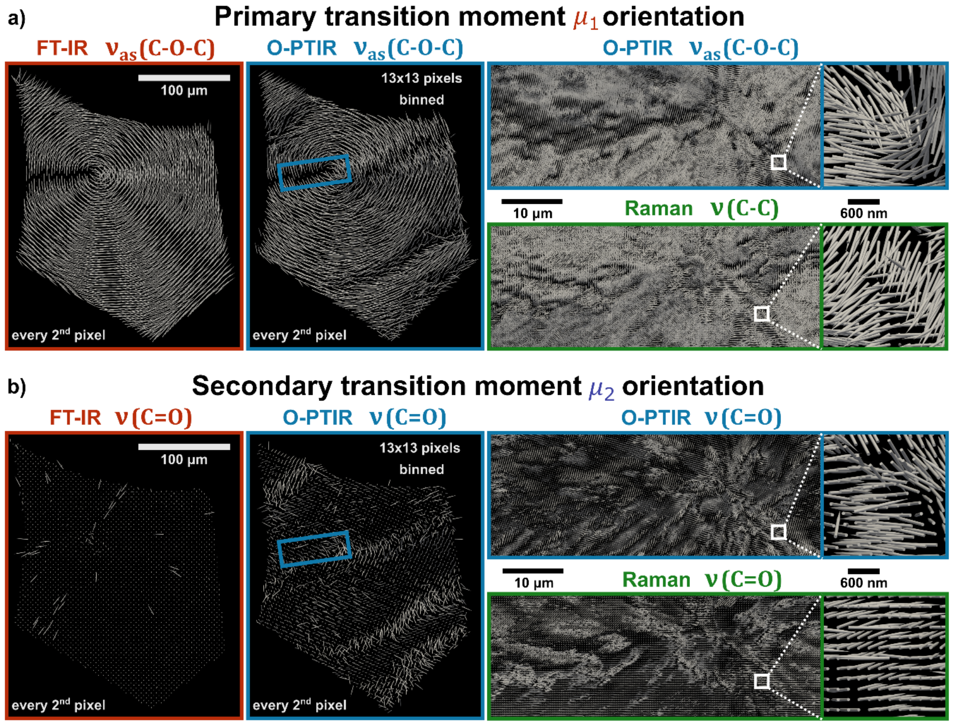
# CIRI beamline

Chemical InfraRed Imaging beamline - CIRI (former SOLAIR) will allow radiation extraction in a very wide wavelength range (0.2 - 500 µm), including far (FIR) to near infrared (NIR).




P. Koziol, K. Kosowska, D. Liberda, F. Borondics, T. P. Wrobel, „**Super-resolved 3D mapping of molecular orientation with vibrational techniques**” JACS, 2022, 144, 31, 14278–14287

A new method for obtaining 3D orientation of vibrational transition moments (e.g. m1 and m2) using polarized light at the diffraction limit. It enables high resolution visualization of internal material organization and was shown to work using classical FT-IR imaging, Raman mapping and superresolved O-PTIR mapping for the first time on a polymer spherulite.

# How to explore our capabilities?

**Scientific access**

**Free of charge access**

**Data should be published**

Open call– applications in March and October (DUO)

Applications marked by the international committee

Rapid access: access to the infrastructure within 3 weeks

**Commercial access**

**Dedicated access to the infrastructure**

**Full confidentiality of the results**

Operators and expert's support

Help and guidance in experiments preparations

Options for advanced data analysis

Industry Liaison Officer: dr. Piotr Ciochoń, piotr.ciochon@uj.edu.pl

# International collaborations

This project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No. 952148.


# Thank you for your attention!