DELIVERY OF THE ESRF NEW EBS SOURCE AND BEAMLINES, AND FIRST RESULTS

XVI International School and Symposium on Synchrotron Radiation in Natural Science

ISSRNS 2025

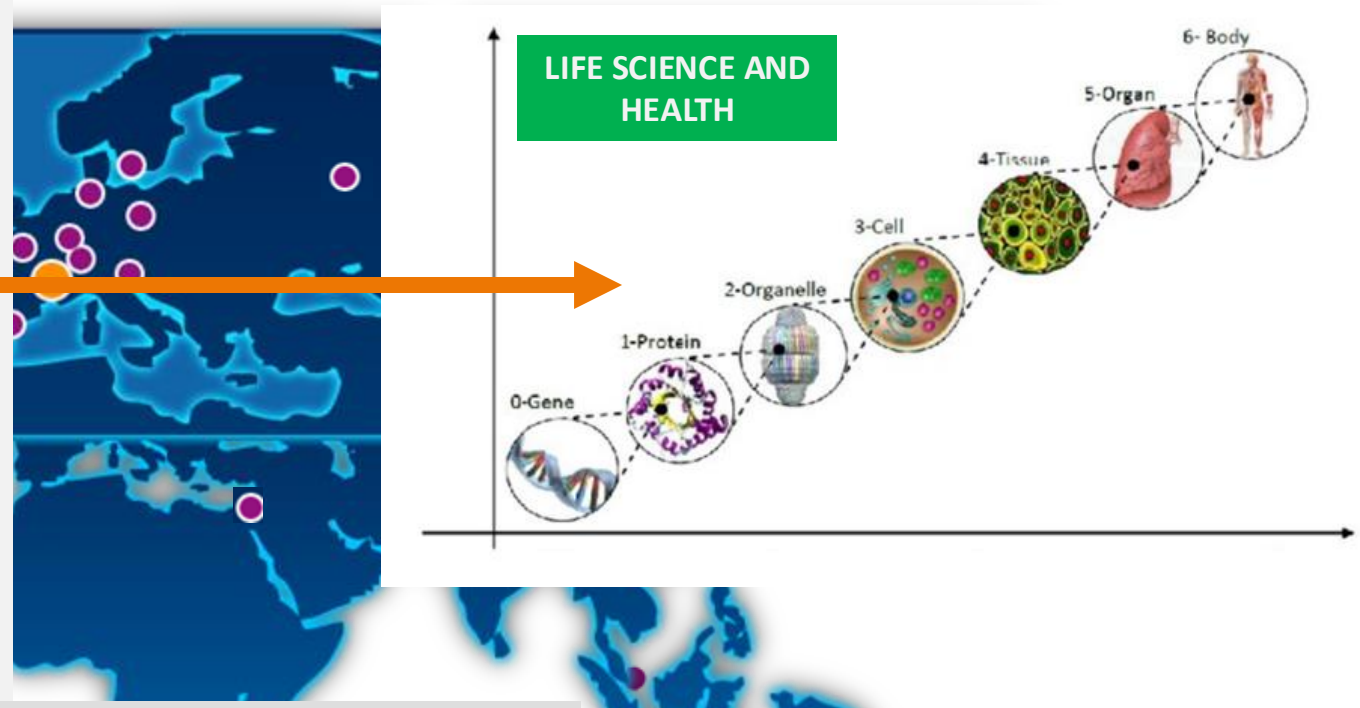
Szczyrk, Poland, 25-30 May 2025

Francesco Sette – ESRF

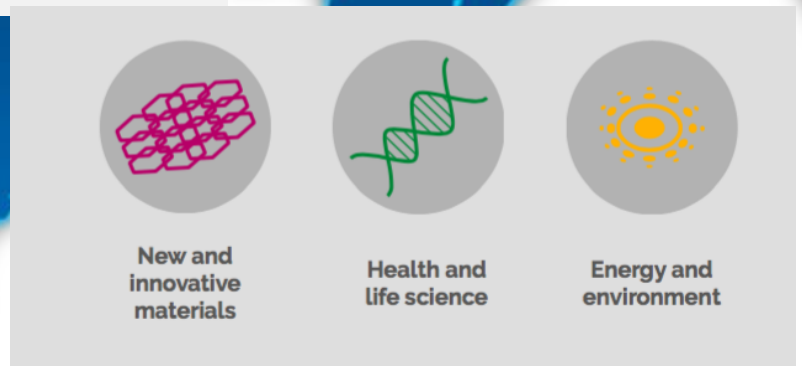
- When and why it started
- Some examples
- Il Cannone – the Violin of Niccolò Paganini
- Concluding remarks

X-RAY SCIENCE

Explore time and space scales down to X-ray wavelength/frequencies?
XFELs and NEW STORAGE RINGs
IMAGING and MICROSCOPY with SCATTERING and SPECTROSCOPY:
COMPLEXITY IN MATTER FROM ATOMIC STRUcTURE AND ELECTRON MOTION TO A FULL FUNCTIONING MACROSCOPIC BODY

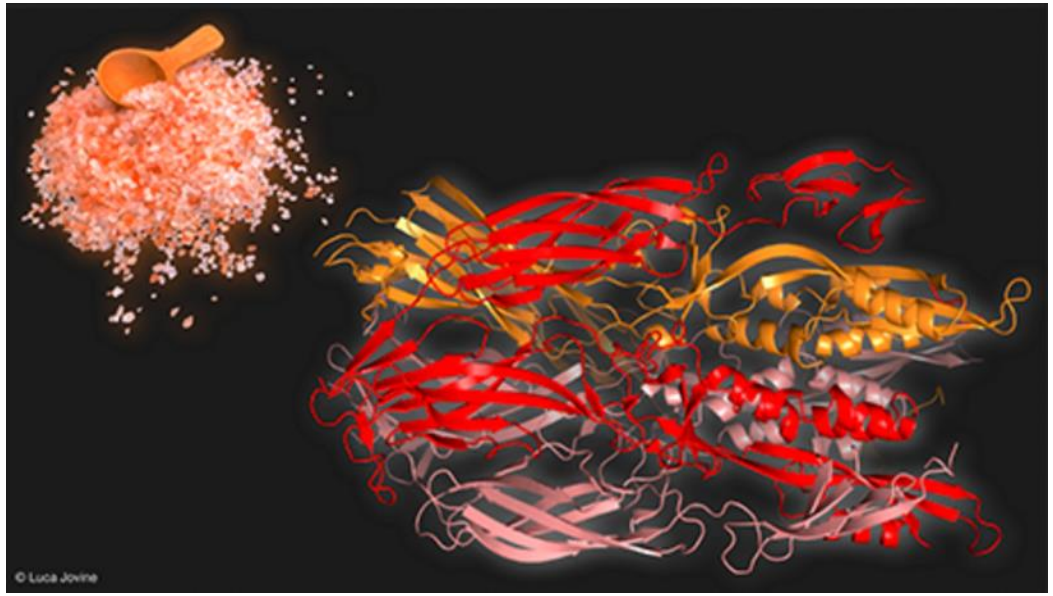


The Nobel Prize in Physics 2021 was awarded "for ground-breaking contributions to our understanding of complex systems" Manabe, Hasselmann and Parisi



DECODING PROTEINS BY COMBINING ARTIFICIAL INTELLIGENCE AND CHARACTERISATION

THE NOBEL PRIZE



Crystal structure of Fusexin1 obtained using computational evolutionary biology, AlphaFold-based protein modeling, X-ray crystallography at the ESRF and functional studies

Protein Data Bank (PDB) structure depositions from ESRF:

- X-ray diffraction: 17 866
- Cryo-EM: 333

Total ESRF deposited structures: 18 199 (out of ~ 250 000)

- Effective service provider to the Structural Biology community

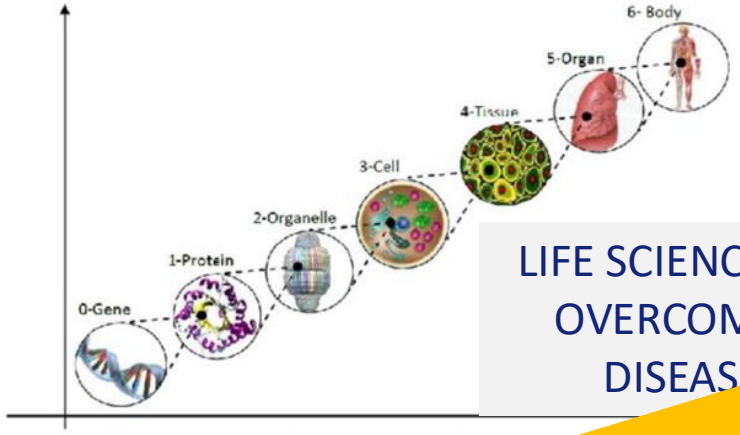
- The **2024 NOBEL PRIZE IN CHEMISTRY** was awarded to David Baker, John Jumper and Demis Hassabis for their pioneering work on 'computational protein design' and 'protein structure prediction', **highlighting the advancements AI brings to this field**.

- **The ESRF has been actively involved in breakthrough research** on these subjects, collaborating notably since 2008 with teams that include Baker and Jumper
  - **For designing proteins with specific properties:** structural characterisation being an integral part of developing computational models of proteins, bridging the gap between theoretical predictions and real-world molecular behaviour
  - **For predicting structures**: by combining AlphaFold's predictions with experimental data to reveal the structure of proteins that are particularly challenging to study.

Goverde, C.A., et al. Nature 631, 449–458 (2024).
Chidyausiku, T.M., et al, Nat Commun 13, 5661 (2022).
Cao, L., et al. Nature 605, 551–560 (2022).
Moi, D., et al. Nat Commun 13, 3880 (2022).
Stsiapanava A. et al., Nature Structural & Molecular Biology, 10 March 2022

FUNDAMENTAL AND APPLIED SCIENCE WITH X-RAYS: UNDERSTANDING COMPLEXITY IN CONDENSED AND LIVING MATTER

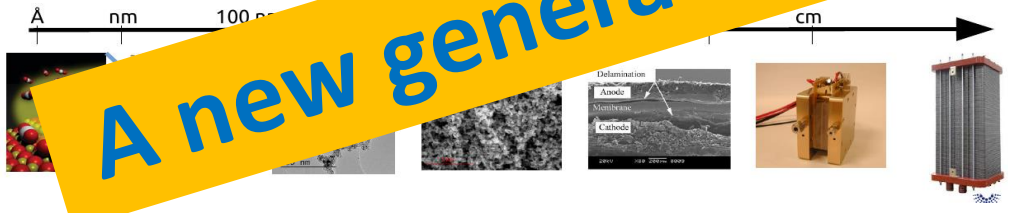
A new generation of X-ray (time-resolved) microscopes

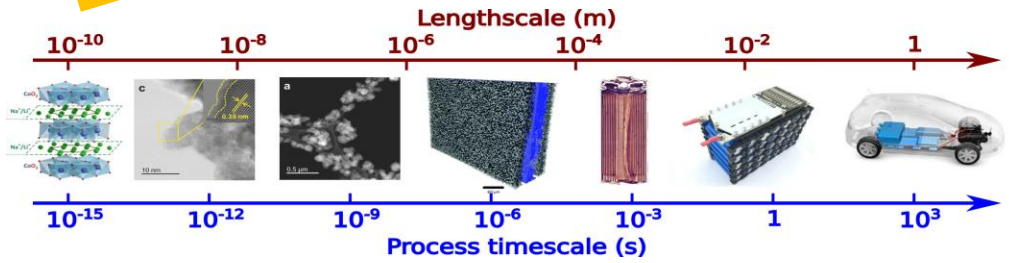


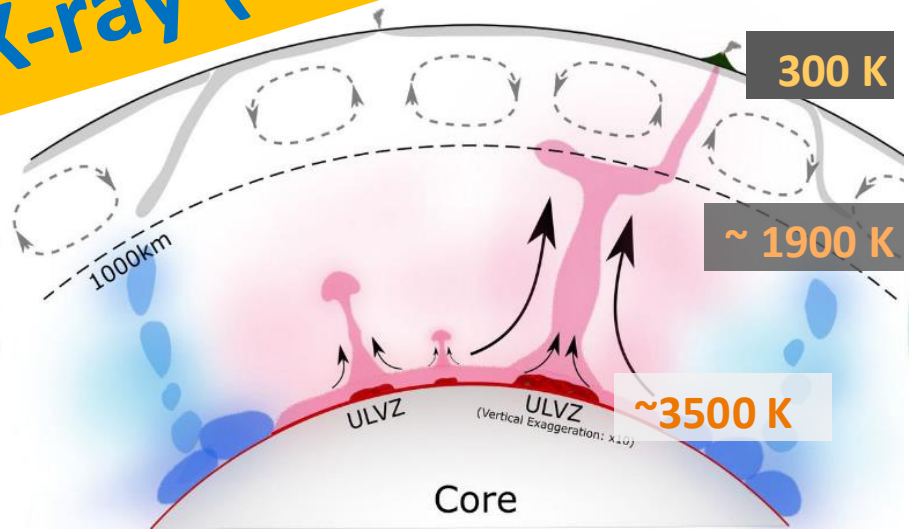
LIFE SCIENCE AND OVERCOMING DISEASES

ENT AND SUSTAINABILITY

MATERIALS AN

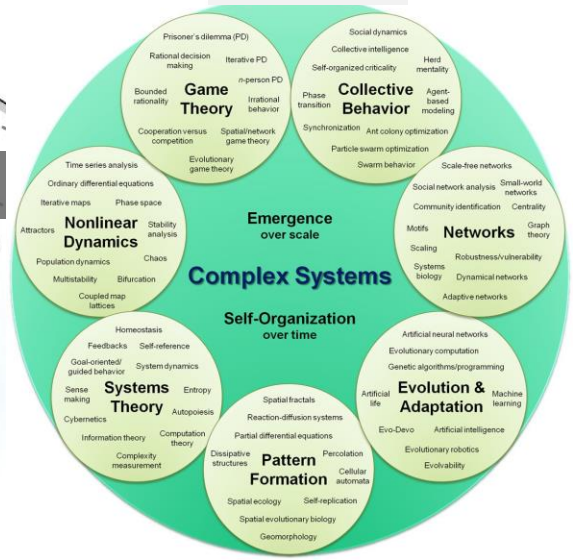






GEOSCIENCE

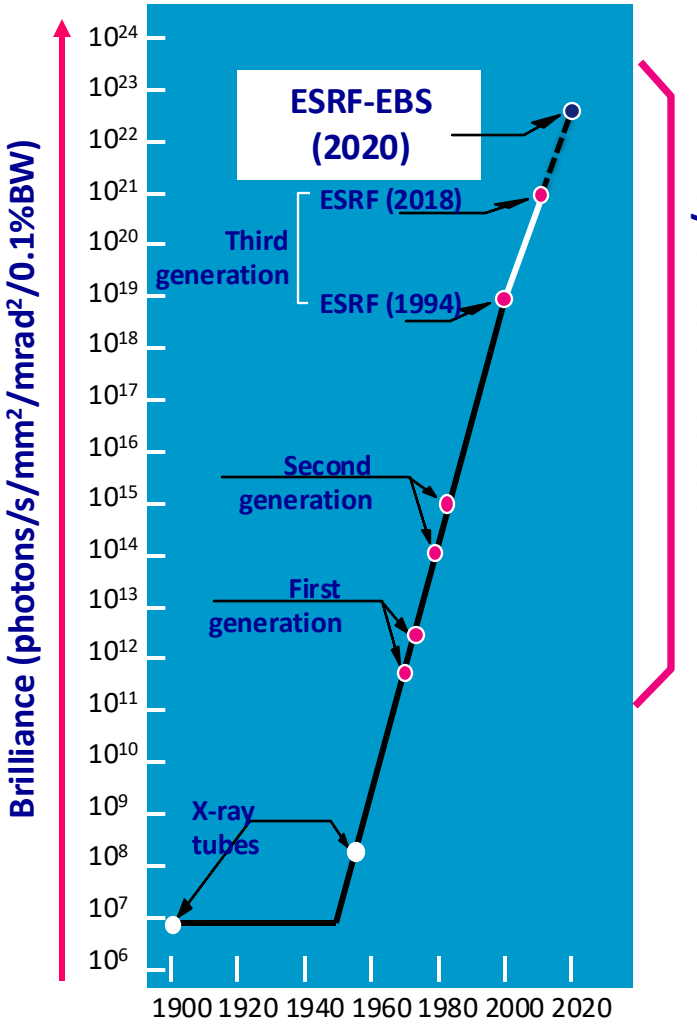
PHYSICS



New Scientific Opportunities at the European Synchrotron Radiation Facility

From my presentation at the ESRF 2004 User Meeting

F. Sette
ESRF UM
10 02 2004



- Benefits and new opportunities from increased brilliance:
  - Decreased Horizontal Emittance
  - Long ID Beamlines
- Micro(Nano)-focus with X-ray absorption and scattering

ESRF EBS: AN AMBITIOUS NEW STANDARD FOR SYNCHROTRON STORAGE RINGS

Purple Book
January 2008

W.G. Stirling
ESRF DG

Quest for:
- **New instruments**
- **More brilliant source**

ESRF UPGRADE PHASE I (2009-2015):
ESFRI ROADMAP 2006-2016
ESFRI LANDMARK (2016)
- **NEW BEAMLINES (LONG) FOR NANOSCIENCE**
- **STUDIES FOR A NEW HIGH-BRILLIANCE–HIGH-ENERGY X-RAY STORAGE RING**

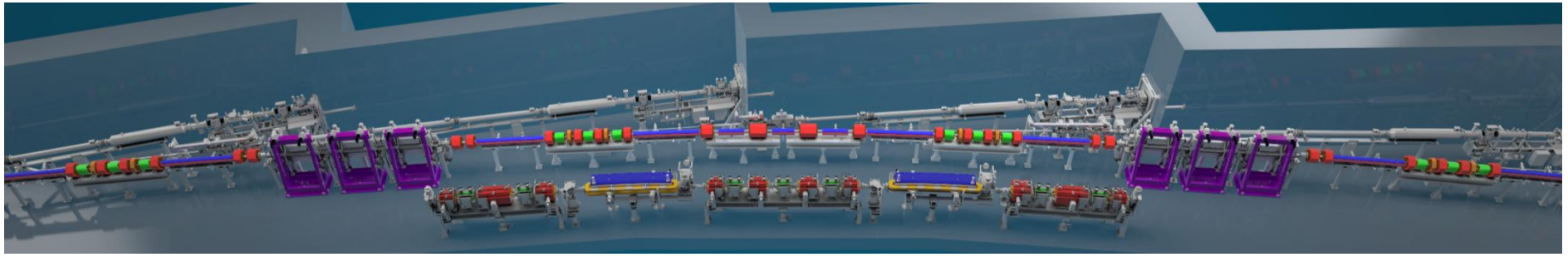
New Golden-Slab Exp. Halls, very long beamlines (ID11&13), place for first open access Cryo-EM platform, ….

- **SUCCESFUL DELIVERY OF BEAMLINES: IN USER OPERATION SINCE 2015**
- **DELIVERY OF A NEW LATTICE CONCEPT AND PROPOSAL FOR THE ESRF EXTREMELY BRILLIANT SOURCE: ESRF UPGRADE PROGRAMME PHASE II – WHITE PAPER IN DECEMBER 2012**

ESFRI

European Commission

THE EBS STORAGE RING SPECIFICATIONS PRESENTED AT THE3-WAY MEETING@APS – AUGUST 2013



OBJECTIVE: A new brighter hard X-ray source with unprecedented stability and reliability enabling the study of the structure and dynamics of atoms at the nanometric level, to the benefit of a broad user community

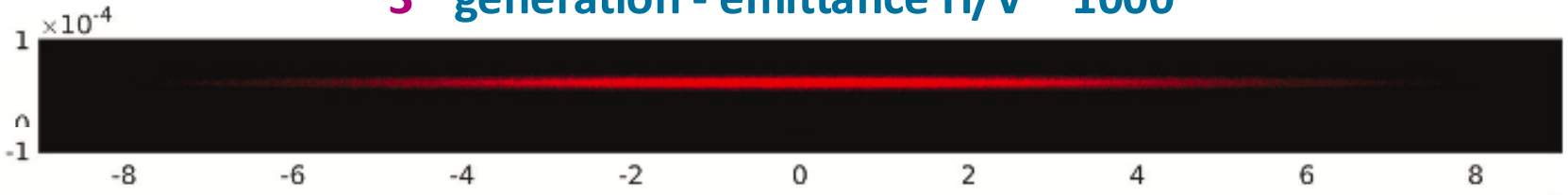
- Reduce the horizontal equilibrium emittance from 4 nm to less than 150 pm
- Maintain the existing ID straights and beamlines
- Maintain the “existing bending” magnet beamlines
- Preserve the time structure operation and a multibunch current of 200 mA
- Keep the present injector complex ….
- Reuse, as much as possible, existing hardware
- Minimize the energy lost in synchrotron radiation
- Minimize operation costs, mainly wall-plug power
- Limit the downtime for installation and commissioning to about one year

FROM THE CHASMAN GREEN DBA TO THE EINFELD MBA

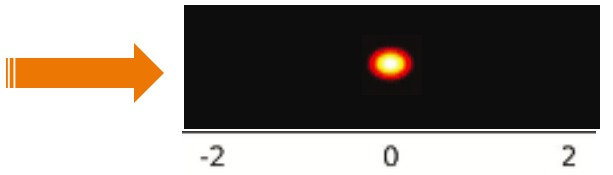
- The Chasman-Green Double Bend Achromat (DBA Brookhaven 1972) has been the most successful and widespread lattice used for synchrotron-based light sources. It has (and still is) been fundamental for the realization and exploitation of high brightness X-rays.

- D. Einfeld (1993): from the double-bend Chasman-Green achromat lattice (BNL 1975) to its multiple(n)-bend lattice version to drastically reduce the Horizontal Emittance – adopted for two *green-field* programmes: MAX-IV and SIRIUS

3rd generation - emittance H/V ~ 1000

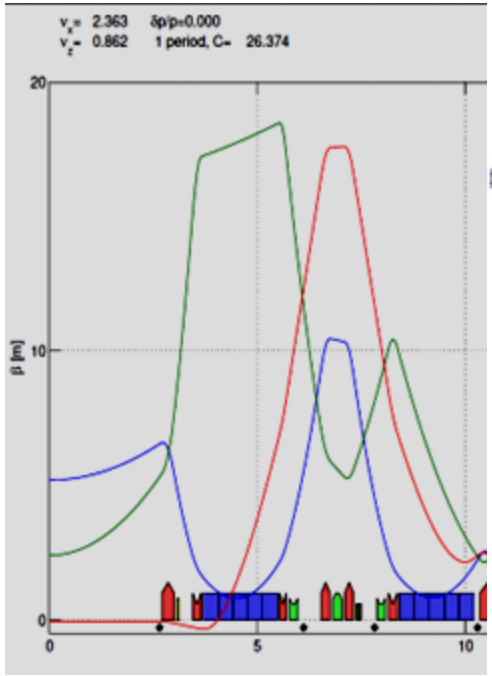


4th generation – emittance H/V ~ 1

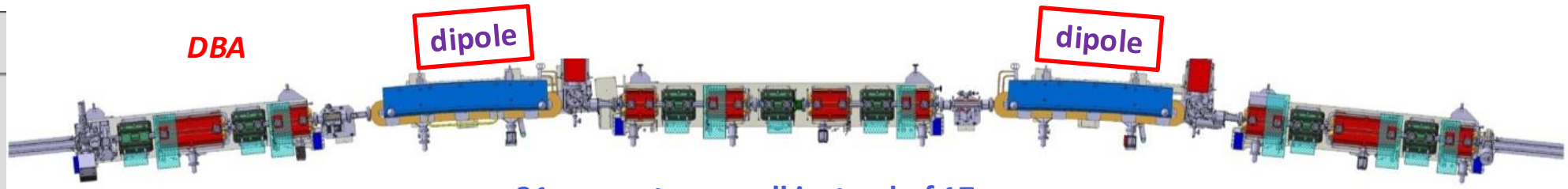


MBA approach, however has proven to be problematic to upgrade existing DBA based storage rings (P. Elleaume. A. Ropert et al., 2004), as it would seriously affect the overall *Operation stability* and require magnets with unprecedented *high field-gradients*

HMBA: THE EVOLUTION OF MULTI-BEND LATTICE (*COURTESY P. RAIMONDI*)



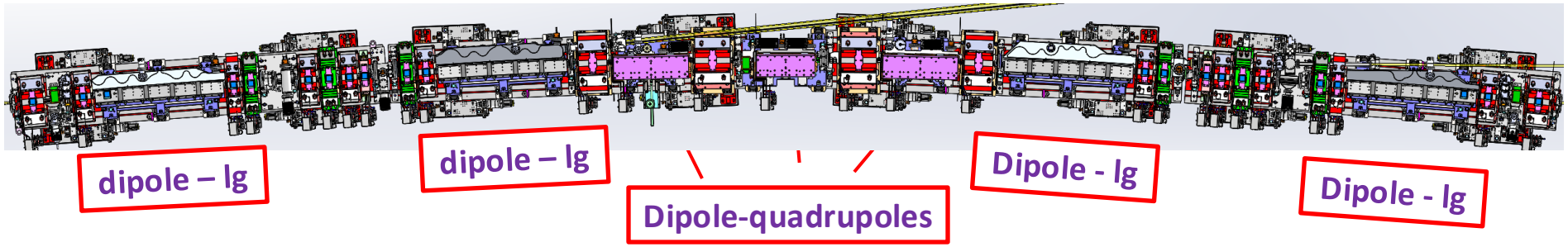
DBA



31 magnets per cell instead of 17

32 cells (arcs) with 4 girders each

EBS-H7BA



- **Fewer sextupoles than in DBA : 6 instead of 7 !**
- **Longer and weaker dipoles => less SR**
- **No need of "large" dispersion in the inner dipoles => Total number of magnets much less than in the 7BA (from 47 to 31 in the EBS lattice)**

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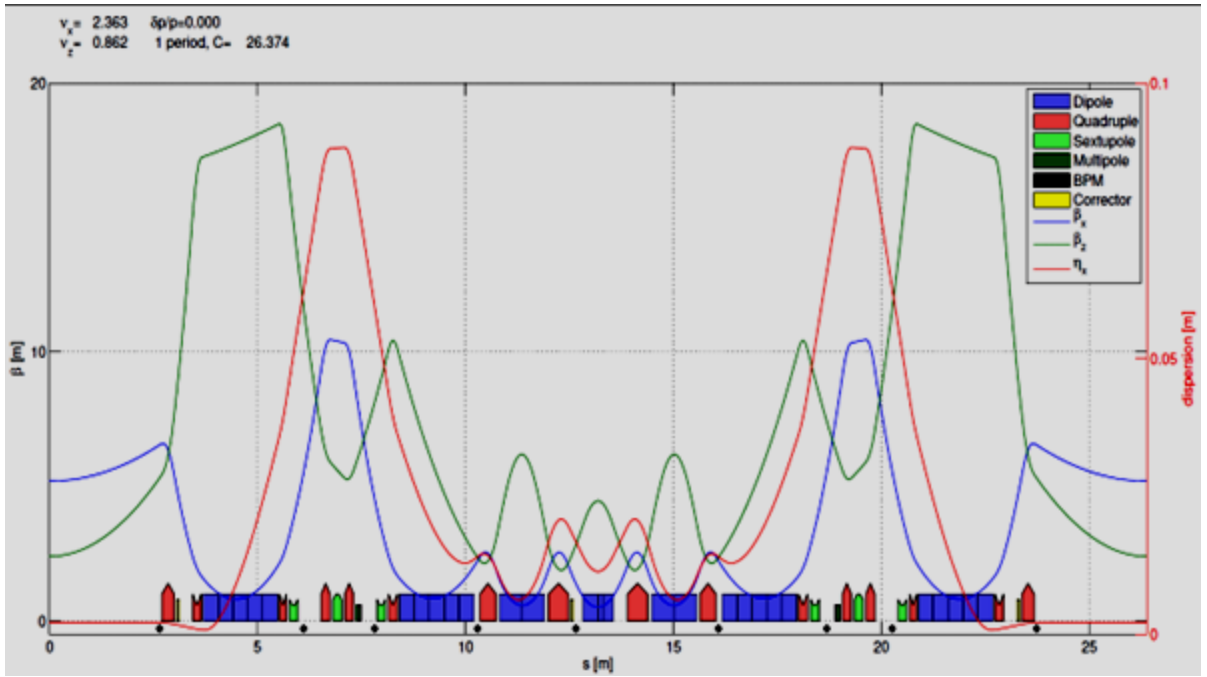

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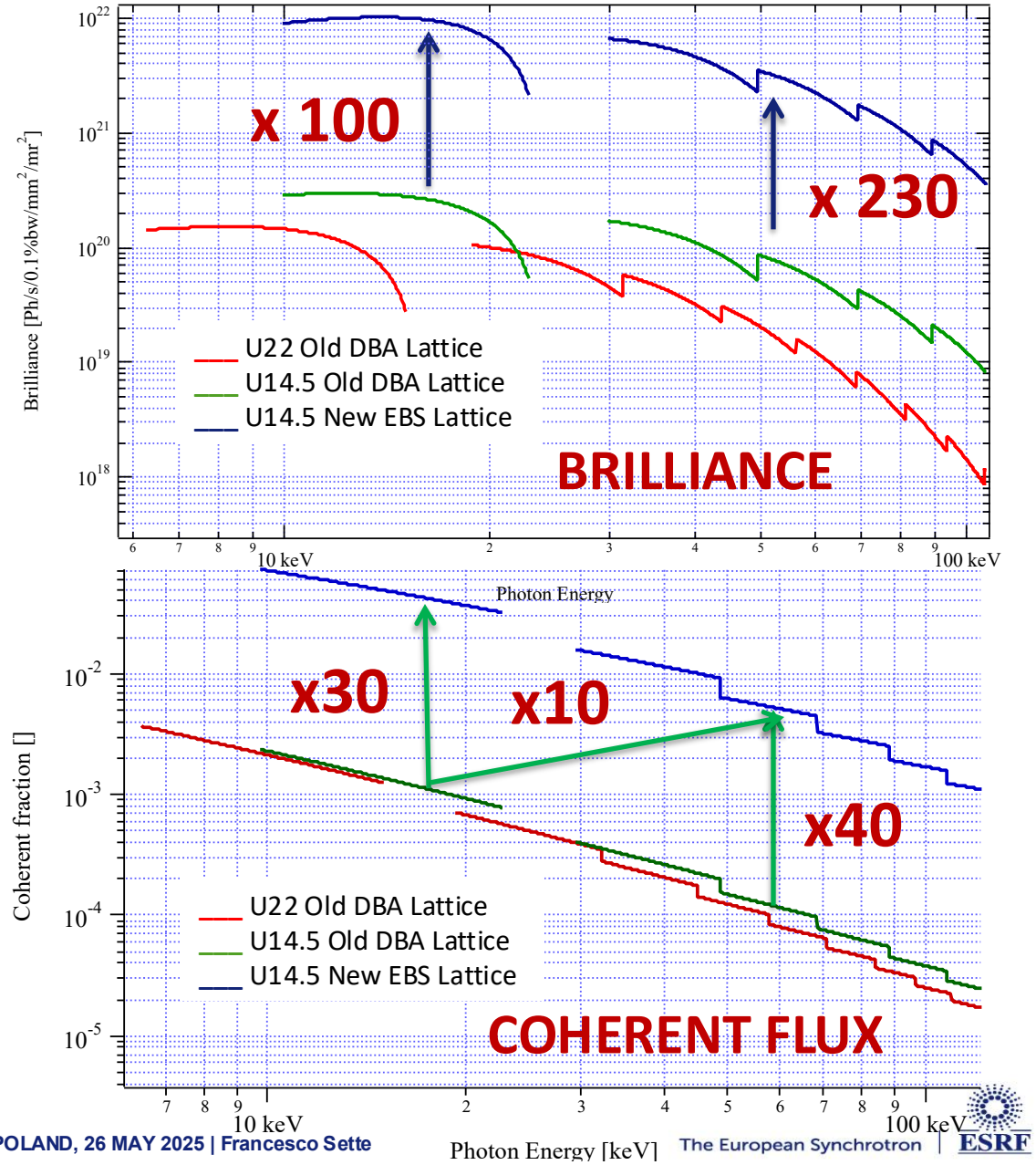
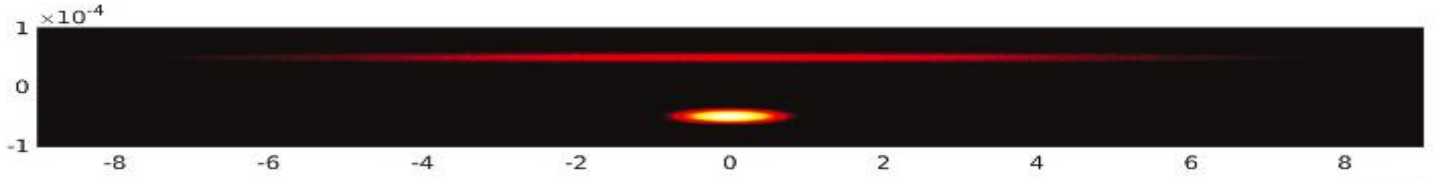


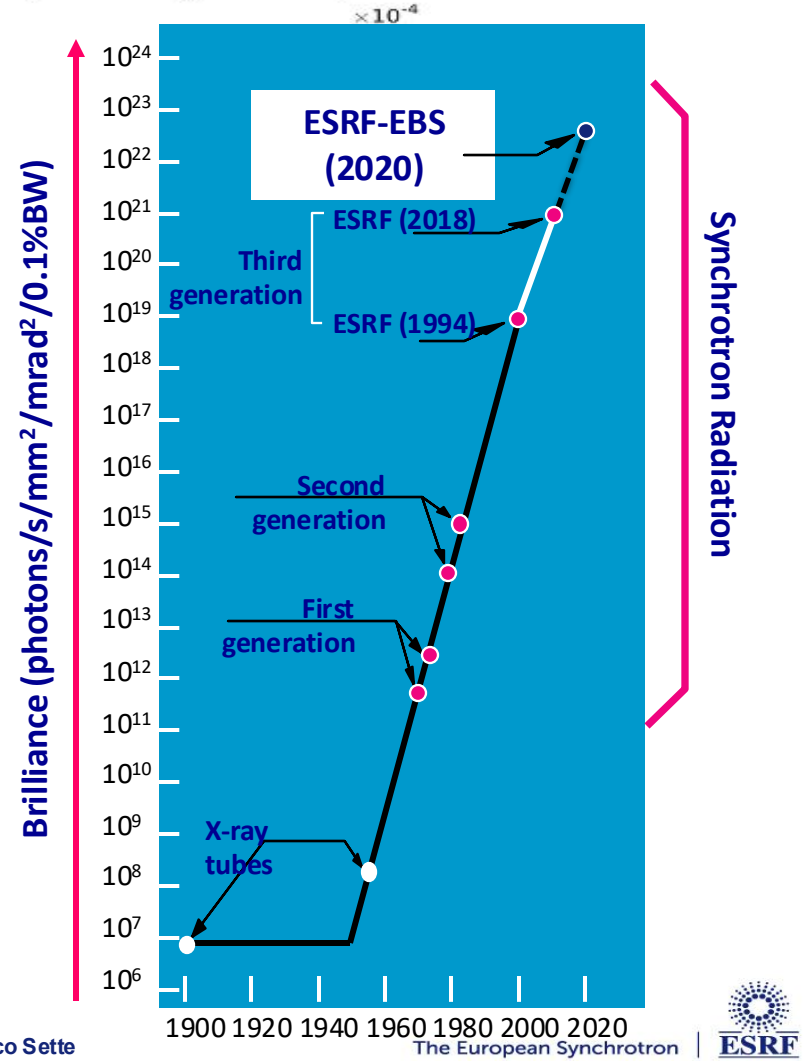
ESRF-EBS LATTICE VS. PREVIOUS ESRF-DBA LATTICE: DBA → H7BA

EBS Emittances: H/V~10



/10

	ESRF-EBS	ESRF-3rd G
Energy [GeV]	6.04	6.04
Tunes	75.21, 26.34	36.44, 13.39
Emittance x [pmrad]	134	4000
Emittance y (target) [pmrad]	1	3
Energy loss per turn [MeV]	2.6	4.9
RF voltage (acceptance) [MV]	6 (5.6%)	9 (4%)
Chromaticity	6, 4	4, 7
Circumference [m]	843.98	844.39
Energy spread [%]	0.095	0.106
Beam current [mA]	200	200
Lattice type	HMBA	DBA
Touschek lifetime [h]	~20	~80



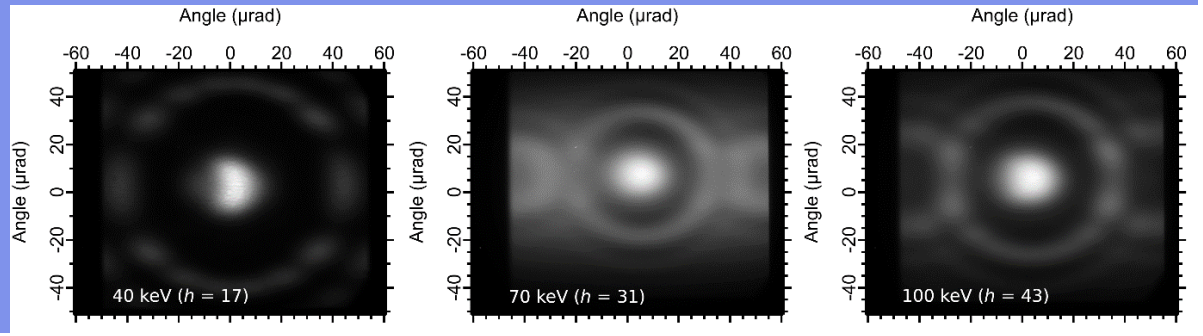
ESRF-EBS MACHINE STATISTICS: 2018 – 2023

Machine Statistics for 2018 at the ESRF and for 2020 – 2023 (EBS)

EMITTANCE VALUES

VERTICAL: 1 +/- 0.5 pm

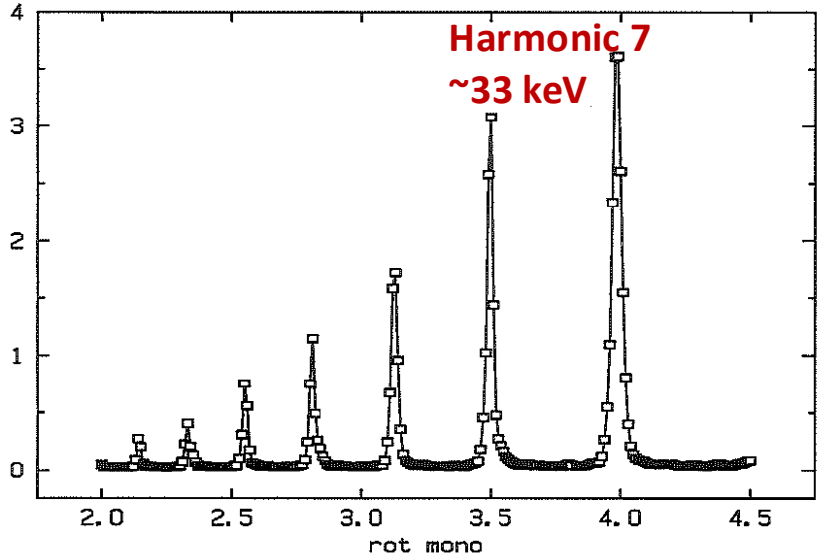
HORIZONTAL: 130 +/- 10 pm



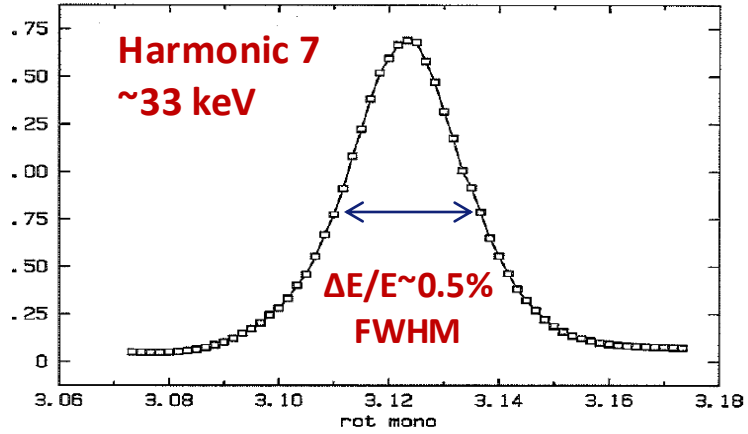
MACHINE – USM	2018	2020 *EBS*	2021 *EBS*	2022 *EBS*	2023 *EBS*
Availability (%)	98.47	96.08	96.35	**99.06**	***99.28***
Mean Time Between Failures (hr)	104.30	46.00	66.4	**88.5**	***107.1***
Mean duration of a failure (hr)	1.60	1.80	2.42	**0.83**	***0.77***

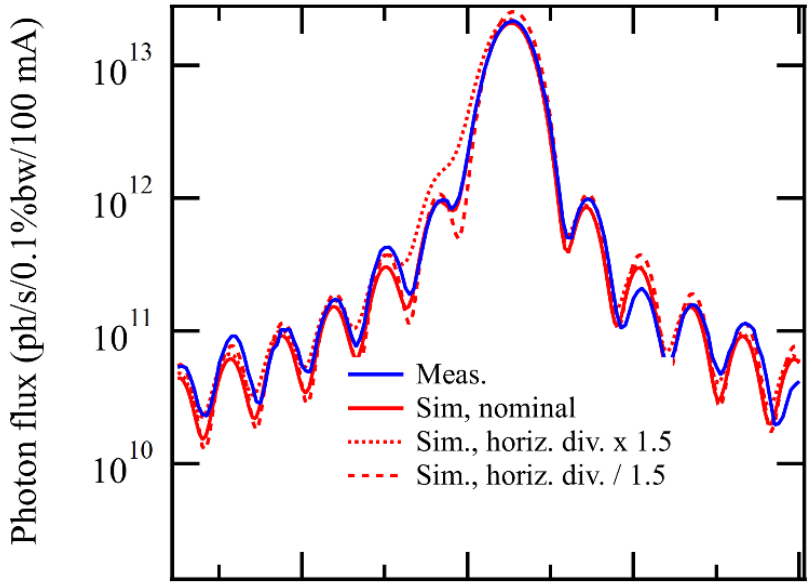
ID27 HIGH PRESSURE BEAMLINE: UNDULATOR SPECTRUM

Undulator spectrum
through a Si(111) Monochromator



X-ray beam from a U35@ID27





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OPEN ISSUES and FANTASTIC OPPORTUNITIES:
- more spectral brilliance -> longitudinal coherence
- transparent injection -> low emittance LINAC, plasma acceleration
- Increased stability
- Timing strategies -> machine timing signals, undulators, beamlines components, shot-by-shot beam diagnostics

ESRF-EBS: 2024 STATISTICS

PUBLIC BEAMTIME USER OPERATION AND STATISTICS

2200
Submitted proposals
in 2024

989
Accepted proposals
In 2024

2392
Proposals received for 2025
A NEW ESRF RECORD
Even with 6 new HUBs and BAGs

USER VISITS & EXPERIMENTAL SESSIONS

9465
User visits
+ 631 parcels/dewars

2773
Experiment
sessions

37%
Of remote
experiments

8%
Of hybrid
experiments

PUBLICATIONS

1411
Publications in 2024
(up to 25 March 2025)

564
Publications with IF>7
in 2024

> 40 000
Peer-refereed publications
over 30 years of USM

ESRF – UPGRADE: A NEW STANDARD FOR SYNCHROTRON SOURCES

Orange Book
January 2015

ESRF UPGRADE PROGRAMME 2009-2023

A « landmark » in the ESFRI roadmap

Combine the effects of THE NEW EBS, NEW LONG-BEAMLINE concept, NEW INSTRUMENTATION and NEW DATA MANAGEMENT TOOLS: EXPERIMENTAL CONDITIONS IMPROVE BY FACTORS OF: 100 TO 10 000

ESRF UPGRADE PROGRAMME

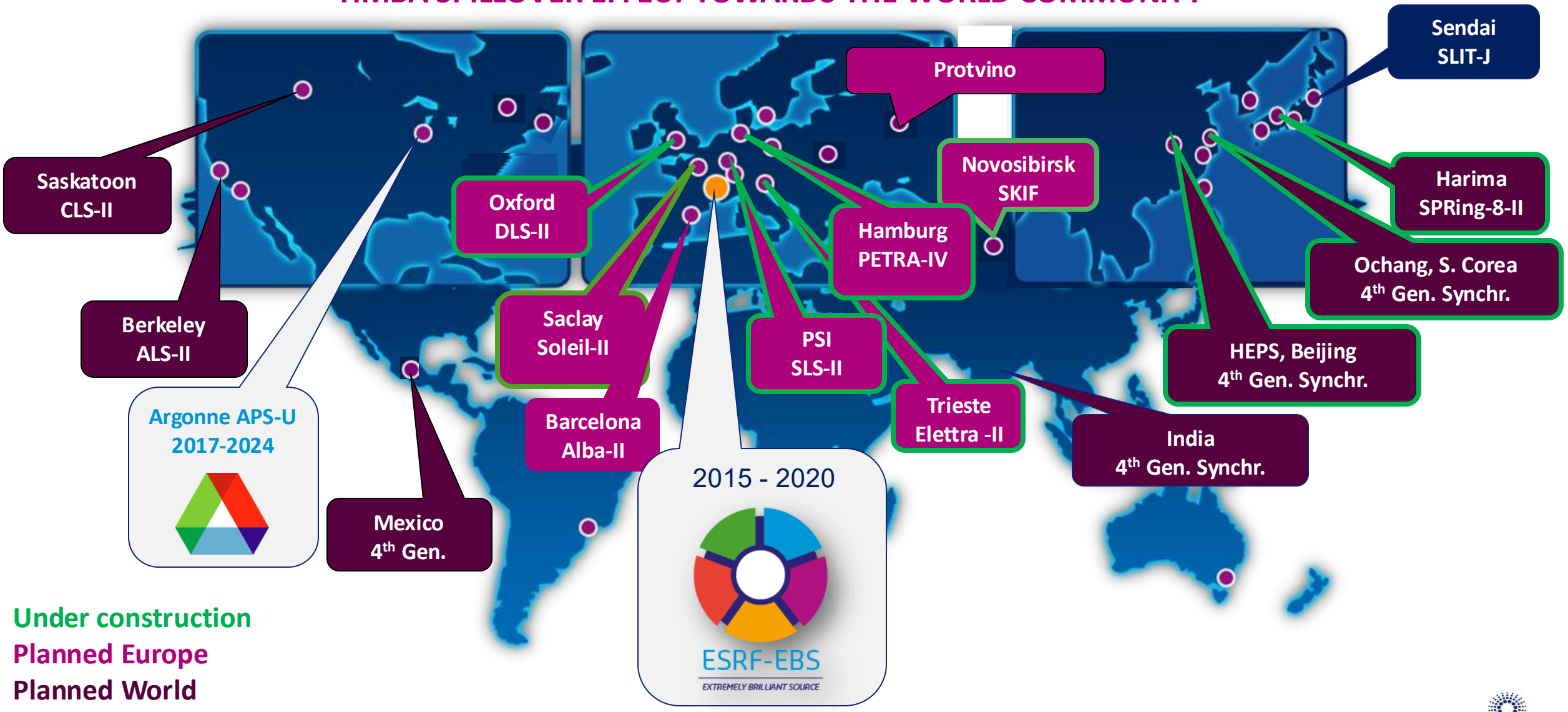
ESFRI

European Commission

- New beamlines (27) and CRYO-EM for health, materials, energy, environment and cultural heritage sciences
- New - first of a kind - low-emittance high-brilliance X-ray source
- New big data and IT internal and external infrastructures
- 25% of energy savings (16.6 Gwh/year)
- 90% of the infrastructure re-used

ESRF-EBS IMPACT: A NEW STANDARD FOR SYNCHROTRON LIGHT SOURCES

HMBA SPILLOVER EFFECT TOWARDS THE WORLD COMMUNITY



MODERN SYNCHROTRON RADIATION SCIENCE: A TRIBUTE TO FIVE ACCELERATOR PHYSICISTS

Renate Chasman (1932 –1977)
George K. Green (1911 – 1977)

They invented the **Chasman–Green lattice**, also known as the **double bend achromat lattice** (**DBA lattice)**, at Brookhaven National Laboratory in the early 70's. This was a revolutionary storage ring lattice concept, differentiating from colliders, and paving the way to 3rd Generation Synchrotron Radiation sources

Jean-Louis Laclare (1942 – 2003)

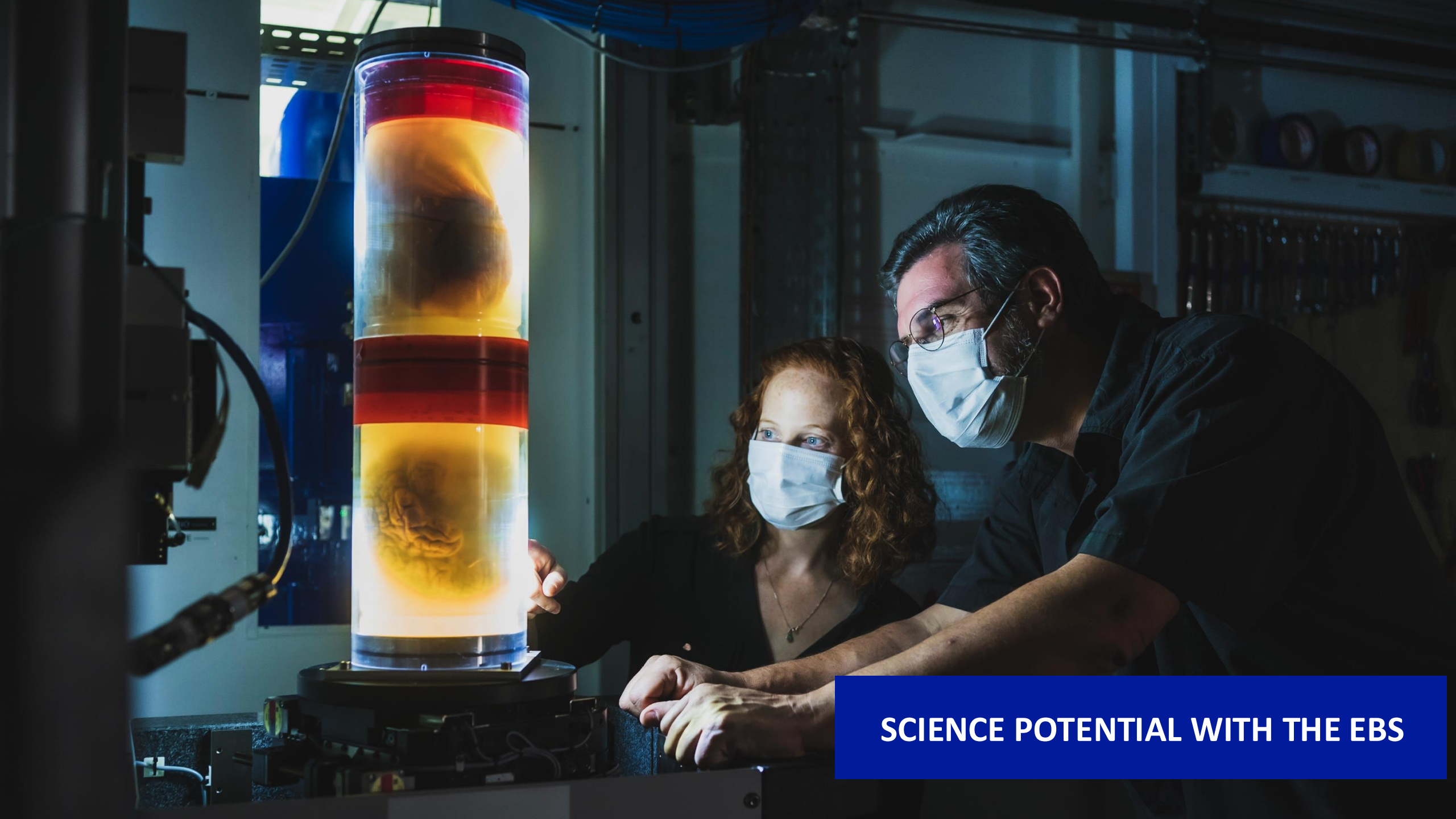
He constructed the first ESRF storage ring (1986-1992): the first 3rd GSR source. Optimising the CG – DBA lattice to host Insertion Devices (IDs) in almost each cell straight-section, he showed that IDs can be independently operated, and made ESRF-like 3rd GSRs the new gold standard for X-ray science

Dieter Einfeld

He designed the Diffraction-Limited (DL) light source: He introduced in 1993 the Multiple BA (MBA) concept, in continuity with, and extending the CG-DBA lattice concept to drastically increase X-ray brilliance by decreasing horizontal e-beam emittance. The MBA is adopted for MAX-IV and SIRIUS lattices

Pantaleo Raimondi

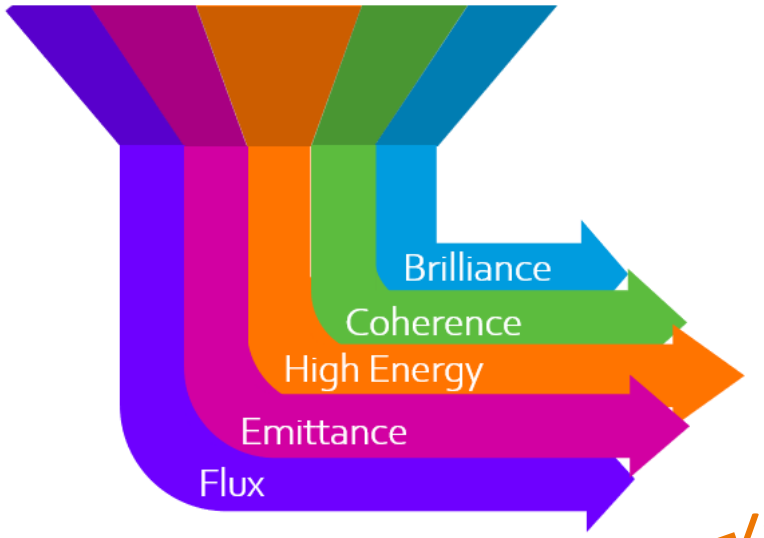
He invented the Hybrid MBA (HMBA) lattice, and its first realisation with the construction of the ESRF-EBS: The HMBA overcomes many drawbacks of the MBA lattice. Demonstrating the HMBA robustness with the ESRF-EBS construction, he sets the new gold standard for for DL 4th Gen SR sources

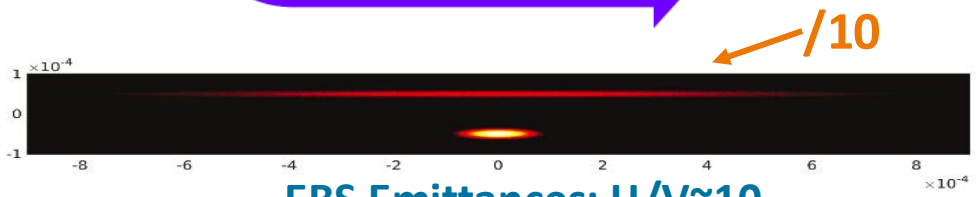


SCIENCE POTENTIAL WITH THE EBS

ESRF-EBS: A GAME CHANGER FOR SCIENCE WITH X-RAYS

HMBA lattice

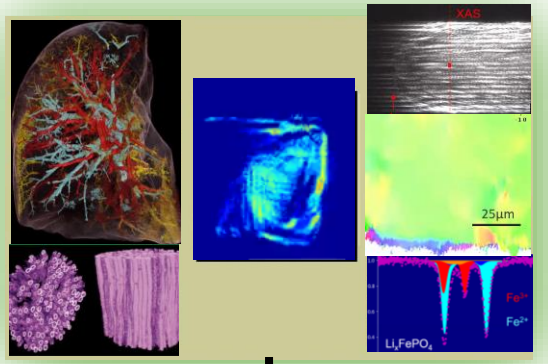




EBS Emittances: H/V~10

ε_x ~ 4000pm ⟶ ε_x ~ 130 pm

After the ESRF-EBS

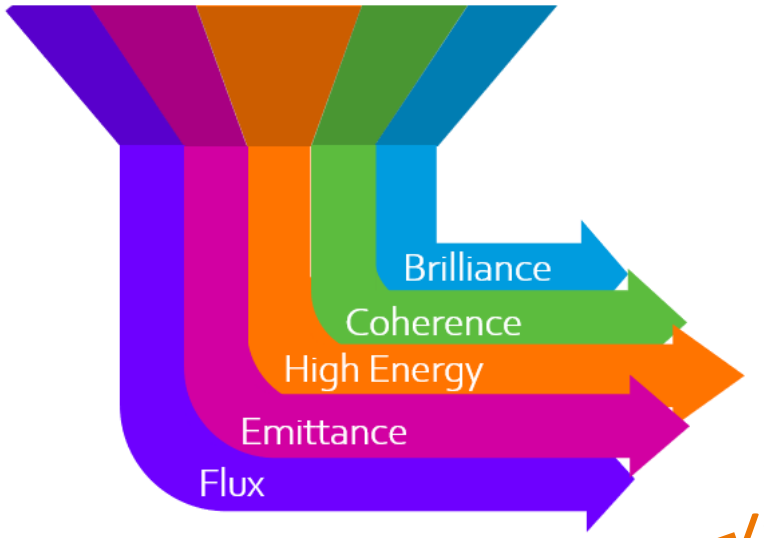


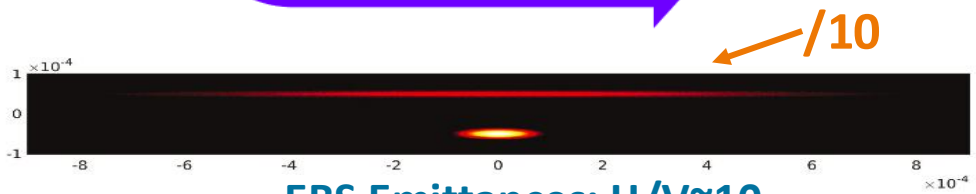
× 30 Trans. Coherence | **× 100 Brilliance** | **÷ 30 Hor. Emittance**

- ✓ Multiscale analysis (m → mm → µm → nm)
- ✓ Pump-probe experiments
- ✓ Exploiting temporal resolution (20 *ps* -> up)
- ✓ Sample conditions: extreme (T,P), *In-situ, operando, etc.*
- ✓ Improved capabilities: detection limits, energy resolution, sensitivity, throughput, selectivity, etc.
- ✓ Operation Standards: Data and detector strategies

ESRF-EBS FOR SCIENCE WITH X-RAYS

HMBA lattice





EBS Emittances: H/V~10

ε_x ~ 4000pm ⟶ ε_x ~ 130 pm

Beam sizes from nm to 30 cm

X-Ray Microscopies and Imaging;
Larger field of view

Beam Coherence exploitation

CDI, Phase Contrast, Holography, XPCS;
High quality Optics

Increased photon flux on the sample

R(NR)IXS, RESX, NRS, XES, XDS, WDS, XBIC, XEOL

Photon flux at High Energy

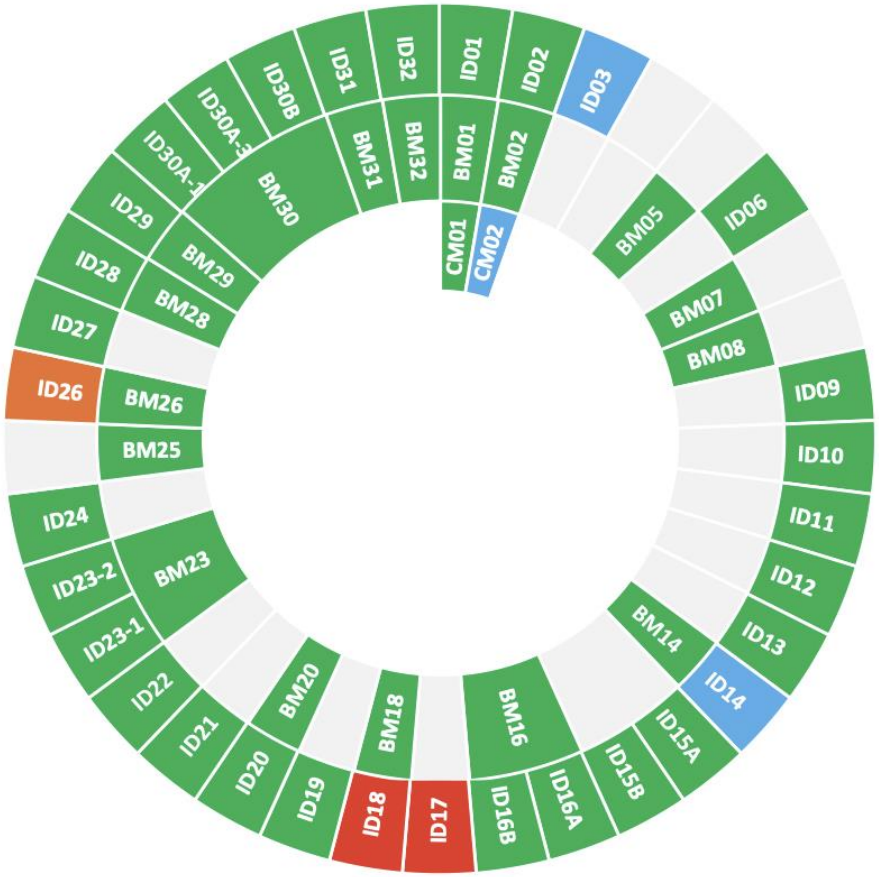
Larger pen
Low dose i
images;
In-situ, -ope
extreme (T

Increased dose tolerance at high energy

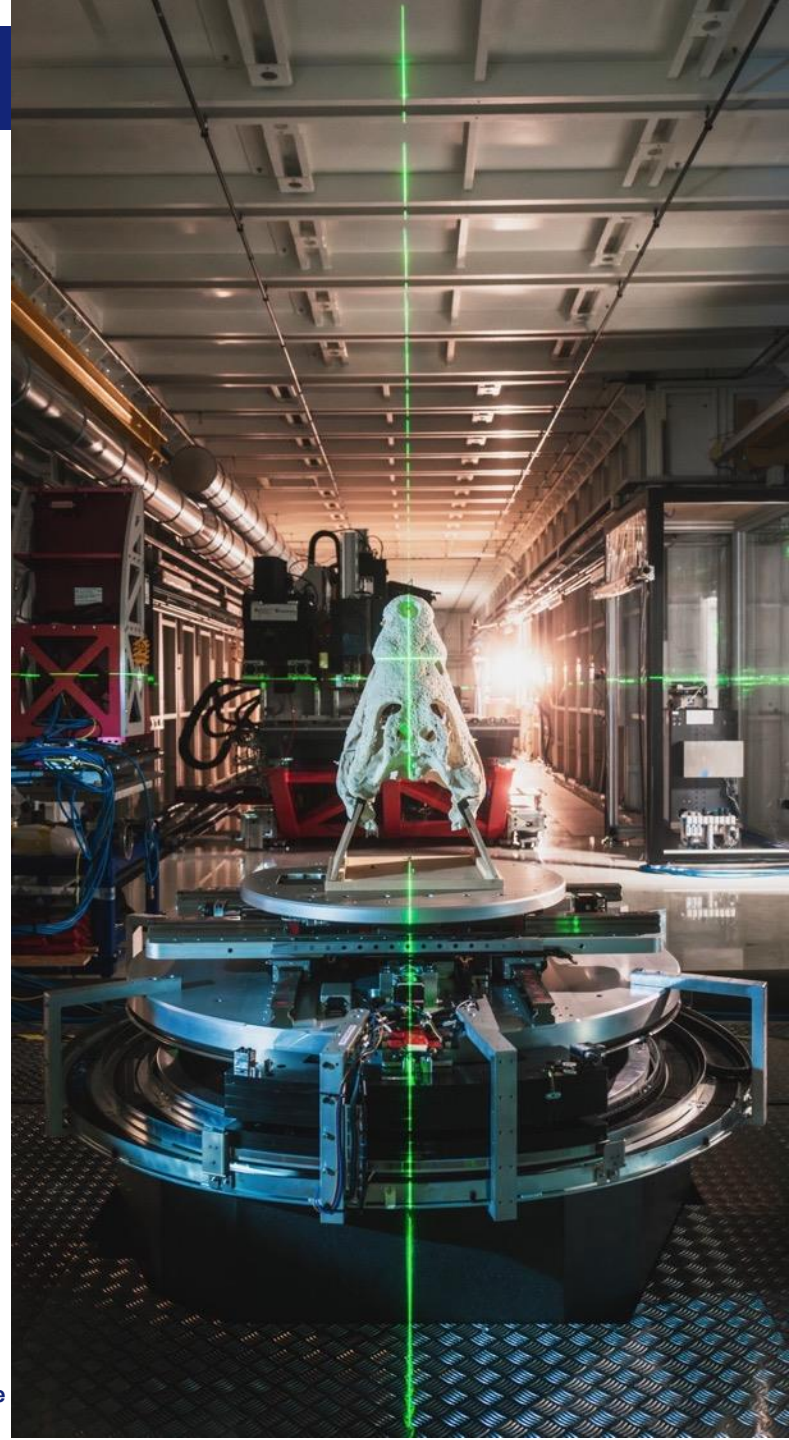
Better Sensitivity, and artifact

OPEN ISSUES and FANTASTIC OPPORTUNITIES:
- DATA science and dedicated management
- NEW Automation concepts involving: mechatronics, timing, adapted X-ray optics and scattering devices for beam diagnostics and analysis
- REVOLUTIONARY Multiple Function Detectors with new AWARENESS strategies

ESRF-EBS BEAMLINES UPDATED MAP IN 2024



- Operational – 47
- Refurbishment
- Open to USM in 2024
- On hold



NEW ACCESS MODES

Science-driven BAG

The user community of a *specific scientific theme* selects the most promising experiments fostering (i) collaboration and (ii) the most effective use of the available beamtime

(HISTORICAL MATERIALS)

+

Technique-driven BAG

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

(SHOCK BAG)

+

Science HUB

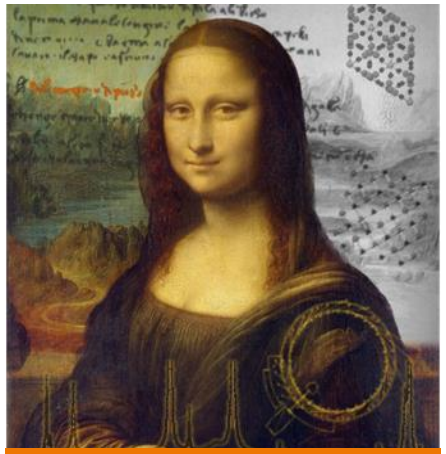
ESRF channels a part of its resources into *a science hub in selected areas* of highest relevance, fostering (i) collaboration and (ii) maximise impact of use of ESRF beamlines

(BATTERY HUB)

https://www.esrf.fr/CommunityAccess

Courtesy: Joanne McCarthy

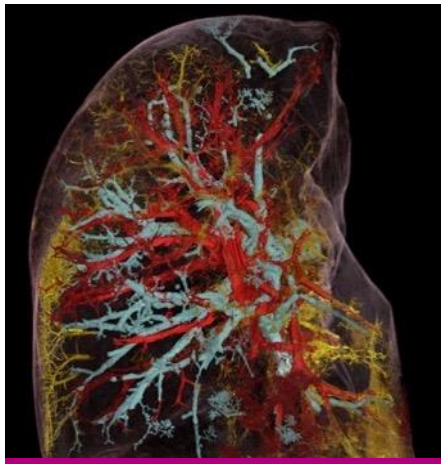
NEW ACCESS MODES TAILORED TO THE NEEDS OF THE COMMUNITY TO FULLY EXPLOIT EBS



HISTORICAL MATERIALS BAG
Launched in 2021

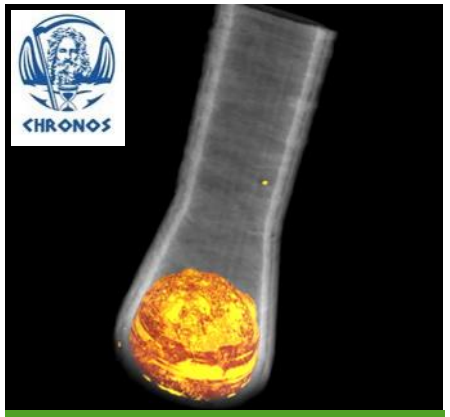
BATTERY HUB
Launched in 2021

SHOCK BAG
Launched in 2022



HUMAN ORGAN ATLAS HUB
Launched in 2023

ADDITIVE MANUFACT. BAG
Launched in 2023



CHRONOS BAG
Launched in 2024

RAPID ACCESS
Launched in 2023

COORDINATED ACCESS
Launched in 2023

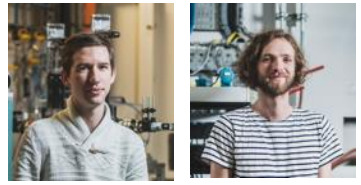
ENLARGE & STRENGTHEN THE USER COMMUNITY

FOSTER SCIENTIFIC COLLABORATIONS

A DRIVER FOR EU SCIENCE: SO FAR 10 ERC GRANTS BASED ON EBS CAPABILITIES

Grant Holder	Grant Type	Project Title	Period
Hugh SIMONS, ID06 and UPBL2-ID03 Technical University of Denmark (DTU)	Starting	3D piezoresponse X-ray microscopy (3D-PXM)	2019-2023
Marie-Ingrid Richard, ID01 Aix-Marseille University	Consolidator	Nanostructures towards atomic resolution: catalysis and interface	2019-2024
Alexandra-Teodora JOITA-PACUREANU, ESRF, ID16A	Starting	Bright, coherent and focused light to resolve neuronal circuits (BRILLIANCE)	2020-2025
Beatrice RUTA, CNRS (F) – ID10 & UPBL1-ID18	Starting	A coherent view of Glasses: complex dynamics of glasses with coherent X-rays	2020-2025
Henning Friis POULSEN, DTU (DK) – ID06 & ID03	Advanced	The physics of metal plasticity (PMP)	2020-2025
François RENARD, BM18, ID19, ID11 University of Oslo and ISTerre	Advanced	Break-Through Rocks (BREAK)	2021-2026
Ilya KUPENKO, ID14, ID28, ID27, ID15B ESRF	Starting	Light Elements in the Coree (LECOR)	2022-2027
Tilman GRUENEWALD, ID13 and ID15A Institut Frenel (CNRS, Aix-Marseille Université, Centrale Marseille)	Starting	X-ray texture tomography for multiscale, in-situ imaging of the enthesis, a biological hinge between bone and tendon (TexTOM)	2022-2027
Alain MANCEAU, ID24-DCM CNRS, Ecole Normale Supérieure Lyon, ESRF	Advanced	Fathoming Seq in DEEP marine emission spect	
Can YILDIRIM, ESRF, ID03	Starting	Deformation ar Metals (D-REX)	

European Research Council
Established by the European Commission



OPPORTUNITY:
- New job profiles requiring skills as X-ray scientist, but also as coordinator of complex projects involving many techniques – not necessarily X-ray based

EBSL2- ID03: BEAMLINE FOR HARD X-RAY MICROSCOPY

Courtesy C. Detlefs

PRINCIPLE

An objective generates a real space image using the diffracted beam as illumination

GOAL

Multi-scale 3D mapping

TECHNIQUE

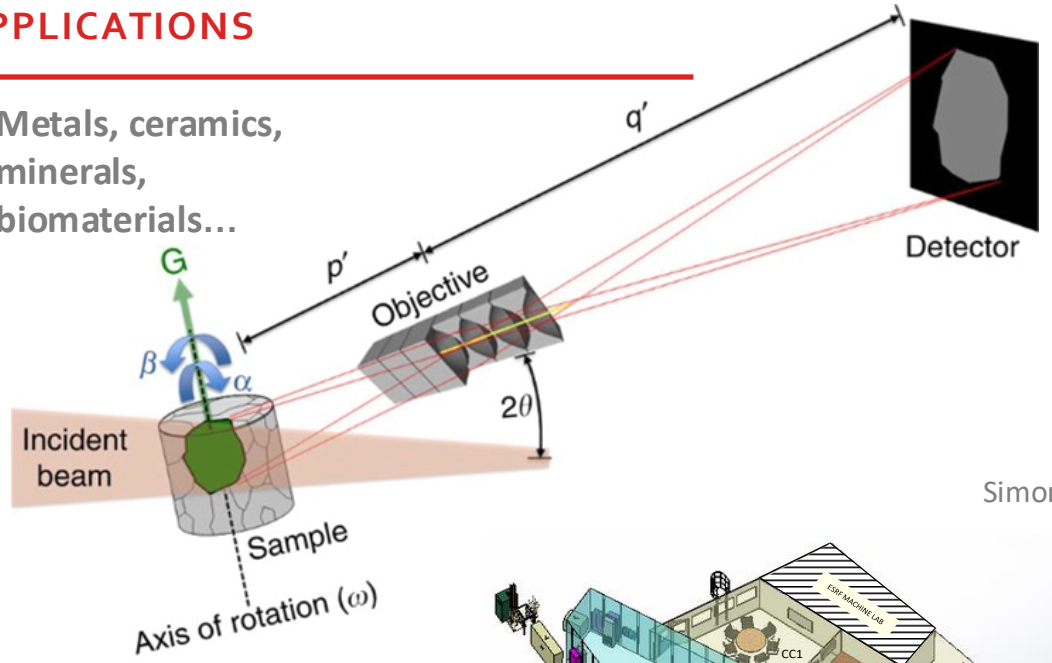
- Dark field X-ray Microscopy for internal orientations, grain shapes and strains on lengths scales from 100 nm to 1 mm within embedded sampling volumes

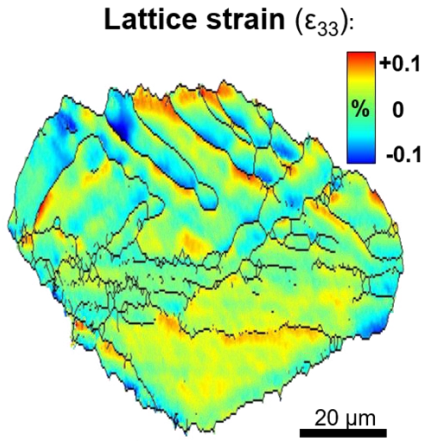
BEAMLINE

Energy: 12 – 60 keV
Operation modes: Pink and monochromatic
Spatial resolution: ~100 nm
Strain resolution: 10^{-5} $\Delta d/d$
Temporal resolution: Sec – Mins
Sample size: up to 1mm

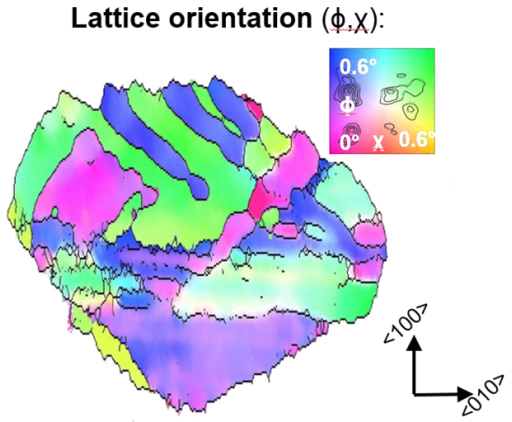
APPLICATIONS

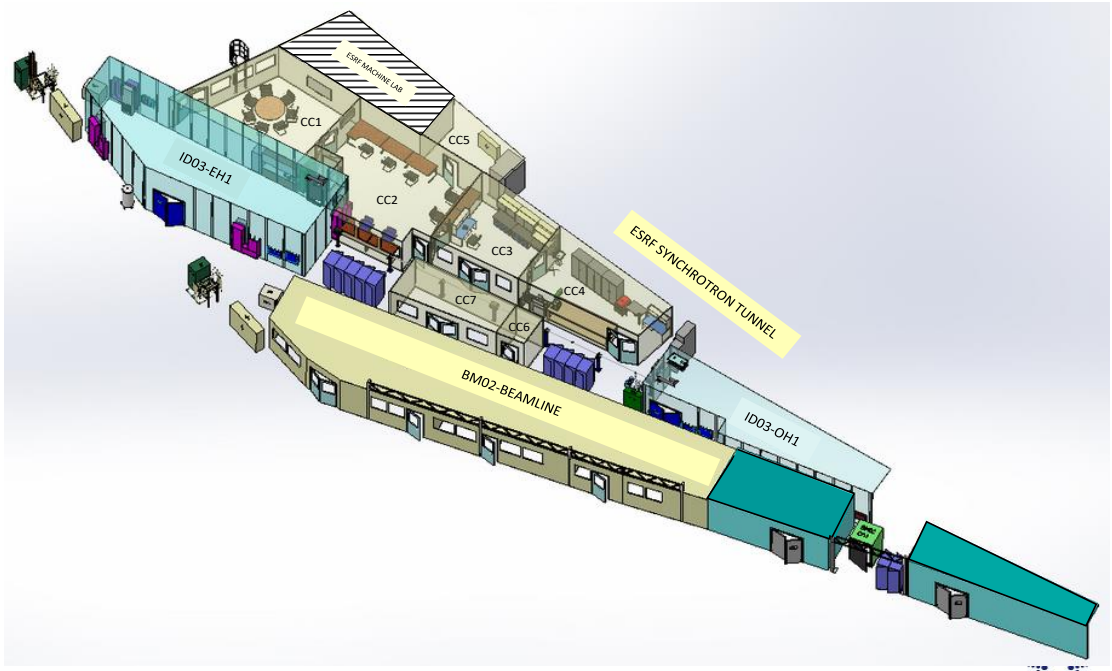
- Metals, ceramics,
- minerals,
- biomaterials…





Simons *et al.*, Nature Materials 17, 814 (2018)

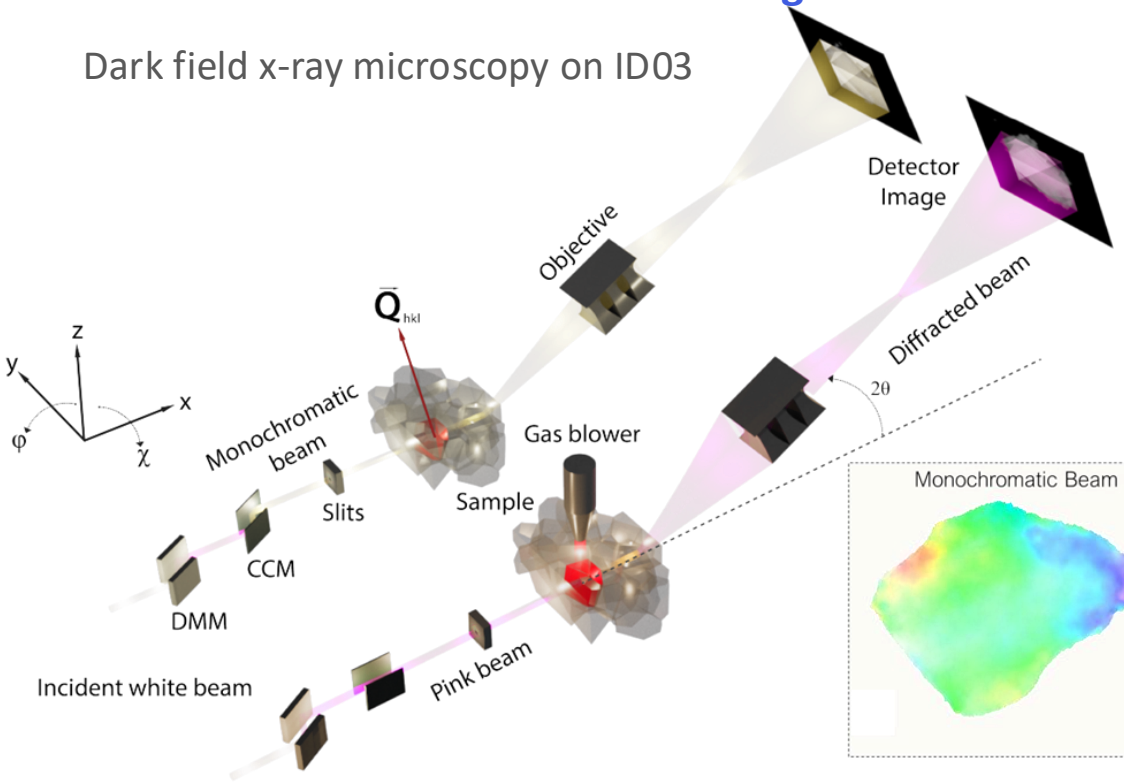


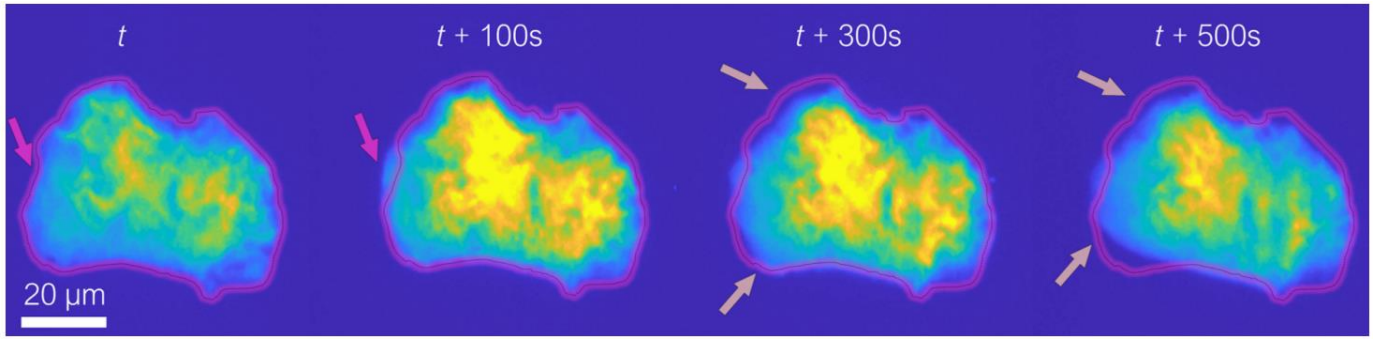


PINK-BEAM DARK FIELD X-RAY MICROSCOPY: EXPANDING 3D/4D IMAGING FOR COMPLEX/DEFORMED SAMPLES

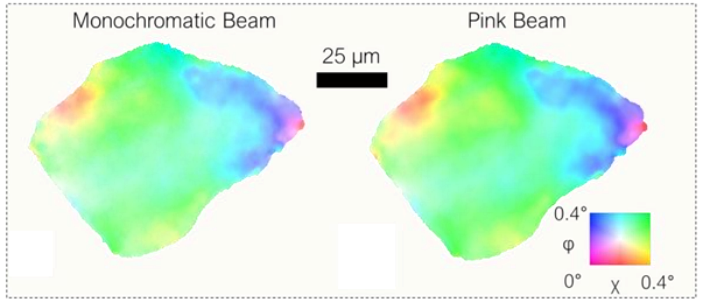
Tracking grain growth in real time - assessing intragranular microstructure and strain evolution within individual grains and near grain boundaries (courtesy C. Detlefs and C. Yildirim)

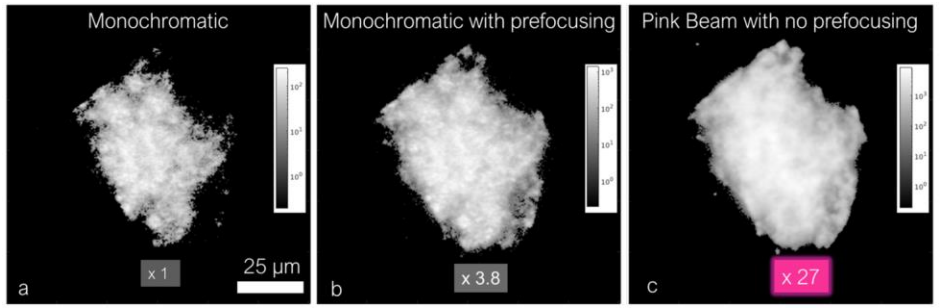
Dark field x-ray microscopy on ID03





In-situ observation of aluminum grain growth during isothermal annealing

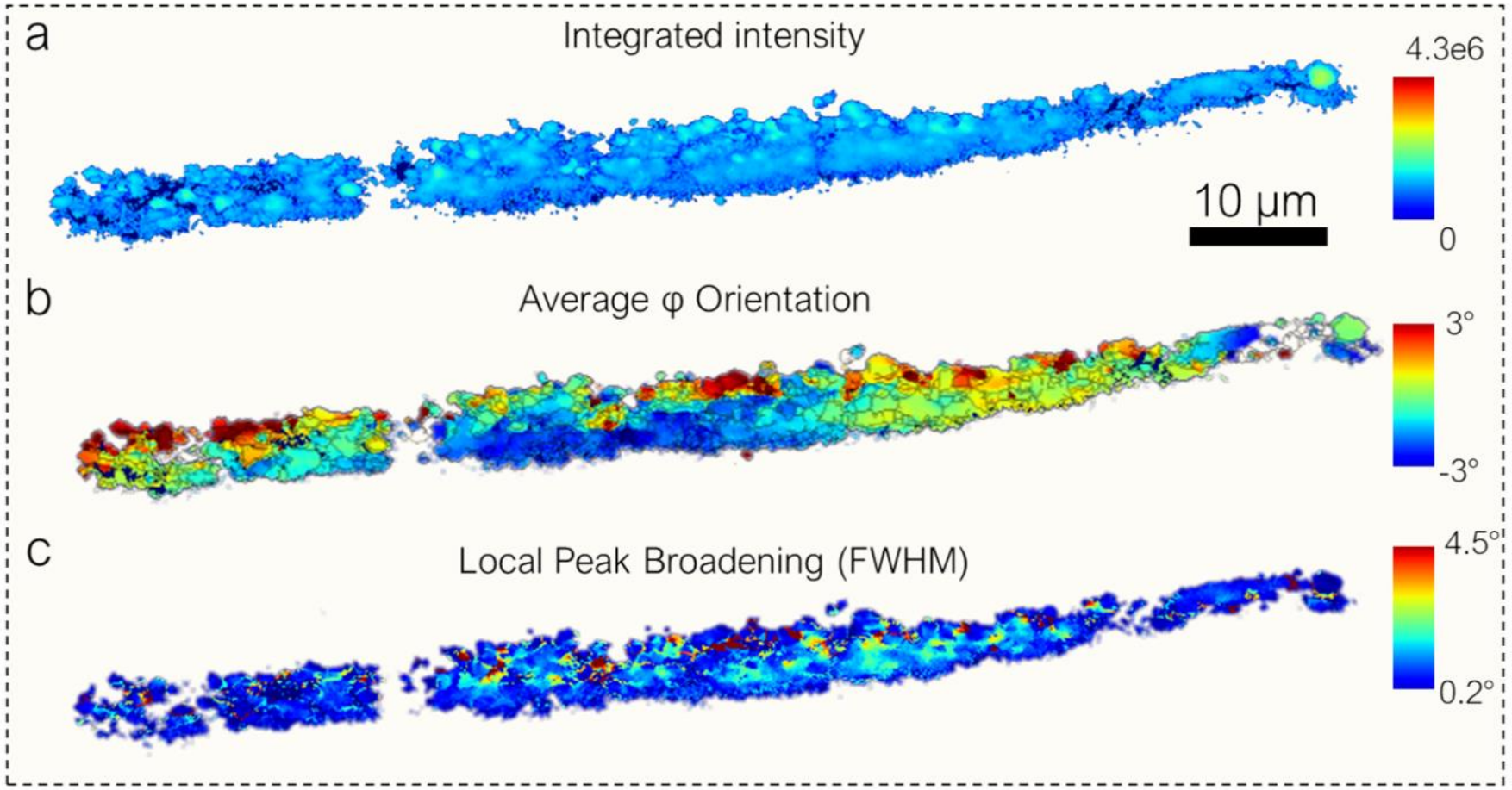




- Boosting imaging capabilities by increasing the diffracted intensity and keeping 100nm resolution
- pDFXM: a viable method for real time, high-throughput studies of deformation microstructures, grain growth, and phase transformations in bulk crystalline materials
- ID03 with **27x more photon flux at 60 keV** allows for ***in-situ, operando***, and **time resolved** studies

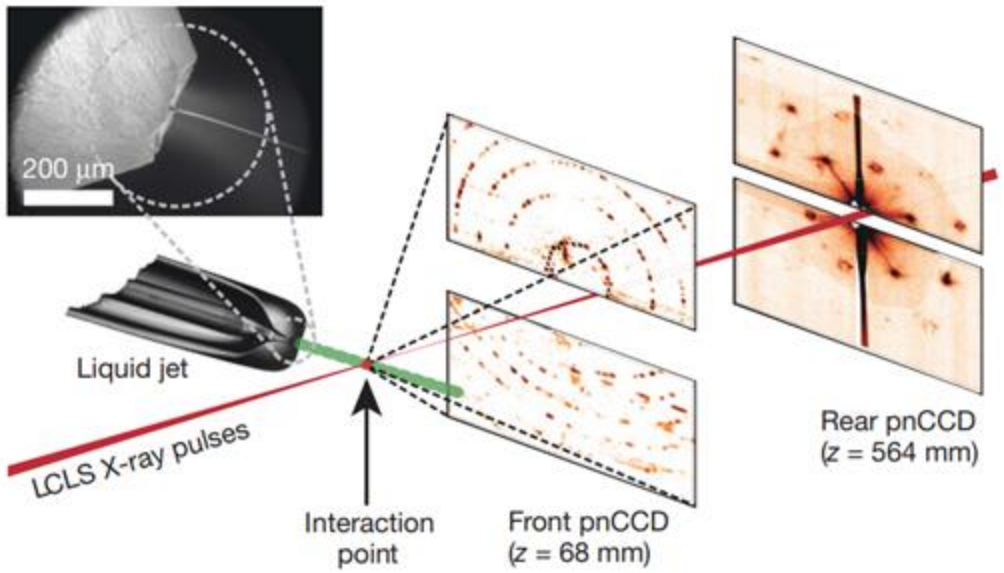
C. Yildirim et al. https://arxiv.org/abs/2503.05921 *(2025)*

Tracking grain growth in real time - assessing intragranular microstructure and strain evolution within individual grains and near grain boundaries (courtesy K. Detlefs and C. Yildirim)



Projection pDFXM maps showing subgrain structure and orientation mapping in highly deformed ferritic Fe-3%Si.

SERIAL FEMTOSECOND CRYSTALLOGRAPHY



Chapman et al 2011

- Diffraction before destruction
  - Radiation damage “free”
- Possible to study nano-to-micro crystals
- Determine structure at Room temperature
- No cryo-protectant artifacts
- New methods and software to index and integrate data
- Diffraction is from “still” crystals (no rocking)
- Thousands of indexed pattern are necessary to reconstruct
- New data quality indicators

EBSL8 – ID29: A SERIAL CRYSTALLOGRAPHY BEAMLINE

Courtesy D. de Sanctis

PRINCIPLE

Detection of molecular changes at atomic and down to sub-μs temporal resolutions

GOAL

Time-resolution SMX to watch proteins at work

APPLICATIONS

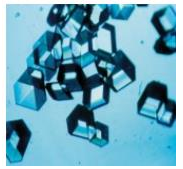
- Drug discovery research,
- Intermediate states of enzymatic processes in biology,
- Structure-based rational design
- …

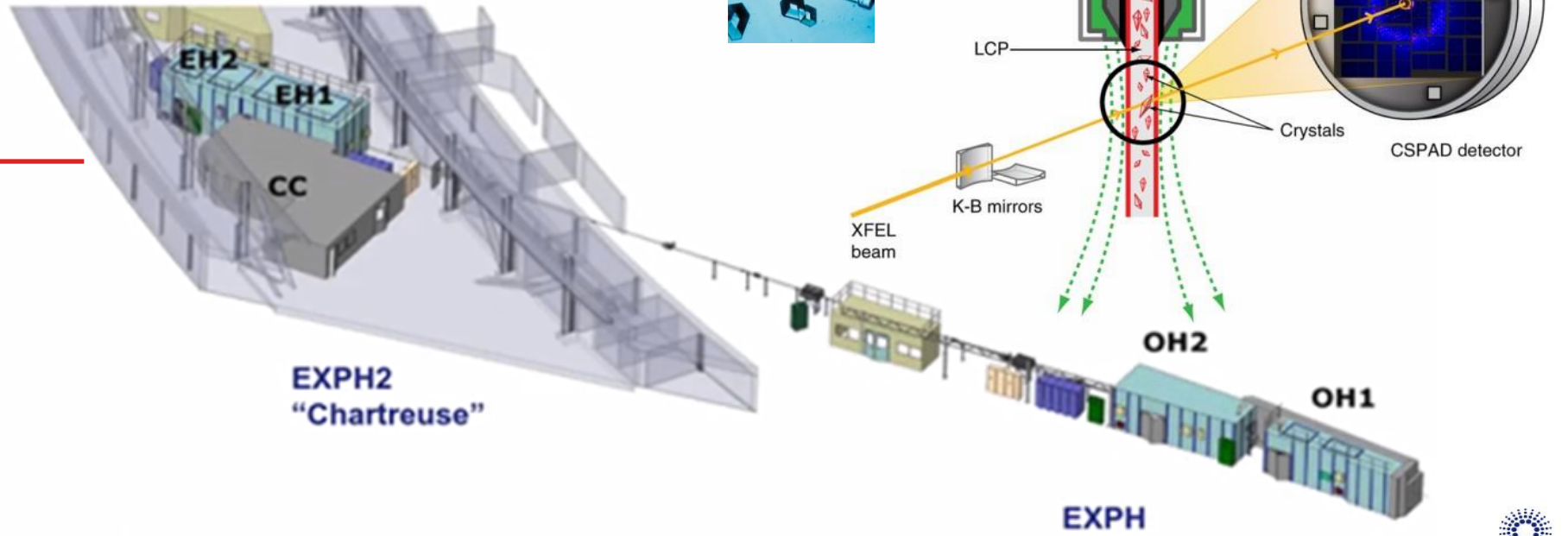
TECHNIQUES

- Macromolecular crystallography

BEAMLINE

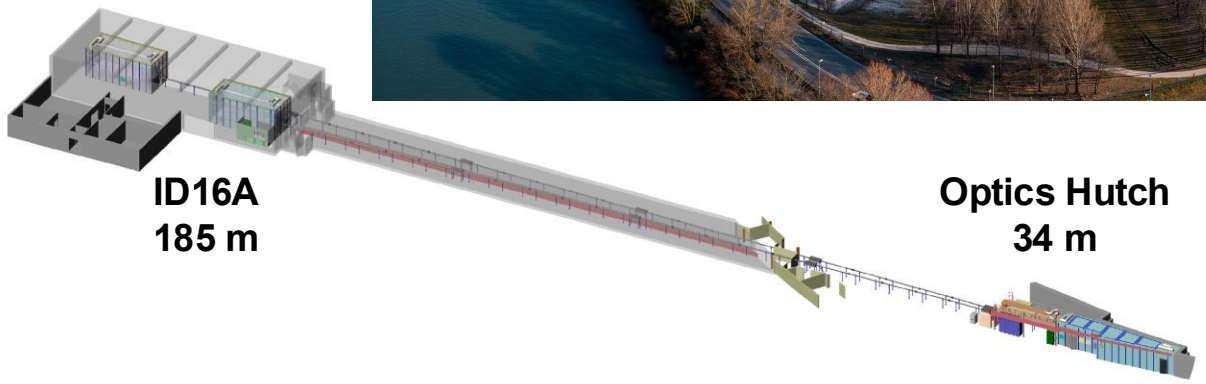
Length: 107 m
Energy: 10 – 35 keV
Beam size: 0.5x0.5 μm²
Photon Flux: 10^{15}-10^{16} ph/s
Crystal sizes: ~ μm
Time resolution: 10 - 150 μs pulses
Bandwidth: 1%
Frame rate: ~1 kHz

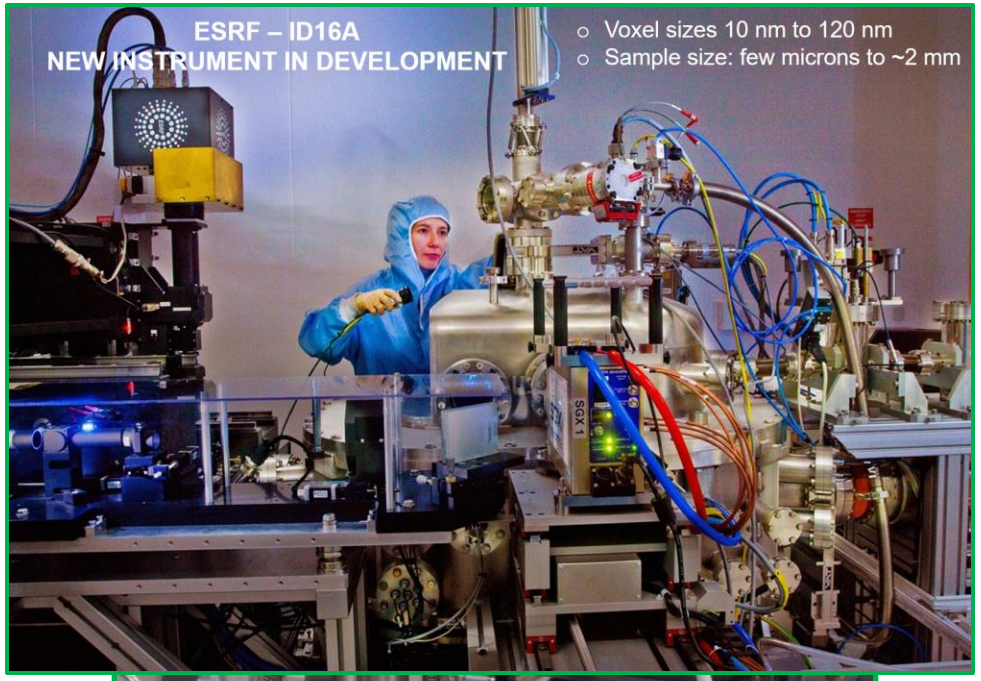


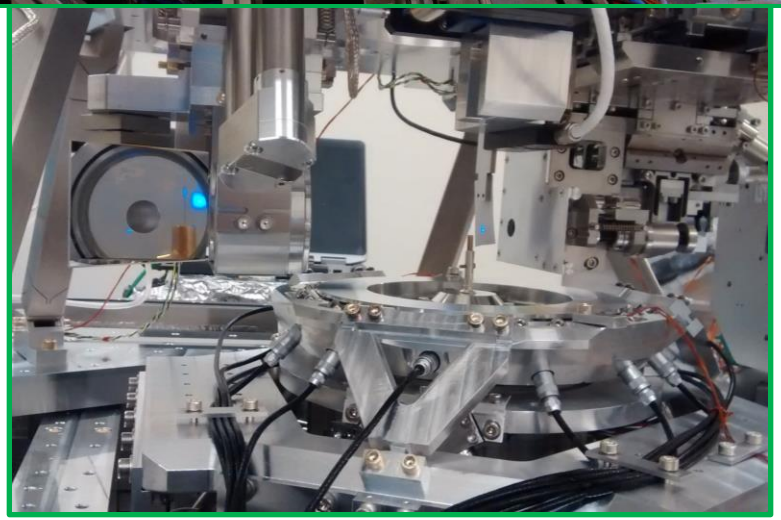


NANO IMAGING BEAMLINE ID16A

Courtesy P. Cloetens



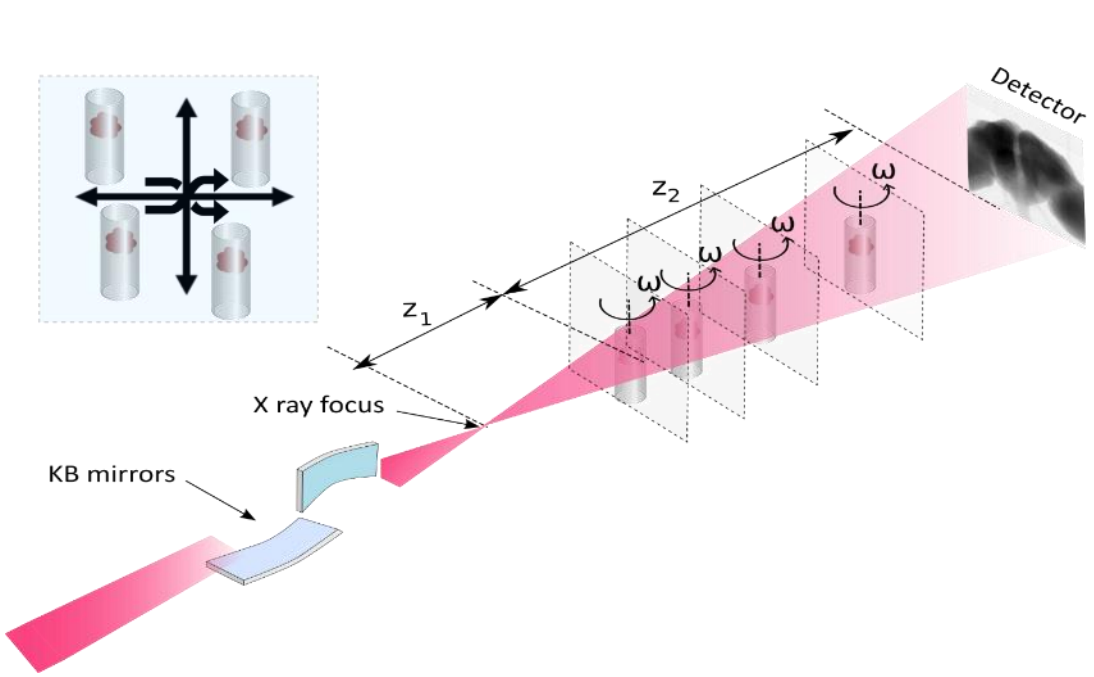


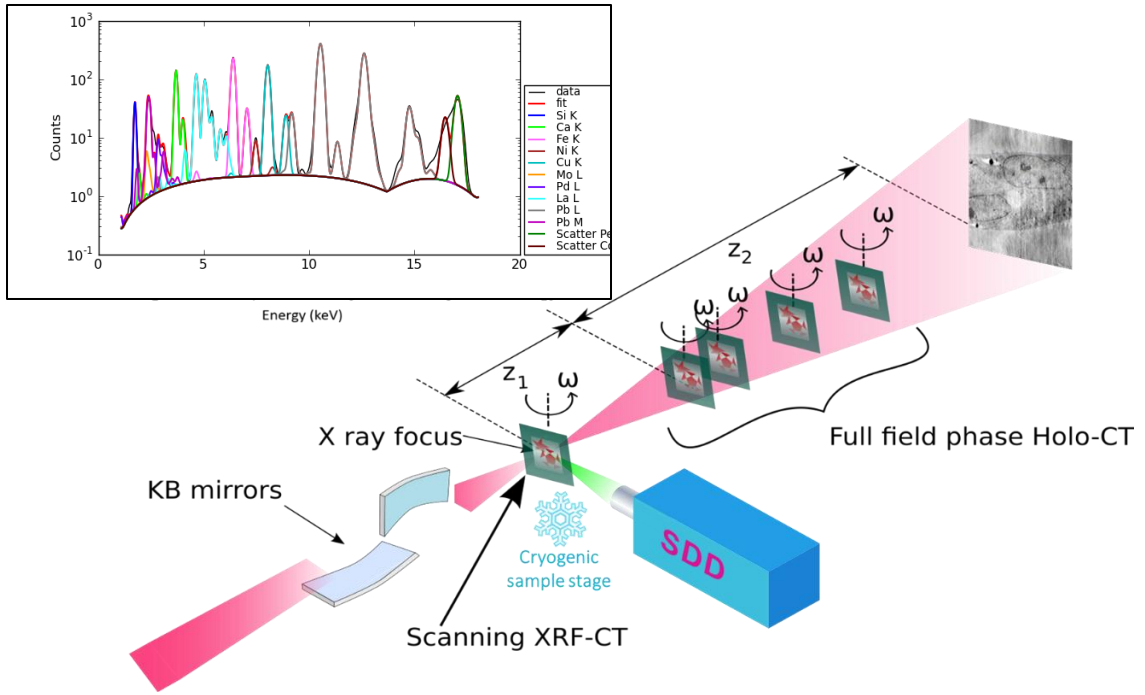


- *Techniques:* Coherent imaging: **X-ray holography** and near-field **ptychography**, and **X-ray fluorescence**
- *Energy:* **17 keV** & **33.6 keV**
- *Flux:* 1.2 10^{13} ph/s & 2.7 10^{12} ph/s @ 0.7%, ~4 10^{11} ph/s in practice
- *Operation:* vacuum, room temperature or **cryogenic**

PHASE CONTRAST – HOLOGRAPHY AND CORRELATIVE X-RAY FLUORESCENCE

Courtesy P. Cloetens





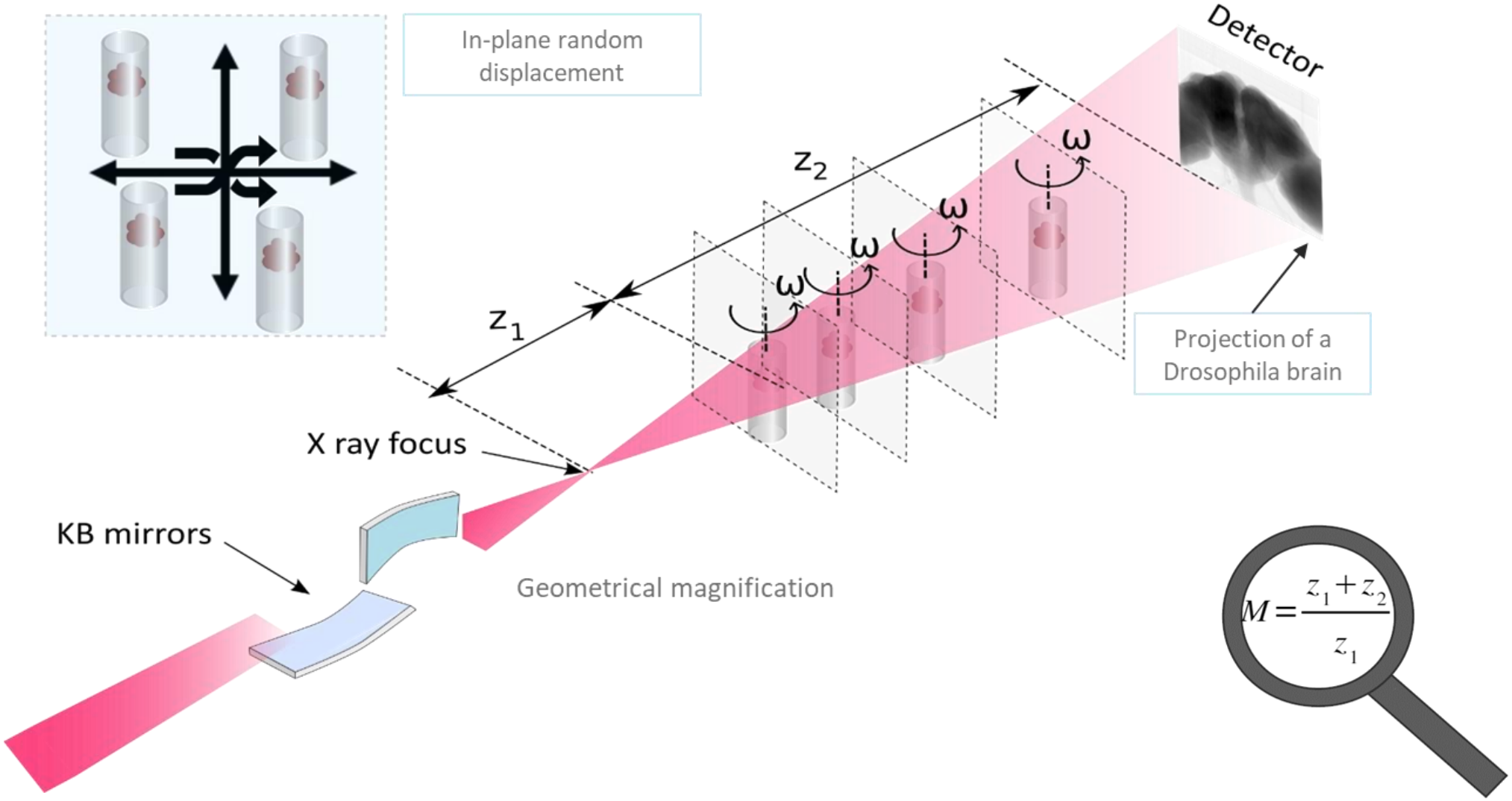
Reconstruct electron density
→ **3D Structure**

↔

Detect trace elements (Z>13) down to **sub-ppm** level
→ **Label free 3D chemical composition**

X-RAY HOLOTOMOGRAPHY FOR CONNECTOMICS – NEUROSCIENCE

Courtesy P. Cloetens

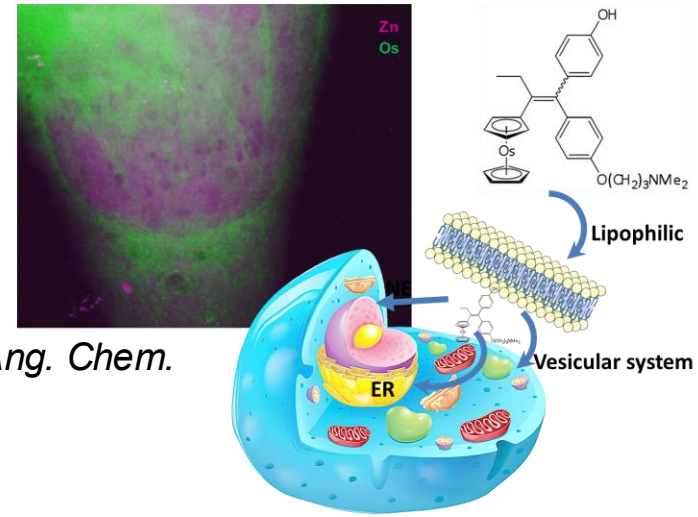


Wiring diagram of the brain ?

Courtesy P. Cloetens

Metallo-Biology

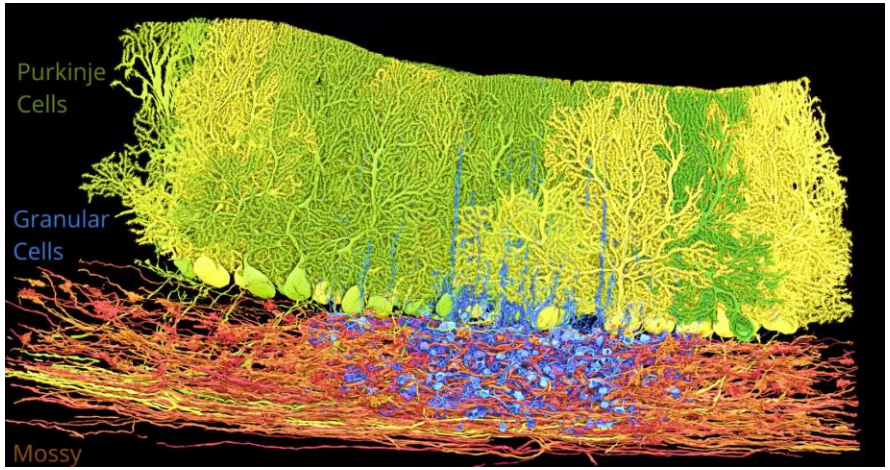
Action mechanisms of drugs / Metallomics



Ang. Chem.

Neurosciences

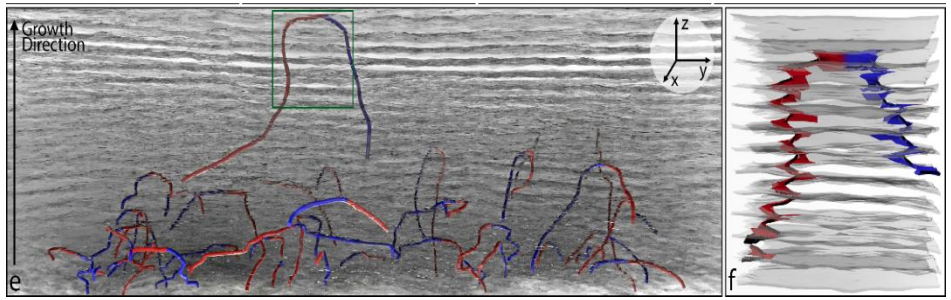
Connectomics / Tissue level



Nature

Bio-Materials

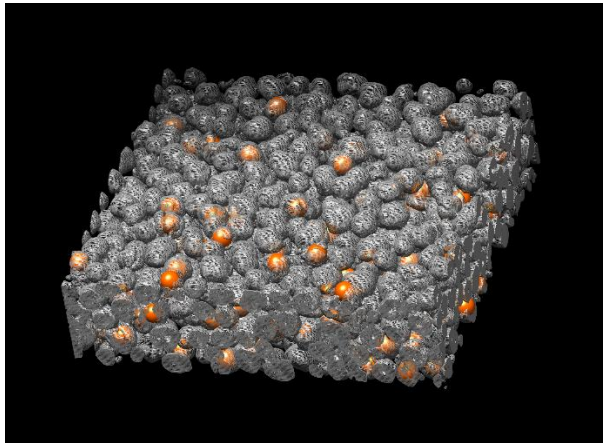
Biomineralization / Bone



Nat. Physics

(Energy) Materials

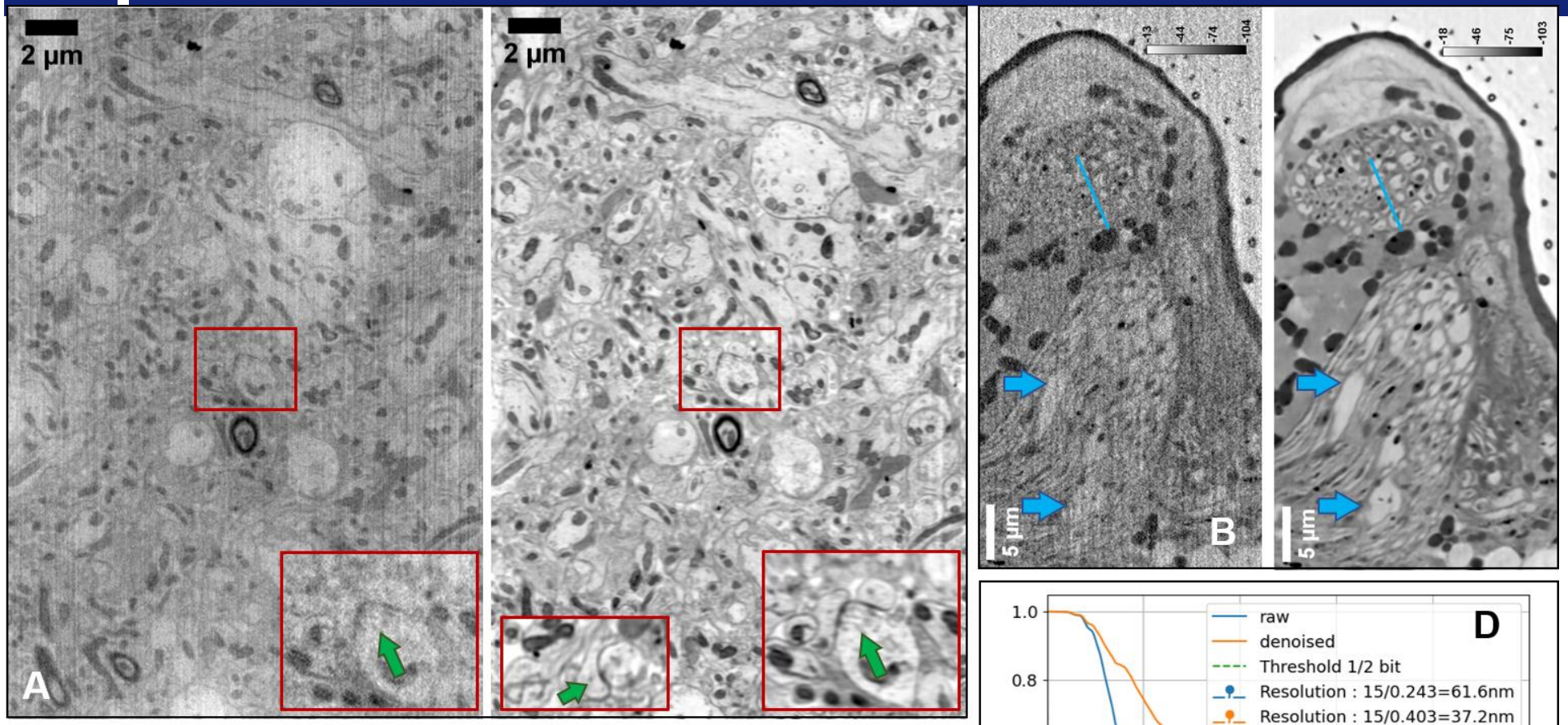
Batteries / Solid Oxide Cells / AM

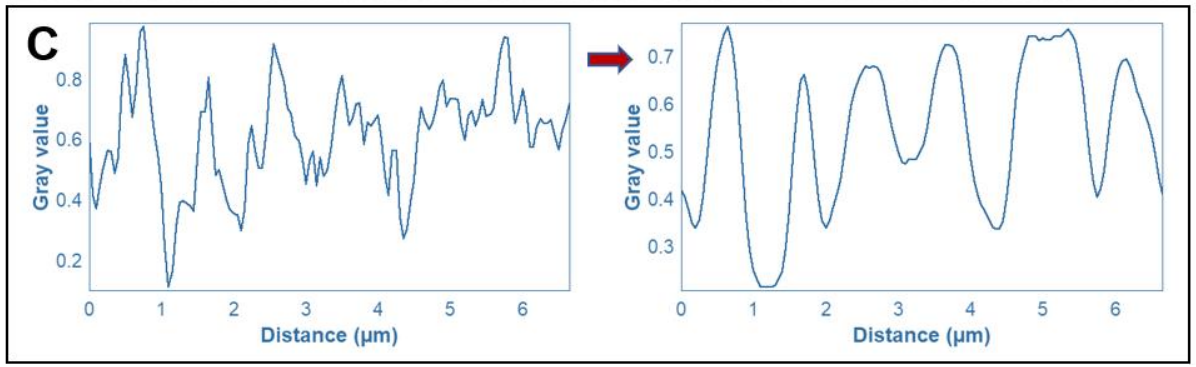


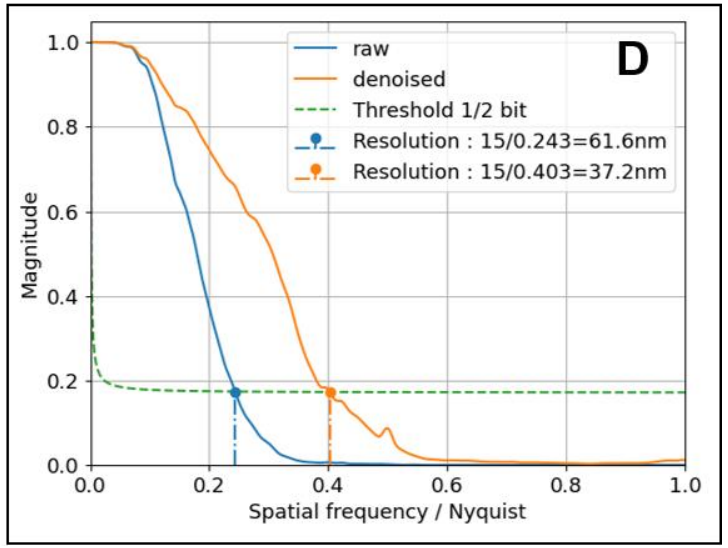
Adv. Energy Mater.

SELF-SUPERVISED IMAGE RESTORATION → SYNAPTIC RESOLUTION AT REACH

Courtesy A. Pacureanu







Alfred Laugros

Peter Cloetens

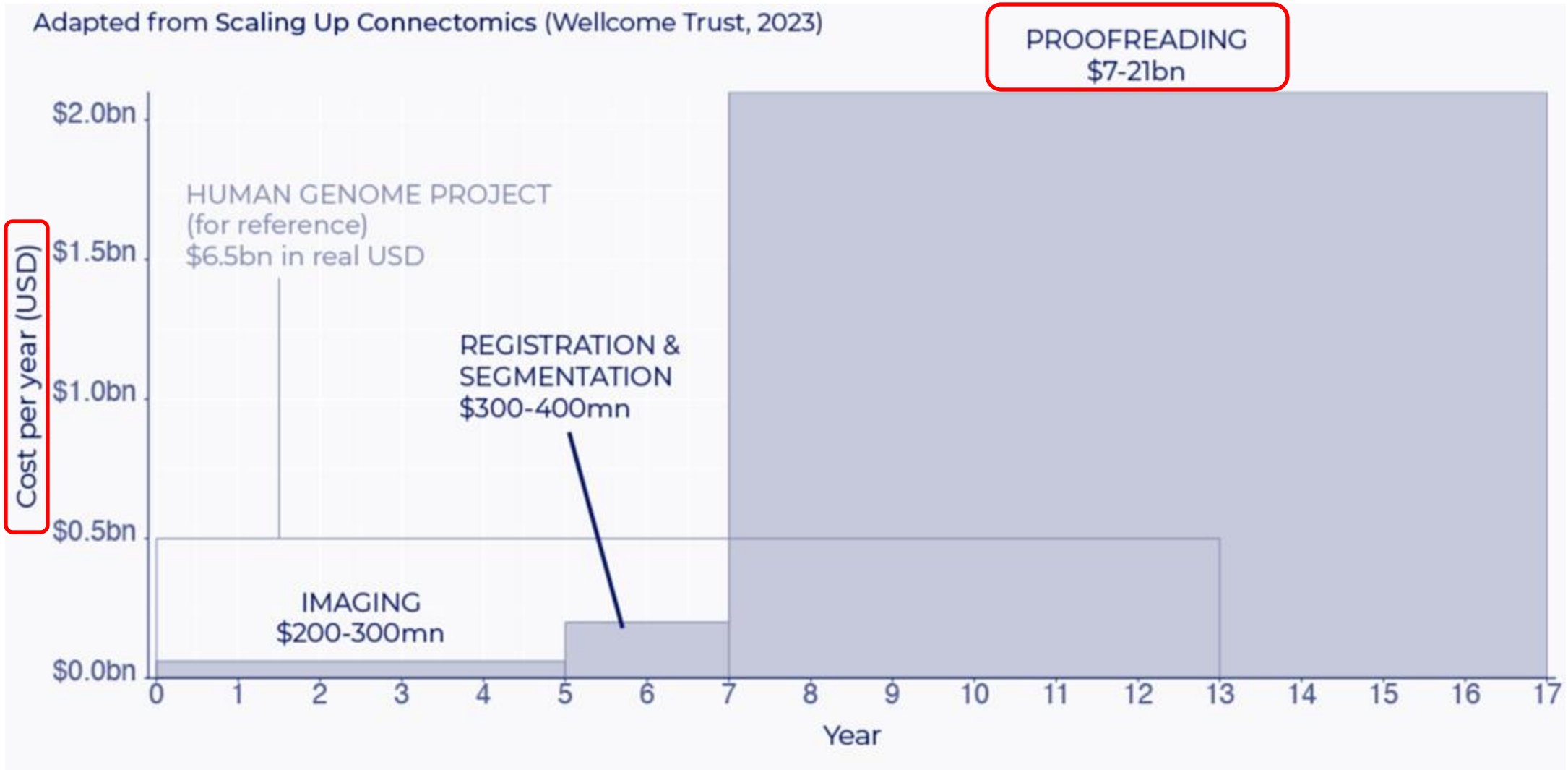
- ✓ 2x in resolution
- ✓ 5x in CNR

Laugros et al. 2025 *bioRxiv* doi:https://doi.org/10.1101/2025.02.10.633538

The European Synchrotron | ESRF

THE CHALLENGE – CONTRIBUTE TO DRASTICALLY REDUCE TIME AND COSTS

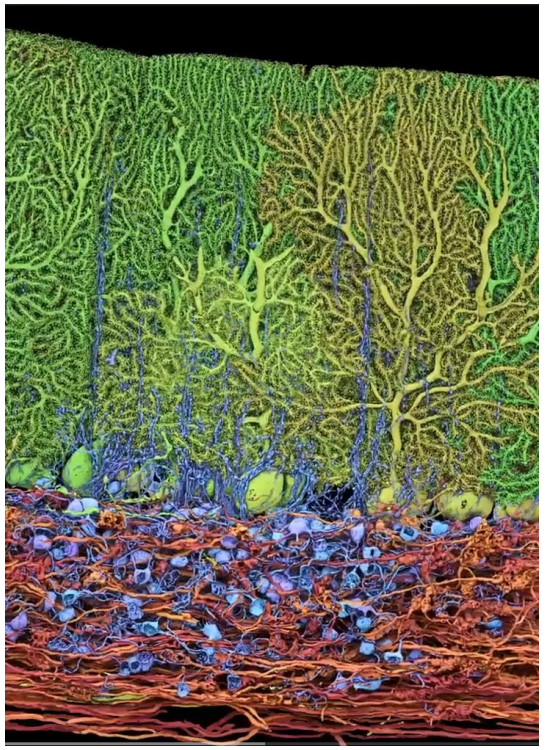
Courtesy A. Pacureanu



FOUNDATION MODELS FOR DATA ANALYSIS → TRANSFORMATIVE

Courtesy A. Pacureanu

- **Leverage the data itself**
- **Generalizable and efficient**: few annotations → segment any biological feature. It handles various resolutions and diverse types of structures.
- **Fast and computationally efficient:** a 100 GB volume can be segmented in 24 hours on one A100.
- **Unlock data analysis for many valuable data sets.**

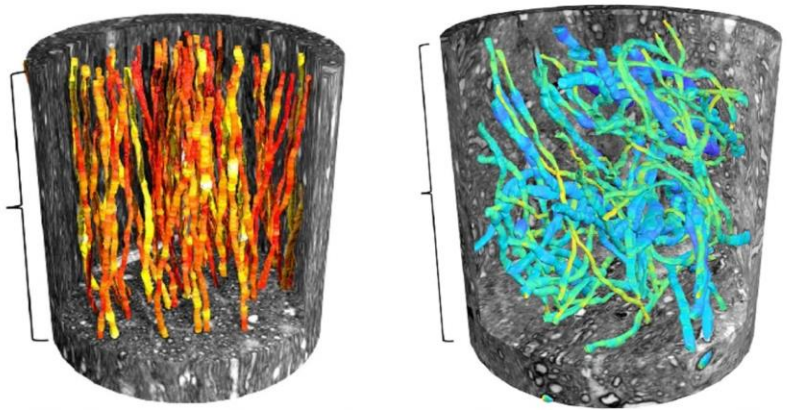


Alfred Laugros

Sebastien Roig

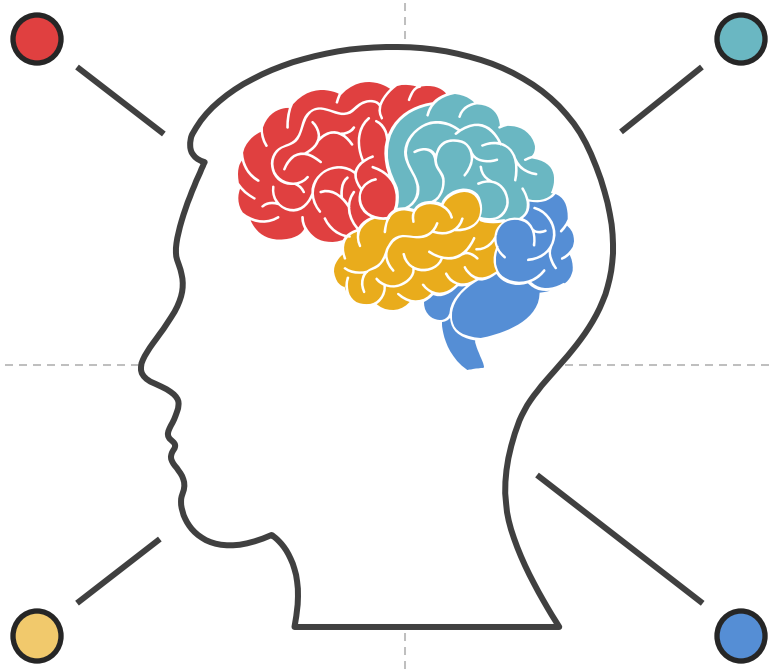
THE NANOIMAGING BEAMLINE FOR LIFE SCIENCES AND BIOMEDICAL RESEARCH

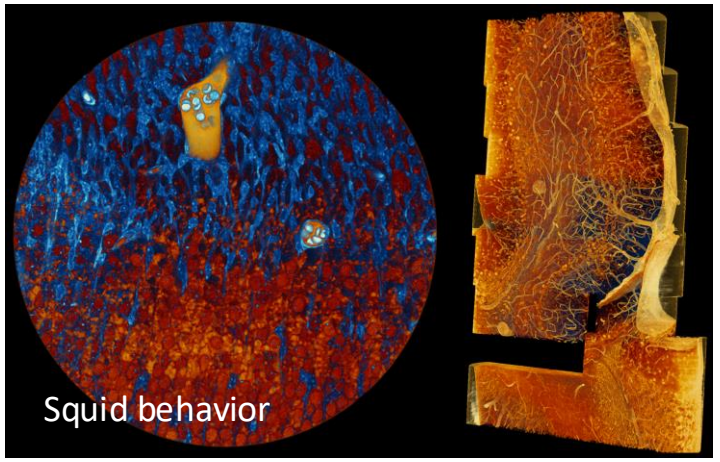
Courtesy A. Pacureanu

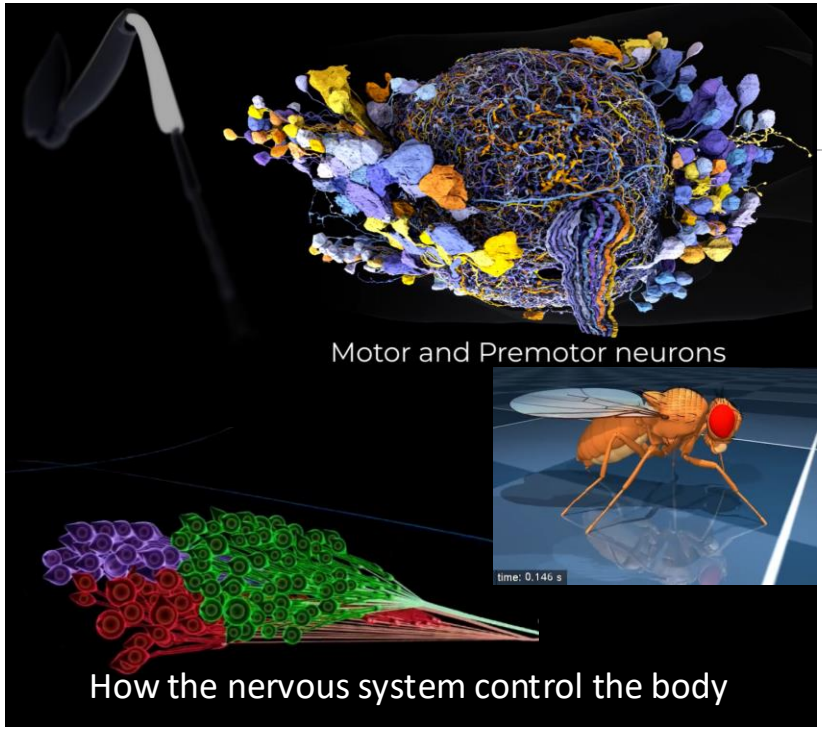


White matter organization in human brain

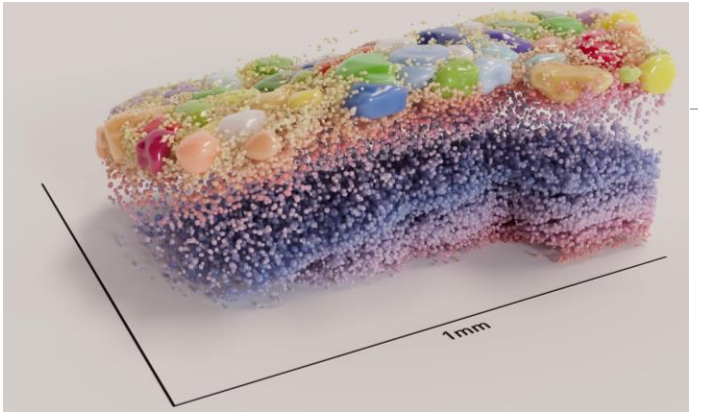
Image millimeter-sized biological tissue samples at sub-cellular resolution







How the nervous system control the body



Inside the mouse olfactory bulb

Azevedo et al. Nature 2024
Mamiya et al. Neuron 2023
Andersson et al. PNAS 2020

Lee Lab, Harvard Medical School
Schaefer Lab, The Francis Crick Institute

ID18 – A NEW NANOIMAGING BEAMLINE FOR LIFE SCIENCES AND BIOMEDICAL RESEARCH

Cell Biology

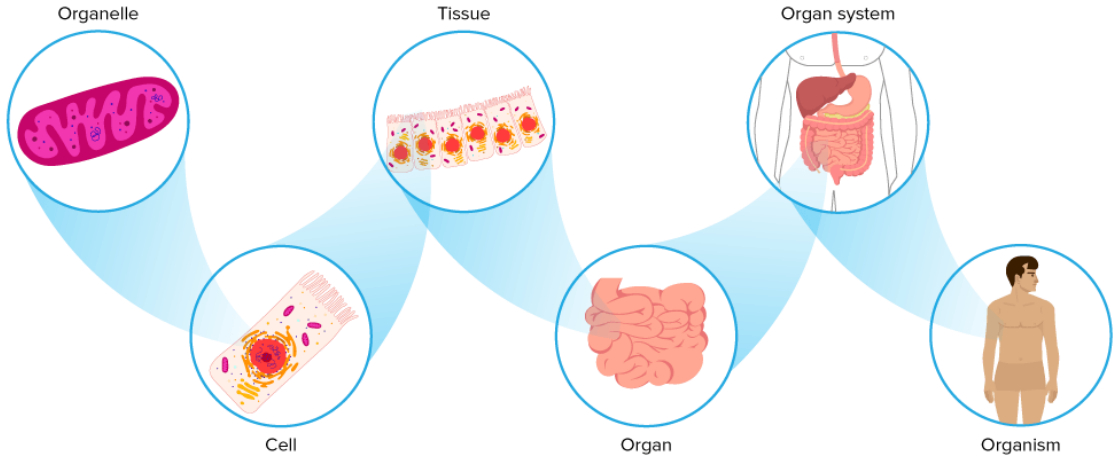
In-cell, natural context
Imaging across scales:
From cells to atoms
Improved spatial resolution
Throughput, automation, etc

Connectomics

Scale-up to larger organisms
Throughput, automation, etc.
Addressing grand challenges

From molecules

EMBL



To brain wiring

THE FRANCIS CRICK INSTITUTE

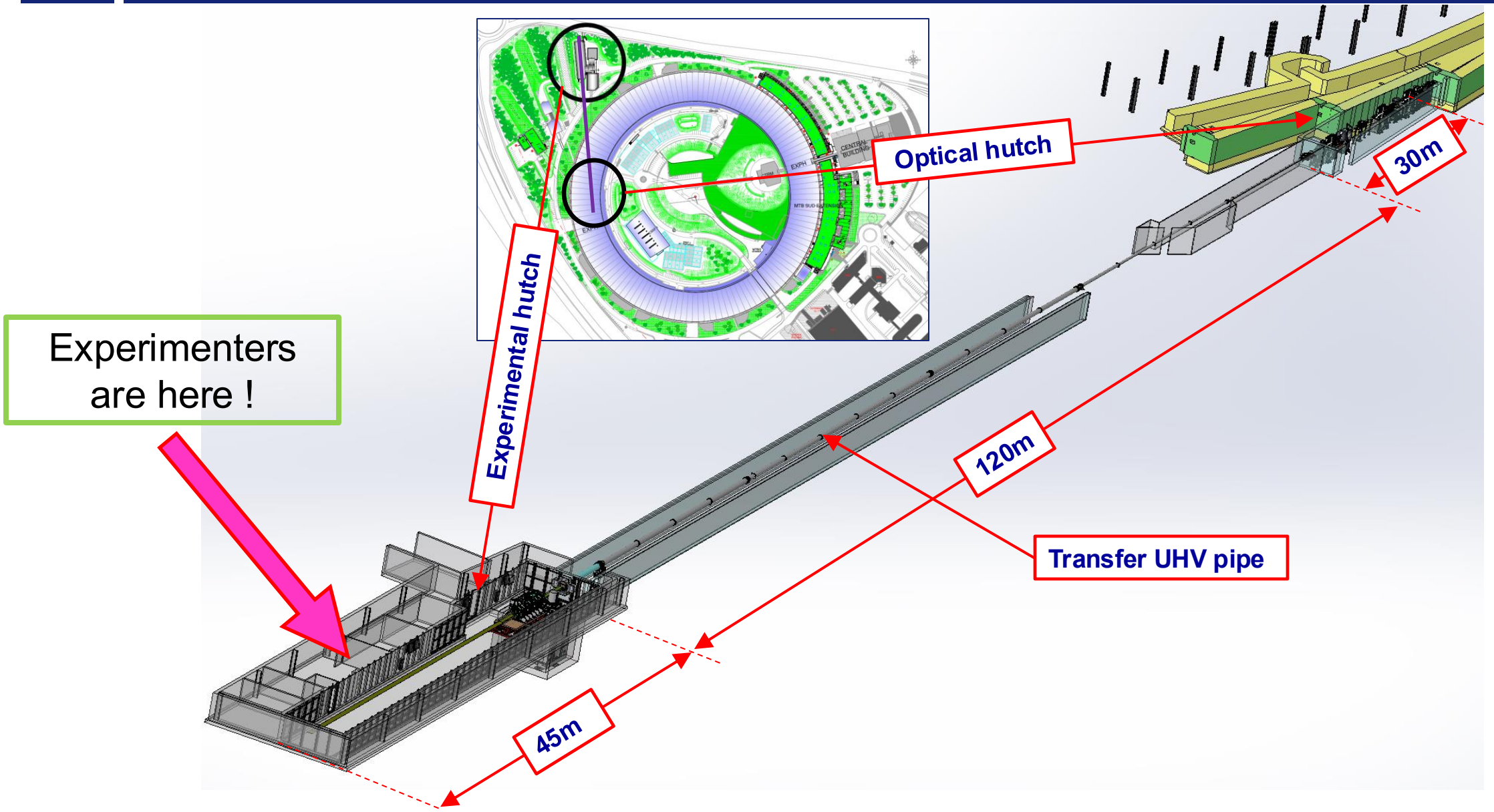
Higher speed, resolving power (20 nm voxel), adapted sample volumes (up to ~ mm³), new measurement strategies (including cryo-EM like approaches)

BM18 BEAMLINE FOR HIERARCHICAL PHASE-CONTRAST TOMOGRAPHY

Courtesy P. Tafforeau

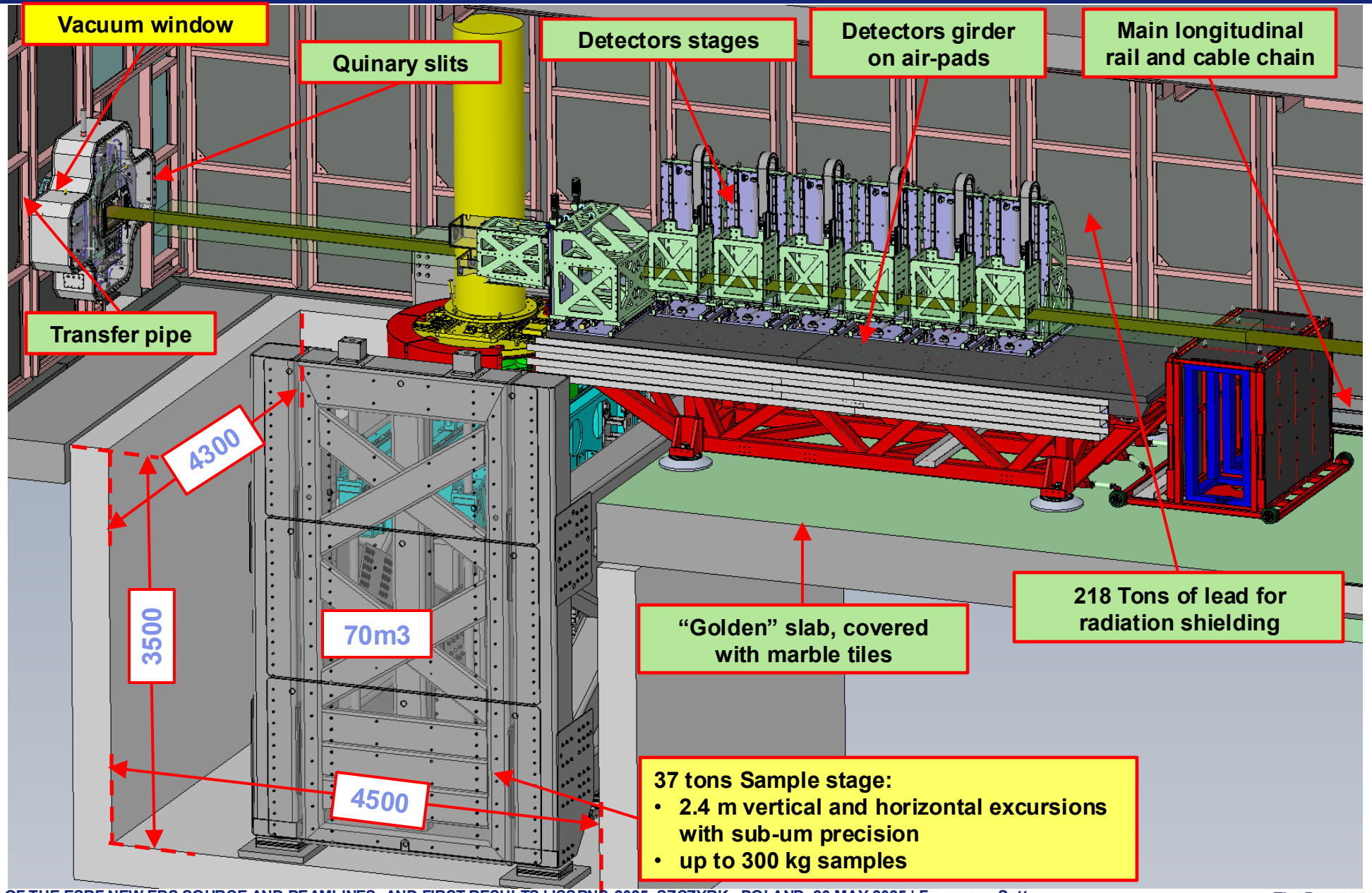
BM18 – LAYOUT 220M IN TOTAL

Courtesy P. Tafforeau



BEAMLINE LAYOUT – EXPERIMENTAL HUTCH – 0.3 MEV WHITE X-RAY BEAM

Courtesy P. Tafforeau



BM18: HIERARCHICAL PHASE-CONTRAST TOMOGRAPHY

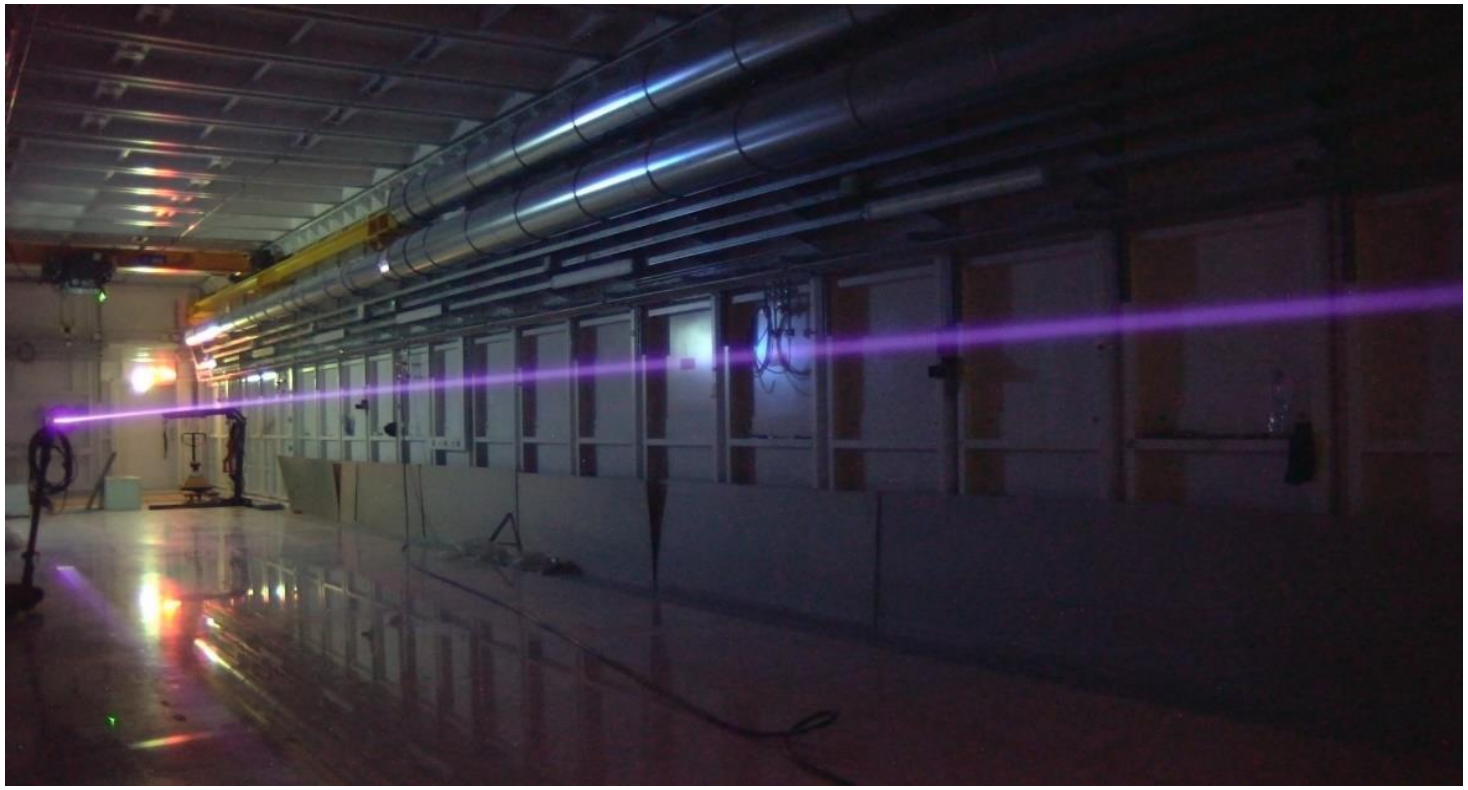
Courtesy P. Tafforeau

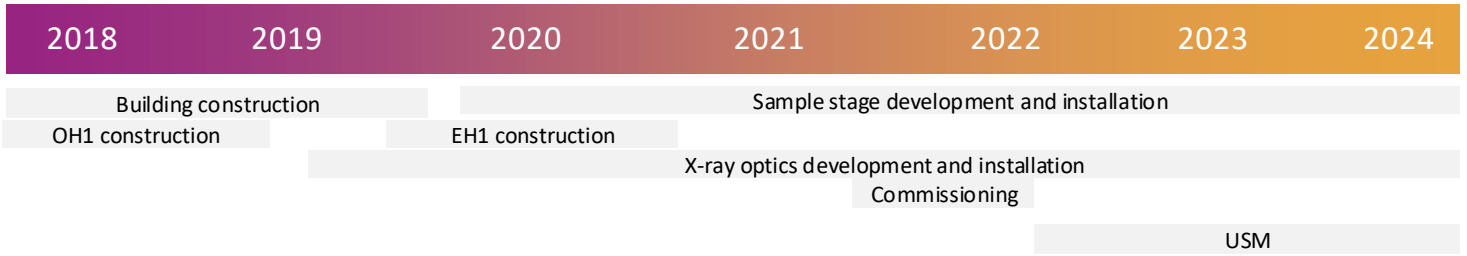
Main techniques:
- Hierarchical tomography
- Propagation phase-contrast imaging

Main beamline specifications:
- *Energy range:40-300 keV (polychromatic)*
- *220m long beamline, up to 36m for propagation phase-contrast*
- *sample size up to 2.4m and 300 kg*
- *High automation level for high throughput*

EBS and refurbishment improvements:
- *Smallest possible X-ray source of the EBS*
- *beam of 35cm with highest coherence worldwide for high-energy X-ray imaging.*
- *Large resolution range (0.8 - 120 um)*

45m long experimental hutch with large polychromatic beam at high energy





BM18: HIERARCHICAL PHASE-CONTRAST TOMOGRAPHY

Courtesy P. Tafforeau

Biomedical imaging

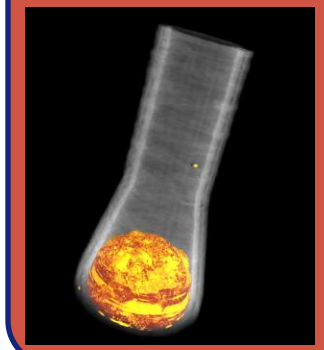
- A new scale in human body knowledge
- Understanding effects of diseases

Natural and cultural heritage

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

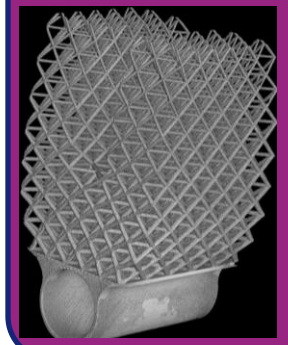
High sensitivity phase-contrast tomography in large and complex samples

Geology



- origin of earthquackes
- Mecanisms of volcanoes
- Climate change

Material sciences

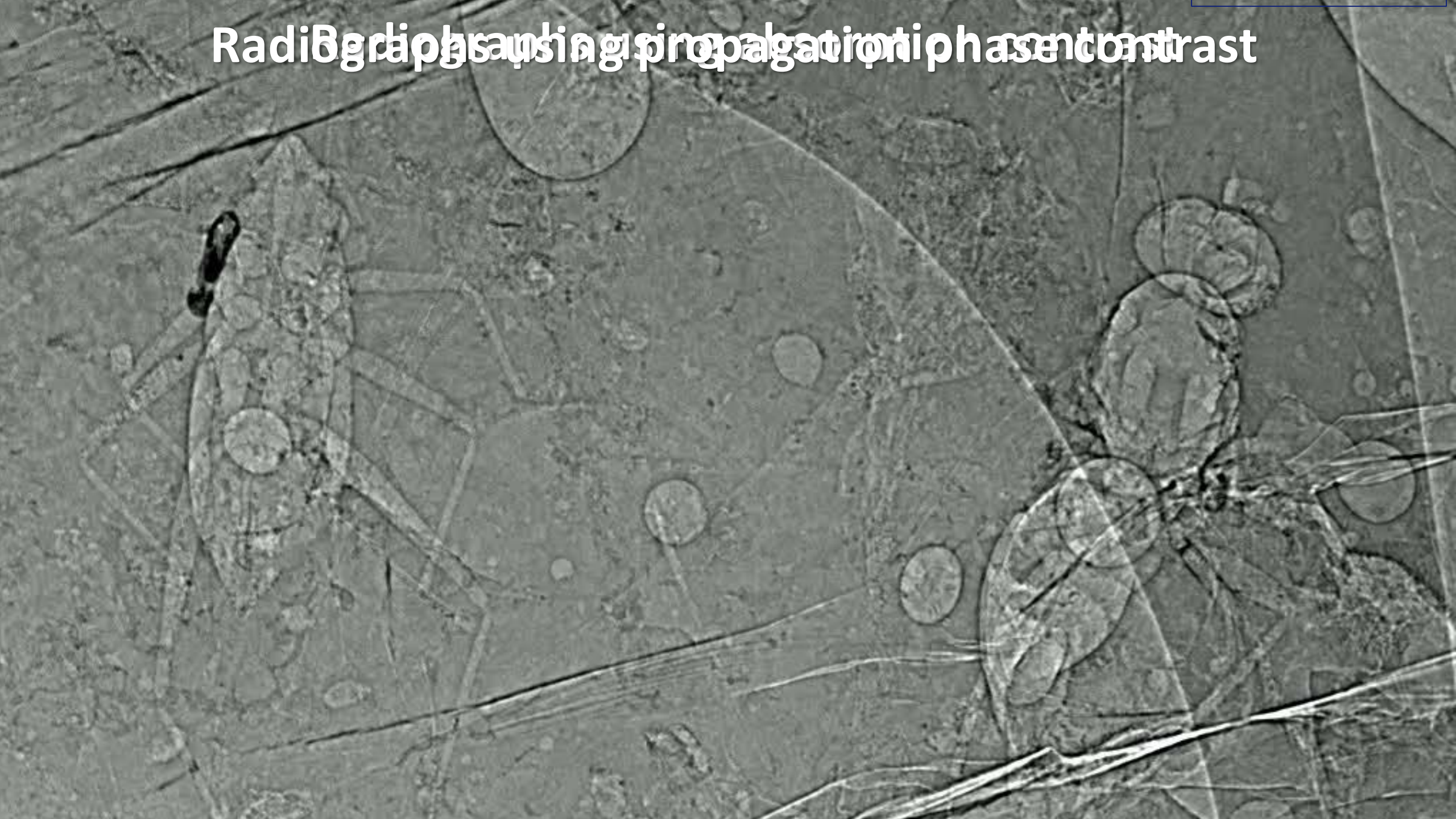


- Non-destructive control of large devices (batteries, complex mechanical parts)
- Additive manufacturing (in-situ and ex-situ)

Industrial applications

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

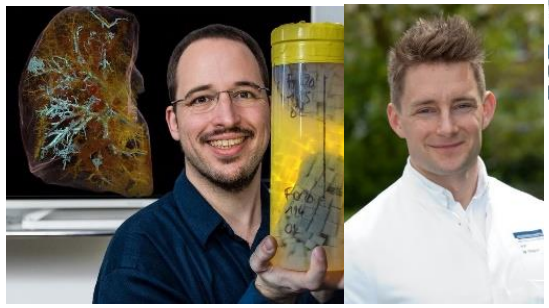
Radiographs using propagation phase contrast



COVID-19 PANDEMICS, SPRING 2020, ORIGIN OF THE HIP-CT DEVELOPMENT

Courtesy P. Tafforeau

CHAN ZUCKERBERG INITIATIVE



HEIDELBERG UNIVERSITY HOSPITAL

MHH Medizinische Hochschule Hannover

Jeden Tag für das Leben.

UCL

école de Chirurgie LADAF

Laboratoire d'Anatomie Des Alpes Françaises

DZL Deutsches Zentrum für Lungenforschung

ESRF/Stef Candé

ESRF The European Synchrotron

ESRF/vuedici.org

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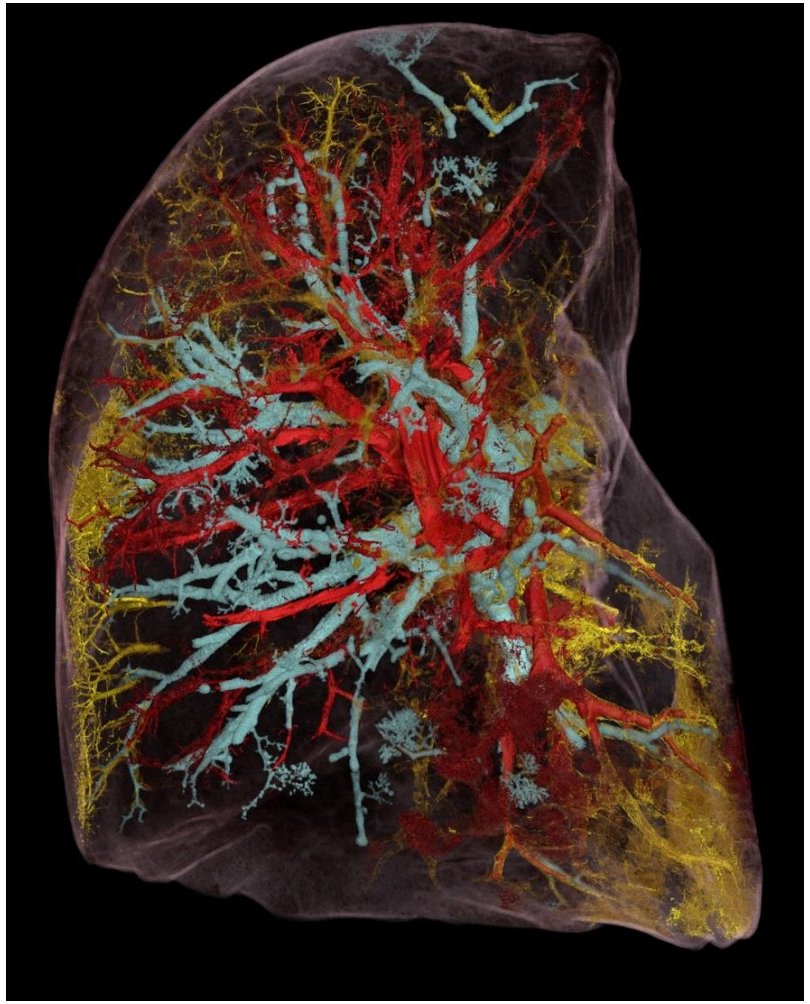
EBS SCIENCE: THE HUMAN ORGAN ATLAS PROJECT



A REVOLUTION FOR BIO-IMAGING UNDERSTANDING HUMAN DISEASES THANKS TO A NEW INSIGHT INTO OUR BODY

UCL · ESRF The European Synchrotron · UGA Université Grenoble Alpes · école de Chirurgie LADAF Laboratoire d'Anatomie Des Alpes Françaises · University of Antwerp · JGU Johannes Gutenberg Universität Mainz

CHAN ZUCKERBERG INITIATIVE · UNIVERSITY OF AMSTERDAM · HARVARD MEDICAL SCHOOL · UNIKLINIK RWTH AACHEN

Mark Zuckerberg ✓
2 h ·

Impressive advance in biological imaging technology. With support from the Chan Zuckerberg Initiative, researchers developed new technology to capture the brightest x-ray ever to show how lung vessels change in response to Covid. In the future, researchers could use AI on clinical scans like CT and MRI to diagnose diseases quicker.

ESRF The European Synchrotron

UCL

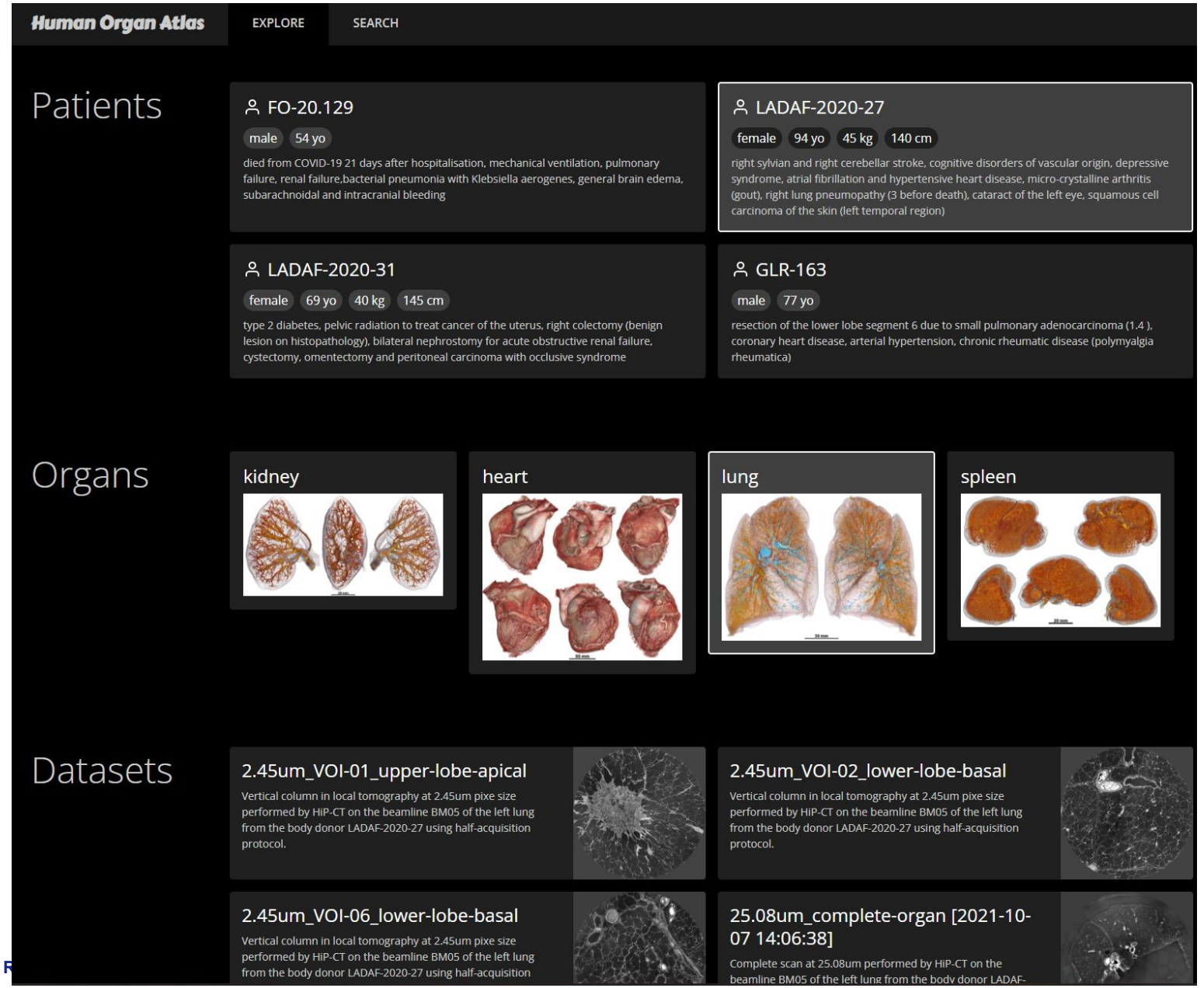
CHAN ZUCKERBERG INITIATIVE

école de Chirurgie LADAF
Laboratoire d'Anatomie Des Alpes Françaises

The Human Organ Atlas

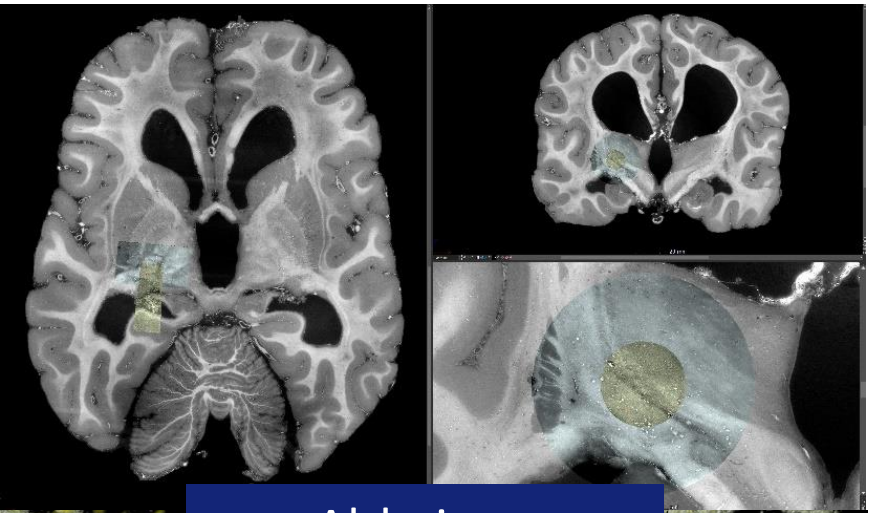
Public database with complete organs imaged by HiP-CT in health and disease

Online since 25/10/2021

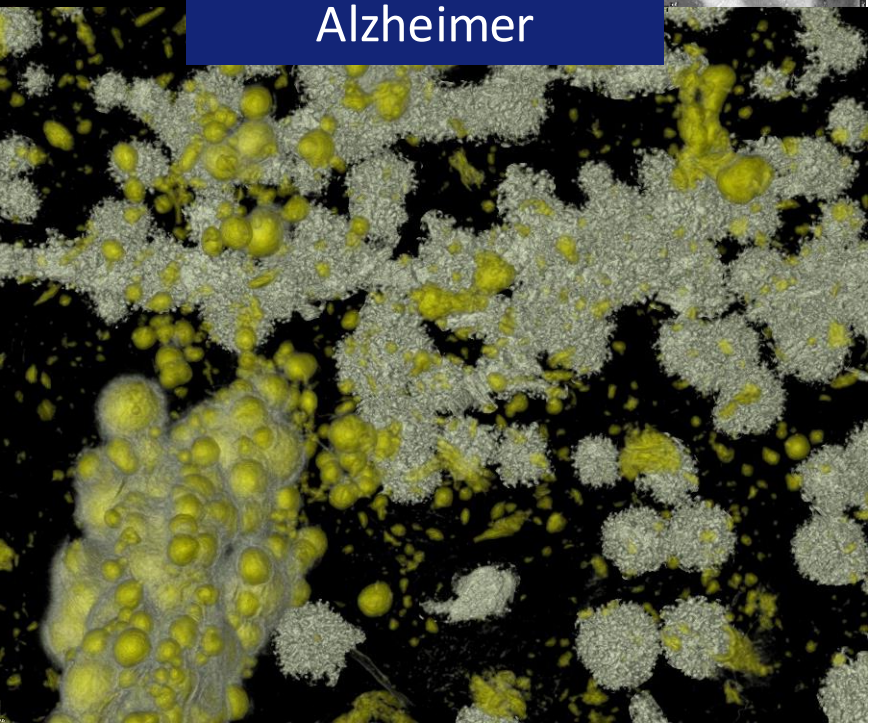


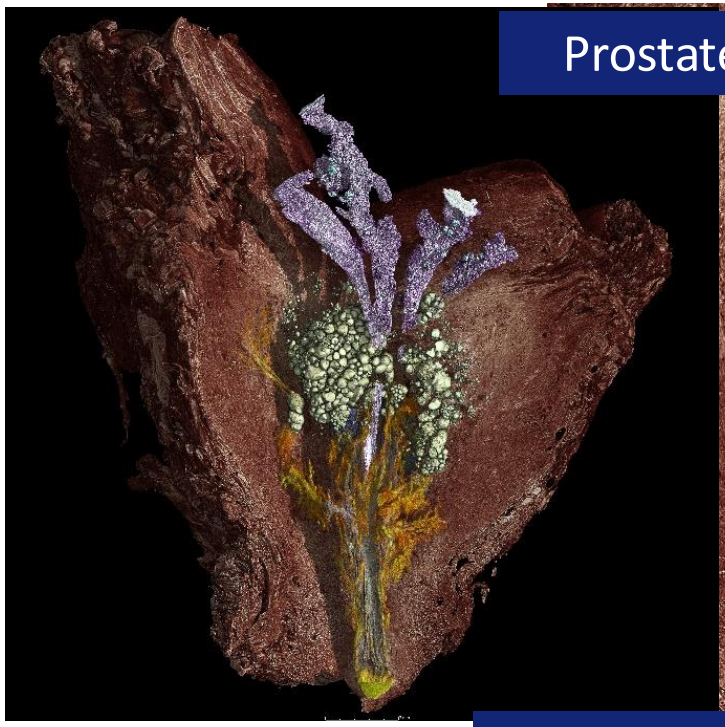
NEW SCIENTIFIC COLLABORATION EACH WEEK!

Courtesy A. Pacureanu

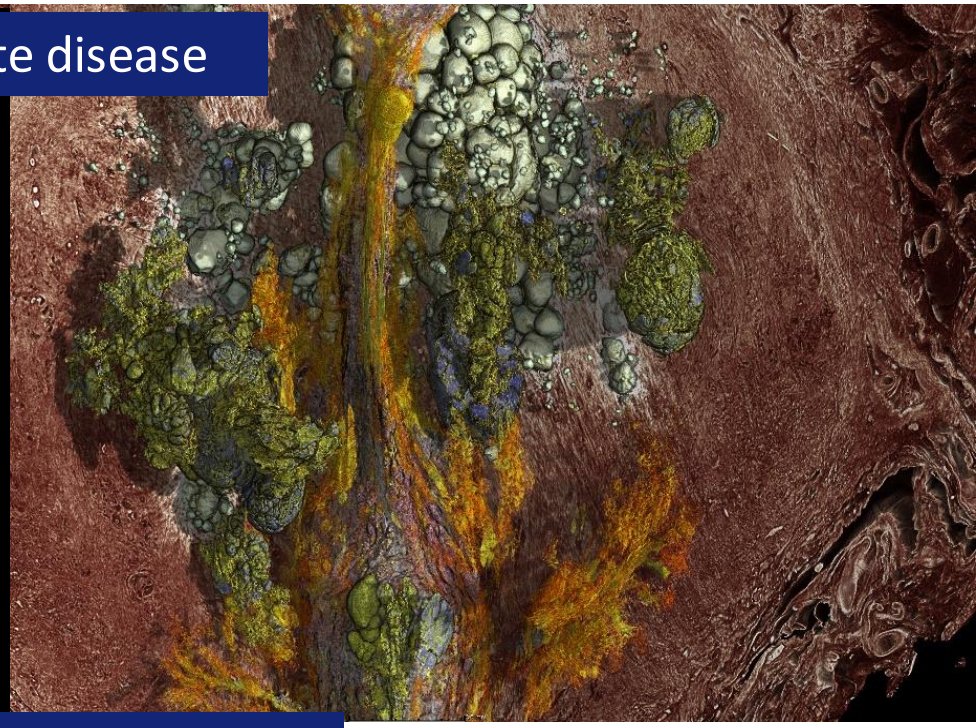


Alzheimer

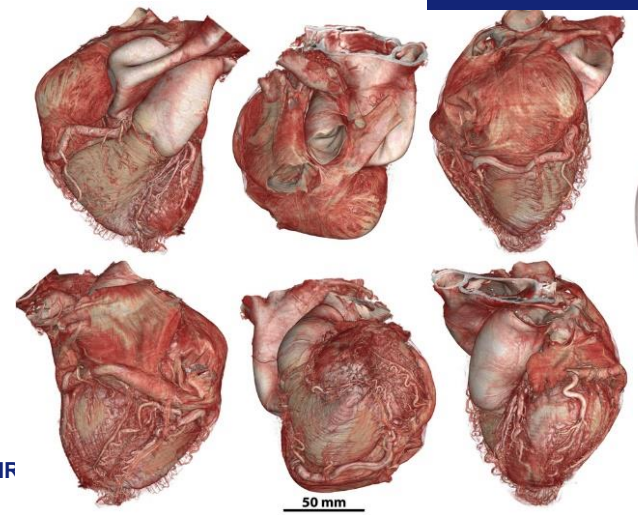


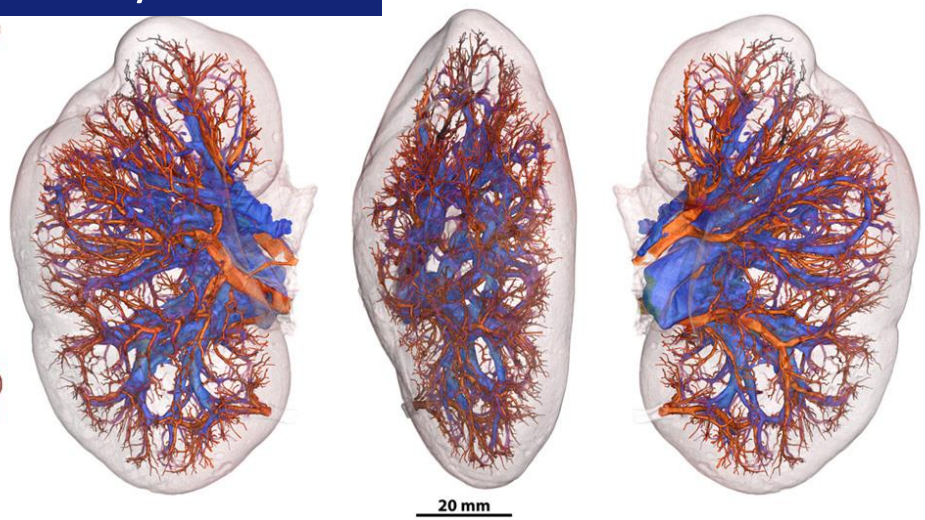


Prostate disease



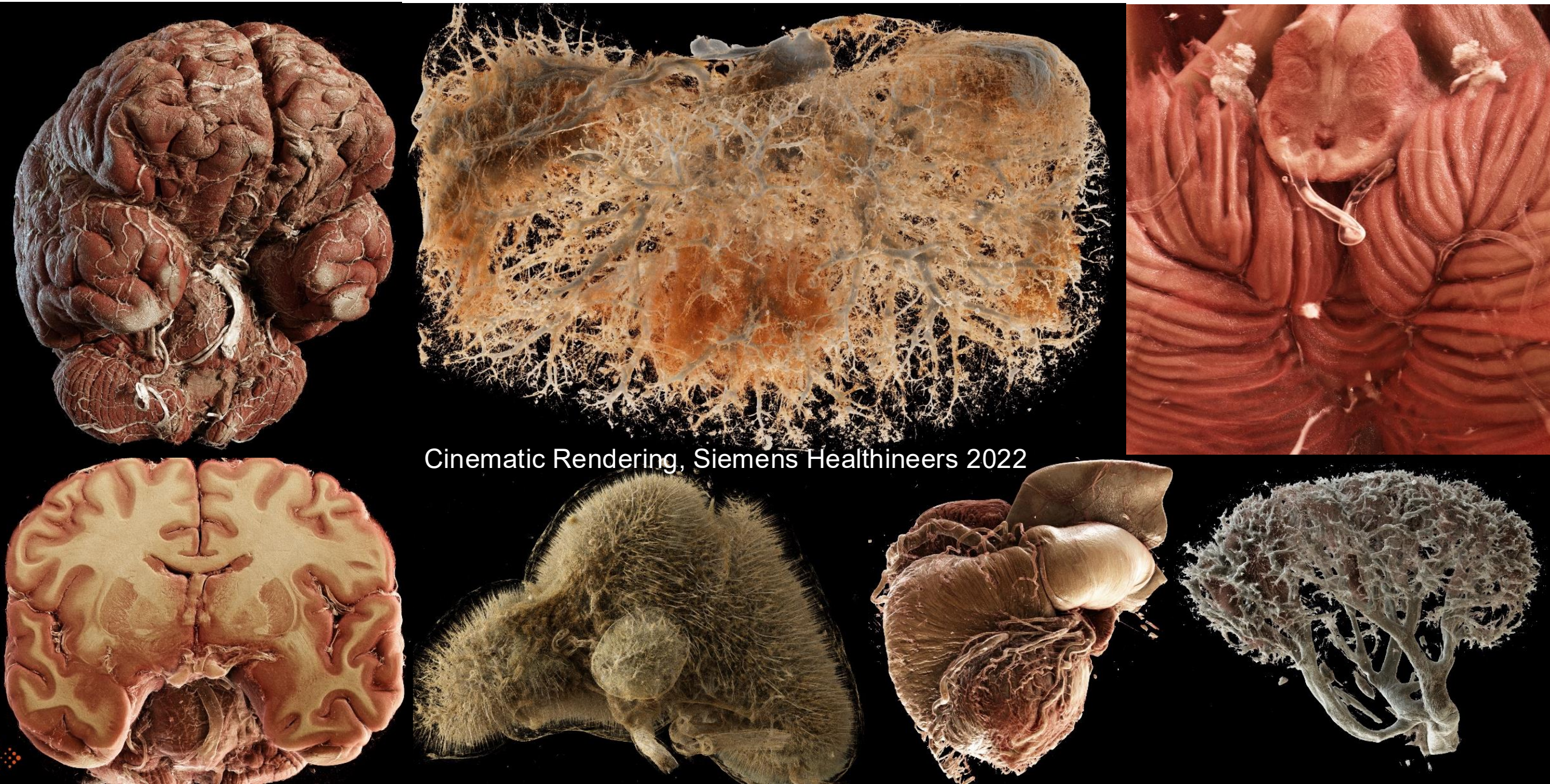
Heart / Kidney diseases





BIOMEDICAL IMAGING ON BM18: AN UNEXPECTED SUCCESS !

Courtesy P. Tafforeau



Cinematic Rendering, Siemens Healthineers 2022

Courtesy P. Tafforeau

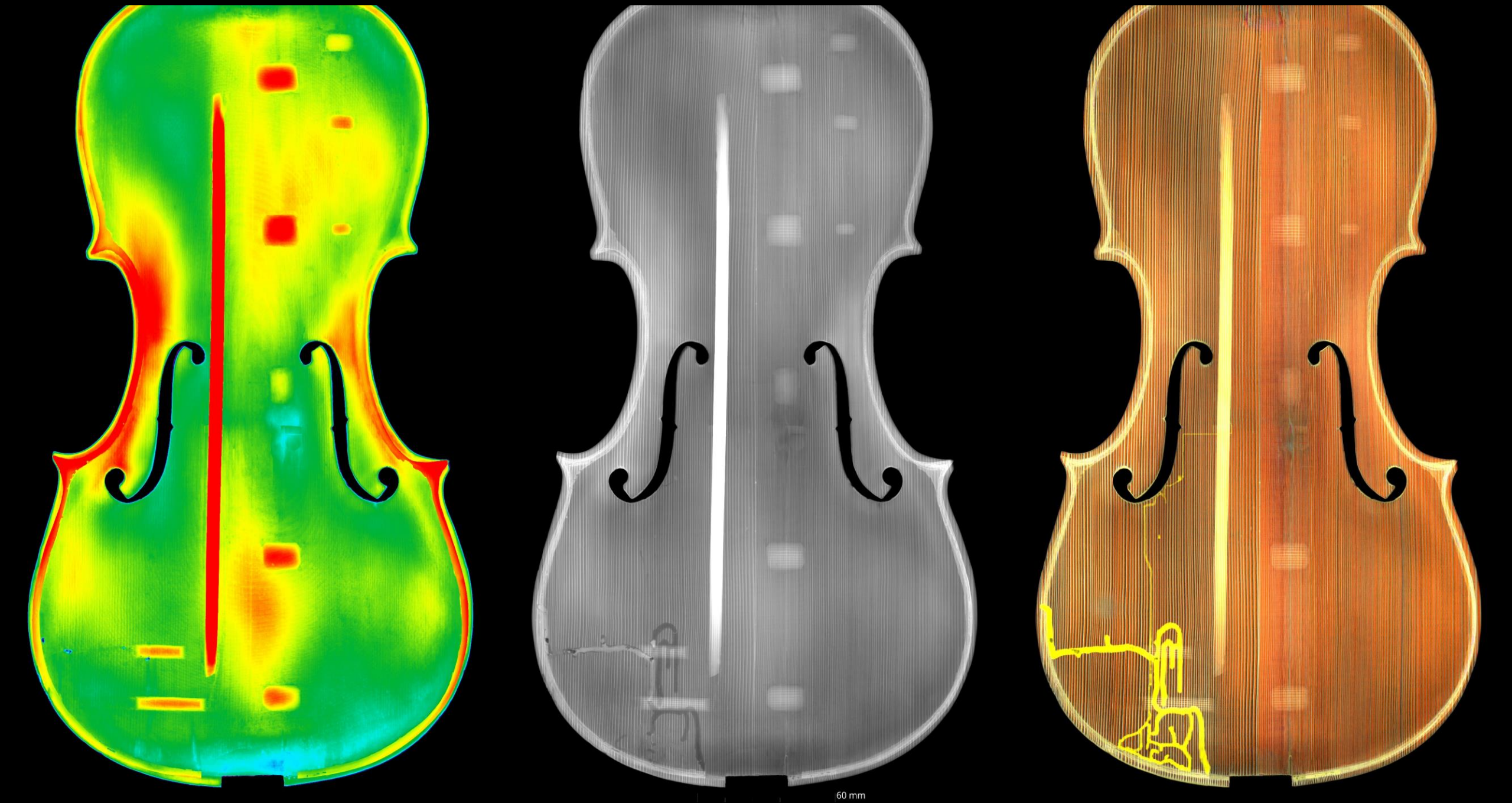
- Genova City Hall inquired with the ESRF on the possibility to study “Il Cannone” at BM 18 for a general “health checkup”
- The aim was to determine if the violin could be played without risk by the winner of the 2024 Premio Paganini Context, in a concert planned on 15 October 2024 in London in presence of King Charles III.
- On 3 December 2023, we performed a first test experiment on BM18 on a modern violin, crafted by ESRF scientist Luigi Paolasini during the COVID lockdown (4h scan at 33um voxel)

Courtesy P. Tafforeau and L. Paolasini

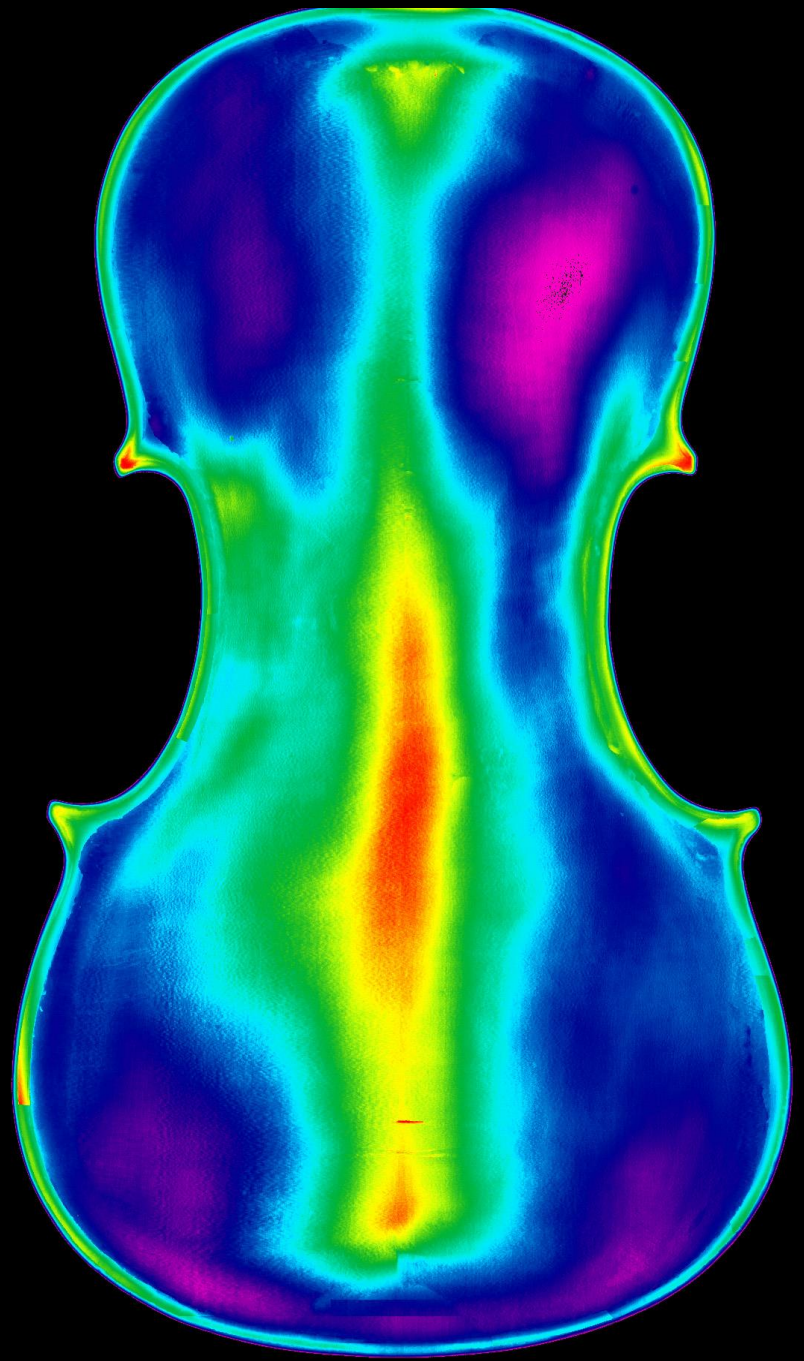
From December 2023 to January 2024, few test campaigns took place on two modern violins and a violin crafted by Paolo Castello between 1750 and 1760:
Determining system reliability and sensitivity, and a measurement protocol for “il Cannone”.

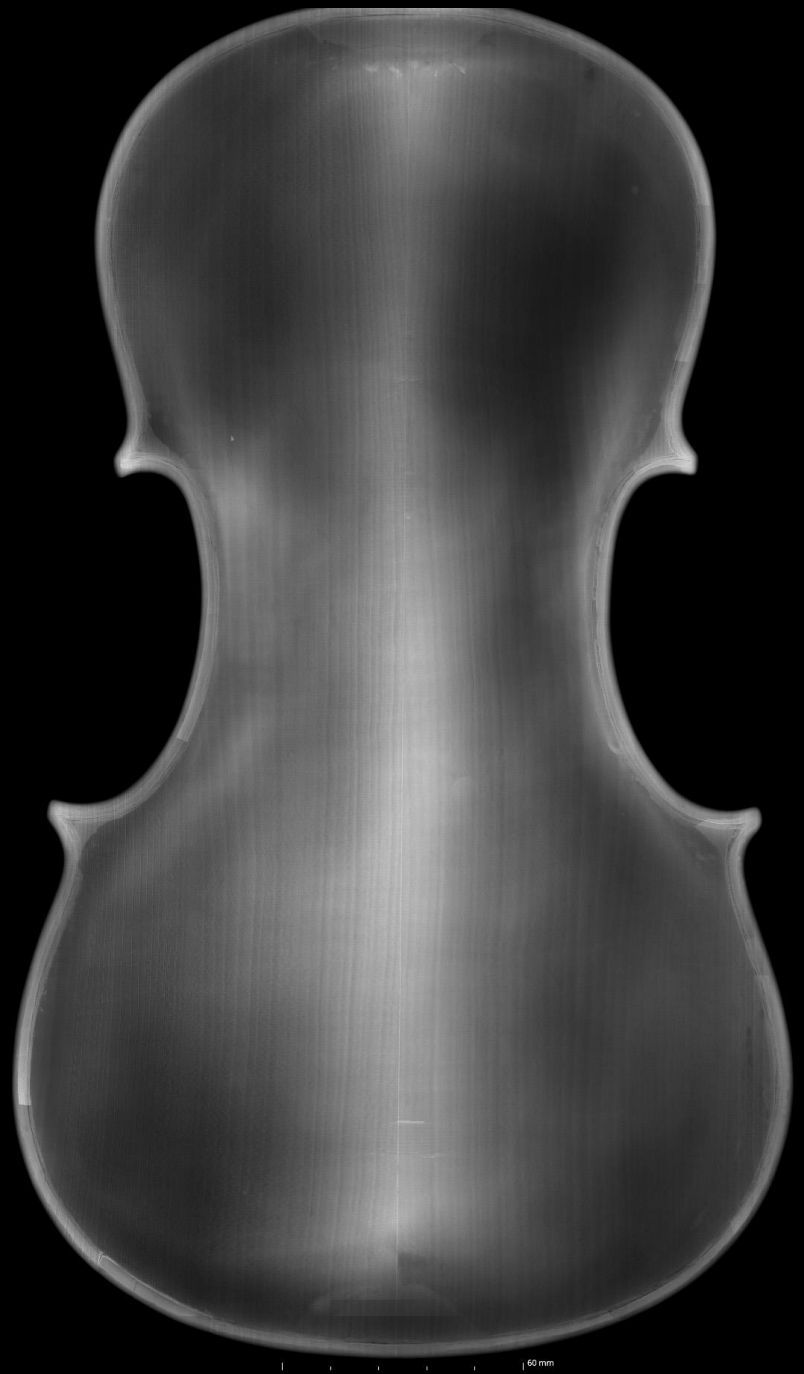
Courtesy P. Tafforeau and L. Paolasini

Rapid analysis of the table structure : thickness map, average projection, standard deviation projection



Rapid analysis of the back structure : thickness map, average projection, standard deviation projection





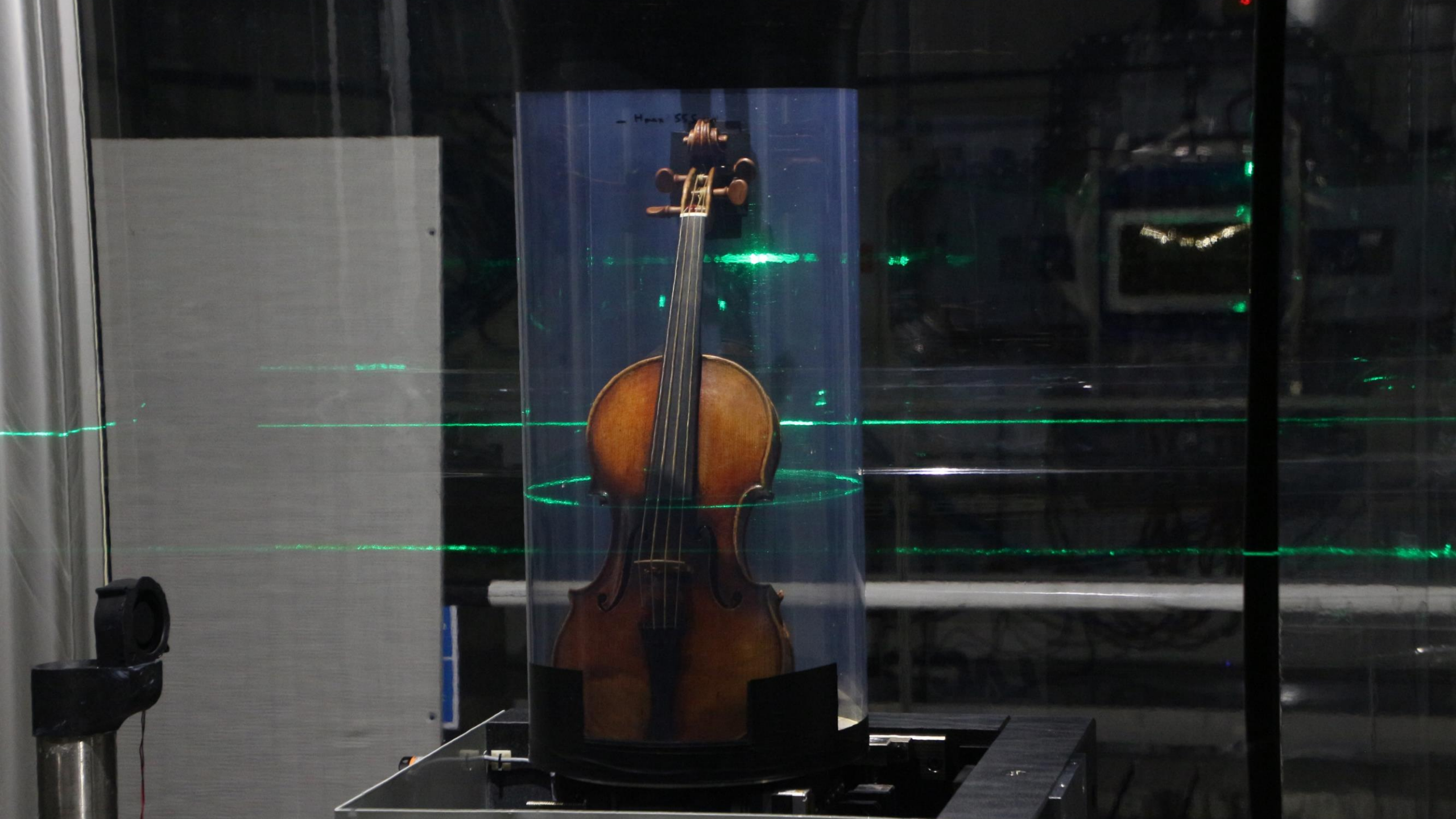
THE EXPERIMENT
BM18 9th and 10th of March 2024

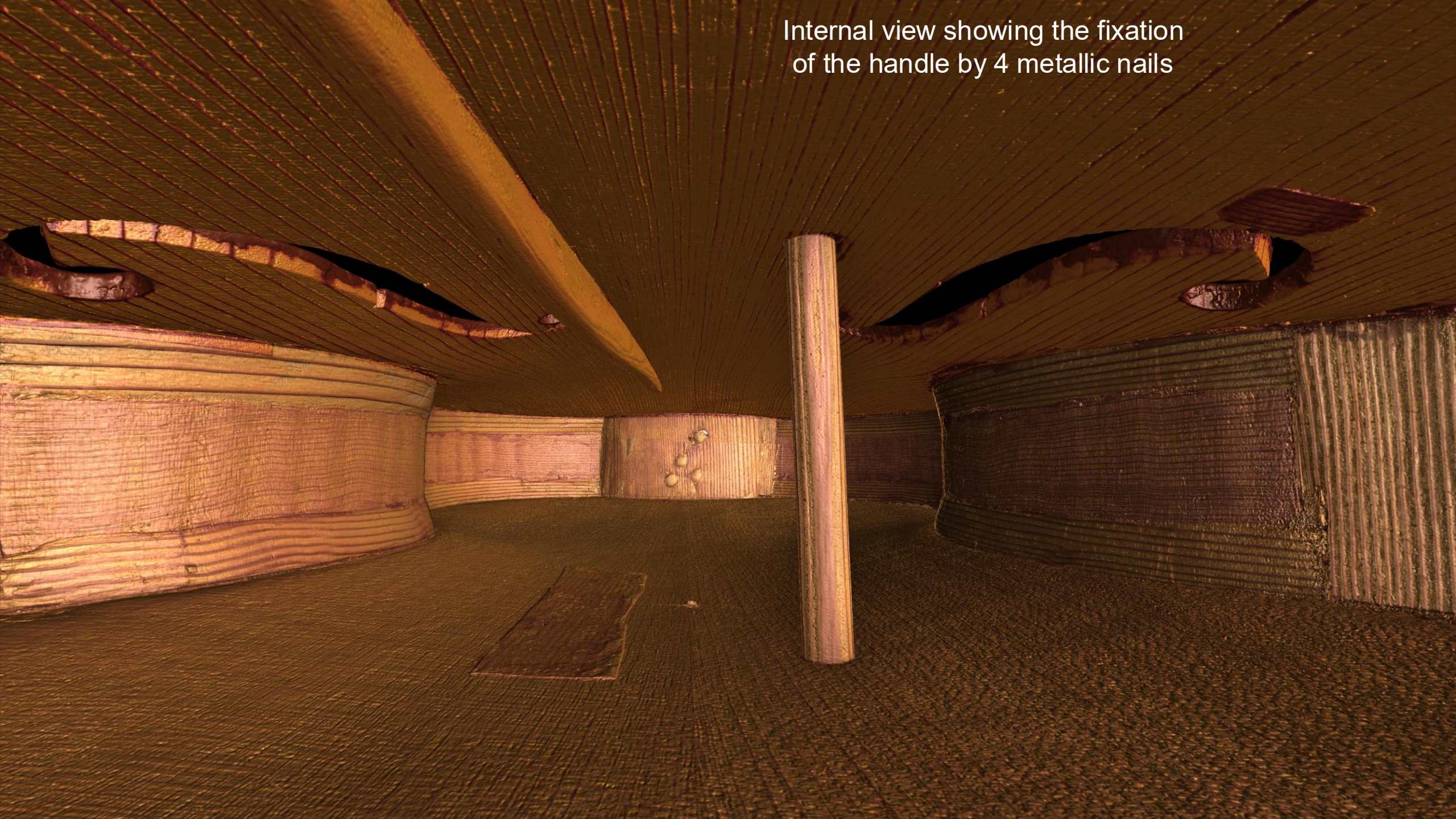
Non-destructive investigation of the structure of the
Niccolò Paganini's violin "il Cannone"

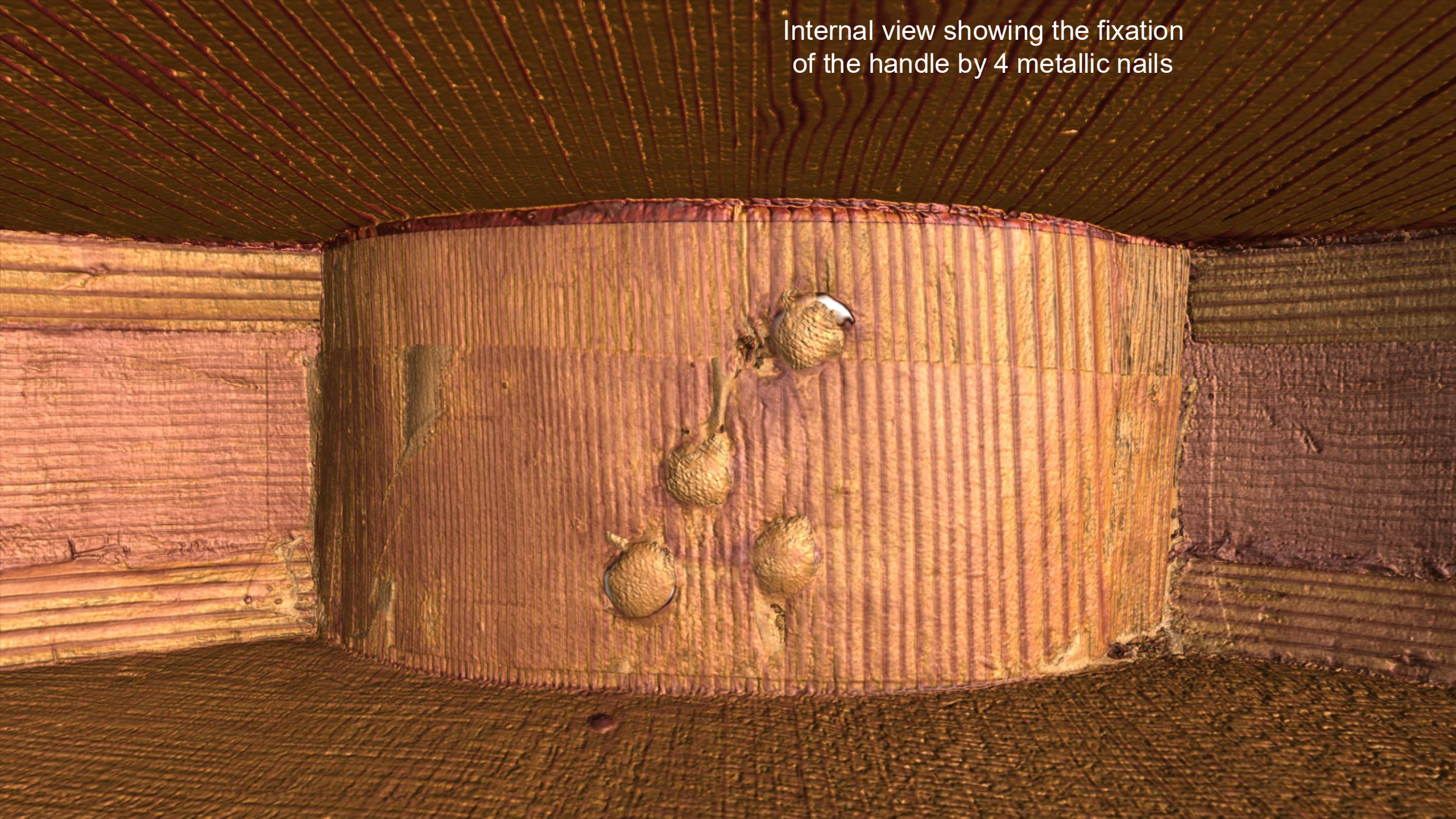
Crafted in 1743 in Cremona by Bartolomeo Giuseppe Guarneri "del Gesú"

2 complete scans at 35.66um (with and without load on the strings), followed by series of zooms down to 2.2um for precise imaging of the most critical parts of the instrument.

Courtesy P. Tafforeau
and L. Paolasini




Internal view showing the fixation
of the handle by 4 metallic nails


Internal view showing the fixation
of the handle by 4 metallic nails

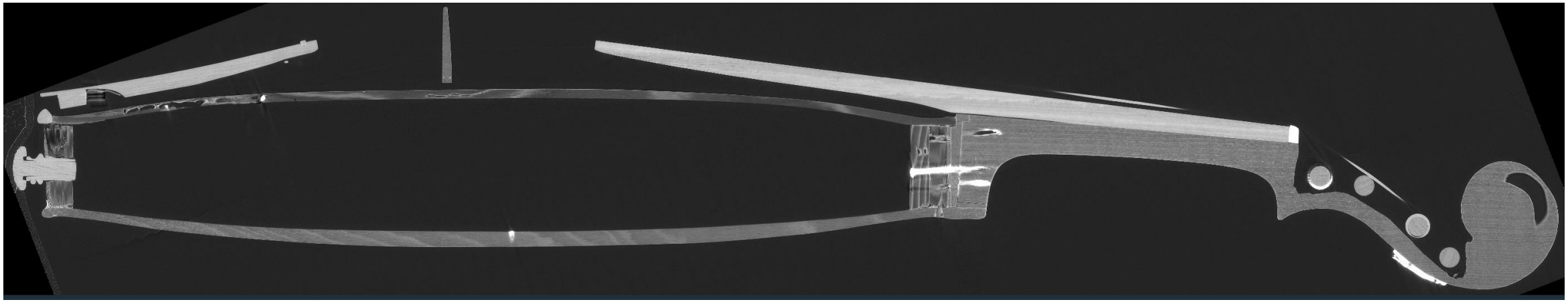

In fact, at least three other nails where used in the history of this violin, the handle was modified

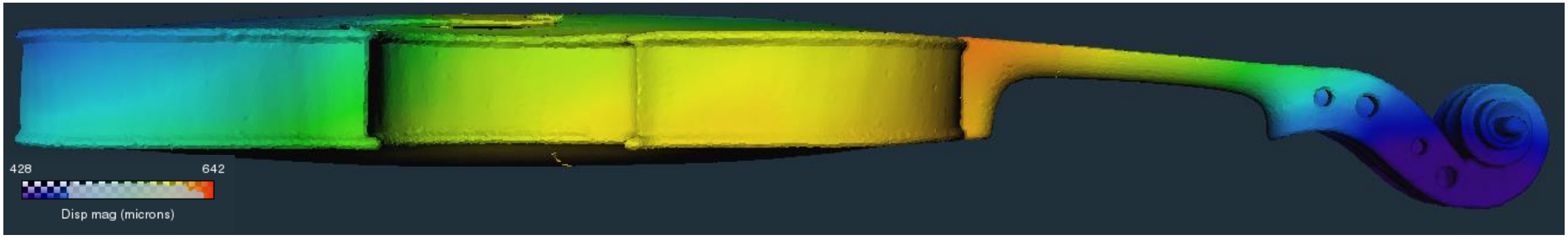
First results of the Digital Volume Correlation (DVC analysis)

In collaboration with Kamel Madi and Loïc Courtois (3Dmagination Ltd)

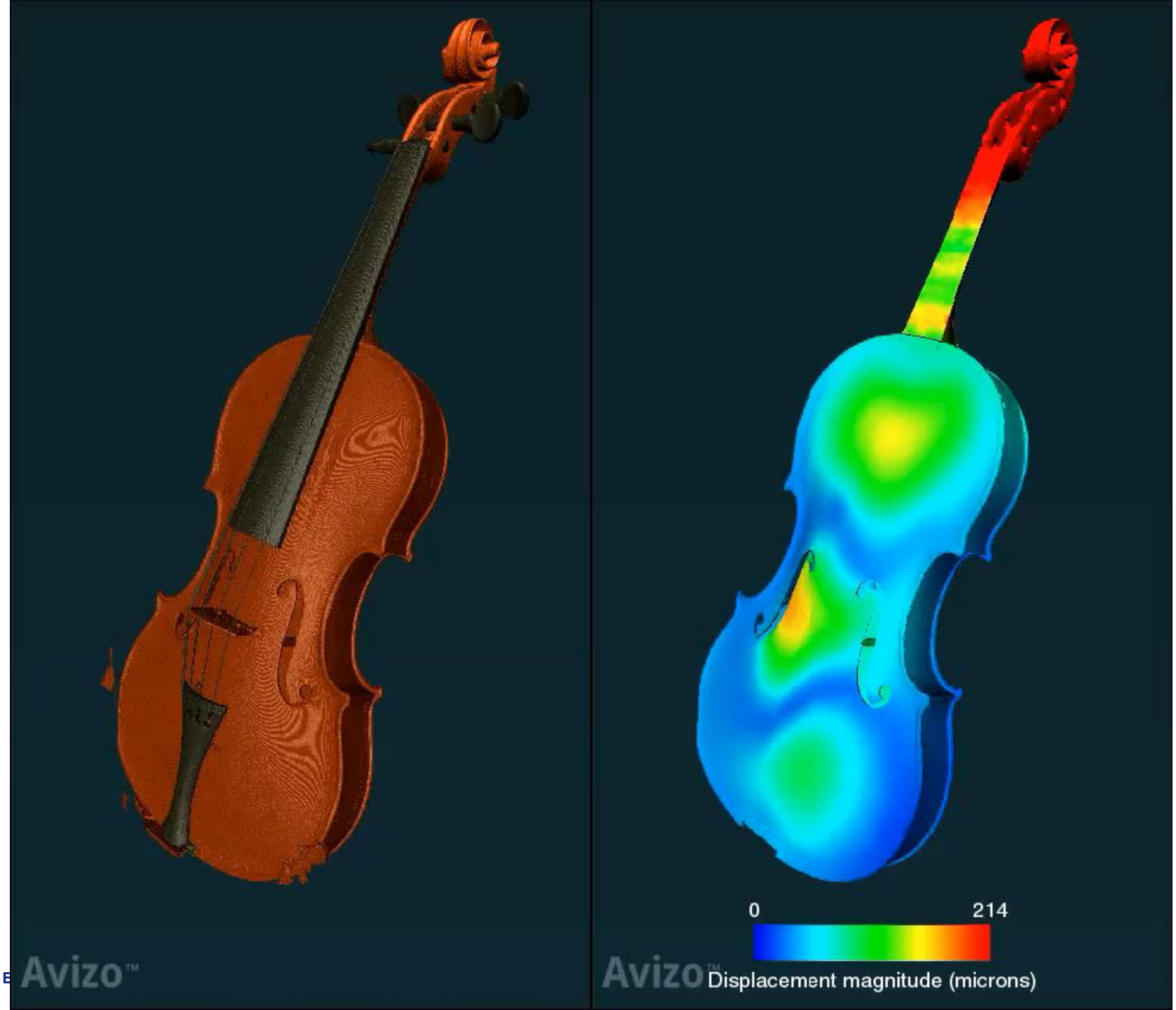
3D analysis of the displacements and distortions of the violin due to the string tension based on the two complete scans. Observation of the critical areas identified on the scans.

Courtesy P. Tafforeau and L. Paolasini





Courtesy P. Tafforeau and L. Paolasini

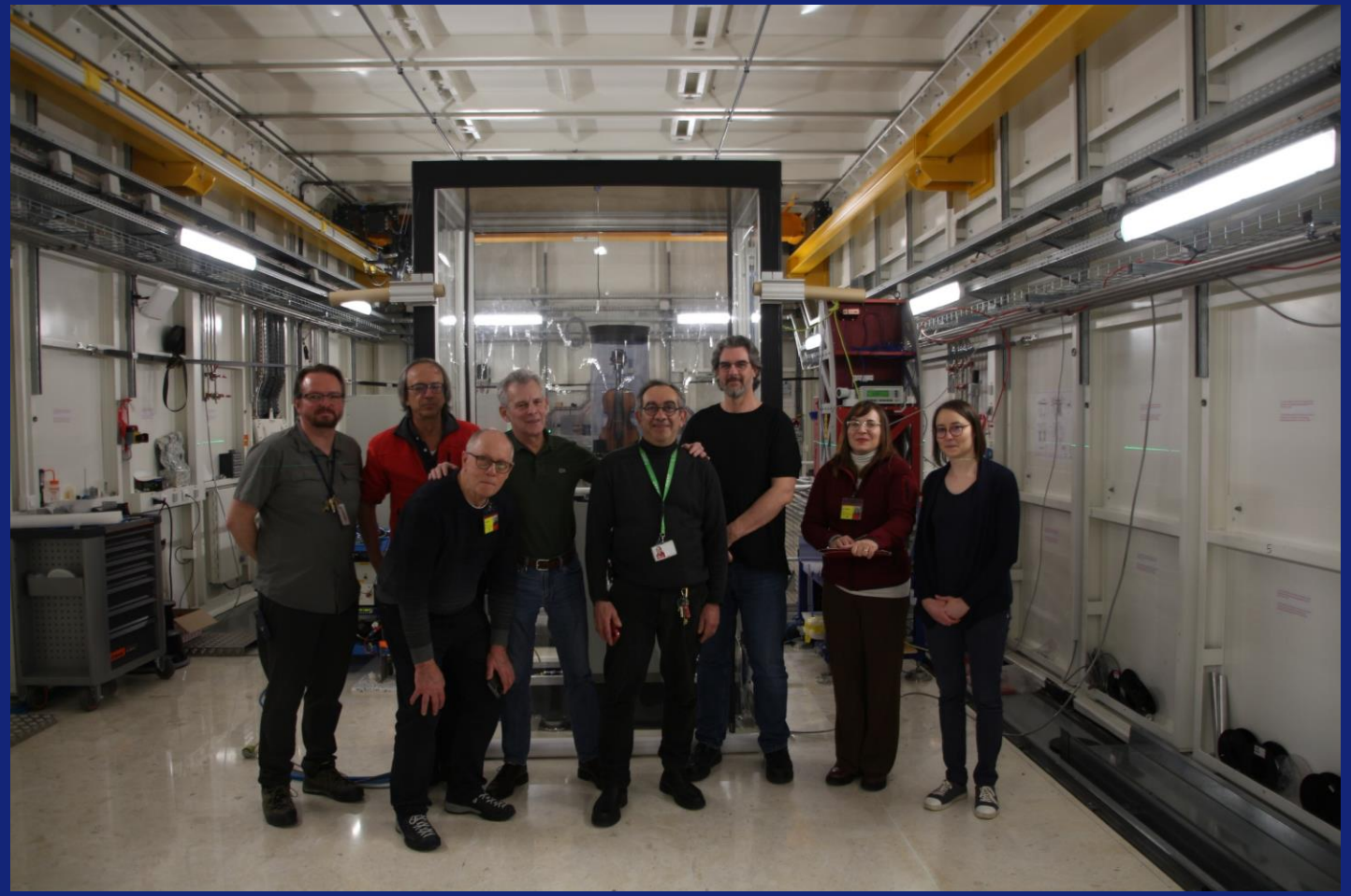


Courtesy P. Tafforeau and L. Paolasini

Conclusions of the first round of analysis

- “Il Cannone” despite its 280 years is still in good shape, and could still be played!

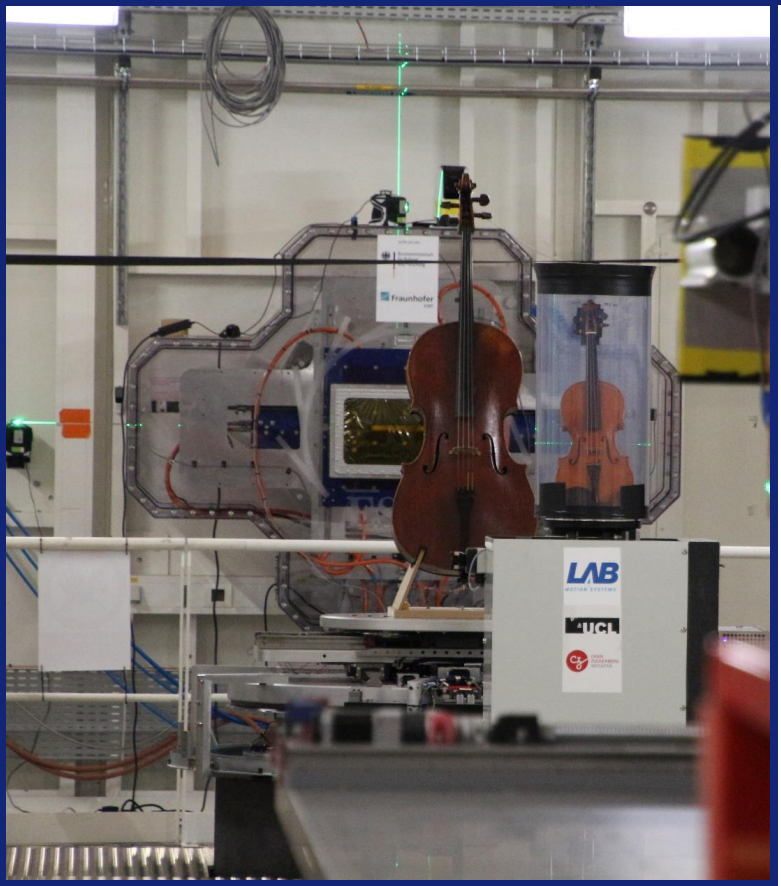
- Defects and cracks have been precisely documented.
- Comparison of the two scans with and without load enabled stress maps, without worrying effects as movement of critical components.
- The insect track is impressive, but does not represent a danger for the instrument while playing, and the main risk would be to press on it.
- Close monitoring has to be done to ensure the evolution of its status



Thanks to the green light from the ESRF, the concert took place on the 16 October 2024 in London, with the winner of the “Premio Paganini”, Simon Zhu, who had the honor to play “Il Cannone” in front of King Charles III

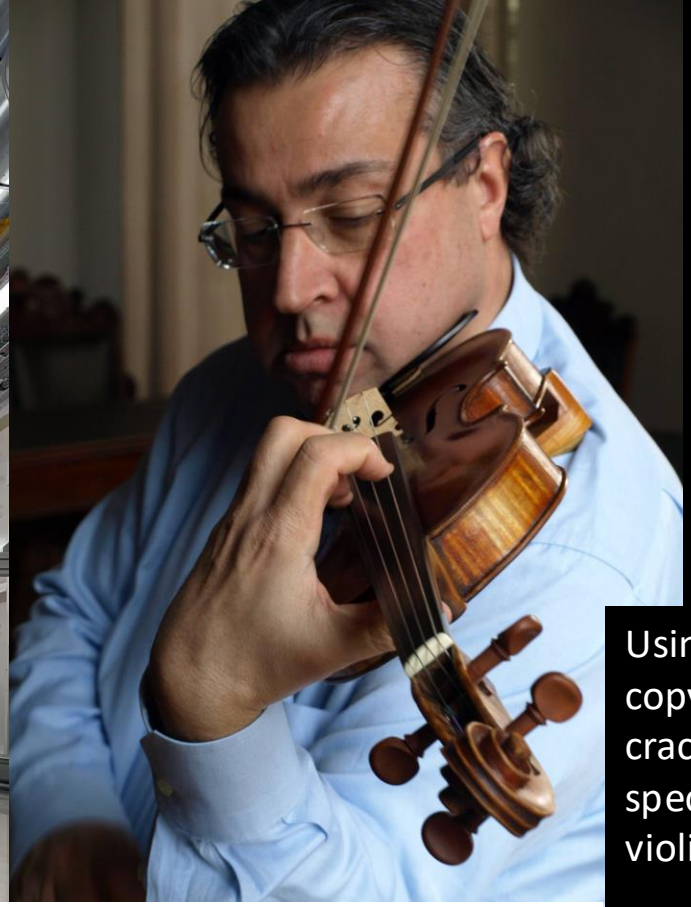
This is just the beginning of new stories!

The ESRF and BM18 are already further solicited contributing to the study and preservation of historical instruments



The big sample stage allows scanning the full violin's family on BM18, up to the 2m tall double bass.

The exceptional quality of synchrotron data can also help make modern instruments better, and perhaps closer to the mythic performances of some ancient ones



Courtesy P. Tafforeau and L. Paolasini

Luca Fanfoni, born in Parma, is a world renowned violinist. He has received numerous awards in international violin competitions, and has performed in some of the world's most renowned concert halls, earning unanimous acclaim from both audiences and critics. His **exceptional artistry and technical mastery establish him as one of Italy's most distinguished violinists**.

In a recent recording, *"Paganini Rediscovered",* featuring six unpublished works by Paganini, Luca played the renowned 1743 Guarneri del Gesù violin, *"Il Cannone" (see picture).*

Using the 8-9 March 2024 BM18 data, Luigi Paolasini crafted a copy of "Il Cannone", replicating all topological features (except cracks and the bug's tunnel) that would make this violin so special, and its sound (bass) so different from all other known violins

The two violins are close to be identical (see above), and each part is made of the same woods, although of very different age!

What you are hearing is Luigi's violin played by Maestro Luca Fanfoni at the ESRF on 10 March 2025, one year after the exper.

Luca, to his most pleasant surprise, remarked that – within his ~50 years career, in which he played "Il Cannone" several times – he finally finds a violin with a "voice" getting close to that of Paganini's celebrated Violin!

SOME CONCLUSIONS ON ESRF UPGRADE AND EBS:

- *EBS and HMBA Lattice: it works!*
- *A change of paradigm in Synchrotron X-ray Imaging:*
  - *Address complexity of nano-science: how the world of atoms makes the world of humans*
  - *Still a lot to do for both adiabatic and disruptive improvements: on the storage ring, but most of all at the beamlines: data management, smart automation, timing experiment – source; detectors, and more*
  - *Exciting opportunities for a new generation of synchrotron X-ray scientists and engineers*

INFINITE THANKS TO ALL THOSE WHO CONTRIBUTED TO THE ESRF UPGRADE AND TO THIS PRESENTATION, ALLOWING ME TO PRESENT SOME OF THEIR OUTSTANDING WORK!

A SPECIAL THANKS TO PANTALEO

Francesco Sette


“The higher he climbs, the farther he sees; the farther he sees, the longer he dreams” W. Bonatti
THANKS FOR YOUR ATTENTION