The Extremely Brilliant Source (EBS) – a European effort to pioneer synchrotron X-ray science

9th Meeting of ENURS/CDRSP

Marinha Grande, 21 June 2023

Michael Krisch
on behalf of the ESRF staff

ESRF
The European Synchrotron

30 years of science

BRINGING NATIONS TOGETHER, PIONEERING SYNCHROTRON SCIENCE

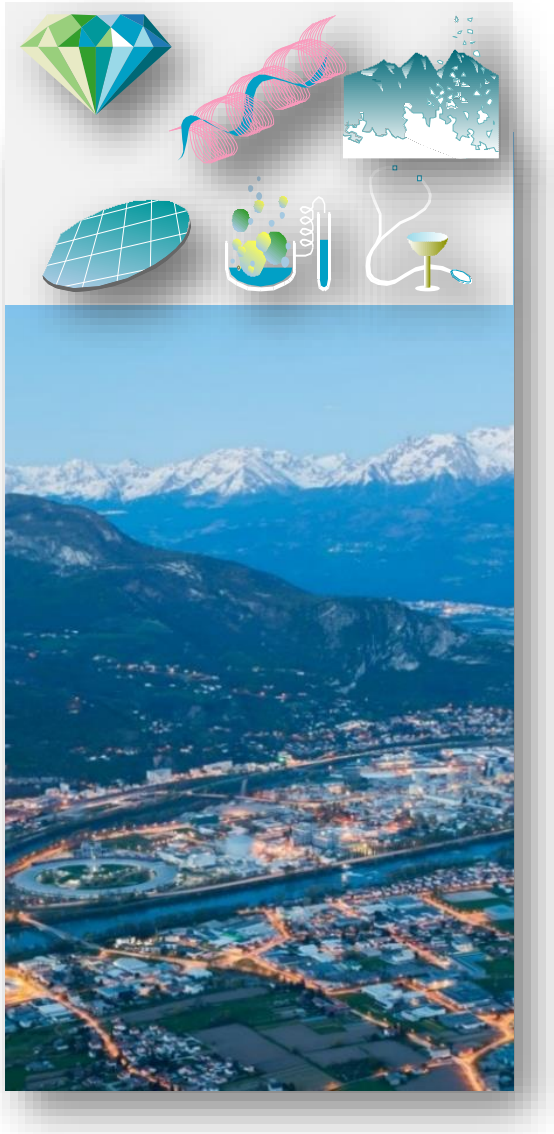
21 PARTNER COUNTRIES

13 Member states:	
France	27.5 %
Germany	24.0 %
Italy	13.2 %
United Kingdom	10.5 %
Russia	6.0 %
Benesync (Belgium, The Netherlands)	5.8 %
Nordsync (Denmark, Finland, Norway, Sweden)	5.0 %
Spain	4.0 %
Switzerland	4.0 %
8 Associate countries:	
Austria	1.75 %
Israel	1.75 %
Poland	1.00 %
Portugal	1.00 %
India	0.66 %
Czech Republic	0.60 %
South Africa	0.30 %
Hungary	0.25 %

ESRF MISSIONS AND VALUES

- **Bring nations together** through science and contributing to the construction of the European Research Area
- **Pioneer X-ray synchrotron science** and provide value to all partner countries: new science, new technology, training scientists, engineers, as well as technical and administrative staff
- **Provide State-of-the-art X-ray facilities** to unveil and link atomic structure complexity to functioning of materials and living matter in: health, energy, environment, new and sustainable materials for industry, etc...
- **Train and inspire** the young generation and society

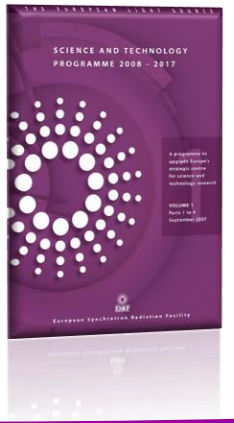
OUTLINE OF THE PRESENTATION

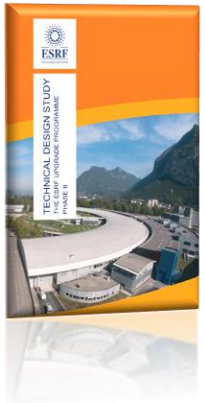


- ESRF-EBS: a dream becomes reality
- Status of the beamline portfolio
- New access modes
- Conclusions

ESRF UPGRADE PROGRAMME PHASE I (2009-2015) & PHASE II (2015-2023) – EBS

Purple Book
January 2008





Orange Book
January 2015

ESRF UPGRADE PHASE I (2009-2015) - 180 M€ :

- 19 upgraded or deeply refurbished beamlines
- Upgrade and renewal of facilities and support labs
- Study for a new storage ring

ESFRI

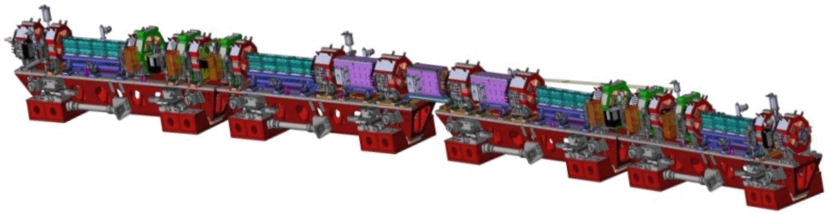
European Commission

ESRF-EBS
Extremely Brilliant Source (2015-2023) - 150 M€

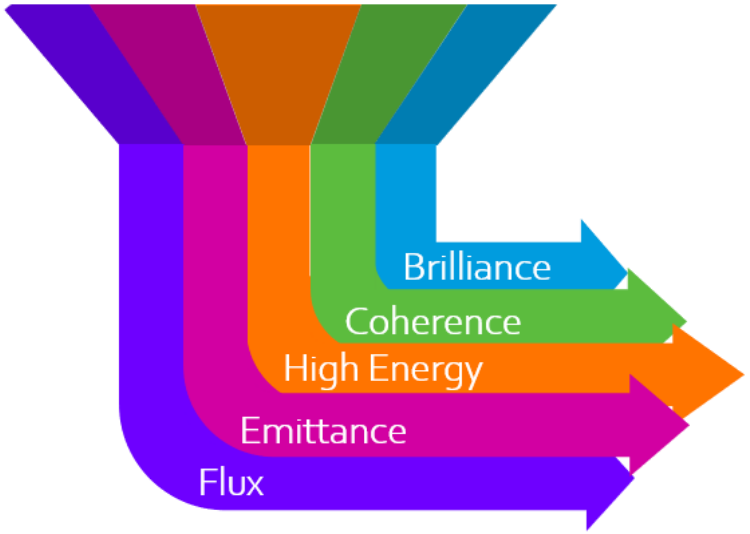
- A new generation of synchrotron storage ring
- Four new EBS beamlines
- Detector and instrumentation
- Data Analysis as a Service

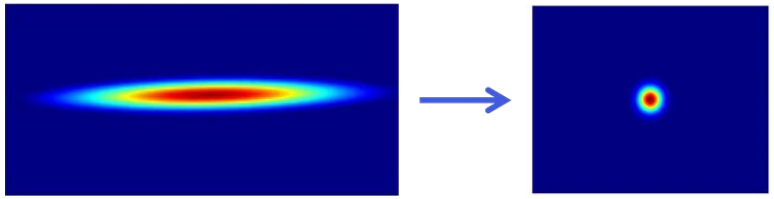
2009 → 2015 → 2023

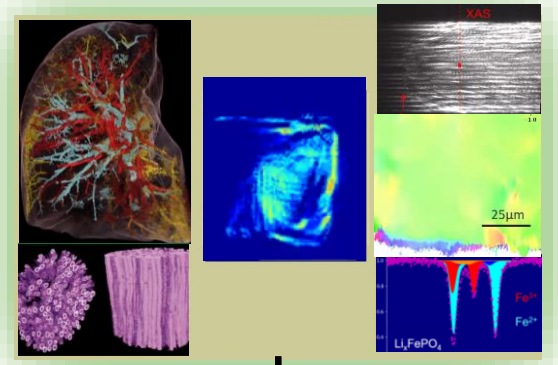
ESRF-EBS IMPACT ON THE EXPERIMENTAL PROGRAMME



HMBA lattice



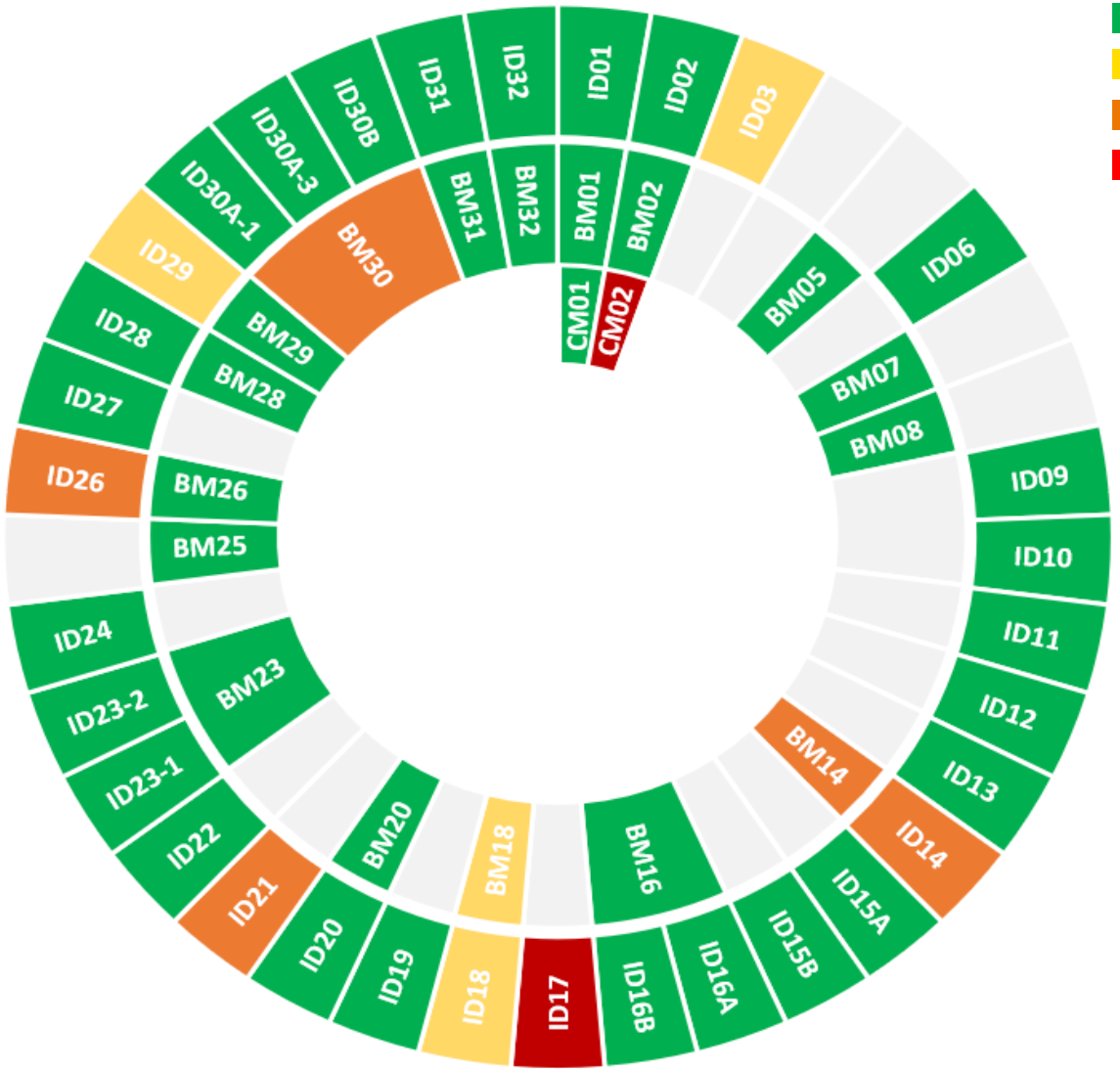




× 30 Trans. Coherence | **× 100 Brilliance** | **÷ 100 Hor. Emittance**

- ✓ Multiscale (mm → µm → nm)
- ✓ Pump probe experiments
- ✓ Time resolution
- ✓ Conditions: extreme (T,P), *in-situ, operando*
- ✓ Better capabilities: energy resolution, sensitivity, throughput, selectivity..

BEAMLINE PORTFOLIO



- Operational
- EBSL project
- Refurbishment
- On hold/New construction

Courtesy: Delphine Pauwels

PROGRESS ON NEW / REFURBISHED BEAMLINE CONSTRUCTIONS (2022 – 2025)

EBSL8 (ID29) : Serial Macromolecular Crystallography Beamline
Operational September 2022

EBSL3 (BM18)*: High throughput large field phase-contrast tomography
Operational September 2022

EBSL2 (ID03): Beamline for Hard X-Ray Microscopy
Operational March 2024

EBSL1 (ID18): Beamline for Coherence Applications
Operational 2025 ?

ID24-DCM: High brilliance XAS beamline (XAS/XES)
Operational February 2023

ID21:** X-ray Microscopy beamline
Operational September 2021

ID18 (→ ID14): Nuclear Resonant Scattering
Operational February 2024

ID26*:** XES beamline
Operational September 2020

** Large sample stage installation on-going*
*** Finalization of the commissioning of the new DCM and nanoscope*
**** Upgrade in progress (double mirror vessel, detector and crystal spectrometers); new DCM in 2025*

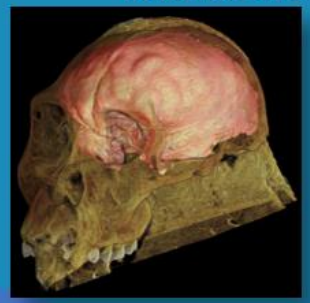
EBSL3 – BM18: HIGH THROUGHPUT LARGE FIELD PHASE-CONTRAST TOMOGRAPHY

High sensitivity phase-contrast tomography in large and complex samples

Biomedical imaging

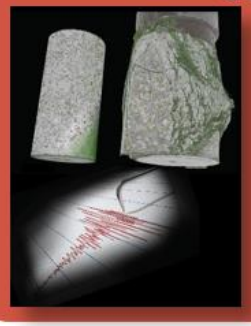
- A new scale in human body knowledge
- Understanding effects of diseases

Natural and cultural heritage



- Understanding the evolution of life on earth
- Non-invasive structural study of archaeological specimens and art pieces

Geology



- Origin of earthquakes
- Mechanisms of volcanoes
- Climate change

Material sciences

- Non-destructive control of large devices (batteries, complex mechanical parts)
- Additive manufacturing (in-situ and ex-situ)

Industrial applications

- Testing high-value objects
- Analysis of 3D structures of industrial products
- Industrial processes

ID14 (ID18): NUCLEAR RESONANCE SCATTERING

Geoscience and Exoplanets

- Identification of chemical phases
- Electronic and magnetic transitions
- Sound velocities, elastic moduli, thermodynamics and heat conductivity

Magnetism at Megabars

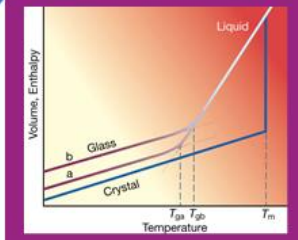
- Magnetic states
- Magnetic transitions
- Transition from ferromagnetism to superconductivity

Electronic properties, magnetism and atomic dynamics at extreme conditions

Superconductivity

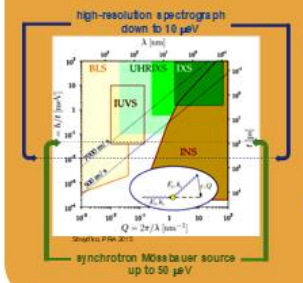
- Superconductivity at high pressure
- Visualization of the vortex structure

Glass transition



- Dynamical heterogeneities
- Time and length scale

No-man's land



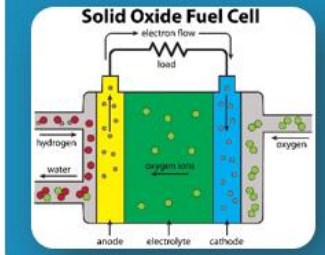
- Entering "No-man's land" between meV and neV energy transfer
- Anharmonicity, phonon life-time

ID21: X-RAY MICROSCOPY BEAMLINE

Cultural Heritage

- What are the masters' secrets?
- Why and how do artworks degrade?

Manufactured materials



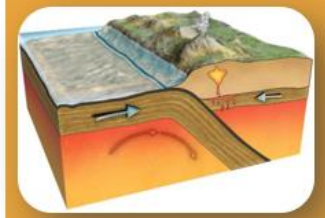
- Efficiency and stability of manufactured materials
- Chemical reactions at boundaries in electrodes, catalysts and micro-electronics

Identification and location of chemical markers in complex materials

Environmental science

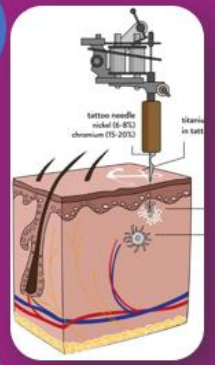
- Positive and negative impacts of materials in the environment
- Metal accumulation in plants

Earth and planetary sciences



- Chemical signature (element composition, trace elements, speciation) of geological processes
- Paleoclimate

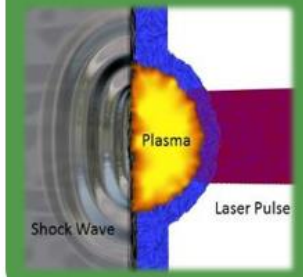
Health



- Interactions of manufactured materials (drugs, implants, tattoos, etc.) with living systems
- Chemical modifications induced by neuro-degenerative diseases

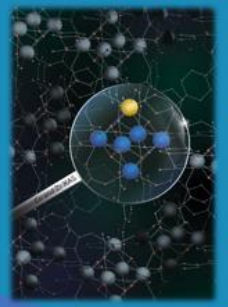
ID24 – ED: HIGH POWER LASER FACILITY

Laser shock science



- Warm Dense Matter
- Planets and Inertial Confinement Fusion
- Dynamic behavior of matter

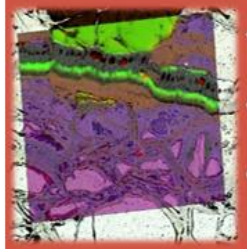
Structure of novel materials



- Batteries and fuel cells
- Nanoparticles
- Gas sensors and separators
- Drugs

Physics and chemistry of complex materials under relevant conditions

Environmental science

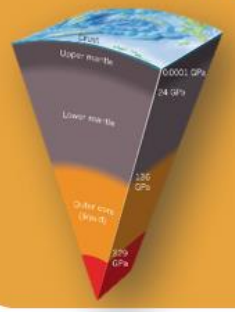


- Geo-resources
- Biogeochemical processes
- Impact of human activity on our environment

In-situ and *operando* chemistry

- Catalysis
- Synthesis
- Electrochemistry
- Photochemistry

Matter at extremes



- Planetary interiors
- Condensed matter physics
- Material sciences
- Materials under high pulsed magnetic field

ID27: HIGH FLUX NANO-XRD BEAMLINE FOR SCIENCE UNDER EXTREME CONDITIONS

High Density Physics

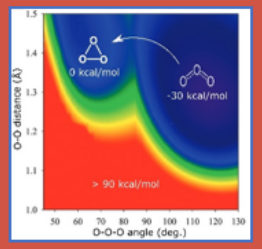
- Search for room temperature superconductivity
- Structure of metallic hydrogen

Materials under Extreme P&T

- Synthesis of superhard materials
- Materials under high stress

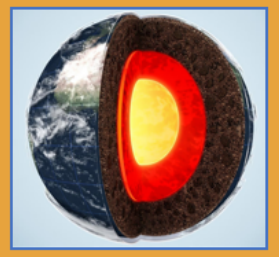
In situ studies of materials subjected to extreme P,T conditions

High Pressure Chemistry



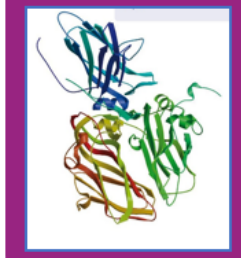
- Emergence of structural complexity
- New high pressure compounds

Earth and planetary sciences



- Structure and dynamics of deep Earth materials
- Understanding large scale geological phenomena (volcanism, plate tectonics)

Soft and biological matter under pressure



- Polymerization
- Protein conformation

NEED FOR NEW USER ACCESS MODES

1. STANDARD Research Proposals (6 months)

   Two deadlines: 1st March - for beamtime between August and February the following year; 10th September - for beamtime between March and July.

2. LONG TERM PROJECT Proposals (1-3 years)

   One annual deadline for LTP submission on 15th January (evaluation in April BTAP)

3. Structural Biology BAG Proposals (2 years)

   Applications submitted once per year (beamtime is awarded automatically for the interim 6 months): 1st March or 10th September

4. Structural Biology Rolling Proposals (6 months)

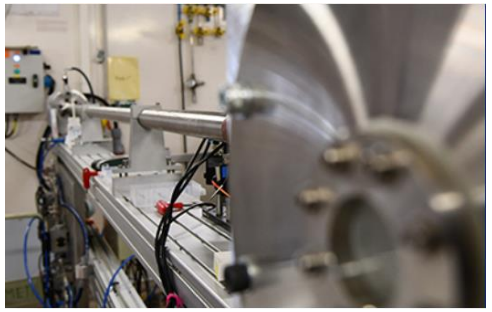
   Proposals may be made at ANY time – no deadline (designed to ensure rapid access to ESRF MX beamlines)

\+ New Access Modes

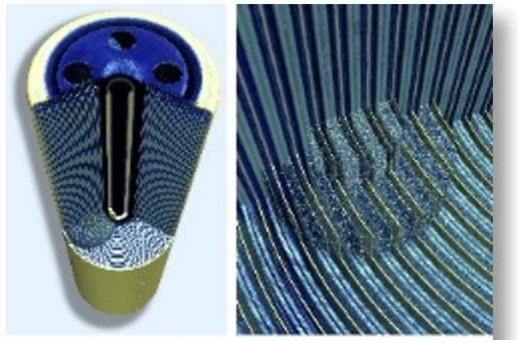
COMMUNITY ACCESS PILOTS

Historical Materials BAG

Shock BAG



Battery HUB



Rapid Access

Coordinated Access

ReMade@ARI
A hub for materials research

Pilots were launched in II/2021 (Shock BAG in I/2022)

NEW ACCESS MODES

Science-driven BAG

a *specific science community* selects the scientifically most promising experiments fostering (i) collaboration and (ii) the most effective use of the available beamtime

(HISTORICAL MATERIALS)

+

Technique-driven BAG

the entire user community of *a specific technique* selects the scientifically most promising expts fostering (i) collaboration, (ii) pooling of community expertise and resources, and (iii) the most effective use of the beamtime

(SHOCK BAG)

+

Science HUB

ESRF channels a part of its resources into *a science hub in selected areas* of the highest societal relevance, fostering (i) collaboration and (ii) maximise impact of the use of ESRF resources

(BATTERY HUB)

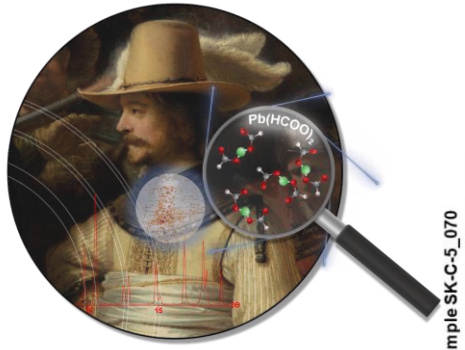
https://www.esrf.fr/CommunityAccess

Courtesy: Joanne McCarthy

EBS SCIENCE

Investigation of historical & model lead compounds in the paint

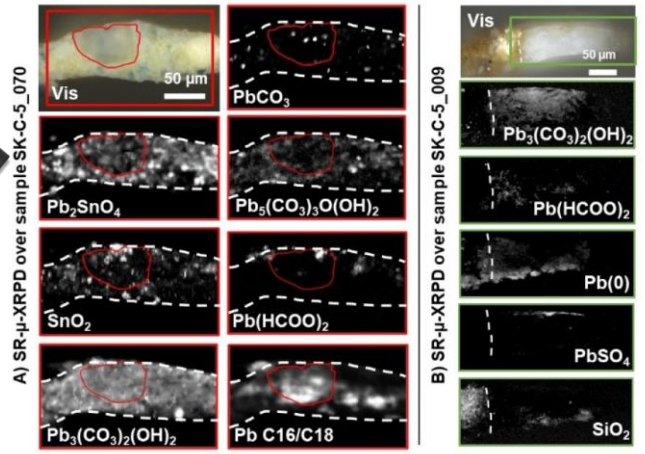
Rembrandt 1642, Rijksmuseum, Amsterdam



Historical Materials BAG

Conservators, historians, scientists
Operation Night Watch (2019)

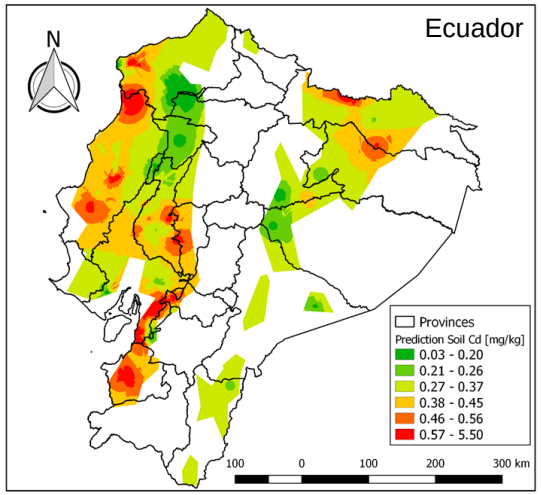
μ-X-ray diffraction on ID13

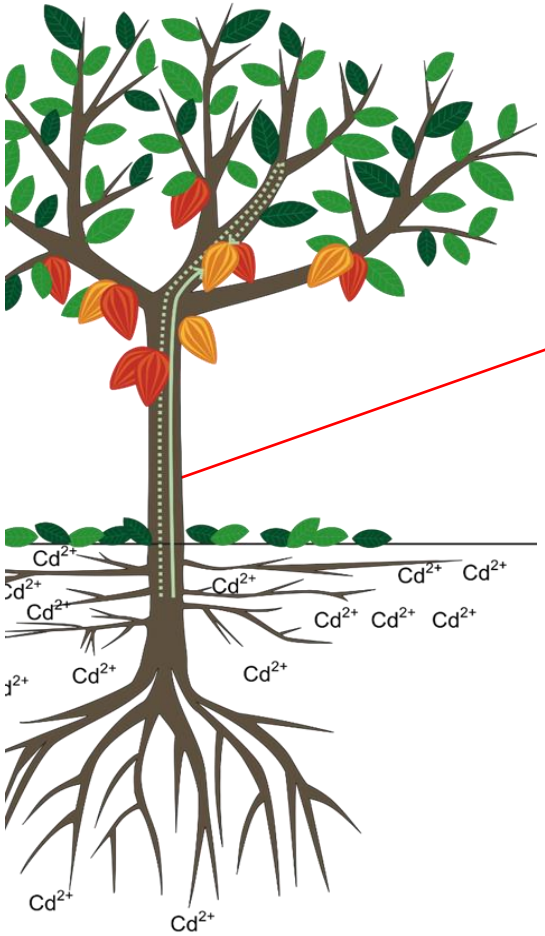


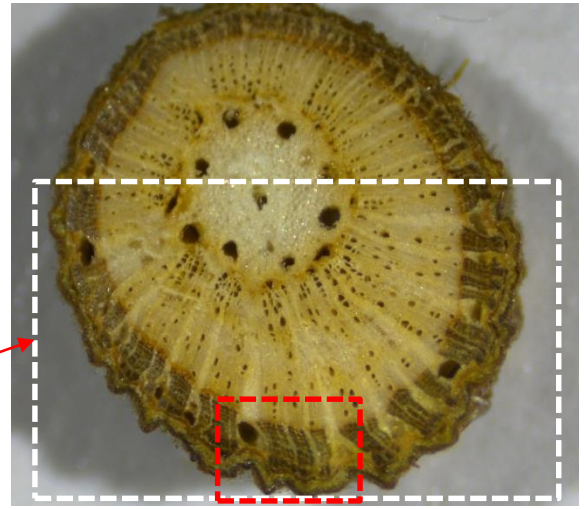
- Discovery of an unusual lead compound in the several areas of the painting
- New insights regarding the reactivity of lead driers in oil matrices in historical paintings
- New pathways for better conservation of the painting

Victor Gonzalez et al, Angewandte Chimie International Edition 2023

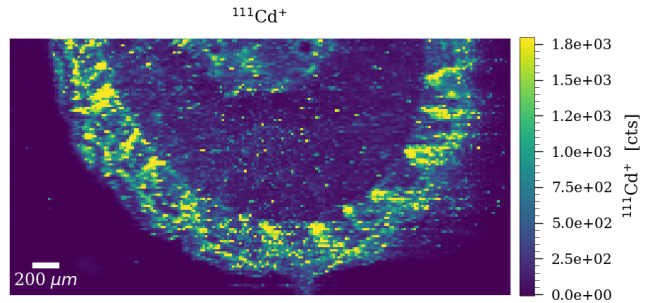
Cd IN CACAO BEANS: KEEPING CHOCOLATE SAFE

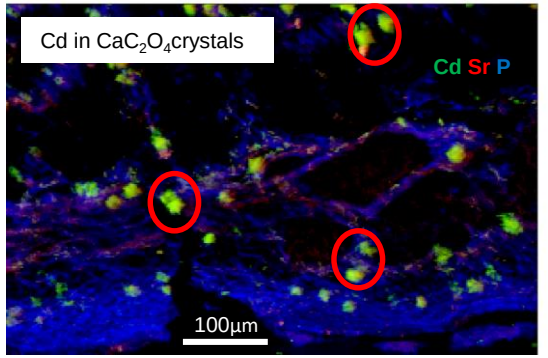






µXRF





µXRF at ID21

- ✓ Cryo-analysis
- ✓ Elemental + chemical information
- ✓ Resolution (EBS) 0.7x0.4µm^2 step size 1 µm
- ✓ Acquisition time:

Before EBS	EBS + new XRF detectors
13.3 h	20 min

<u>New EU and CODEX legal limit</u> (2019):
0.8 mg kg^{-1} Cd in dark chocolate (50% cacao)
0.1 mg kg^{-1} in milk chocolate (30% cacao)

<u>Use of 2 cultivars</u>

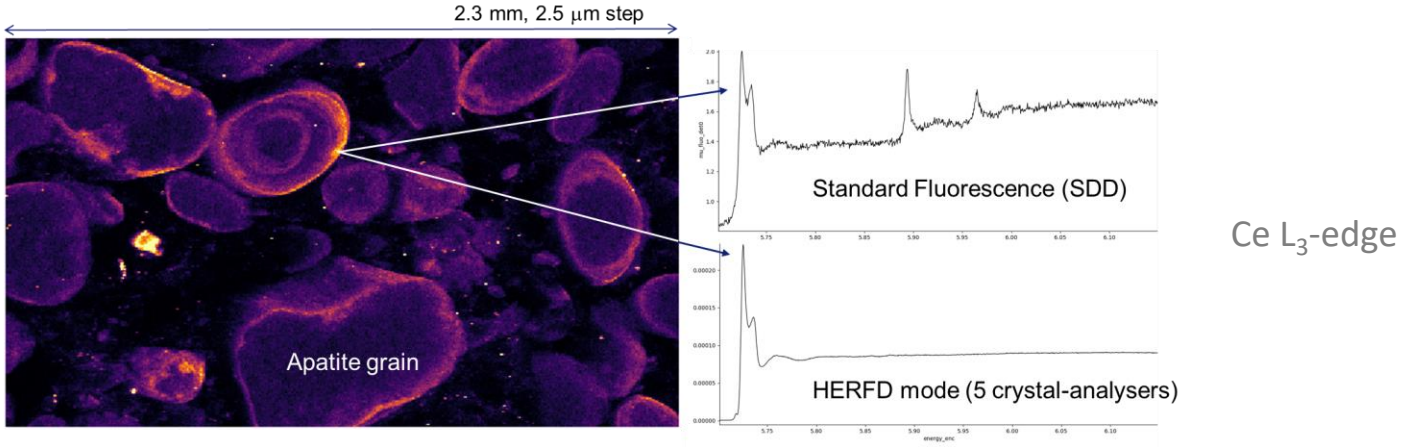
- Contamana (high Cd)
- Trinitario (low Cd)

ISTerre Institut des Sciences de la Terre
lcbm Laboratoire de Chimie et Biologie des Métaux

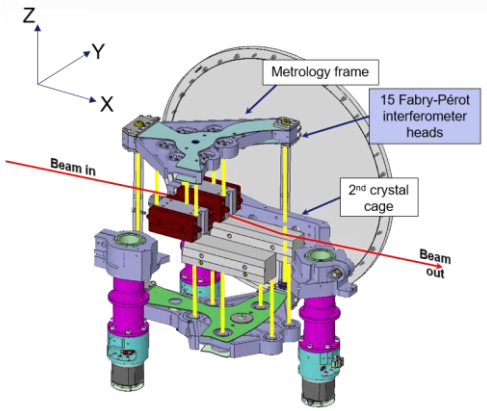
Courtesy of H. Michel-Castillo

Detection of trace elements in soils

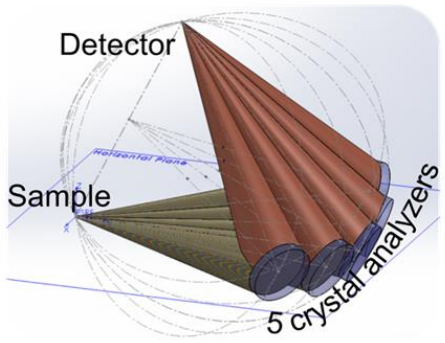
ES-1173: Ce in sedimentary Phosphate Deposit. By C. Bonnet (ESRF/Montpellier Univ);
Average Ce concentration = 40 ppm



ESRF monochromator (ID24)



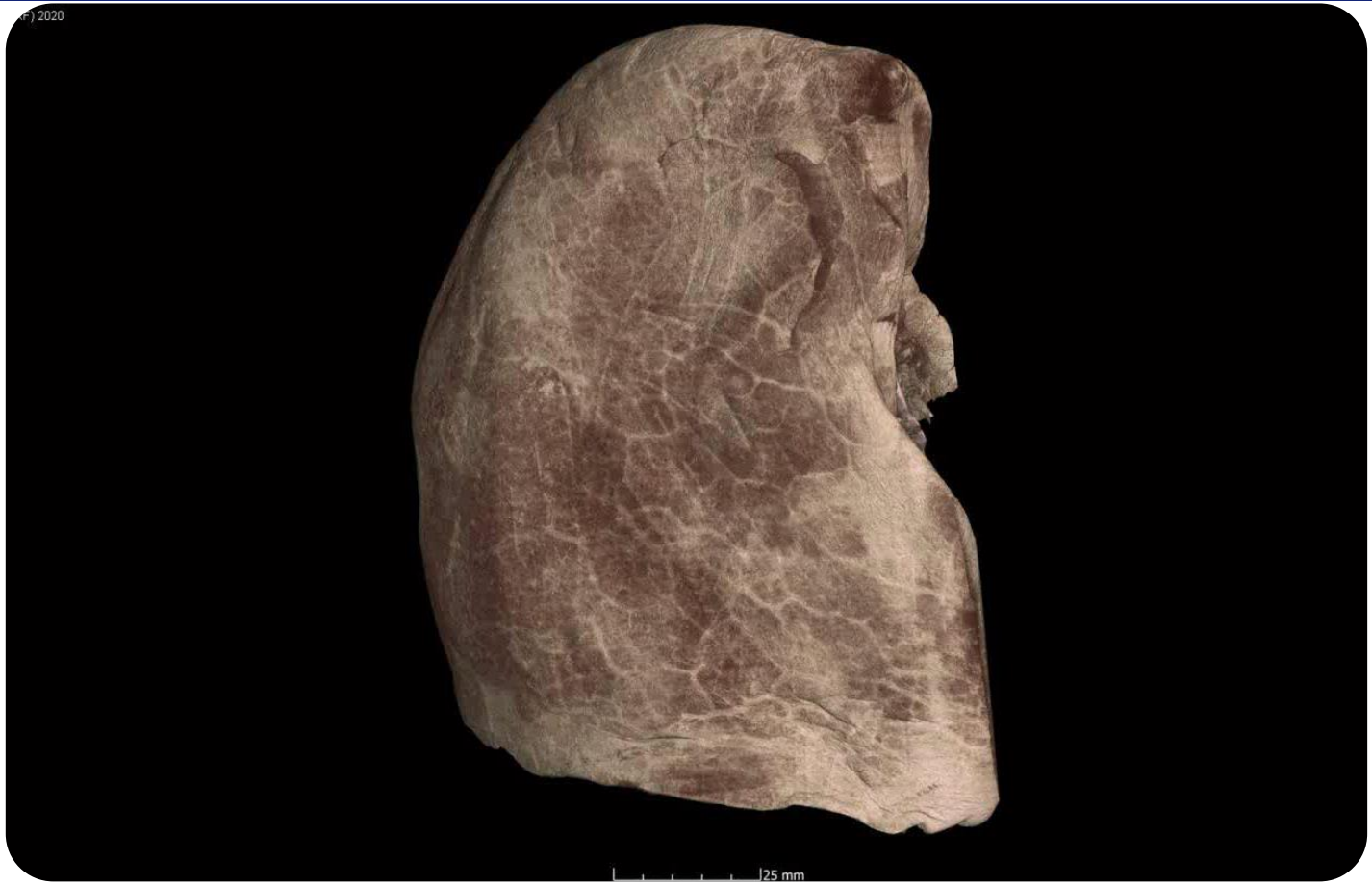
5 crystal analyser spectrometer



- ESRF-EBS source & stability
- Innovative instrumentation

New science

THE HUMAN ORGAN ATLAS HUB



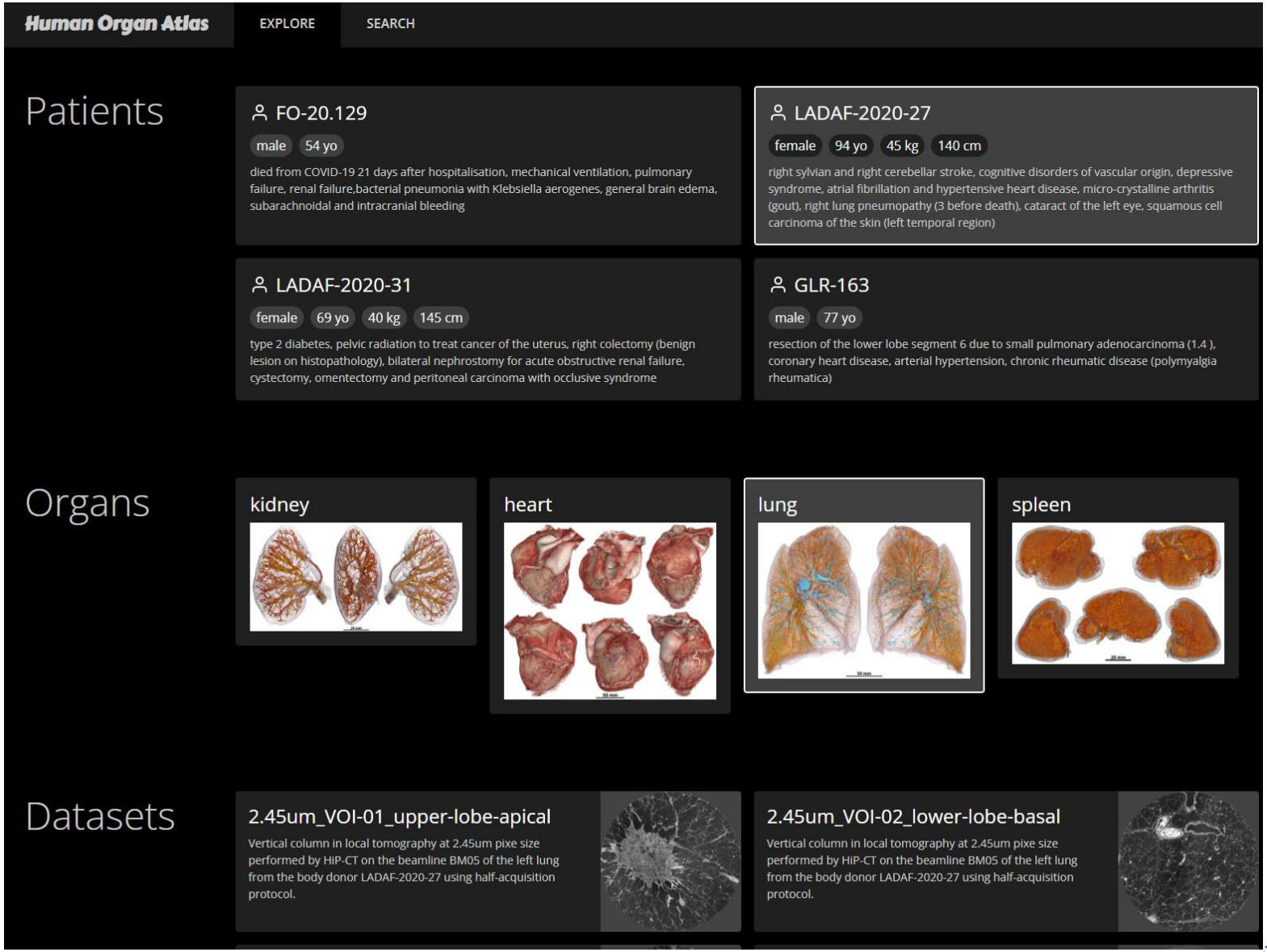
- excessive blood clotting
- massive blood vessel damage
- “Shunting mechanism” between two vascular systems: the one that oxygenates the blood and the one that feeds the lung tissue itself (intussusceptive neoangiogenesis)

The Human Organ Atlas

An open access database, developed as part of the EU PaNOSC project.

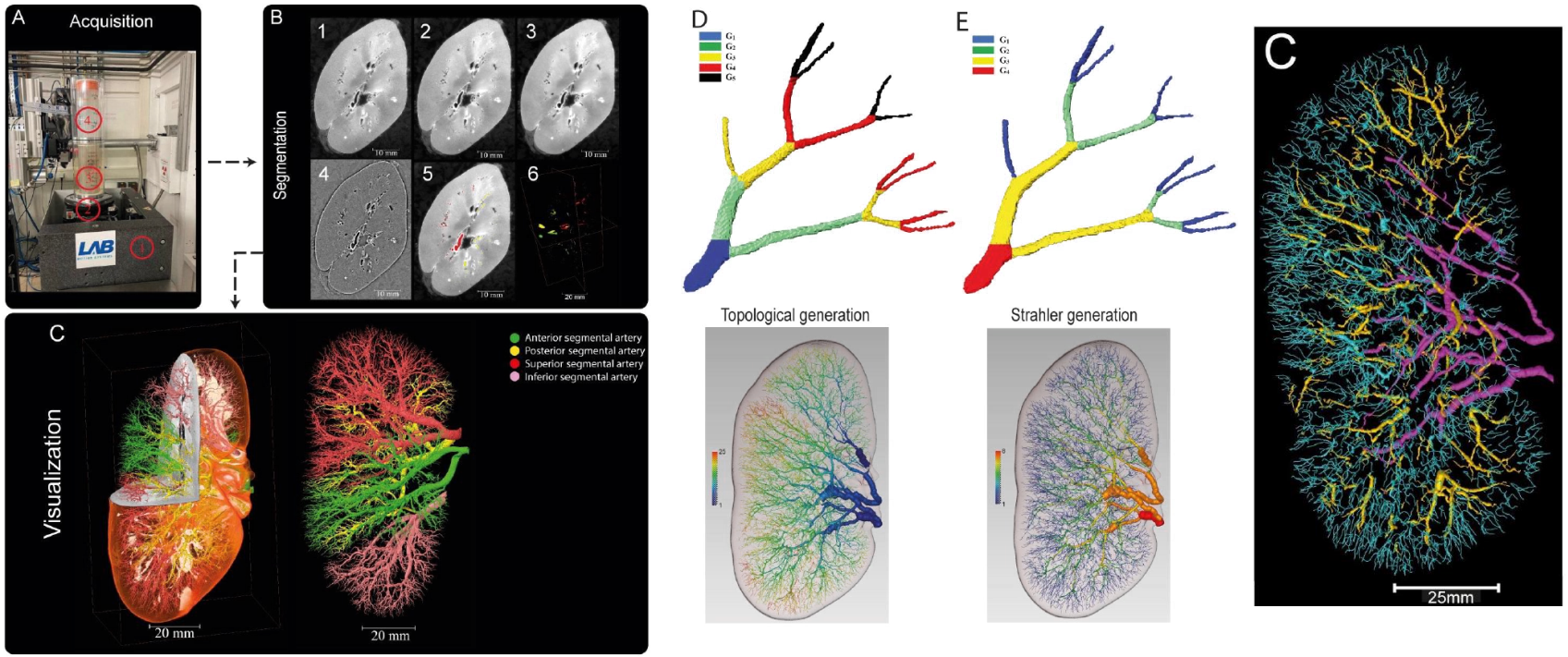
Published online on 4/11/2021
https://human-organ-atlas.esrf.eu/

The Human Organ Atlas uses Hierarchical Phase-Contrast Tomography to span a previously poorly explored scale in the understanding of human anatomy, the micron to whole intact organ scale.



IMAGING OF THE VASCULATURE OF A HUMAN KIDNEY

Micro to macro scale analysis of the intact human renal arterial tree

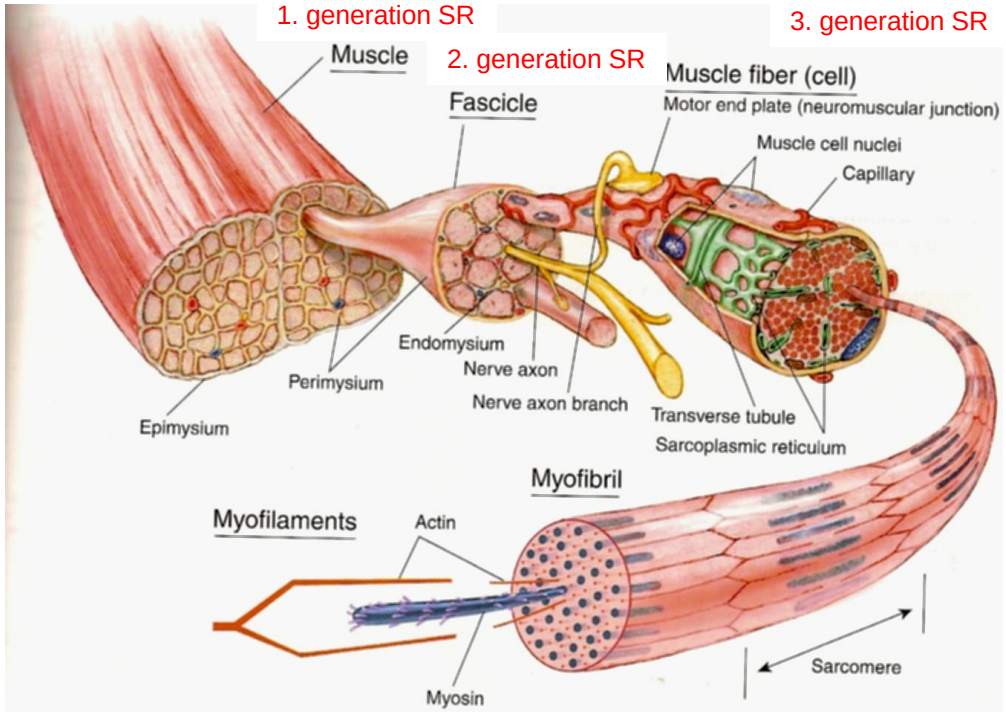


20-fold increase in resolution compared to clinical CT scanners

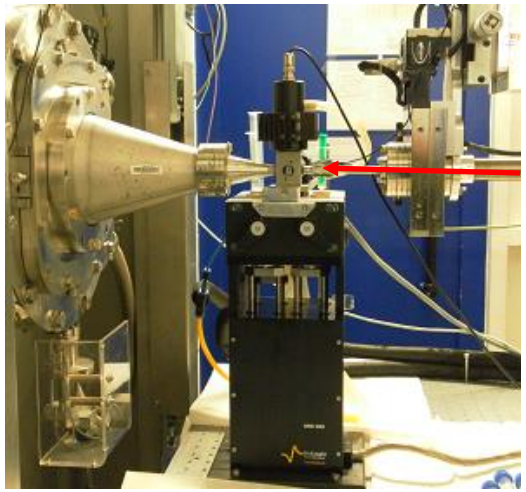
- Understanding how the hierarchy of individual blood vessel segments collectively scales to renal function
- benchmark for the natural variation in human anatomy & pathological variations from e.g. diabetes or renal cancer

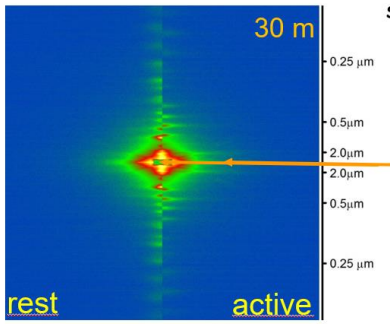
Shahrokh Rahmani et al, bioRxiv preprint 2023

HIERARCHICAL STRUCTURE OF MUSCLE

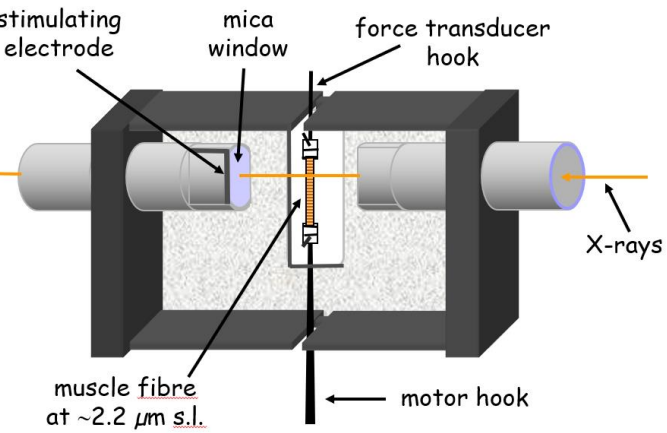


4. generation SR





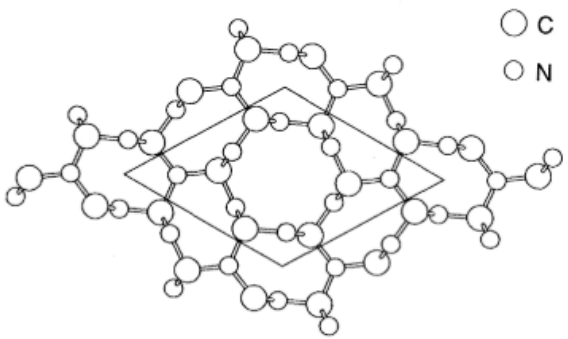
detector at 1 -30 m



Much smaller specimen, applying physiological protocols, addressing clinically relevant questions, etc.

Close the current knowledge gap in cardiac muscle regulation
Gain deeper insights into the molecular basis of cardiomyopathies

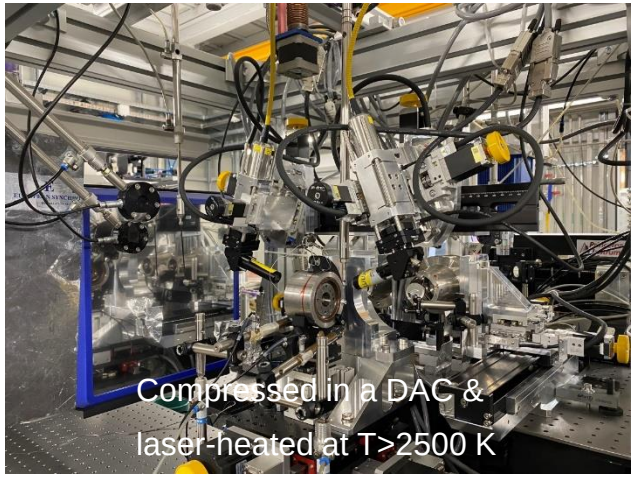
ID27 - IN SITU SYNTHESIS OF ULTRAHARD CARBON NITRIDES IN THE LASER HEATED DAC

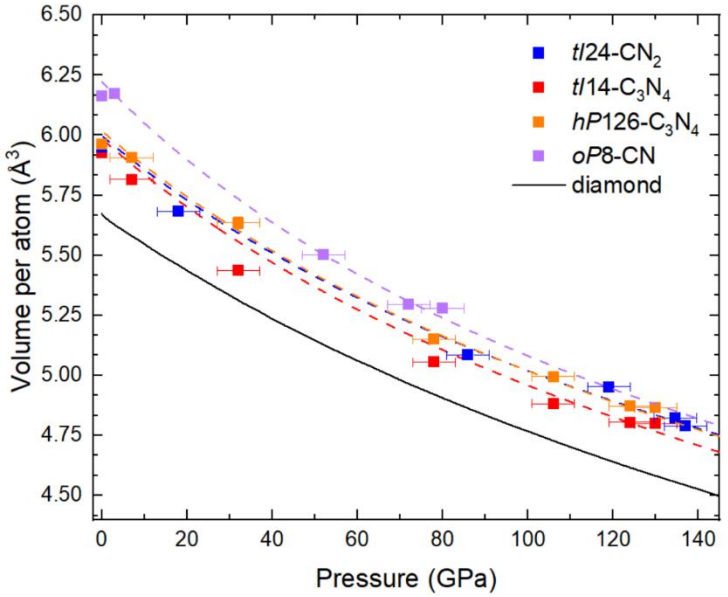


Prediction of New Super-Hard C_3N_4 Solids
A.Y. Liu & M.L. Cohen, *Science*, 245, 841 (1989)

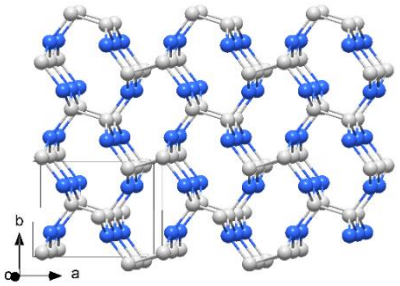
33 years and more than 6000 publications later

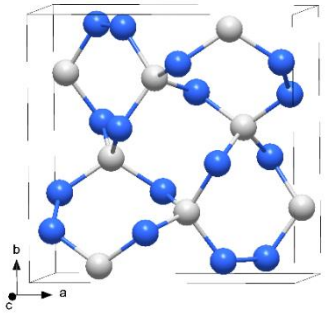
Tetracyanoethylene (TCNE, C_6N_4) in N_2 samples

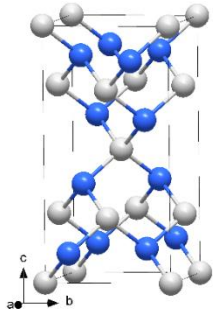


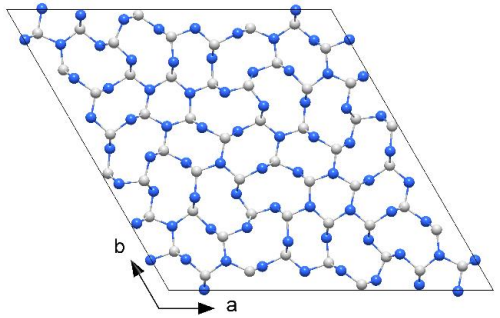


Laniel *et al*. arXiv, under review at *Nature,* (2022)









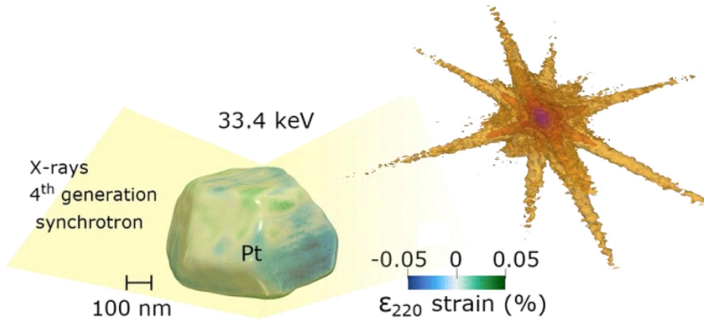
Single crystals: Four new C-N compounds discovered

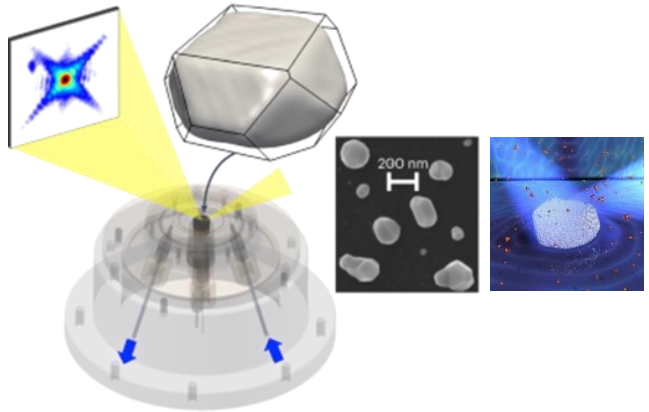
First demonstrated recoverability of solids produced above 100 GPa

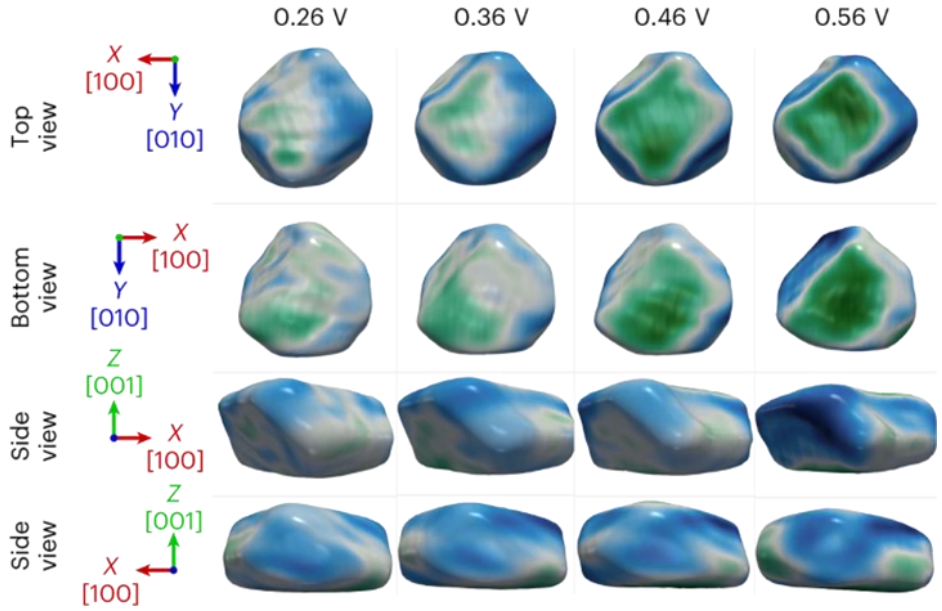
Bulk modulus and calculated hardness very close to diamond [K0=420 GPa/ H=69 GPa] and much larger than c-BN

Courtesy of M. Mezouar

Imaging the strain evolution of a Pt nanoparticle under electrochemical control





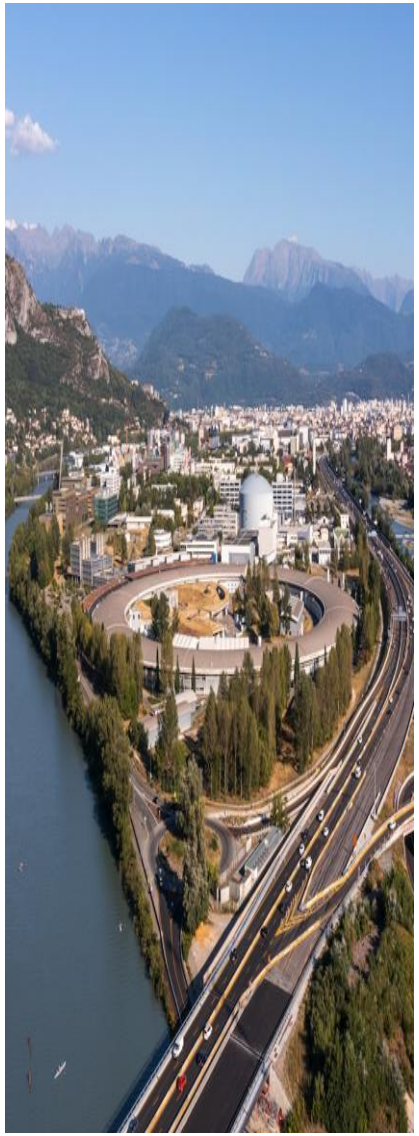


Surface strain → control the binding energies of adsorbates on active sites

- Heterogeneous and potential dependent strain distribution → critical for chemisorption of adsorbates onto metals, and thus acceleration of the rate of (electro)catalytic reactions
- ESRF-EBS: higher coherence & photon flux at high energy (**x28 gain at 33.4 keV**) for BCDI at ID01

C. Atlan et al, Nature Materials 2023

CONCLUSIONS



- ESRF-EBS was delivered within specifications, on time, and in budget
- First scientific results give a flavour of the enormous potential for new science opportunities
- We are here to help you for your ESRF research projects
- Do not hesitate to get in touch with us!

Gema Martinez Criado
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Pieter Glatzel
Electronic Structure, Magnetism & Dynamics Group

Mohamed Mezouar
Matters at Extremes Group

Marine Cotte
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Oleg Konovalev
Complex Systems & Biomedical Sciences Group

Montserrat Soler Lopez
Structural Biology Group

THANK YOU FOR YOUR ATTENTION