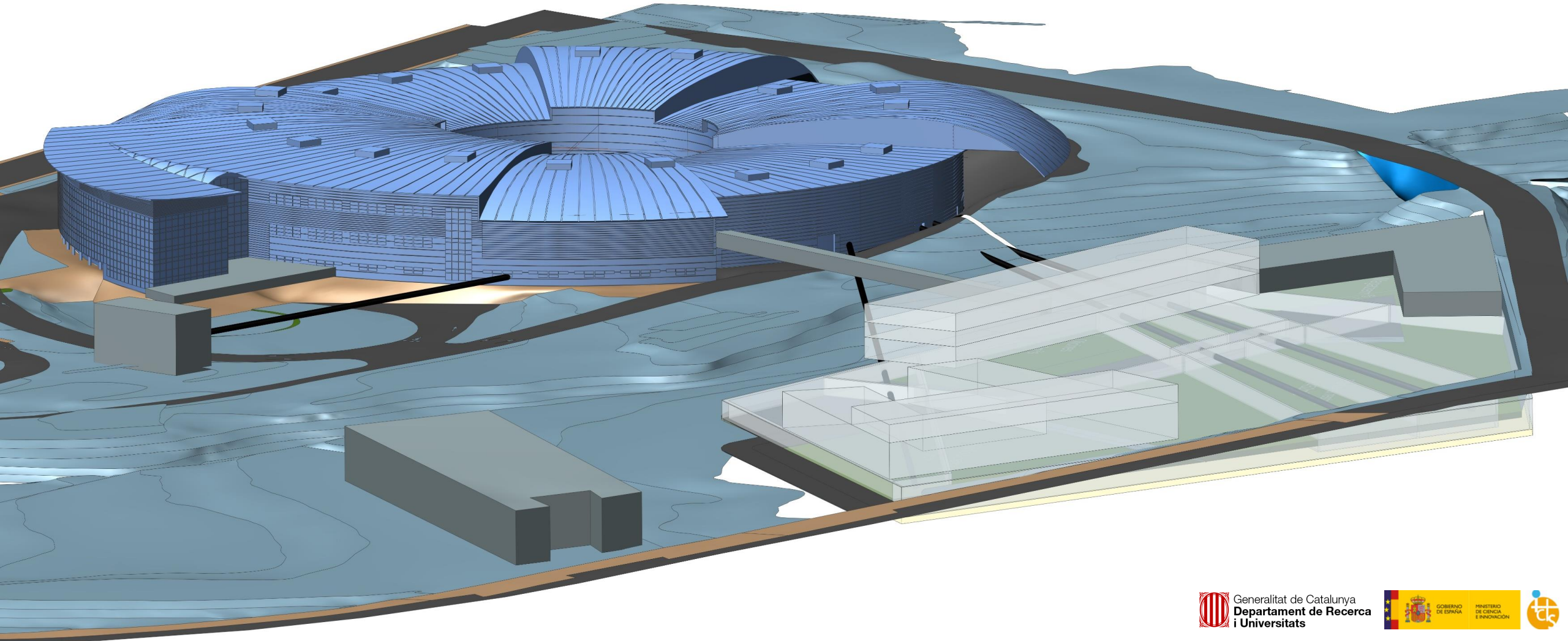
Present and Future of the ALBA Synchrotron

Caterina Biscari

8 September 2023

ALBA

IBER 2023



Generalitat de Catalunya
Departament de Recerca i Universitats

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

ALBA Synchrotron Radiation Facility

National public institution with 50% national + 50% regional funding (Ministerio de Ciencia e Innovación) and GenCat (Department de Recerca i Universitats)

National and international (28%) staff

National and international (40%) users

National and international collaborations

ALBA
key numbers

+ 2400 yearly user visits

+450 yearly experiments

+ 3700 national and + 3500 international users

+2800 publications

$\langle IF \rangle_{2022} = 10$

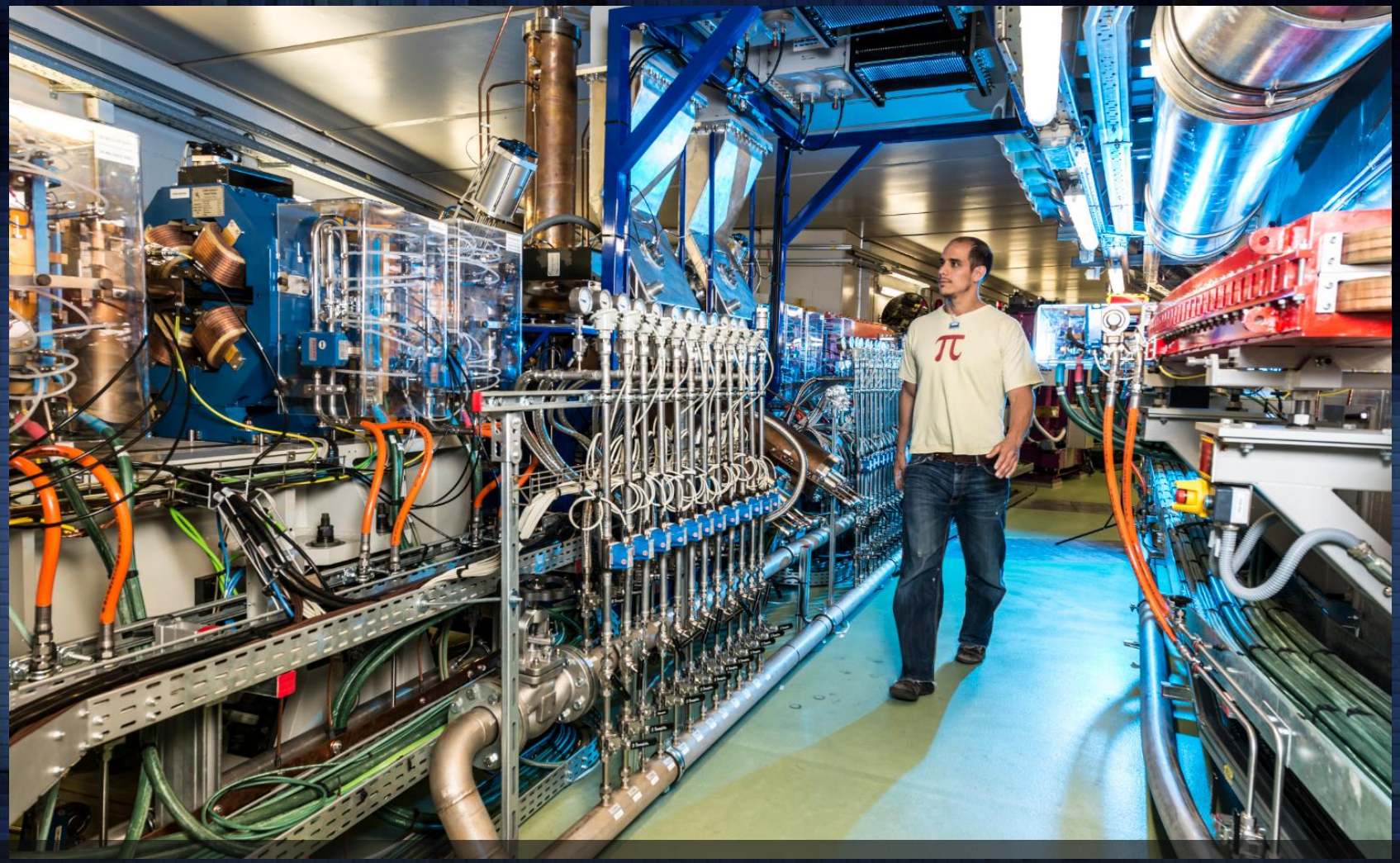
+2500 public experiments

+500 industrial experiments

+900 Proteins in PDB

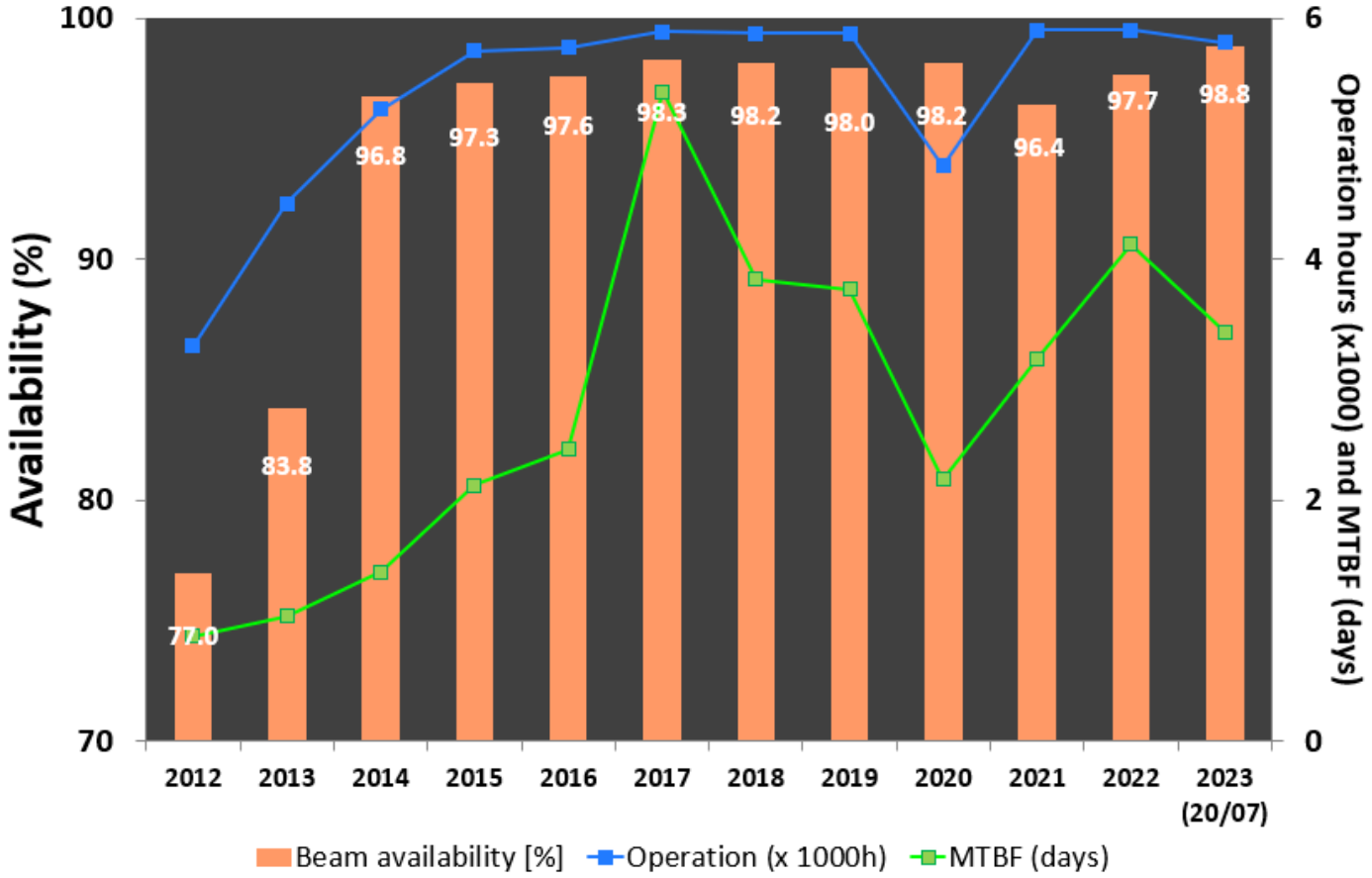
+240 staff

ALBA accelerator



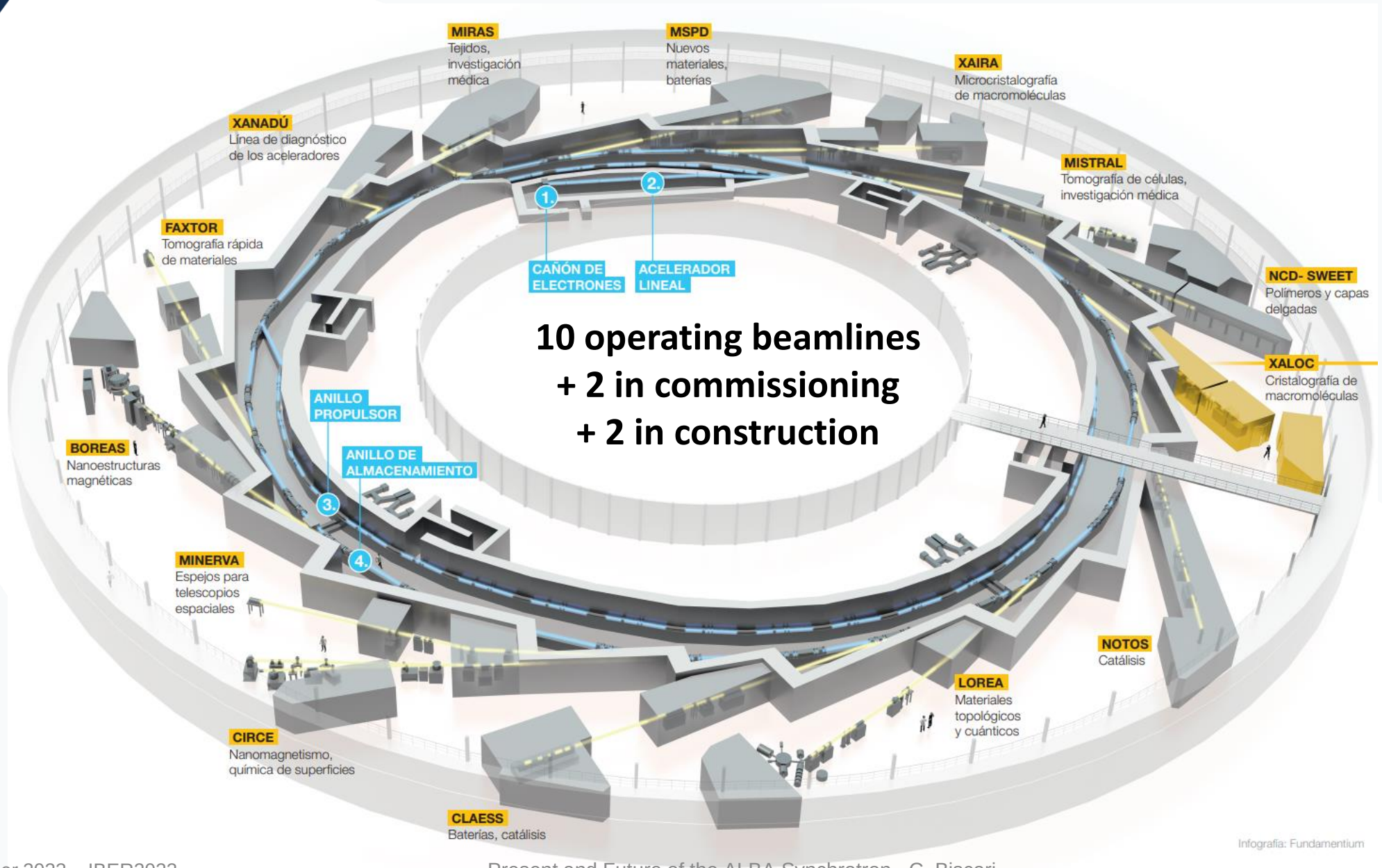
ALBA storage ring – 3rd generation light source
3 GeV electrons - 270 m circumference

Excellence in operation through one-decade

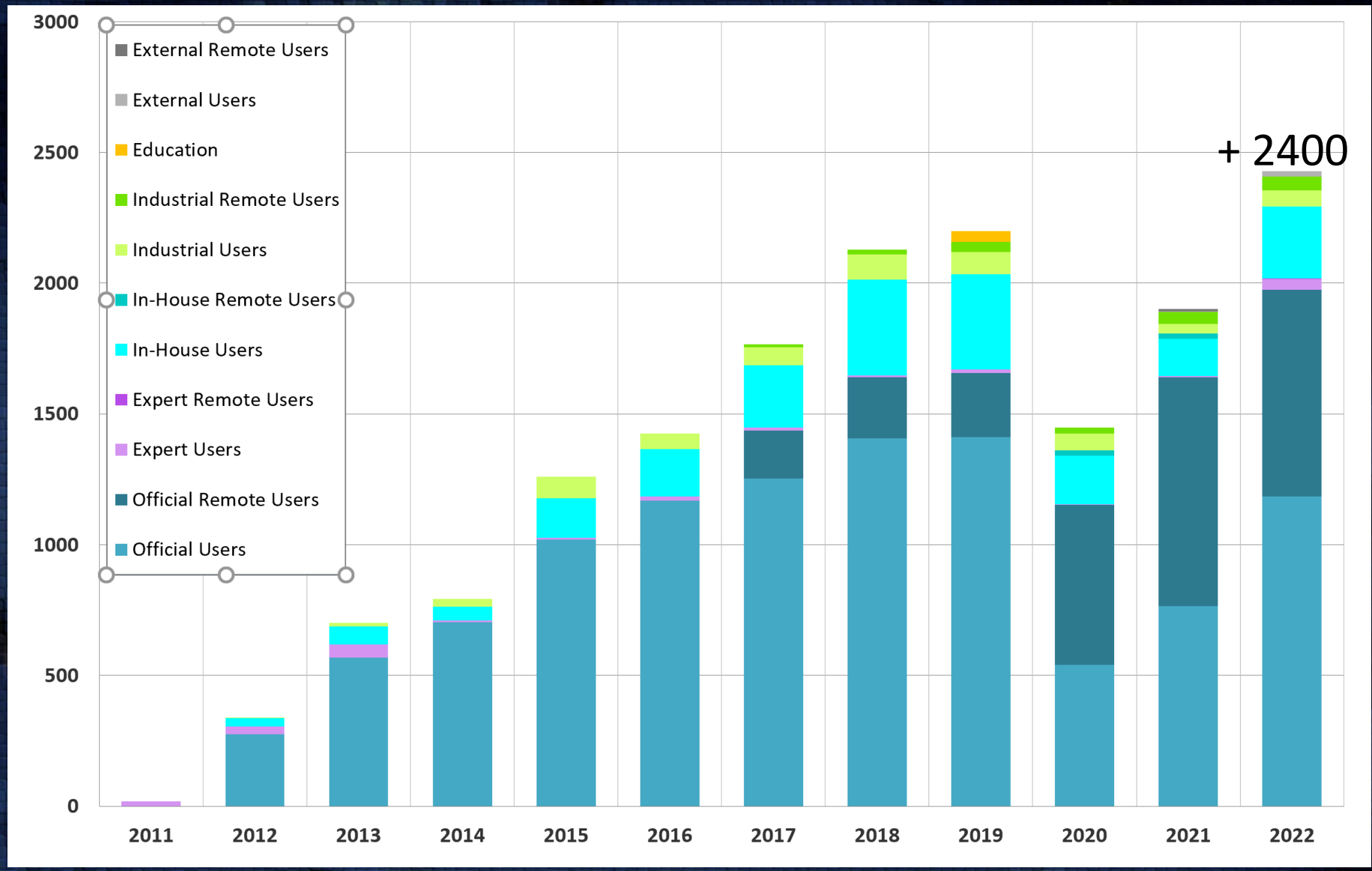


SR Parameter	Value
Energy	3 GeV
Circumference	269 m
Emittance	4.4 n mrad
Current	250 mA
Rf frequency	500 MHz
# cavities	6
Long straights	4 (8 m)
Short straights	12 (4 m)

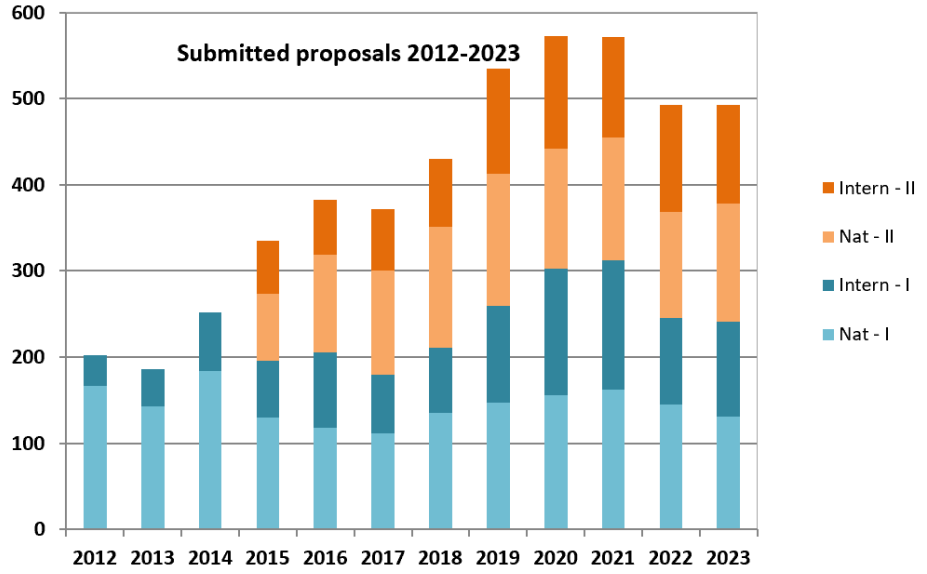
ALBA Synchrotron

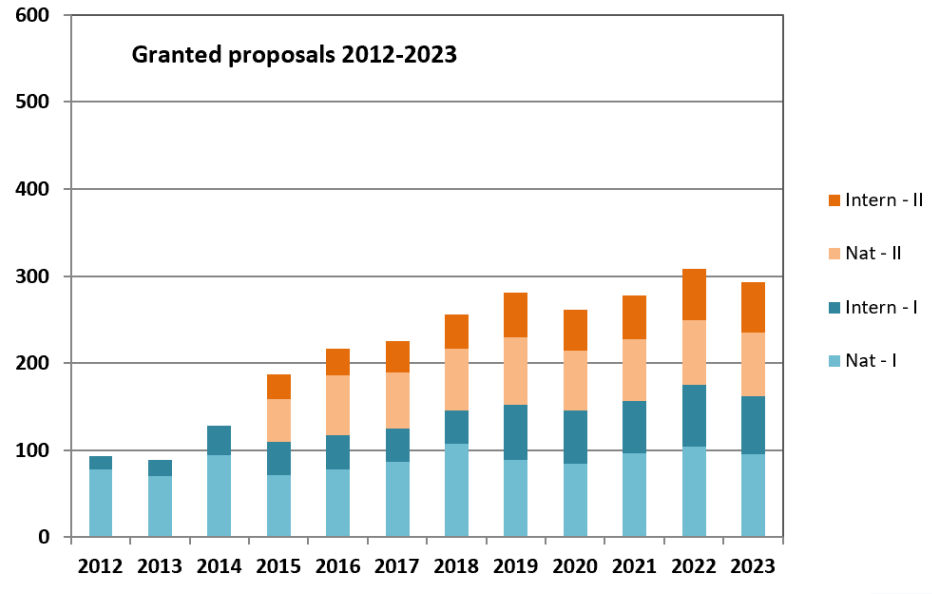


Our USERS in the decade of operation

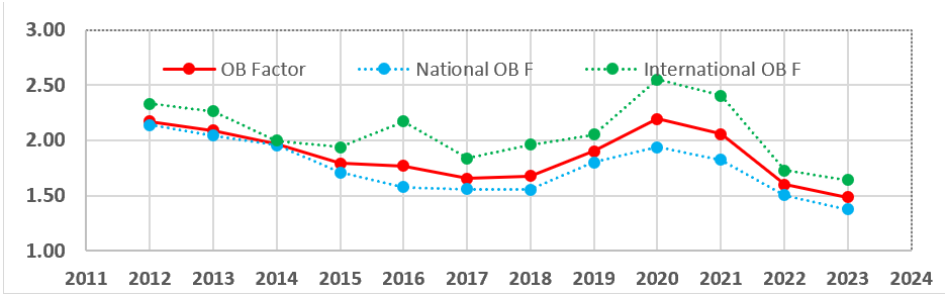


Academic and competitive user access

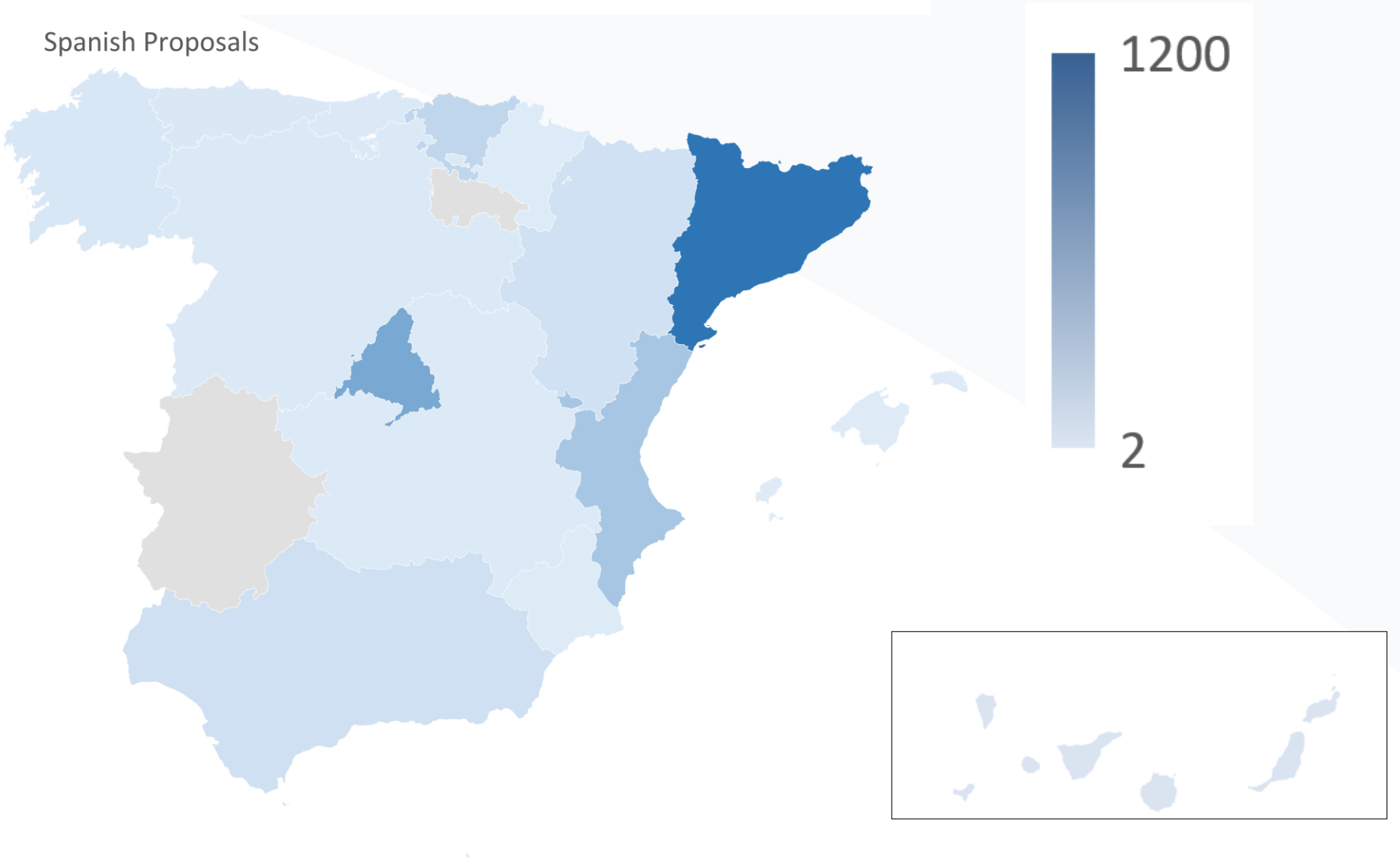




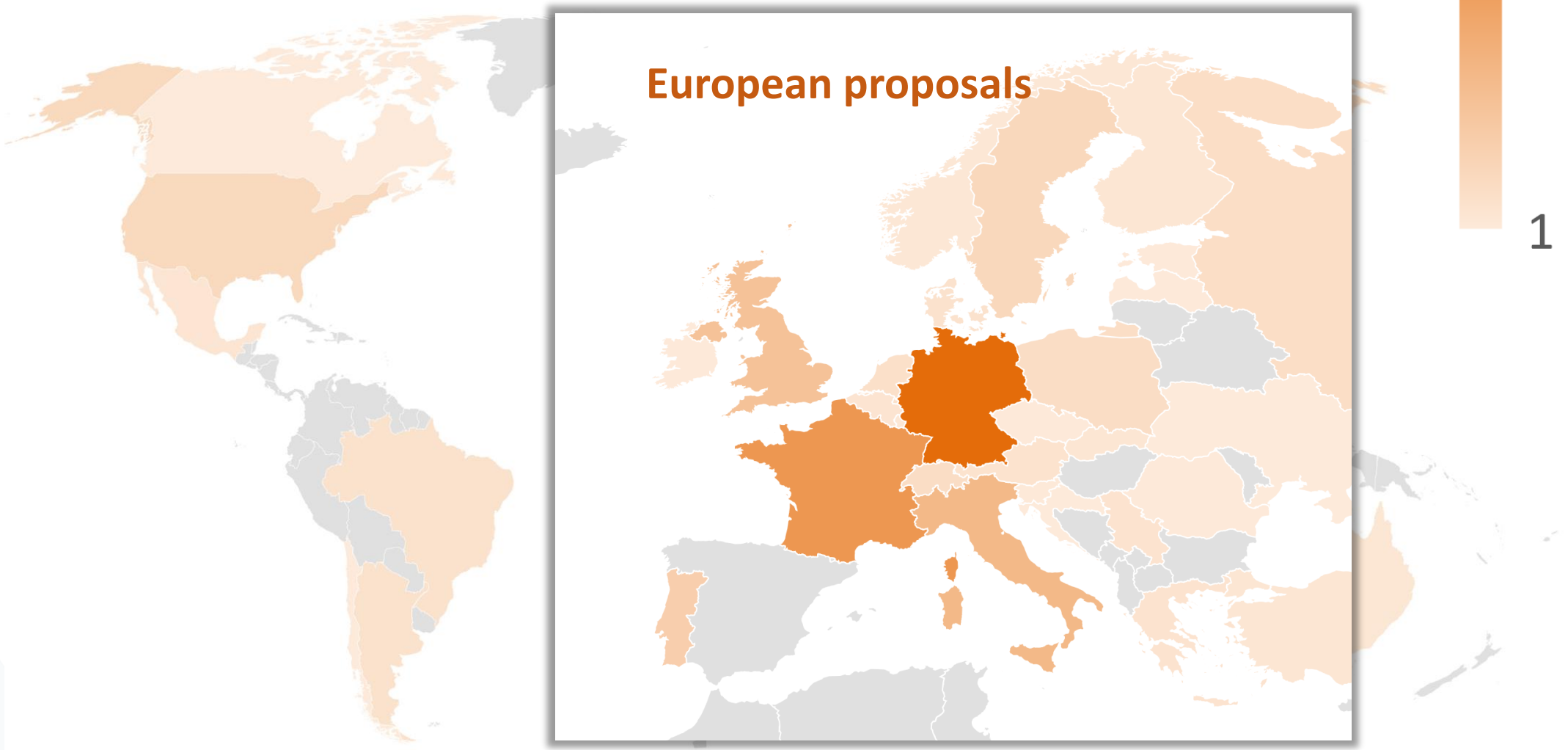
	Submitted	Granted	OF
National	2879	1669	1.7
International	1946	946	2.1
TOTAL	4825	2615	1.8

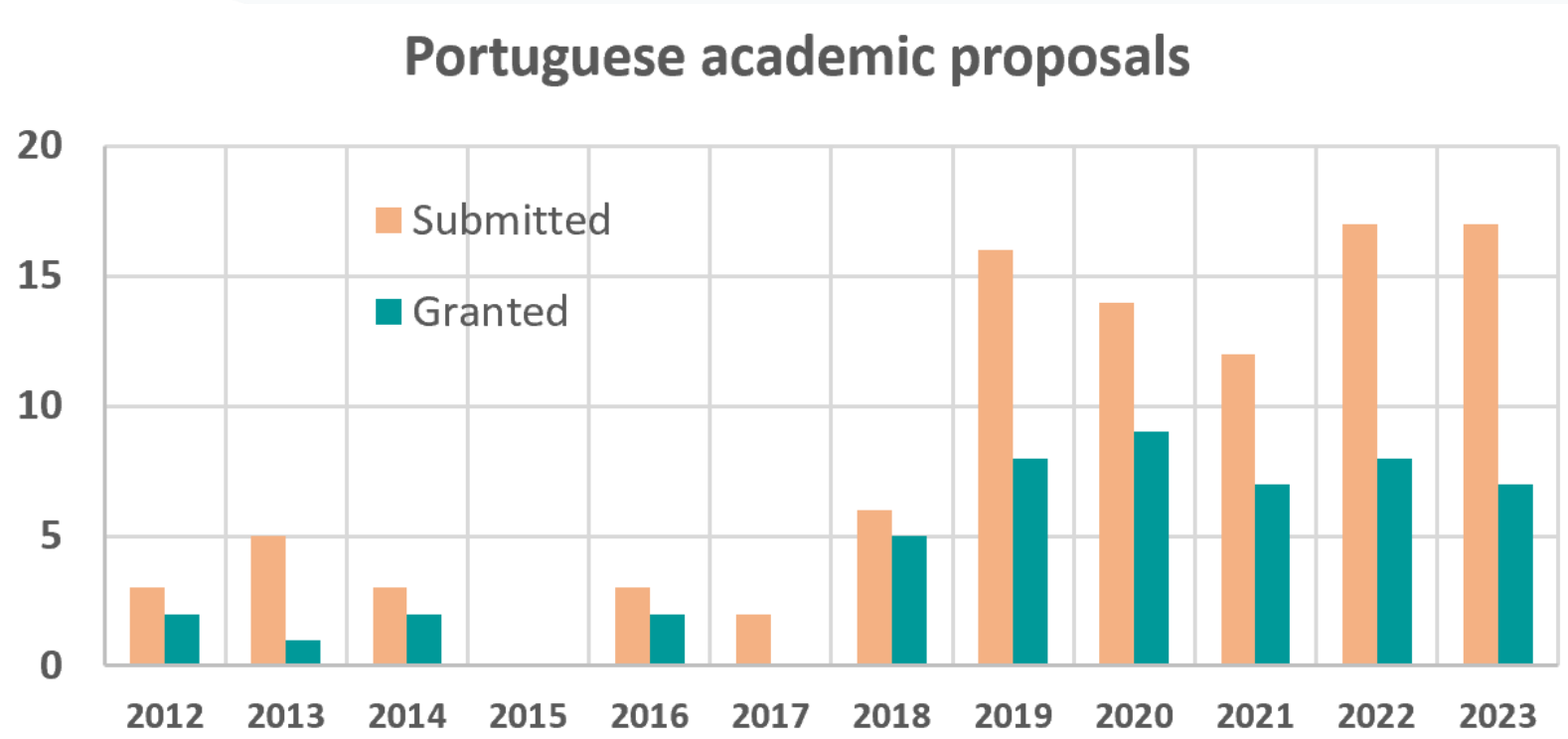


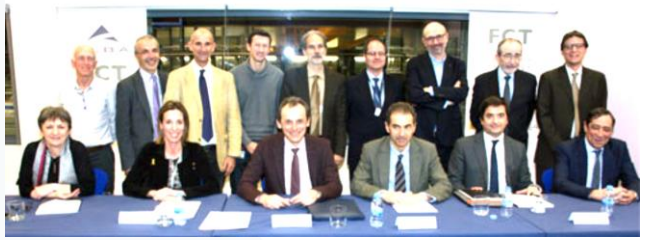
Spanish proposals
(1598 granted over 2876)



International proposals (871 granted over 1972)







February 2019: agreement signed in front of Spanish and Portuguese minister for boosting the collaboration.

“Iberian’ treatment of Portuguese researchers during 4 years - Done

Proposal for common projects with special post-docs grants

HE Project developed in collaboration

FUNCTIONAL LAYERED MATERIALS FOR ADVANCED APPLICATIONS

Coordination and Support Action from the EC (2023-2025)

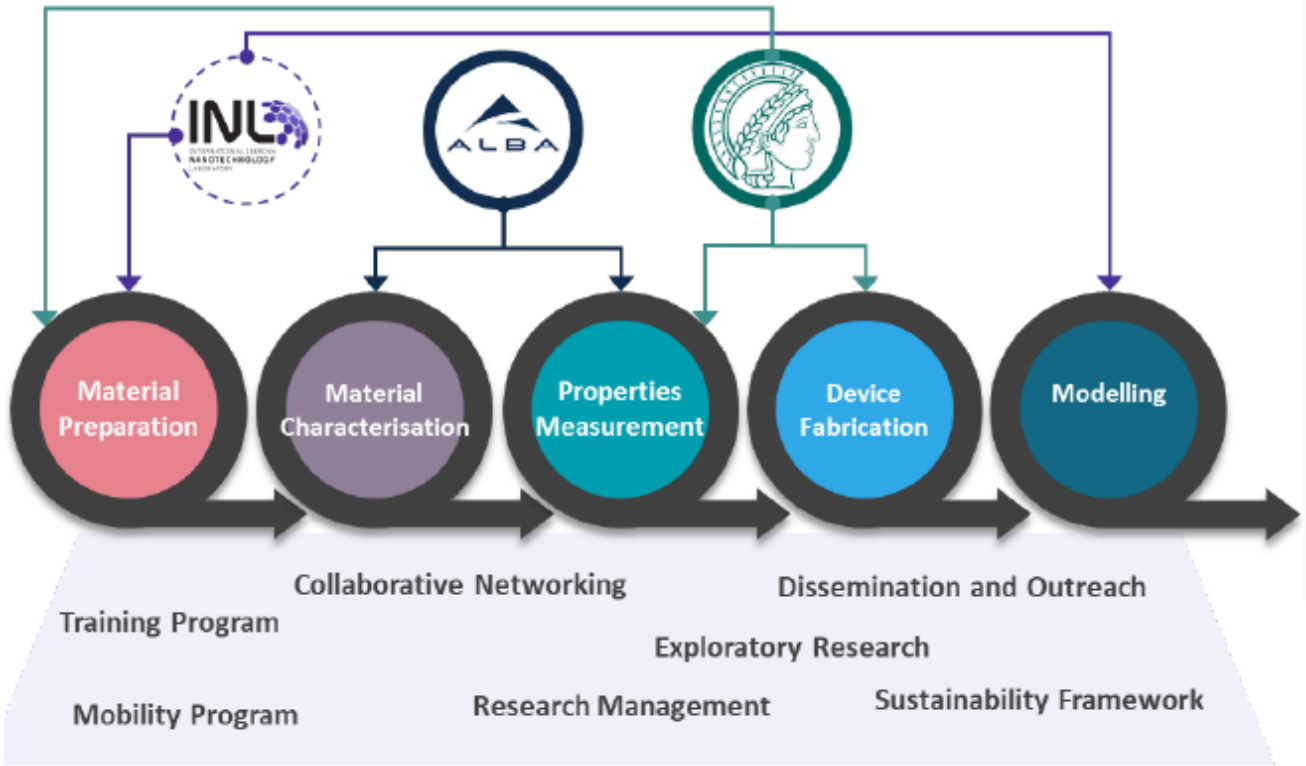
FUNLAYERS

- **GOAL**

Research excellence in the field of **LAYERED MATERIALS** whilst unfolding its potential applications for **energy storage** and **spintronics**.

- Upcoming workshop:

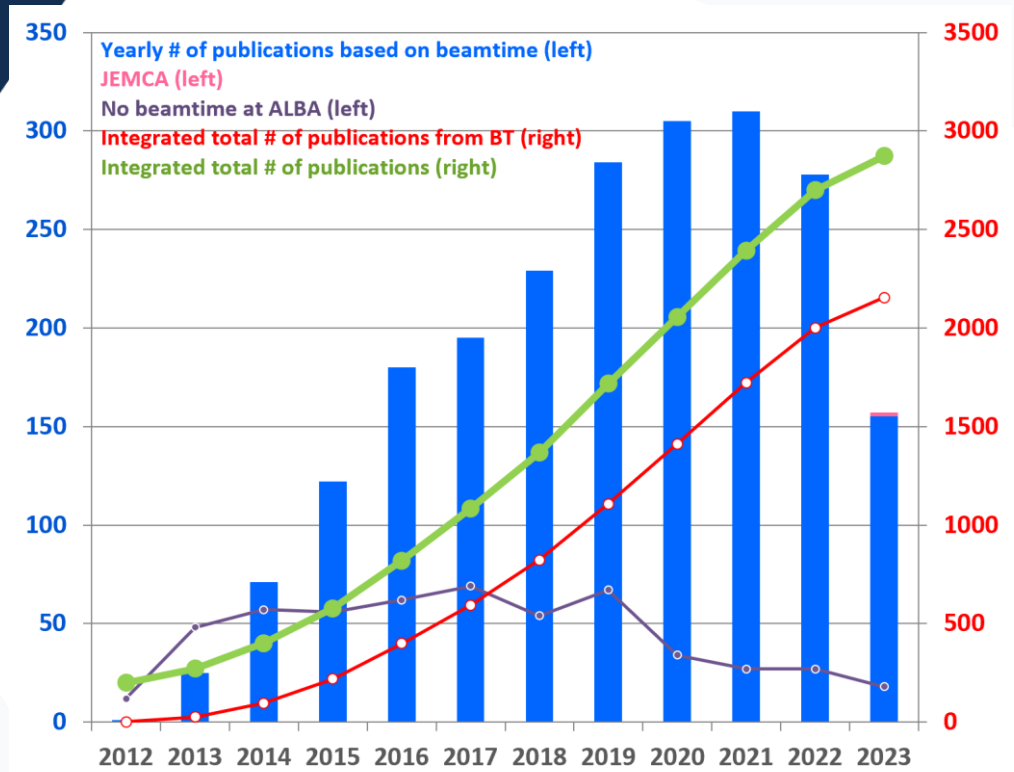
"Emergent Properties of heterostructures"
October 23-25, 2023
at MPG (Halle, Germany)

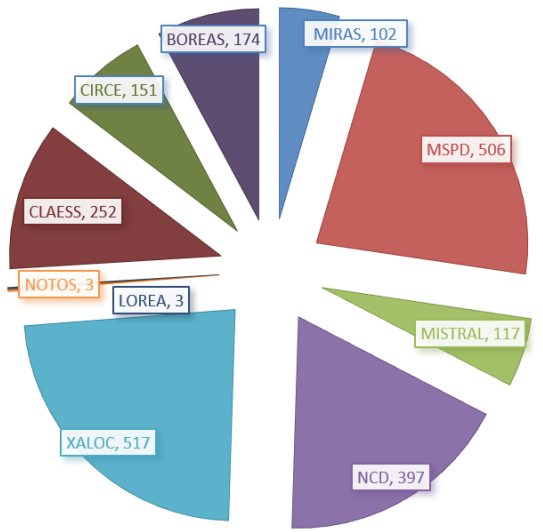


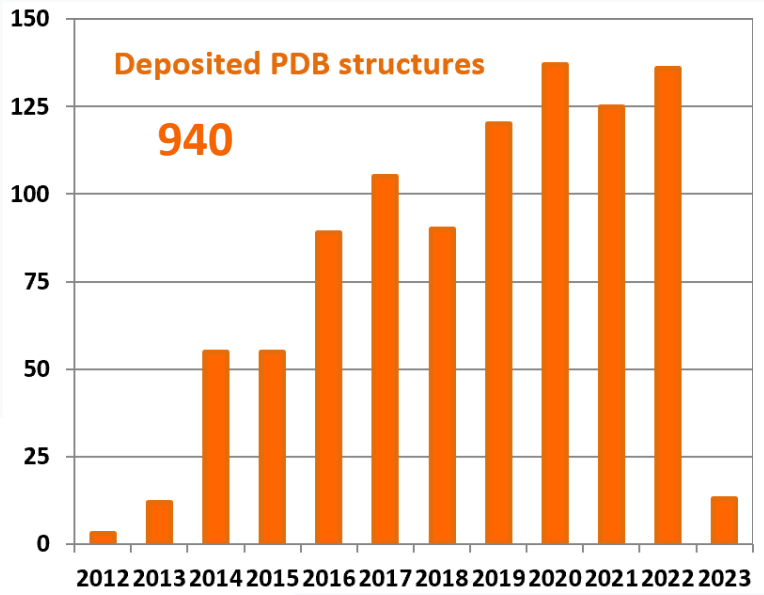
www.funlayersproject.eu

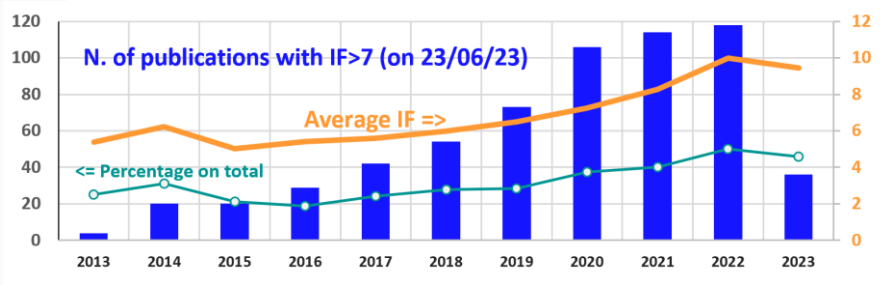
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Research Executive Agency. Neither the European Union nor the granting authority can be held responsible for them. GA no. 101079184

ALBA scientific productivity









Publications per BL

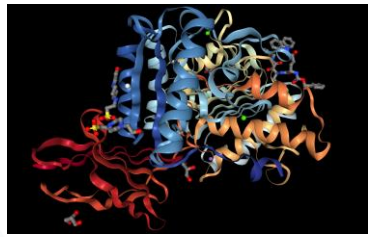
2020/2021: average # of publications per op. BL > 38
2021: <IF> = 8.3; 41% of publications with IF>7
2022: <IF> = 10; 50% of publications with IF>7

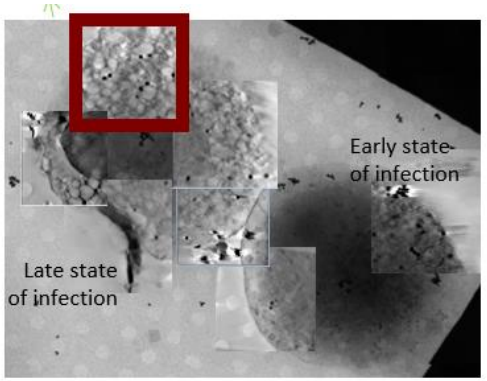
ALBA Synchrotron Research Infrastructure

Three Scientific Sections, three main research lines

Life Science

From the protein, to cell, to tissues

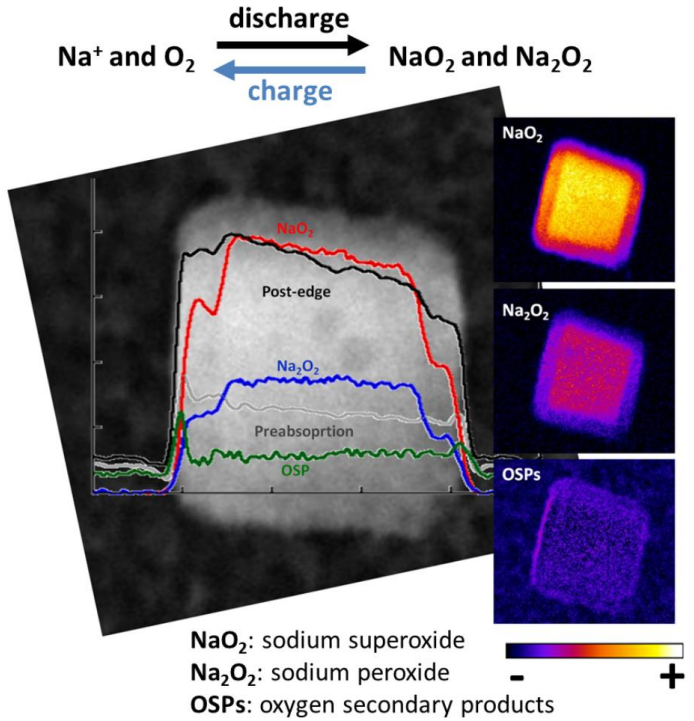




Cell infected by covid-19

Chemistry and Material Science

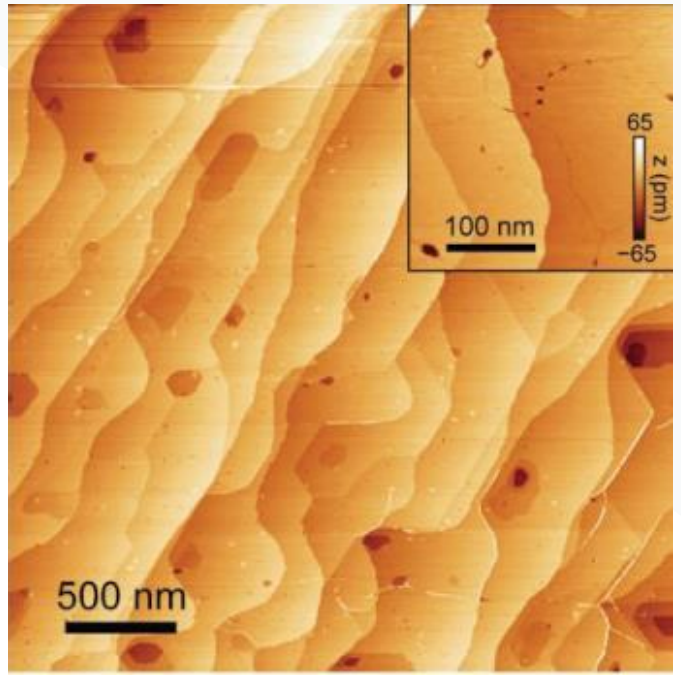
Energy material, catalysts, environment



Battery developments

Electronic and Magnetic Structure of Matter

Advanced materials

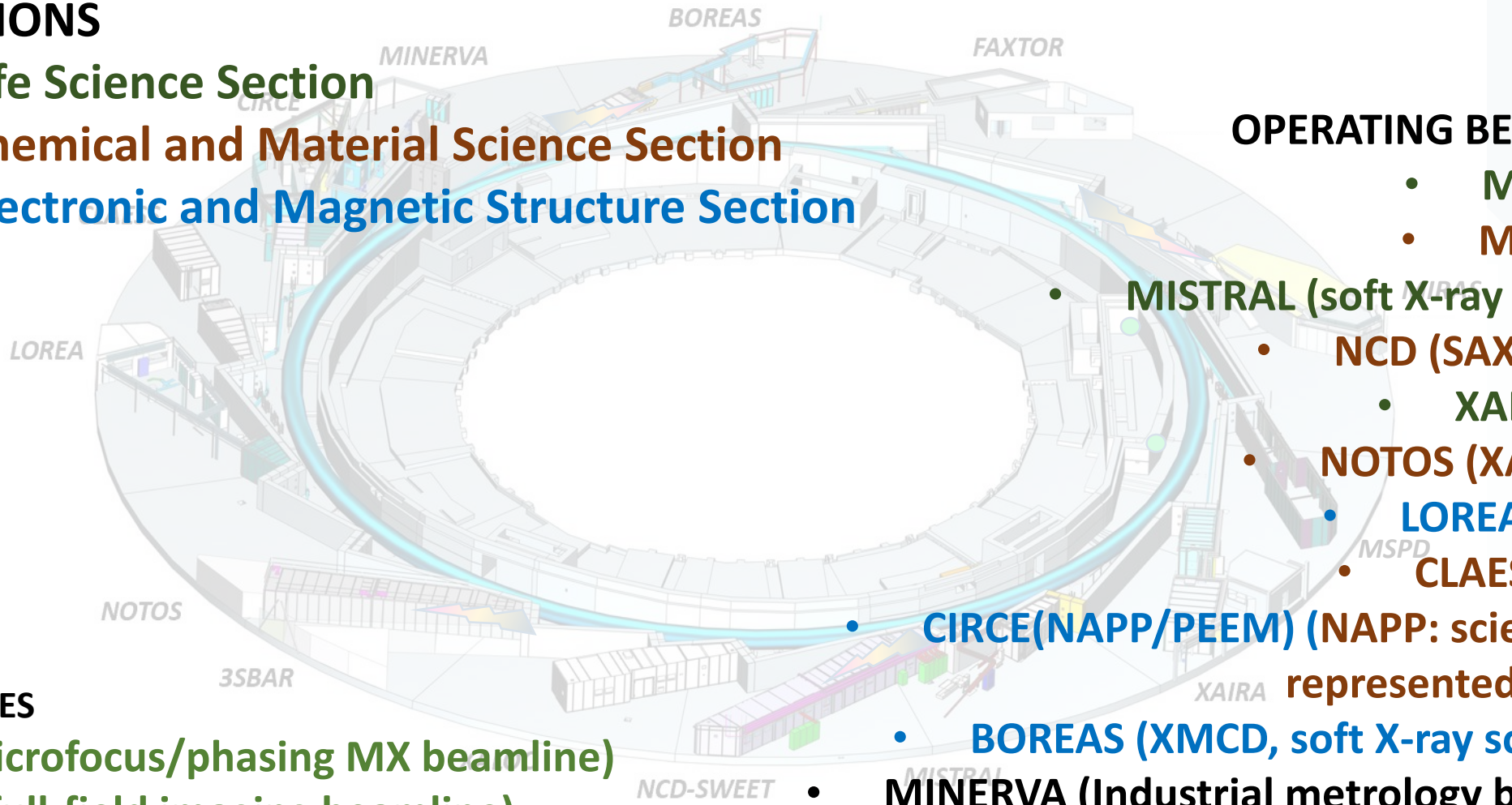


Nanomaterials for data storage

ALBA Beamlines serving the three scientific sections

SECTIONS

- Life Science Section
- Chemical and Material Science Section
- Electronic and Magnetic Structure Section



OPERATING BEAMLINES

- MIRAS (IR)
- MSPD (PD)
- MISTRAL (soft X-ray microsc.)
- NCD (SAXS/WAXS)
- XALOC (MX)
- NOTOS (XAFS + PD)
- LOREA (ARPES)
- CLAESS (XAFS)
- CIRCE(NAPP/PEEM) (NAPP: scientifically represented by CMS)
- BOREAS (XMCD, soft X-ray scattering)
- MINERVA (Industrial metrology beamline)

Next BEAMLINES

- XAIRA (microfocus/phasing MX beamline)
- FAXTOR (full-field imaging beamline)
- 3Sbar (HEXPAS and surface diffraction beamline)

ALBA Beamlines

TABLE 2-1: **MAIN TECHNIQUES OFFERED BY ALBA BEAMLINES**

PORT AND NAME	SCIENTIFIC SECTION	MAIN TECHNIQUES AND STATUS
BL01 - MIRAS	Life Science	*Infrared Spectroscopy & Microscopy – in operation*
BL06 - XAIRA	Life Science	*Macromolecular Microcrystallography – in commissioning; in operation in 2024*
BL09 - MISTRAL	Life Science	*Soft X-ray Microscopy - in operation*
BL13 - XALOC	Life Science	*Macromolecular Crystallography - in operation*
BL31 - FAXTOR	Life Science	*Fast X-ray Tomography and Radioscopy Beamline - being installed; starting operation in 2024*
BL20 - LOREA	Electronic & Magnetic Structure of Matter	*Angle Resolved Photoemission Spectroscopy – in operation*
BL24 - CIRCE	Electronic & Magnetic Structure of Matter	*Photoemission Spectroscopy and Near Ambient Pressure Photoemission – in operation*
BL29 - BOREAS	Electronic & Magnetic Structure of Matter	*Resonant Absorption and Scattering – in operation*
BL04 - MSPD	Chemistry & Material Science	*Materials Science and Powder Diffraction – in operation*
BL11 - NCD-SWEET	Chemistry & Material Science	*Non-Crystalline Diffraction – Small/wide Angle X-ray Scattering – in operation*
BL15 - 3SBAR	Chemistry & Material Science	*Surface Spectroscopy and Structure at 1 bar – in construction; starting operation in 2026*
BL16 - NOTOS	Chemistry & Material Science	*Absorption, Diffraction, Instrumentation innovation and development – in operation*
BL22 - CLÆSS	Chemistry & Material Science	*Core Level Absorption & Emission Spectroscopies – in operation*
BL25 - MINERVA	Instrumentation & optics	*Metrology and instrumentation – in operation in 2023*

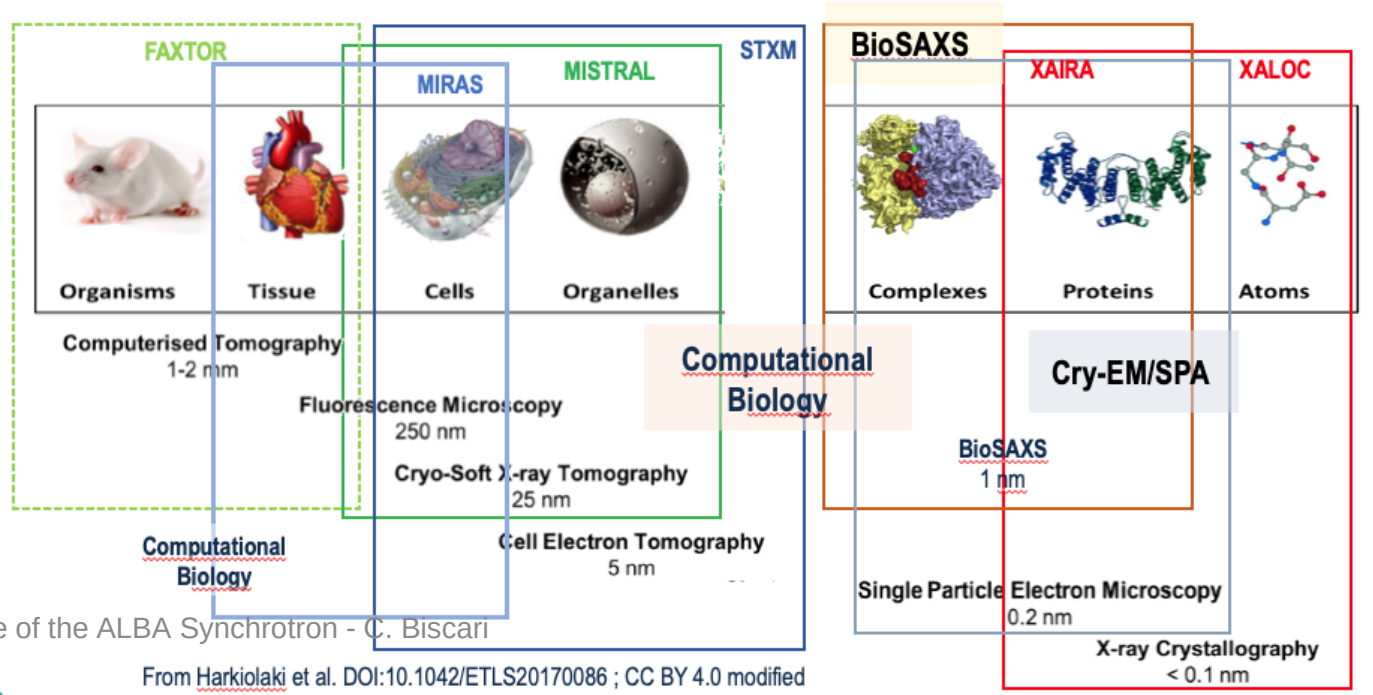
Focus Area: Life Sciences

Multi-length Scale Approach To Understand Behavior Of Biological Systems

using a suite of techniques and services enabling the catalytic role of ALBA

Focused on scientific fields:

- Drug development
- Membrane proteins
- Structure-based enzymology

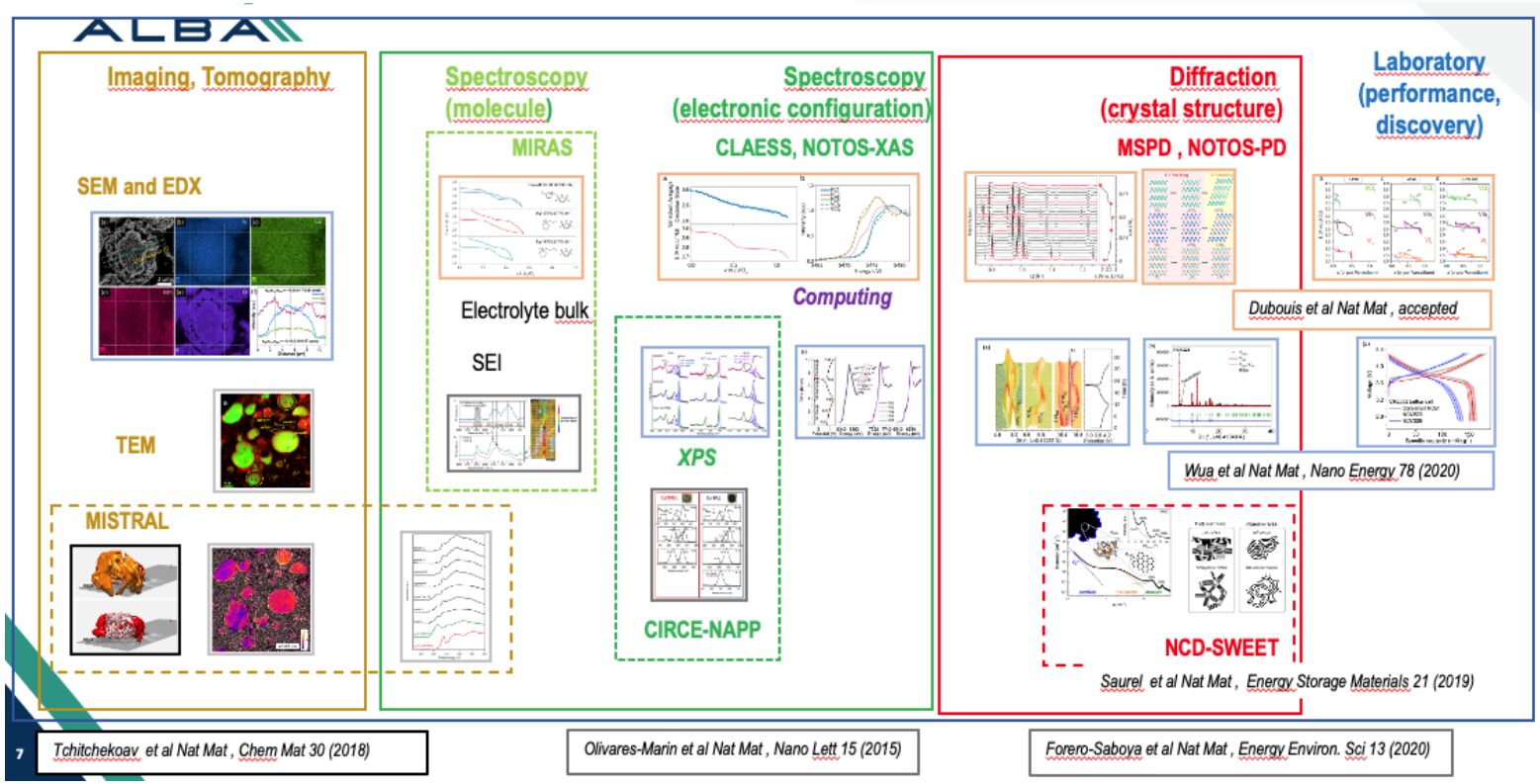


Focus Area: Energy

Tuning Electronic and Chemical Properties by Controlling Atomic Structure of Functional Materials using a suite of techniques and services enabling the catalytic role of ALBA

Focused on scientific fields:

- Energy storage.
- Hydrogen circular economy.
- Carbon sequestration.



Focus Area: Information Technology

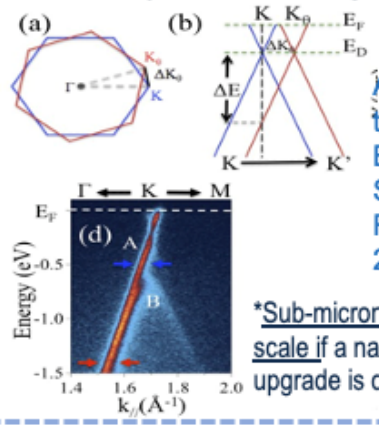
Resolving and Manipulating the Electronic and Magnetic States, and its Spatial and Dynamic Characteristics in Quantum Materials.
Using a suite of techniques and services enabling the catalytic role of ALBA

Focused on scientific fields:

- Spintronics and Spinorbitronics.
- Topological materials.
- Materials discover.
- Device physics.

Microscale* averaged electronic & magnetic properties | **Micro to nanoscale imaging** | **Atomic imaging**

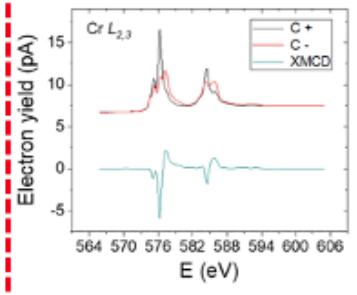
LOREA: ARPES



ARPES in twisted BLG, Soleil, Sci Reports 2016

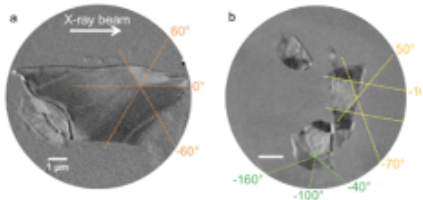
*Sub-micron to nano scale if a nano-focusing upgrade is considered

BOREAS - XMCD



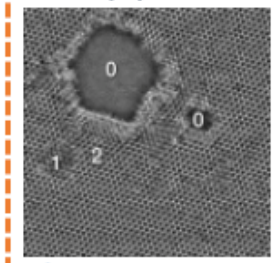
Cr XMCD in CrCl3 sl, ArXiv 2020

CIRCE, MISTRAL & BOREAS



PEEM, Multilayer flakes of CrTe2 VdW, *ACS AMI 2020*

HR-(S)TEM

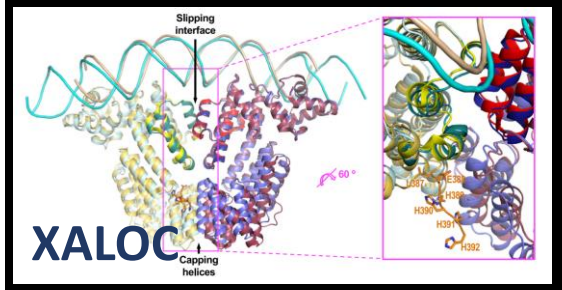


Defects in a MoS2 imaged with high-resolution STEM *Spectra, ThermoFischer*

	Resolution	complementary x-ray + SPM, TEM imaging capabilities
XTM MISTRAL	20-30 nm	fast ; 2D imaging ; 3D tomo ; bulk (only C+ BM)
PEEM CIRCE	20-30 nm (<10nm possible)	fast; 2D; part 3D (shadow tech.) ; surface, mod. Field & LN temp
Coh. Imag. BOREAS	25 nm (3-5 nm possible)	slow (reconst. or scanning) 2D ; 3D possible; LHe ; Hig field

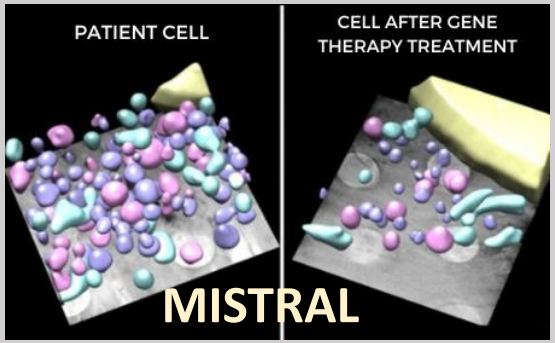
Some highlights from the scientific results published in the last months

MECHANISM OF ACTION OF THE ARBITRIUM COMMUNICATION SYSTEM IN SPBETA PHAGES



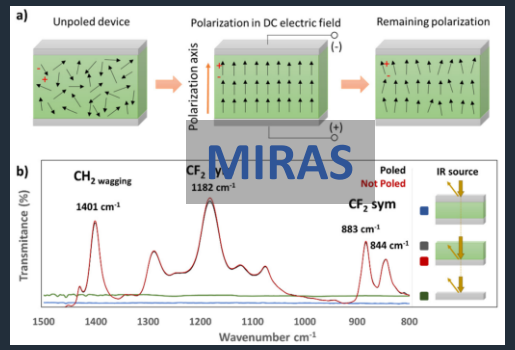
Nature Communications **volume 13**, Article number: 3627 (2022)

GENE THERAPY PROVED AGAINST MUSCULAR DYSTROPHY



Int. J. Mol. Sci. **2022**, 23, 7651doi.org/10.3390/ijms23147651

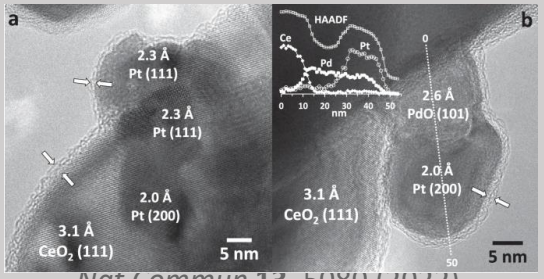
CONTROLLED POLING OF A FULLY 3D PRINTED PIEZOELECTRIC DEVICE



J. Mater. Chem. C, 2022, 10, 11555

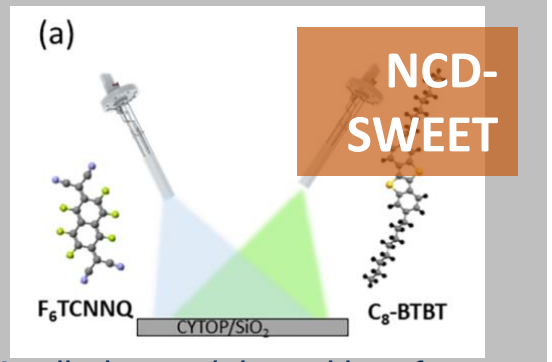
CATALYST TO REMOVE EMISSIONS OF METHANE

CIRCE (+CLAESS & MSPD)



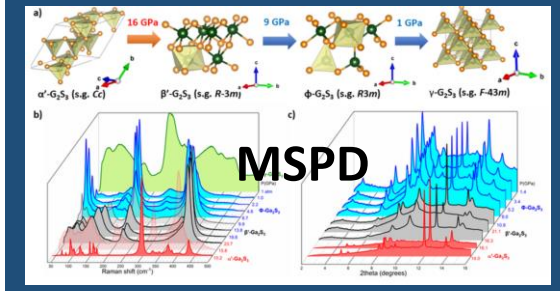
Nat Commun **13**, 5080 (2022). doi.org/10.1038/s41467-022-32765-4

CHARGE-TRANSFER COMPLEXES IN ORGANIC FIELD-EFFECT TRANSISTORS



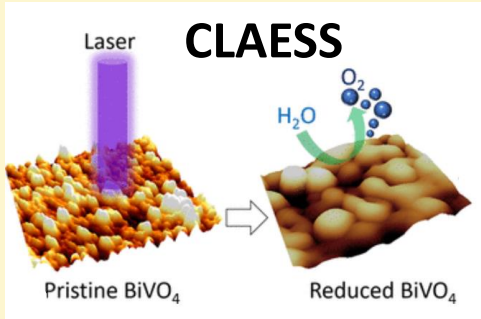
Applied materials and interfaces 10.1021/acsami.2c09168

PRESSURE-INDUCED PARAELECTRIC TO FERROELECTRIC PHASE TRANSITION



Chem. Mater (2022), 34, 13, 6068–6086. https://doi.org/10.1021/acs.chemmater.2c01169

ENHANCED PHOTOELECTROCHEMICAL WATER SPLITTING

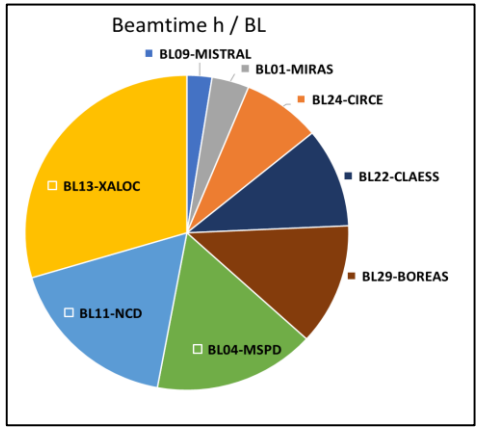


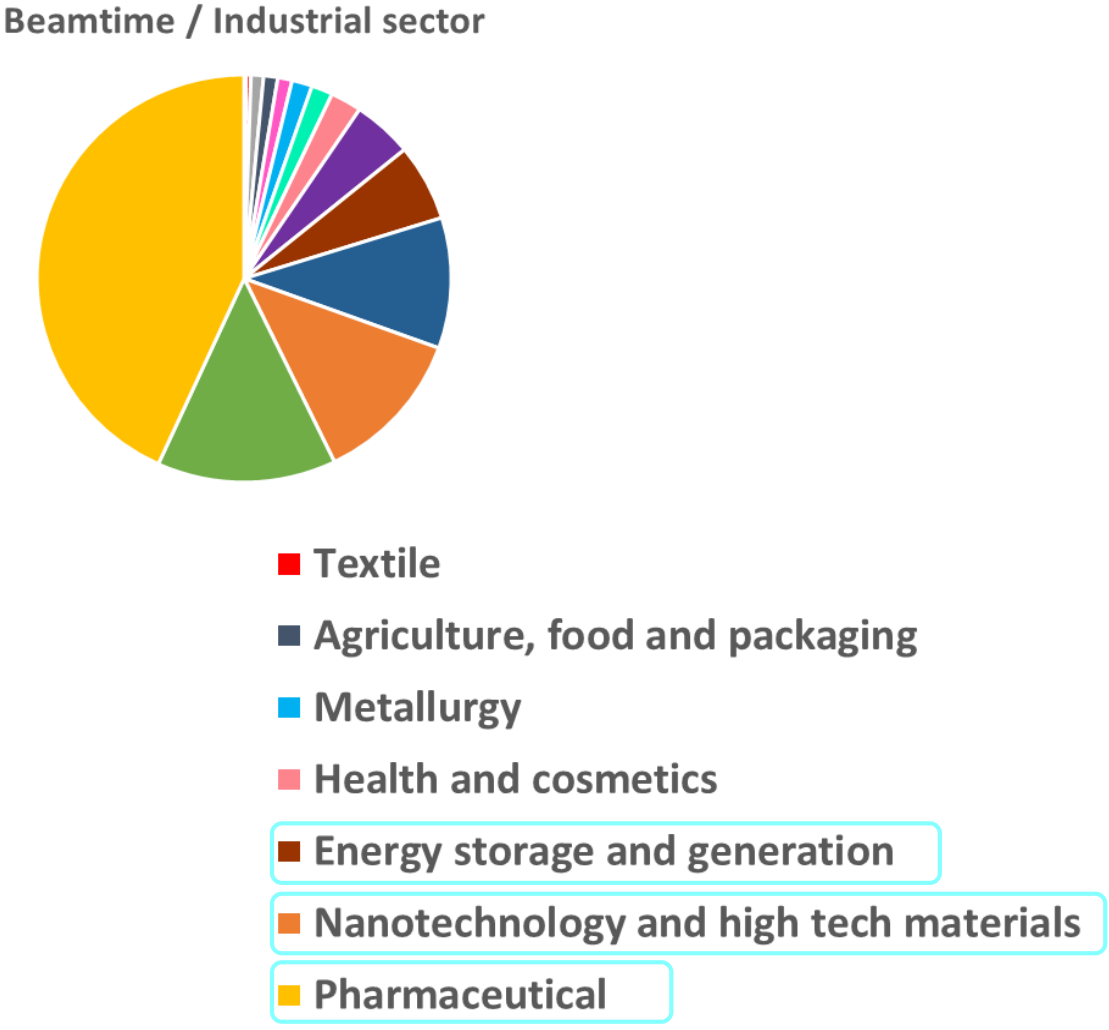
ACS Applied Materials & Interfaces, 2022, 14, 29, 33200–33210

LIGHT-INDUCED SPIN SWITCHING DEVICE WITH APPLICATIONS IN SPINTRONICS

Advanced Materials (2022). **doi.org/10.1002/adma.202202551**

Industrial users – advancing in the innovation
More than 75 companies, 55% from Spain, 1/3 SME,
More than 500 experiments





Examples of industrial use

Pharma industry

- *Structural information of the interactions between a **drug and a therapeutic target** at the atomic level*
- ***Penetration of drugs** and pharmaceutical formulations **in biological tissues** such as the skin*

Environmental industry

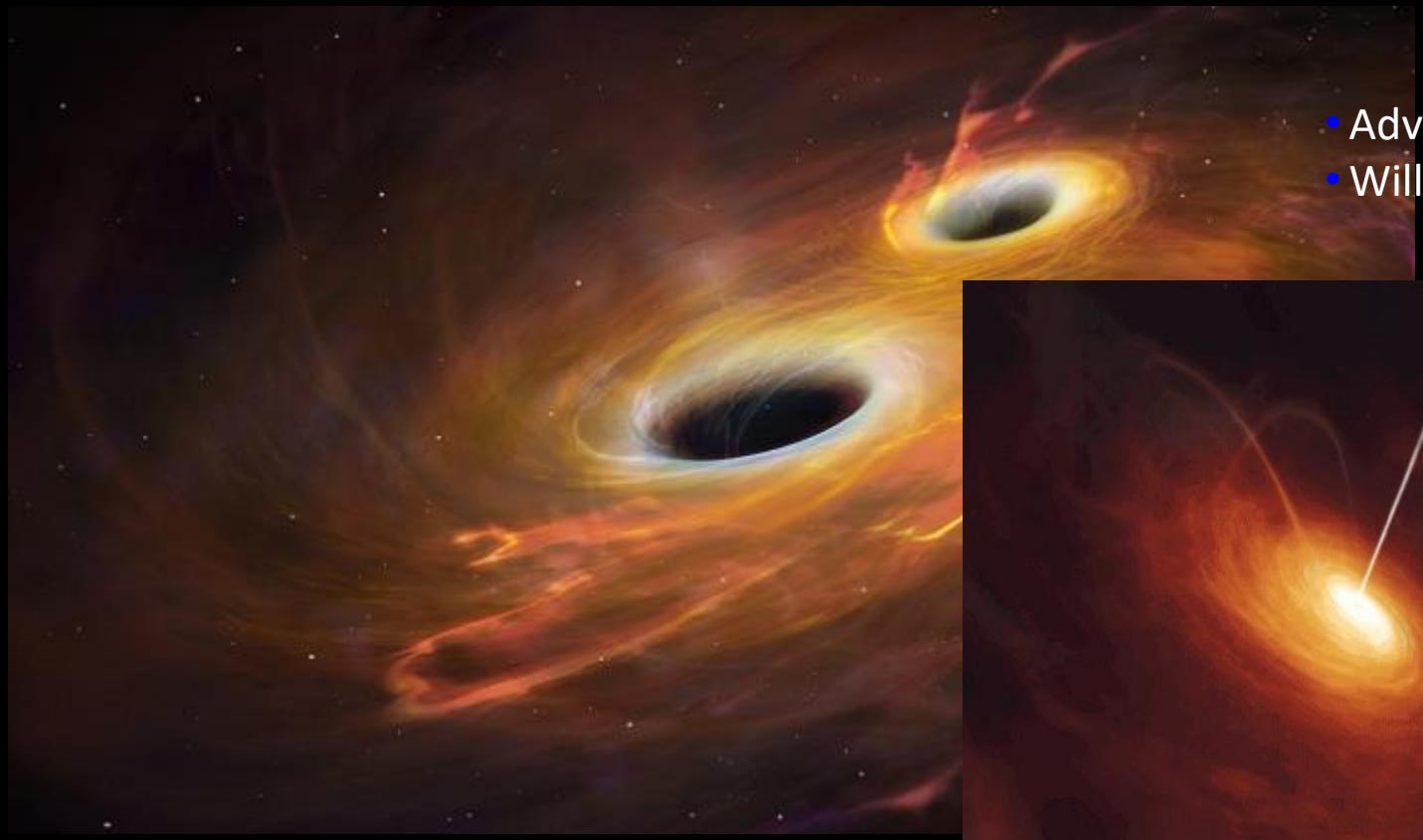
- *Chemical characterization to improve nuclear and mining **waste management***
- *Identification of different **chemical species** in very low concentrations and their distribution **in plants, microorganisms, and animal tissues***
- ***Toxicological effects** of chemicals, corrosion, pollution, etc.*

BASF IMPROVING THE PRODUCTION OF BATTERIES FOR ELECTRIC VEHICLES

New methodology to produce nickel-rich cathode materials used in lithium-ion batteries that optimizes the conventional production process. Increase in throughput by a factor of three, increasing the efficiency of future cathode active materials production for battery electric vehicles

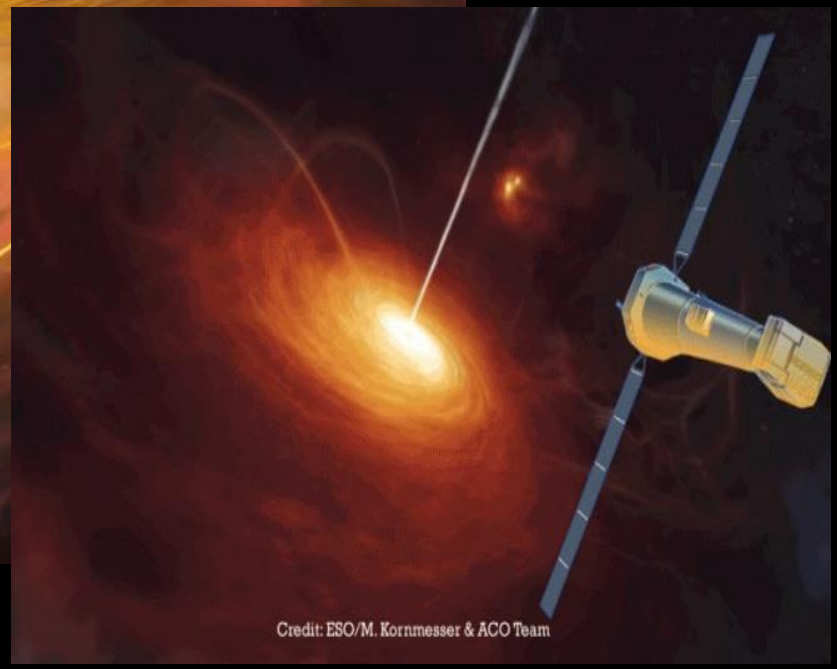
We participate in exploring the universe: ALBA - European Space Agency collaboration

In commissioning. Starting operation now



ATHENA Mission (2036)

- Advanced Telescope for High-ENergy Astrophysics
- Will study the high energy universe, including black holes



MINERVA: BL to test hundreds of mirrors to be mounted in ATHENA satellite

JEMCA

JOINT ELECTRON MICROSCOPY CENTER AT ALBA

INAUGURATION

24 FEBRUARY 2023

The importance of collaboration and complementarity

PARTNERS

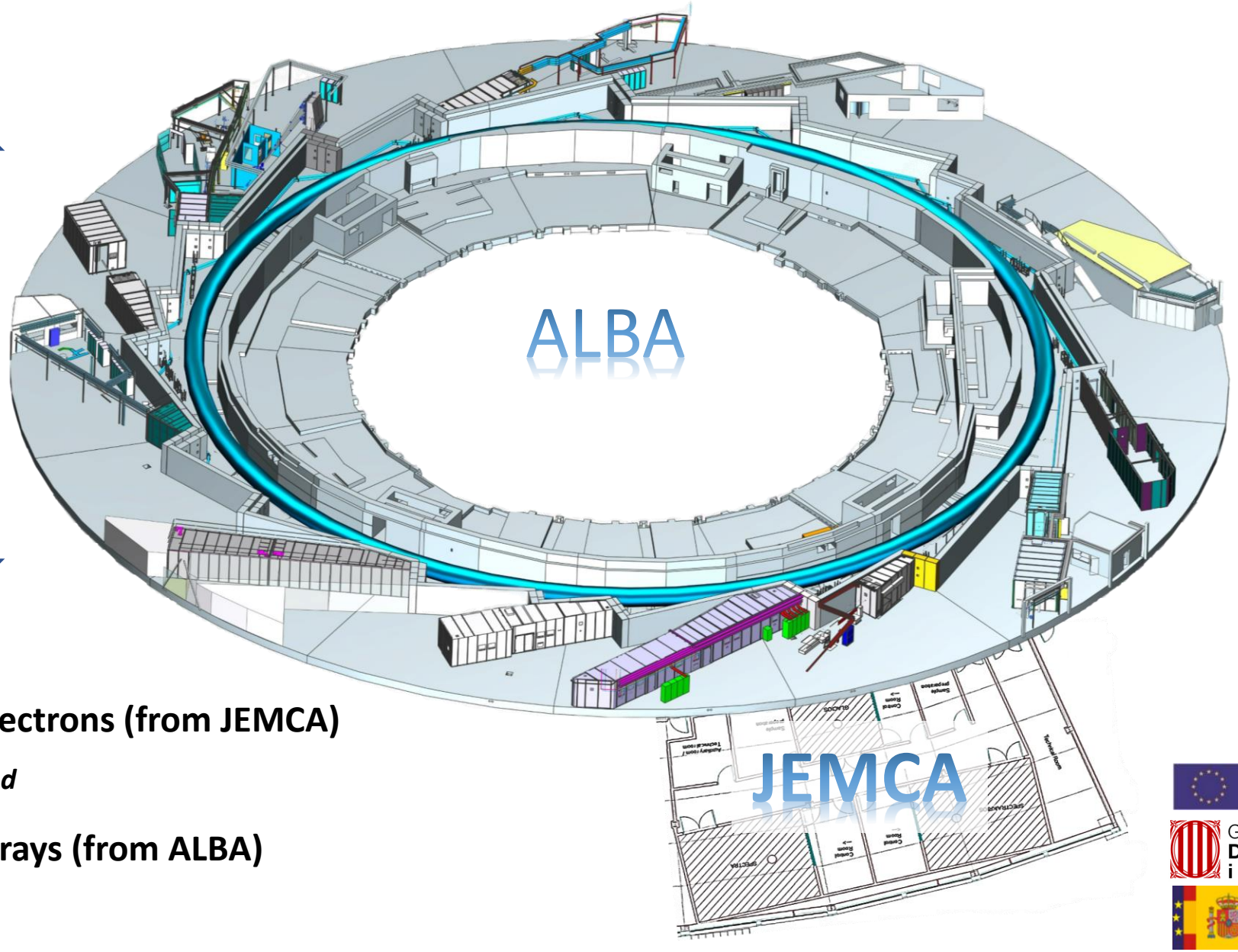
WITH THE SUPPORT OF

CO-FUNDED BY

www.albasynchrotron.es/en/instrumentation/jemca

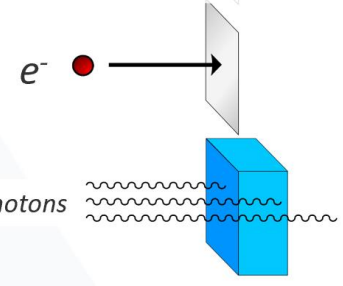
ALBA synchrotron: X rays + electron Microscopes

Complementarity and vicinity



Joint Electron Microscope Center at ALBA

50% Funded through Catalan ERDF and 50% co-funded by different partners



electrons (from JEMCA)

and

X rays (from ALBA)

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Generalitat de Catalunya
Departament de Recerca i Universitats

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

Joint Electron Microscope Center at ALBA (JEMCA)

50% Funded through Catalan ERDF and 50% co-funded by different partners

Life science - 200 kV Glacios cryo-TEM

Cryo-EM receiving users

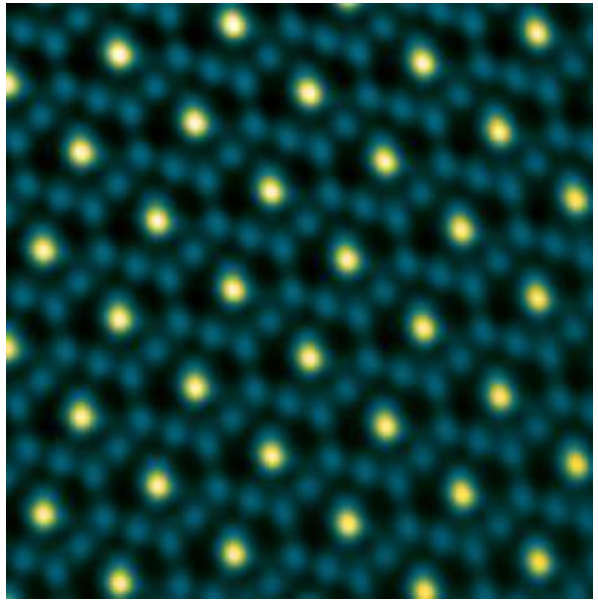
Overbooking Factor >2

IS*21* family transposase

Material Science - 60-300 keV Spectra (S)TEM

TEM just finished commissioning

First users after Summer 2023



Atomic resolution aberration corrected HAADF STEM images of one of the catalyst nanoparticles and a zoom out of the Co_2FeO_4 cubic spinel structure

Journal of the American Chemical Society, 2023. DOI: 10.1021/jacs.3c06288

Joint Electron Microscope Center at ALBA (JEMCA)

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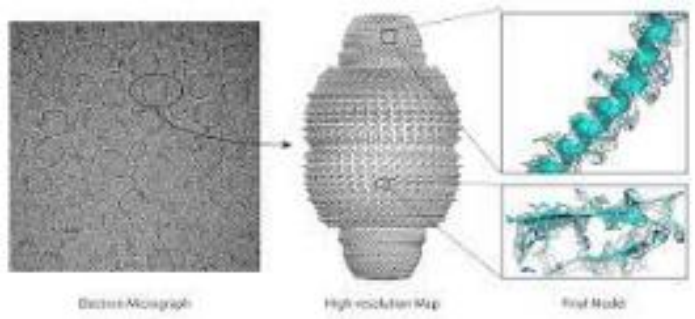
Life science

Cryo-EM

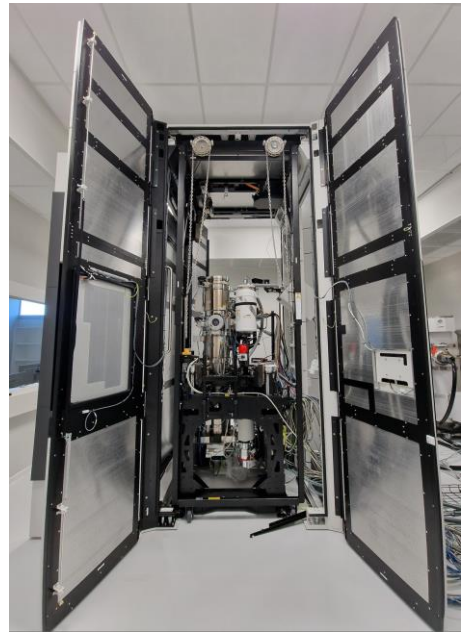
- 200 kV Glacios cryo-TEM
- X-FEG optics
- Autoloader
- Equipped with the last generation of direct electron detector (Falcon 4)
- Falcon 4 server with 60 TB
- ALBA storage with 100 TB
- GPU allowing for on-the-fly processing



Material Science

TEM

- 60-300 keV Spectra (S)TEM
- Double aberration correction
- Monochromatic beam
- Atomic scale spectroscopy by EELS and EDX
- ALBA storage with 100 TB
- Spatial resolution < 1 Å even at 60 kV
  (<50 pm at 300 kV)
- Energy resolution < 30 meV



Generalitat de Catalunya
Departament de Recerca i Universitats

Unió Europea
Fons Europeu de Desenvolupament Regional

In preparation: InCAEM

In Situ Correlative Facility for Advanced Energy Materials

Part of Advanced Materials Program of Planes Complementarios

New Infrastructure in ALBA premises, to be **open to all the scientific community in 2026**

In collaboration with several partners

Multi-modal

Multi-lengthscale

in situ/operando experiments

Correlative

(Scanning) transmission electron microscopy

Scanning probe microscopies

Synchrotron X-rays (spectroscopy, diffraction,…)

Advanced data analytics (HPC, deep learning, AI,…)

Finançat per:
Unió Europea
Fons Europeu
Next Generation
GOBIERNO DE ESPAÑA
Plan de Recuperación, Transformación y Resiliencia
Next Generation Catalunya
Generalitat de Catalunya
Departament de Recerca i Universitats

Today

Partnerships:

- **Joint Electron Microscope Center at ALBA (JEMCA)**
- **InCAEM – Planes Complementarios on Advanced Materials**
- **Battery and catalysis programs with CSIC**

ALBA collaborations

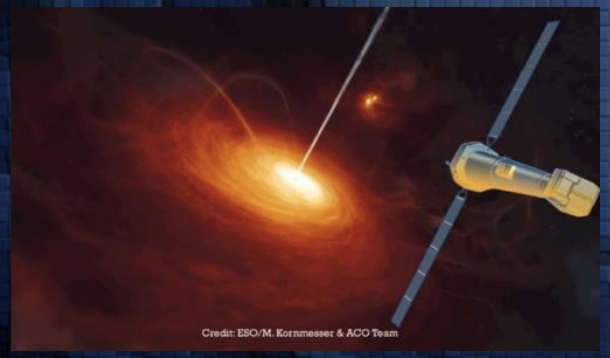
LEAPS League of European Accelerator-based Photon Sources

19 facilities - 16 institutions - 10 countries

ALBA Chairing LEAPS on 2020 and 2021, vice chair now

ARIE spokesperson for start-up the collaboration

Minerva: BL in collaboration with ESA



Participation in European Commission programs

LEAPS League of European Accelerator-based Photon Sources

at International level

LEAPS is the largest consortium of analytical facilities world-wide and further expanding its service to an interdisciplinary European user community

19 facilities - **16** institutions - **10** countries

> 300 operating End Stations

➢ **1.000.000** h beamtime /year
Excellence-driven access free of charge

> 5.000 publications/year

> 15 spin off companies

> 35.000 users from all EU & beyond
researchers from all research area

Today

+350 students trained

230 staff

+7500 outreach visits per year

Outreach projects for children

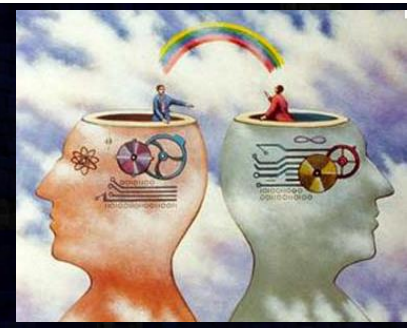
High-qualified job offers

ALBA & society

Organization of scientific and industrial workshops for pharma, chemistry,…

Academic and Industrial PhDs

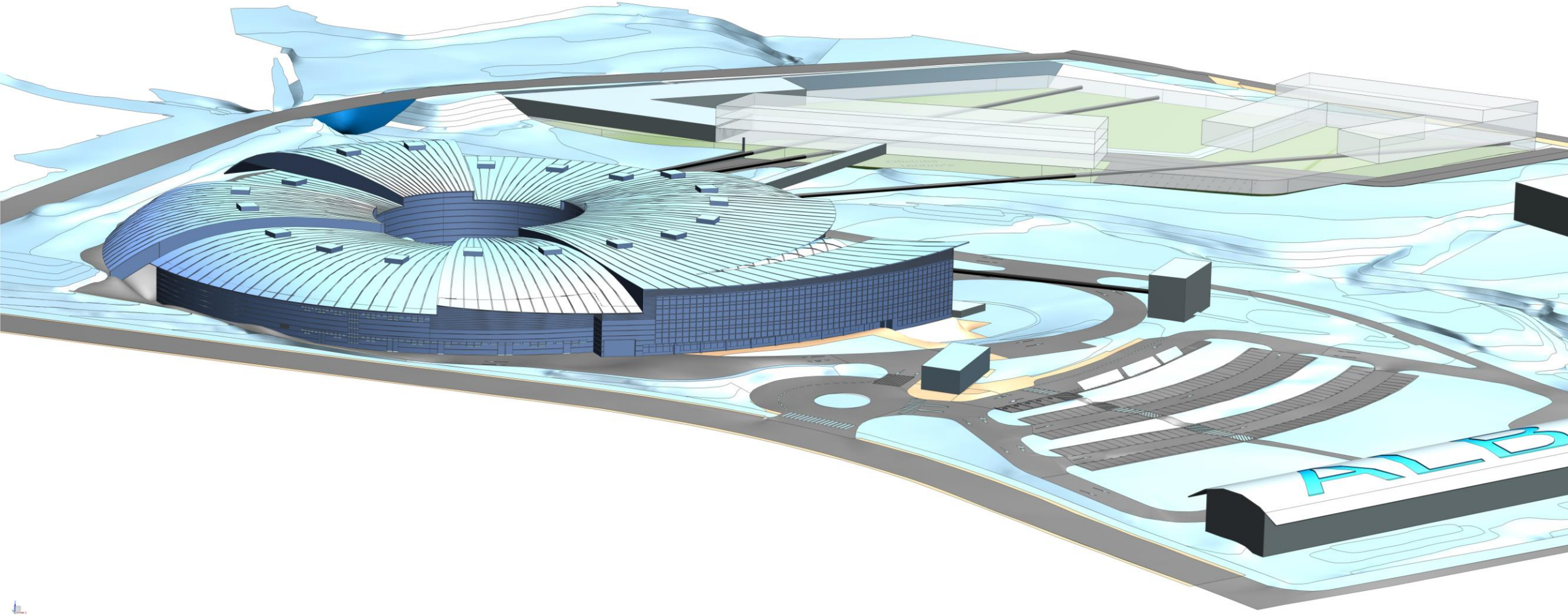
African School of Fundamental Physics and Applications



Involvement in educational programs from schools to universities in Spain and abroad

Contributing to health, clean energy, advanced technologies, climate change, environment, food, agriculture, transport & mobility, security, cultural heritage,…

ALBA II – the future



Evolution of Synchrotron Radiation Sources

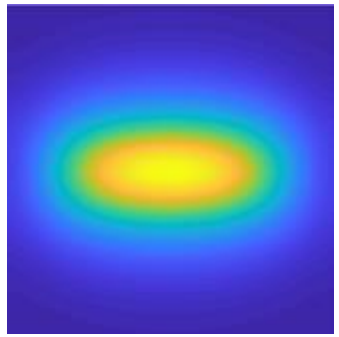
Increase in Brilliance

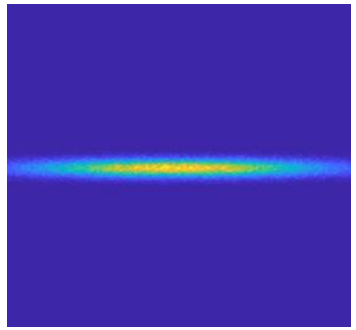
Increase in Resolution Power

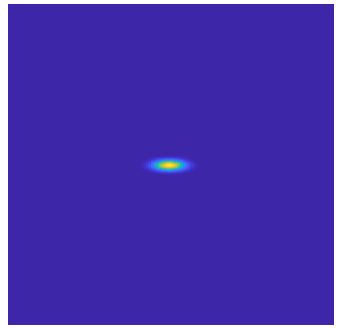
Increase in Coherence

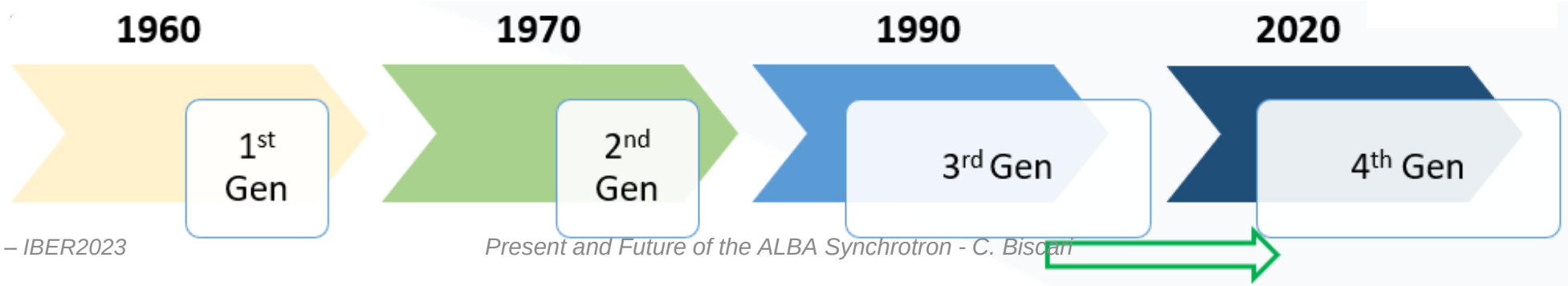
Increase in Data management capacity

Representation of photon beam on sample ⟶

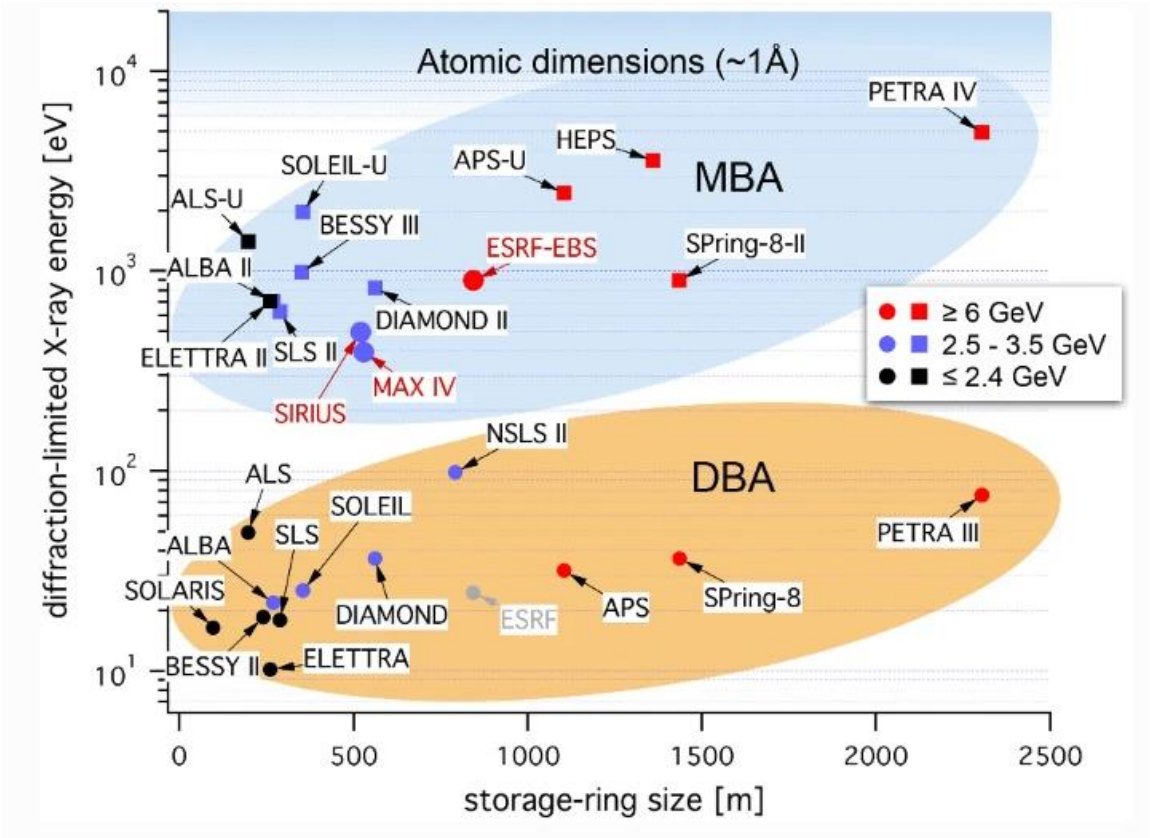


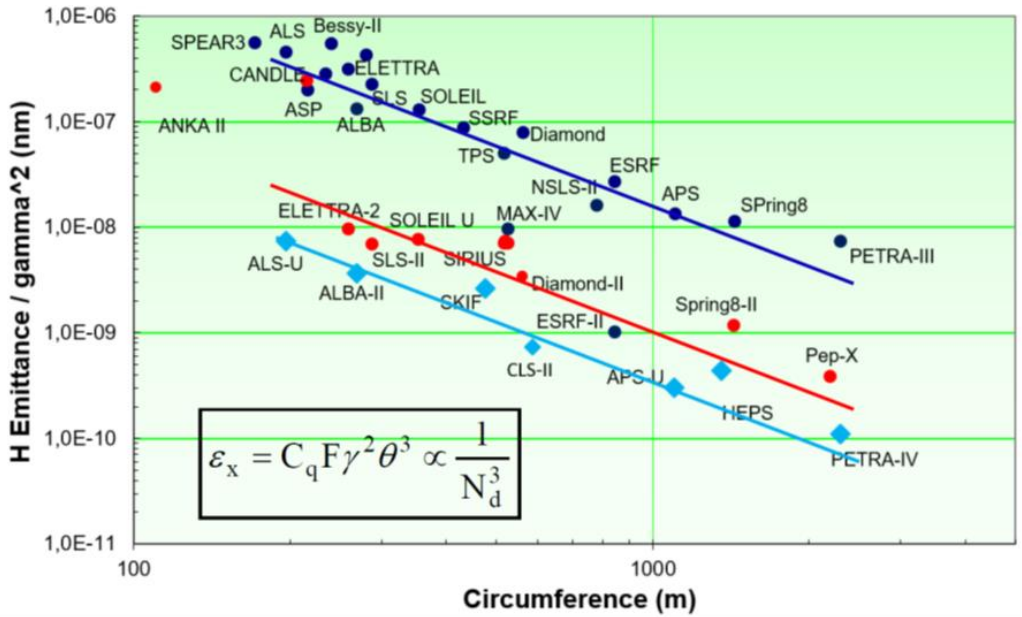






Towards 4th Generation light sources

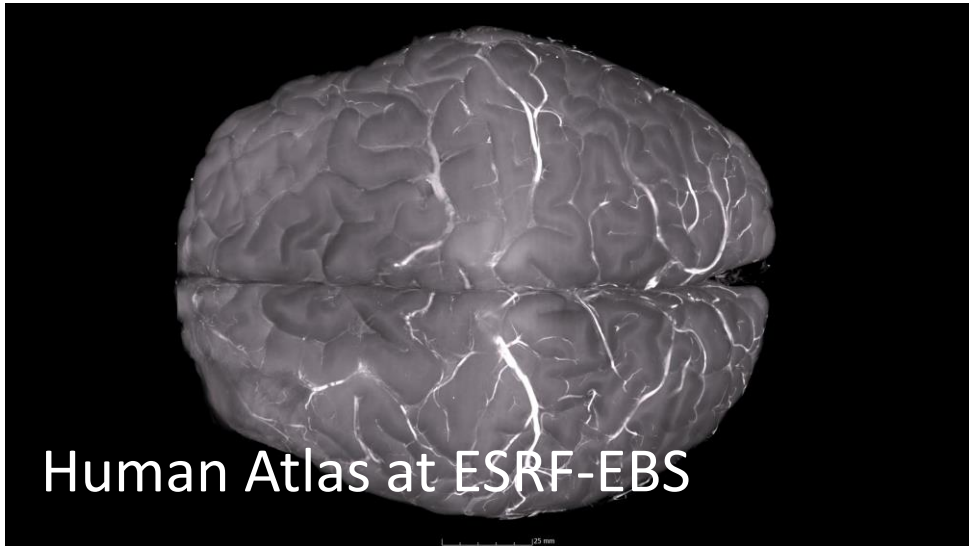


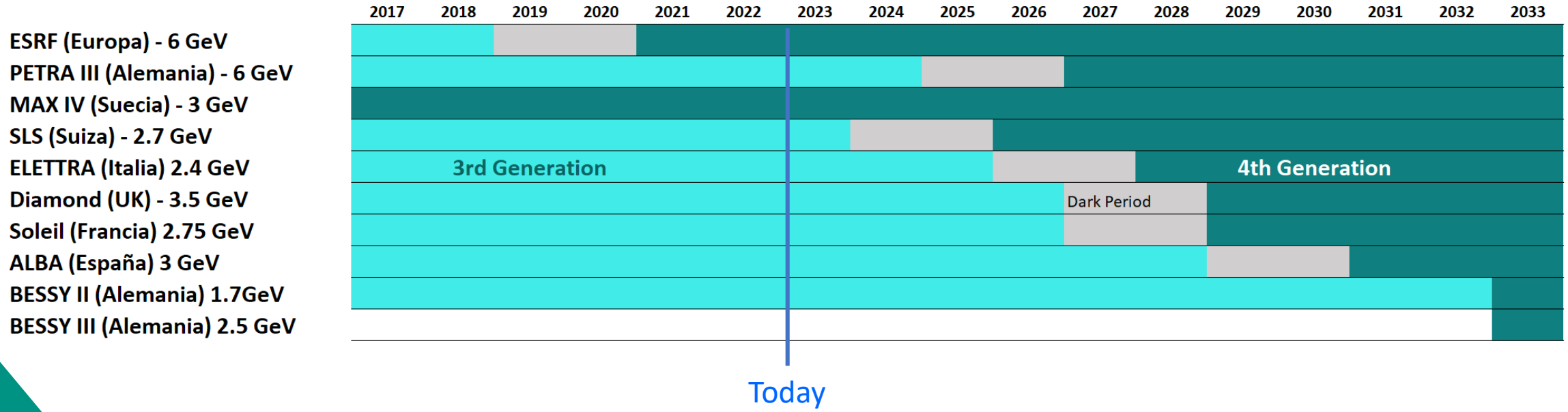


Abela, R., Biscari, C., Daillant, J. *et al.* The European strategy for accelerator-based photon science. *Eur. Phys. J. Plus* **138**, 355 (2023). https://doi.org/10.1140/epjp/s13360-023-03947-w

Evolution from 3rd to 4th generation in Europe

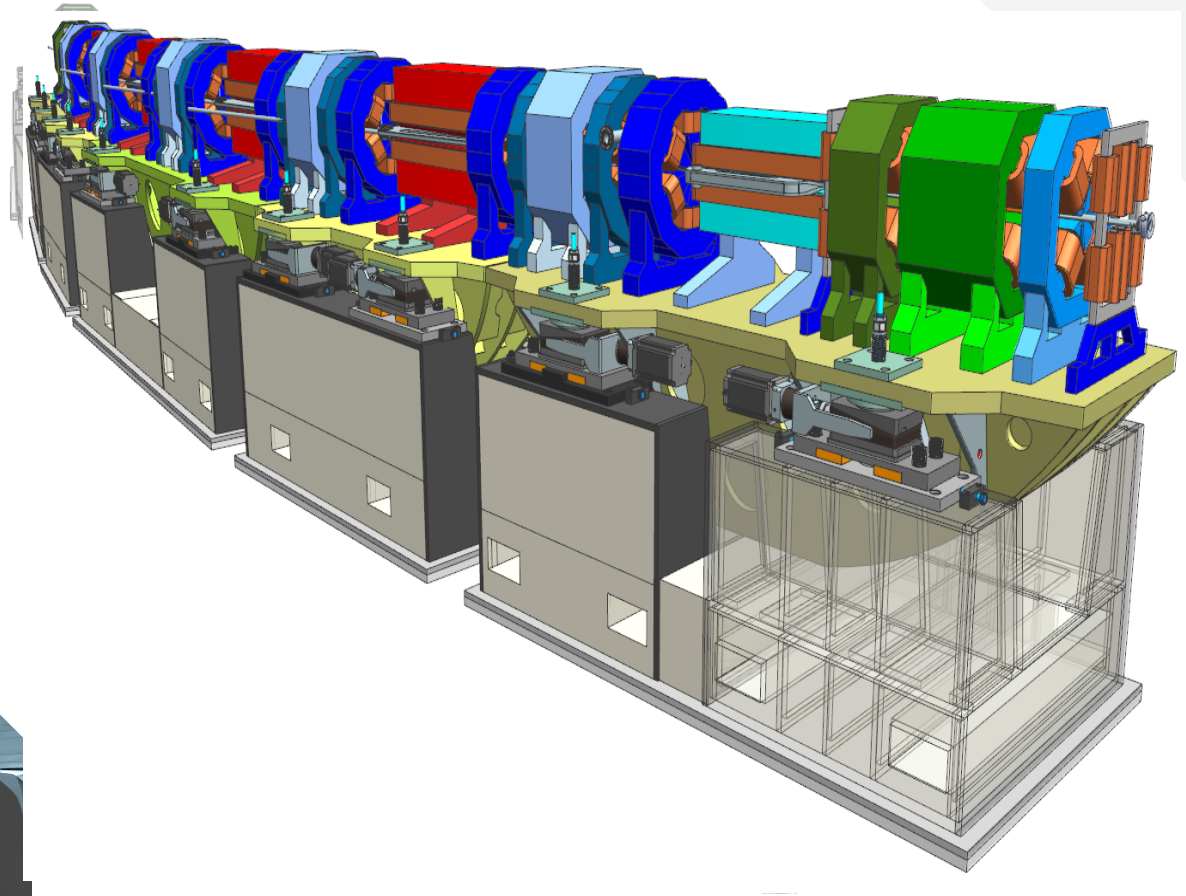
All synchrotrons in Europe (and in America and Asia) are evolving towards the 4th generation

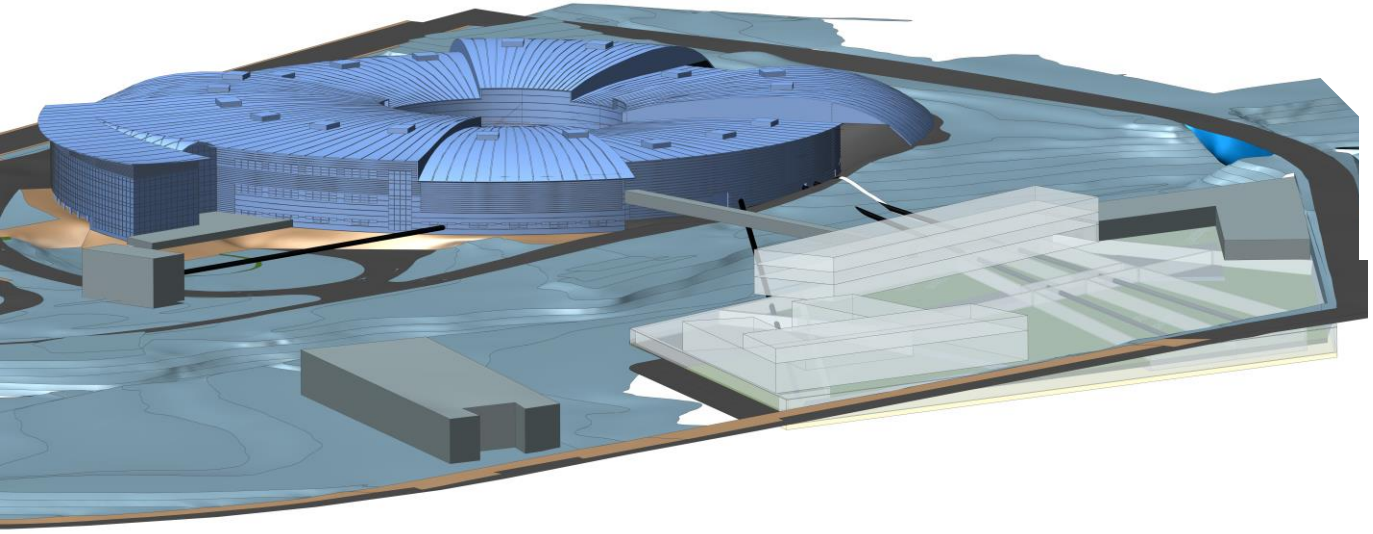




ALBA II design as today

- 4th generation light source
- Emittance 185 pm (25 times smaller than ALBA)
- Current 300 mA (+ 20% with respect to ALBA)
- Increase of brilliance by orders of magnitude
- Increase of coherence
- **Advanced properties for imaging, spectroscopy, diffraction**



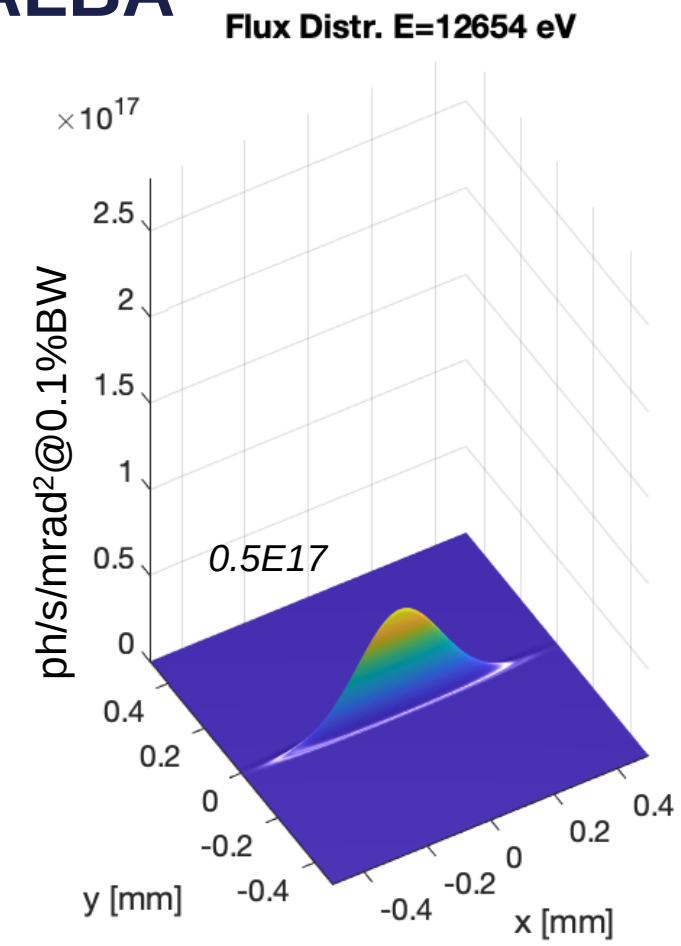


Accelerator design in progress

Flux density on sample (hard x-ray undulator)

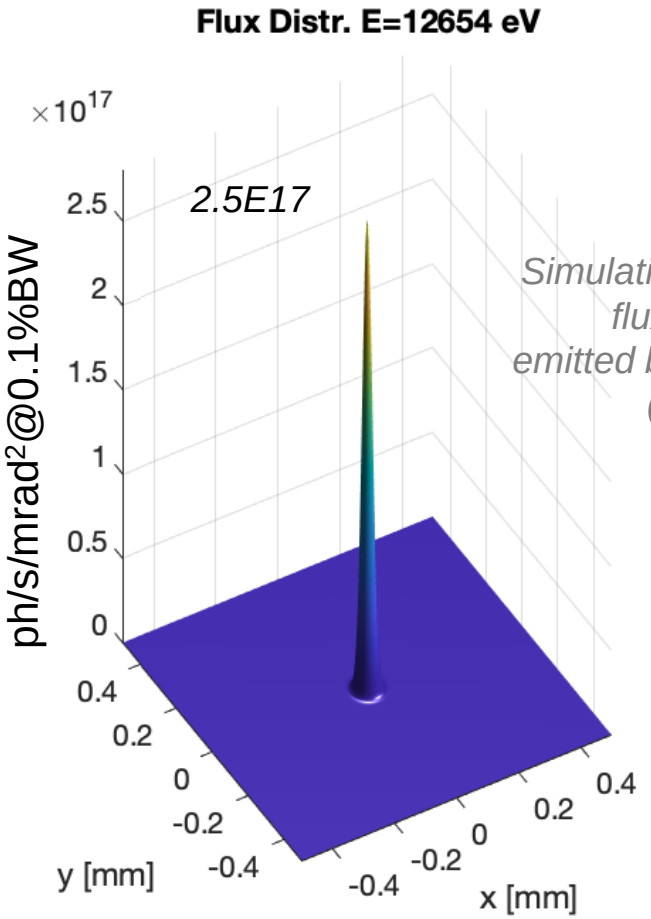
ALBA

e- beam transverse dimensions: 50 μm (like the diameter of a hair, and like the eye resolution power)



ALBA II

e- beam transverse dimensions: <10 μm



Simulation of the flux density emitted by IVU21 (XALOC)

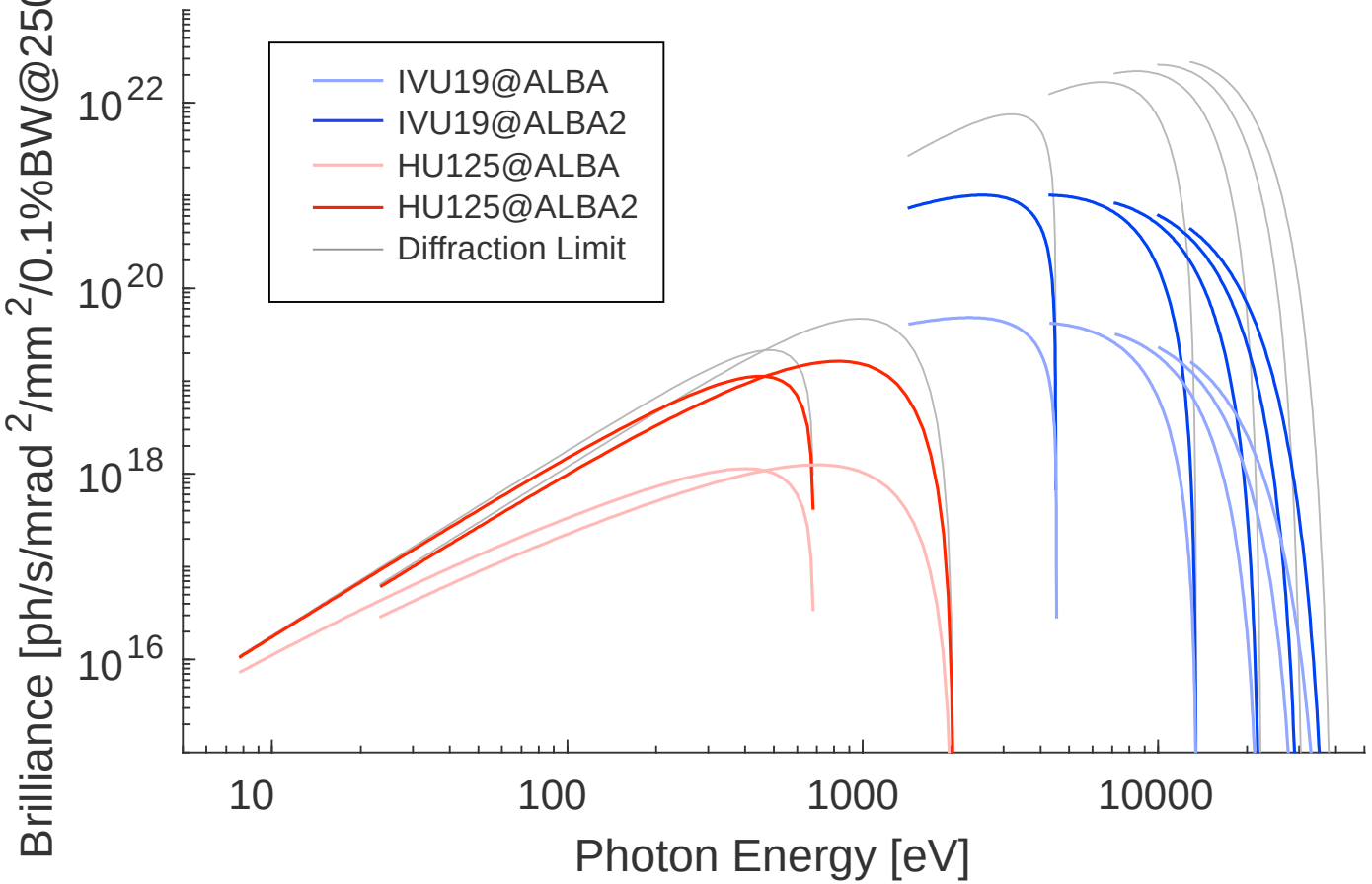
1 μm = 1 mm/1000

For hard x-Ray BLs the emission cone is dominated by the electron beam size, Although the integrated flux does not change, it is concentrated in a narrower cone.

Brilliance and coherence

All present beamlines will be maintained and refurbished

Comparison of the brilliance emitted at ALBA, ALBA-II and the diffraction limit for a SXR and a HXR undulator



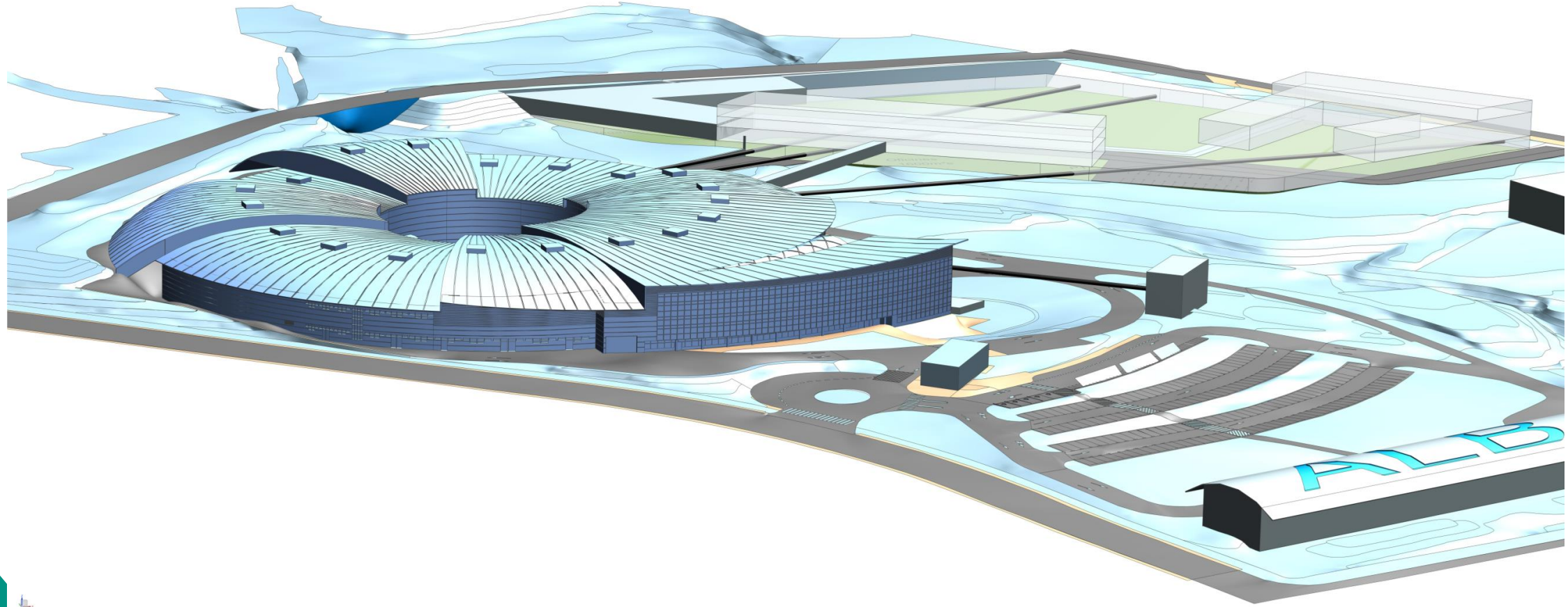
For soft x-rays brilliance does not improve very much, because it is already very ***close to the diffraction limit****.*
The coherent fraction is large.

For hard x-rays ***brilliance improves a lot****, but it is still far from the diffraction limit.*
The coherent fraction is smaller.

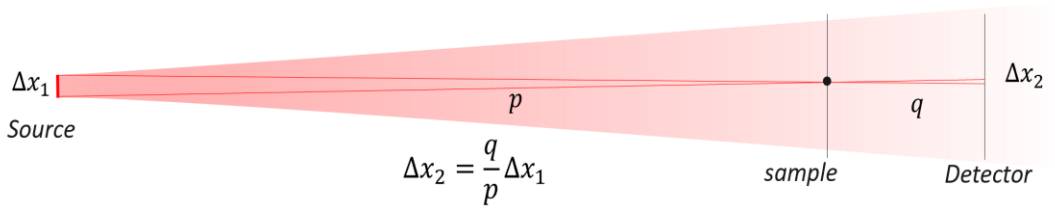
Long beamlines still allow for higher degree of coherence, but at the expense of flux.

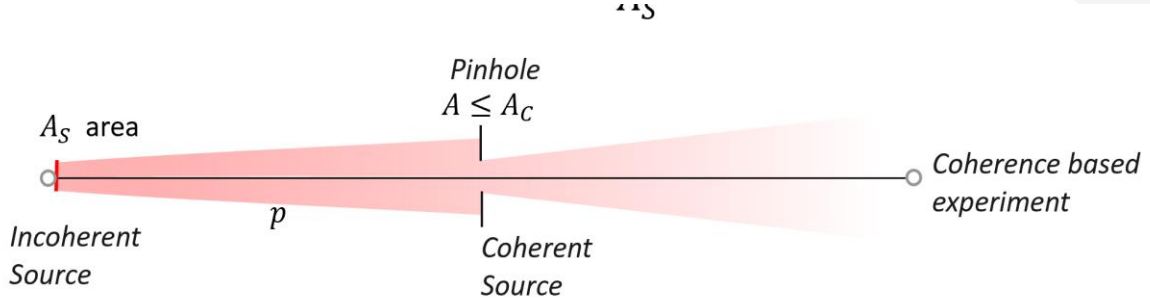
Long Beamlines increase resolution and coherence

New plots have been assigned to ALBA for building long BLs



The longer the beamlines, the higher their resolution and coherent fraction

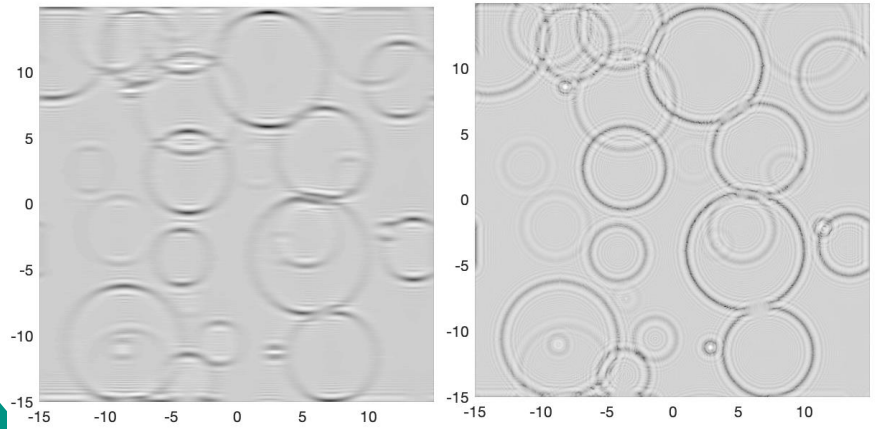




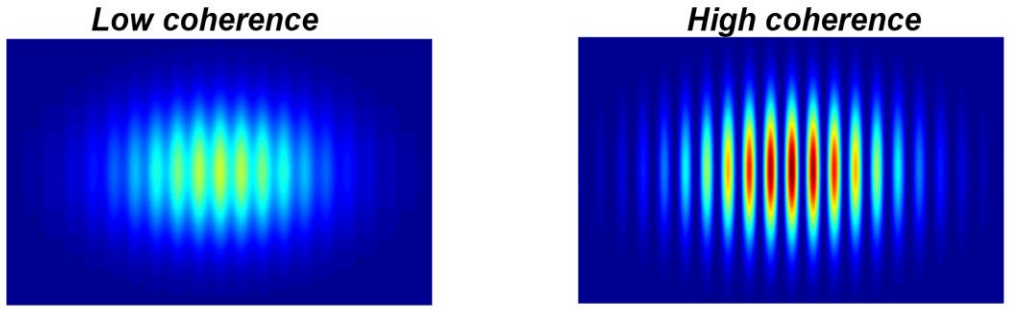
Beam spot size on sample

$$\Delta x_{Geom} = \frac{q}{p}\Delta x_{Source}$$

Large source, short BL, *small source, long BL*



Most basic example: Young's Double slit interference



Coherent fraction

$$A_C(p) = \frac{(\lambda p)^2}{A_S}$$

Long Beamlines – now defining the characteristics

Main building (or extension)

Dead length

Far Experimental Hall

BL02 ID source

BL03 Superbend

BL04 ID source

Stream course (not usable)

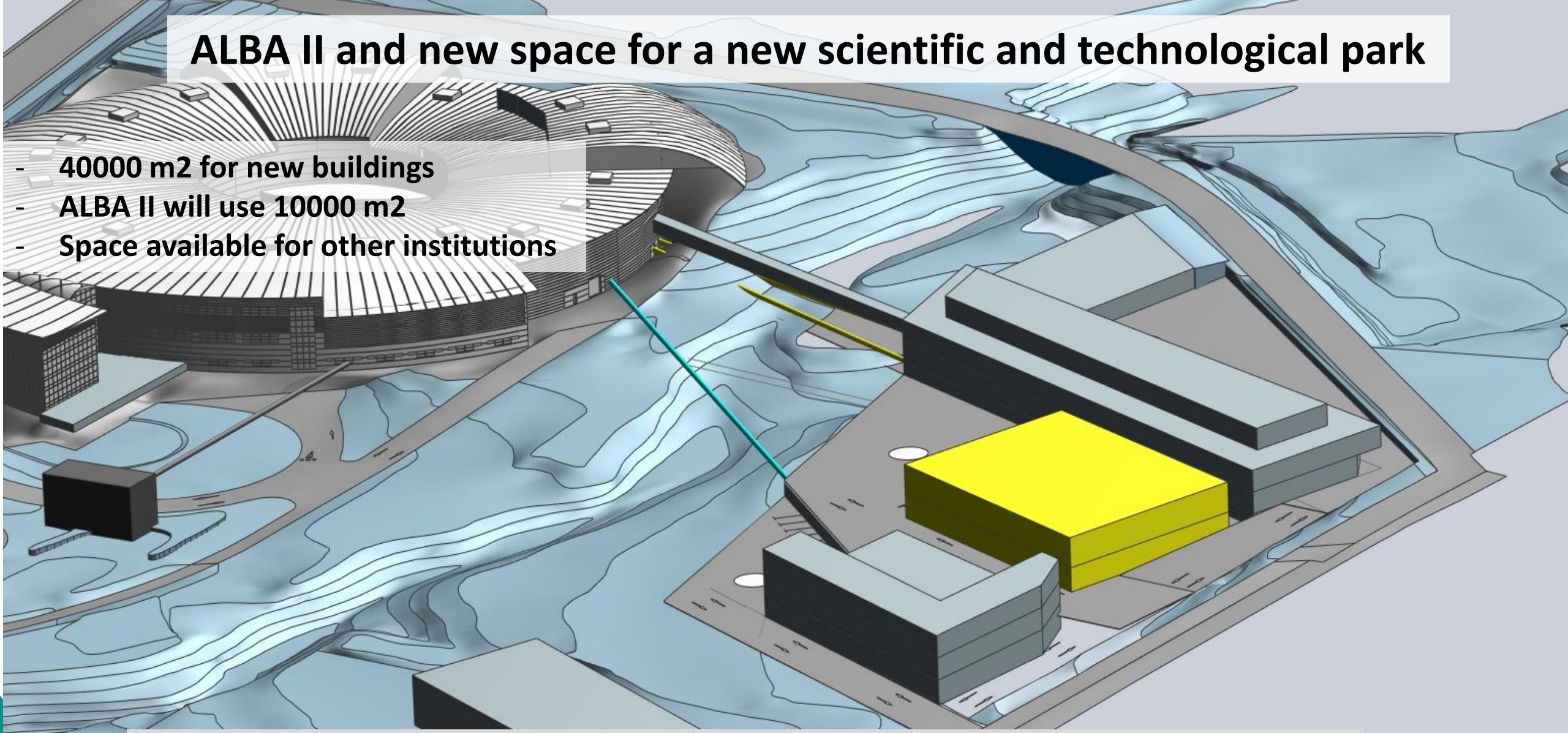
BL08 ID source

Decision on the first two to be taken in the next few weeks

Port	EH	FEH
BL02 (ID)	25-42 m	134-249 m
BL03 (SBM)	28-41 m	141-255 m
BL04 (ID)	25-42 m	173-292 m
BL08 (ID)	22-42 m	85-125 m

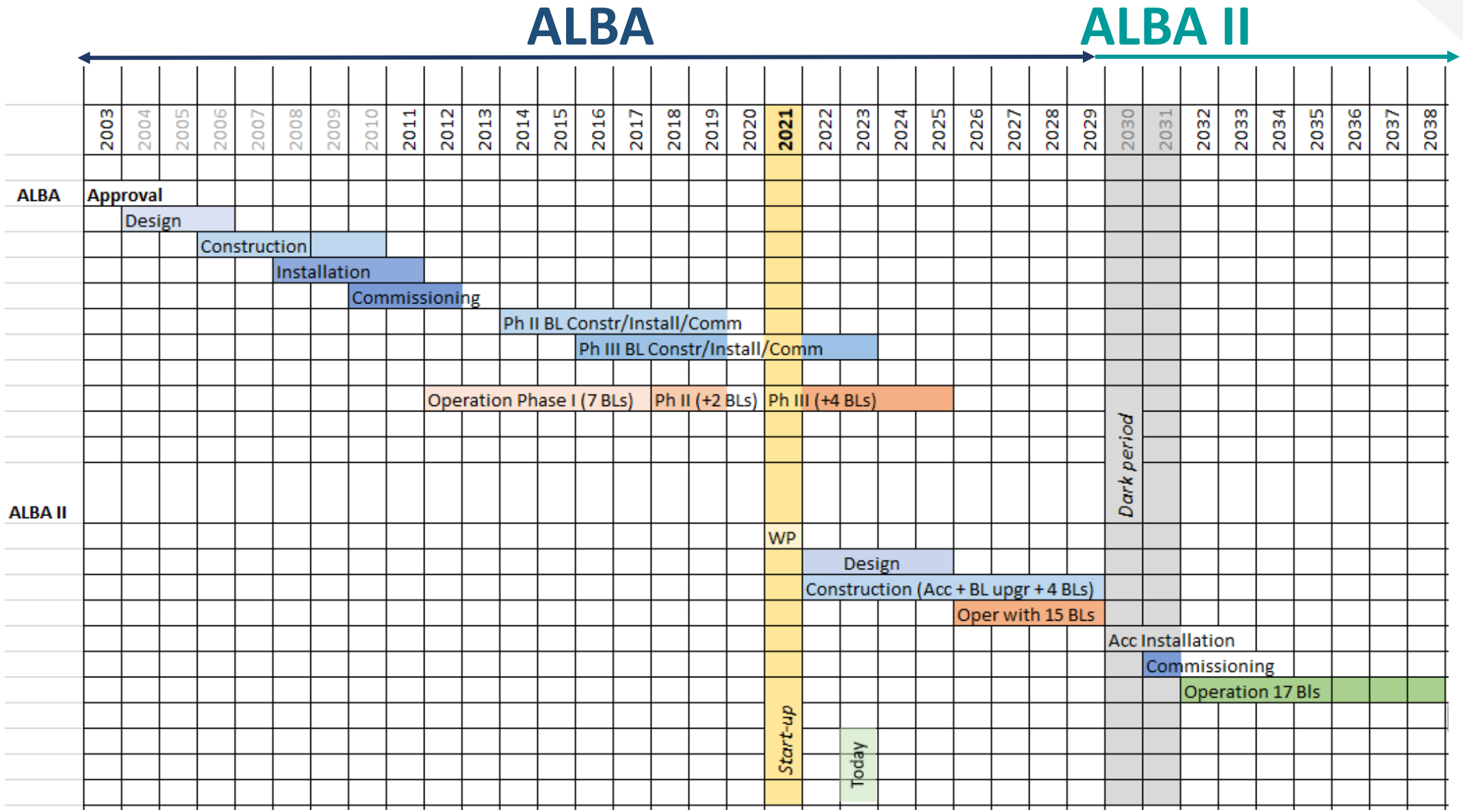
ALBA II and new space for a new scientific and technological park

- 40000 m2 for new buildings
- ALBA II will use 10000 m2
- Space available for other institutions



The potential of ALBAII is boosted by the **availability of nearby green field**
Activities for plot urbanization just started

Tentative ALBA II timeline



What ALBA II will provide

Full infrastructure to tackle the grand challenges of our time for the Spanish and European users

ALBA II combines the excellence and availability of the user program of ALBA with the development of full characterization suites for characterizing multi-lengthscale problems

- Enhanced **microscopy** capabilities
- **Multimodal methodologies** to address complex development tasks
- **High throughput capabilities** and big-data connectivity for fast innovation
- And **optimized operando env**ironments to optimize functional materials and devices


IBER 2023
Thank you for
your attention