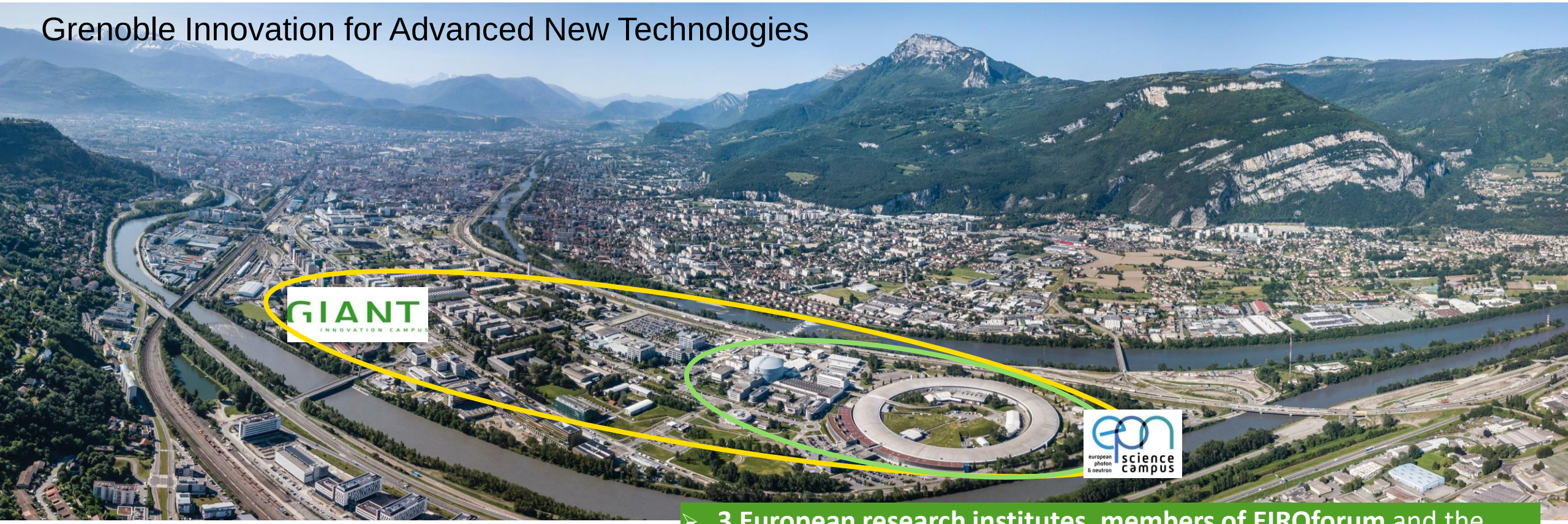
ESRF – ILL International Student Summer School X-ray and Neutron Science

Jean DAILLANT

Director General, ESRF

X-RAY AND NEUTRON AT THE HEART OF THE GIANT INNOVATION CAMPUS

Grenoble Innovation for Advanced New Technologies



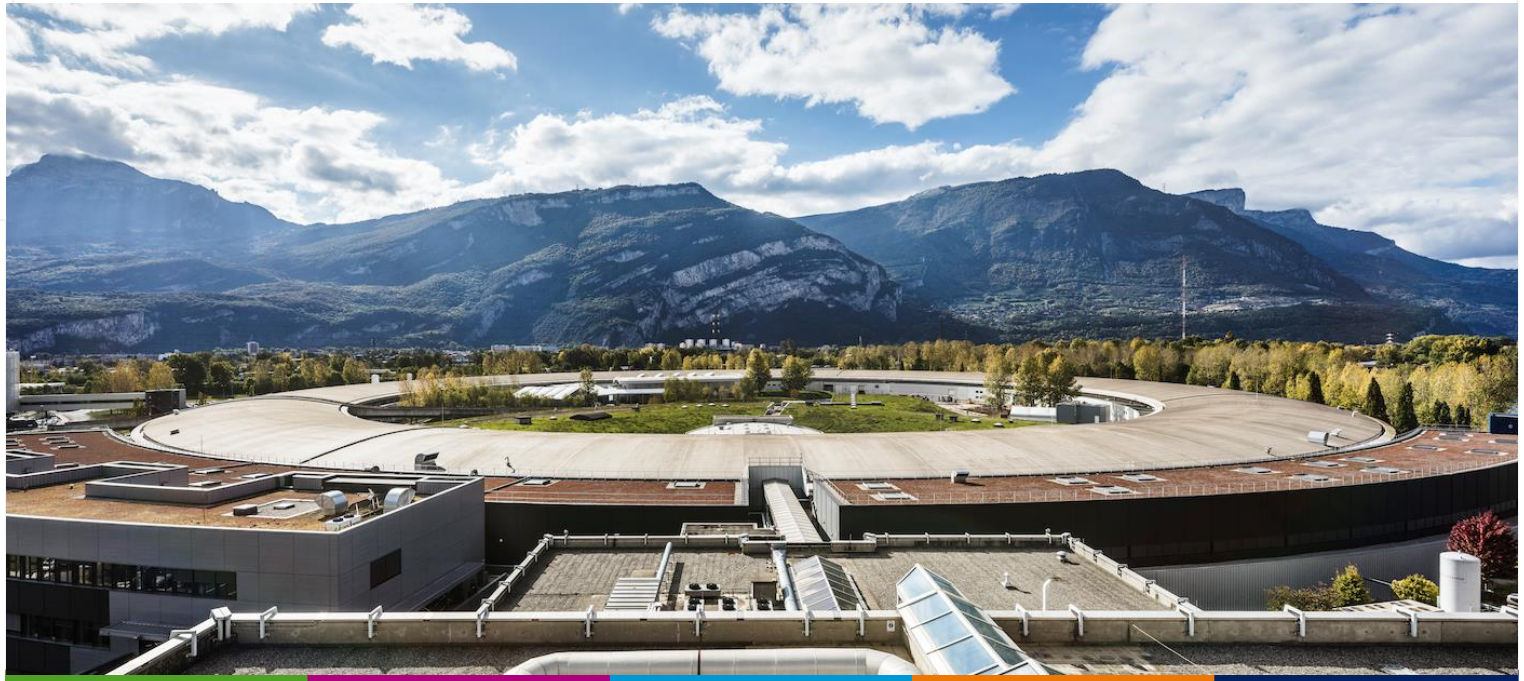
- **3 European research institutes, members of EIROforum** and the Institute for Structural Biology, at the heart of GIANT, the campus of Innovation (*Grenoble Innovation for Advanced New Technologies)*
- Common research and training platforms
- The most powerful research reactor and the brightest synchrotron

THE ESRF: BRINGING NATIONS TOGETHER THROUGH SCIENCE

20 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%

7 ASSOCIATE COUNTRIES	
Austria	1.75%
Israel	1.75%
Poland	1.00%
Portugal	1.00%
IndiaA	0.66%
Czech Republic	0.60%
South Africa	0.30%



10 000 Scientific visitors each year

4 Nobel prizes

52 000 Publications each year

10 ERC grants based on ESRF-EBS

30% Of research with industrial partners

6 GeV Synchrotron

844m Circumference of the storage ring

46 Beamlines

1994 - 2024: PIONEERING SCIENCE, ADVANCING KNOWLEDGE

1988-1994 - USM-1994

ESRF, the first 3rd-generation synchrotron: 11 European countries joining forces to open new vistas for science

1 JANUARY 2009

ESRF UPGRADE PROGRAMME (2009-2022) launched by the ESRF's 21 partner countries. UP PHASE-I delivered in 2015 on time and within the budget

25 AUGUST 2020

Delivery of **ESRF-Extremely Brilliant source** (EBS), a game changer: the first of a new generation of high-brilliance X-ray source

SEPTEMBER 2024

30 years of operation
4 years of successful operation of ESRF-EBS

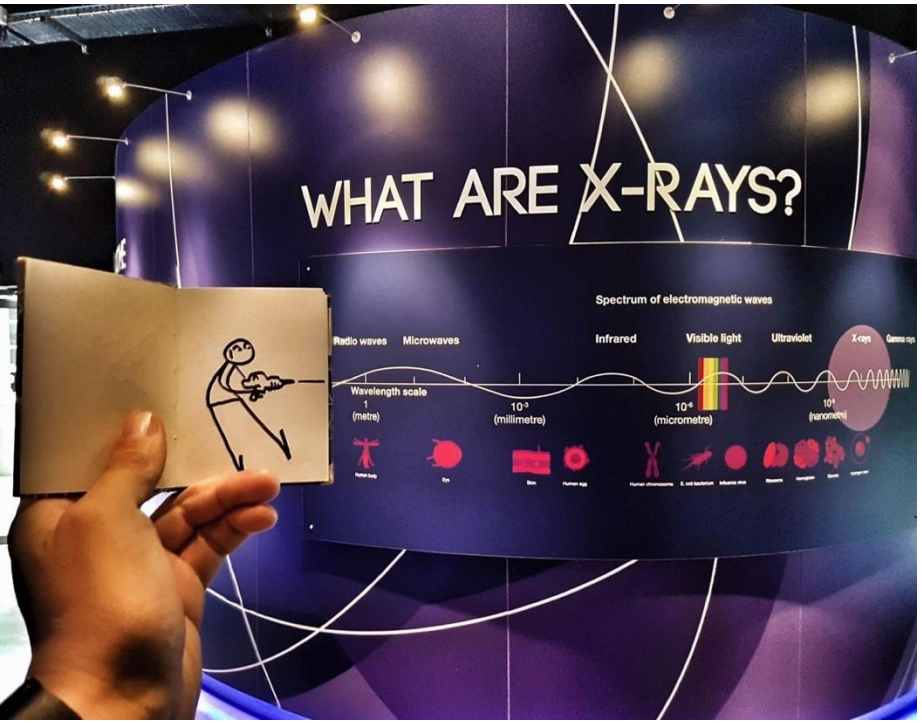
BRINGING NATIONS TOGETHER TO ENABLE SCIENTIFIC EXCELLENCE AND TO ADDRESS GLOBAL CHALLENGES

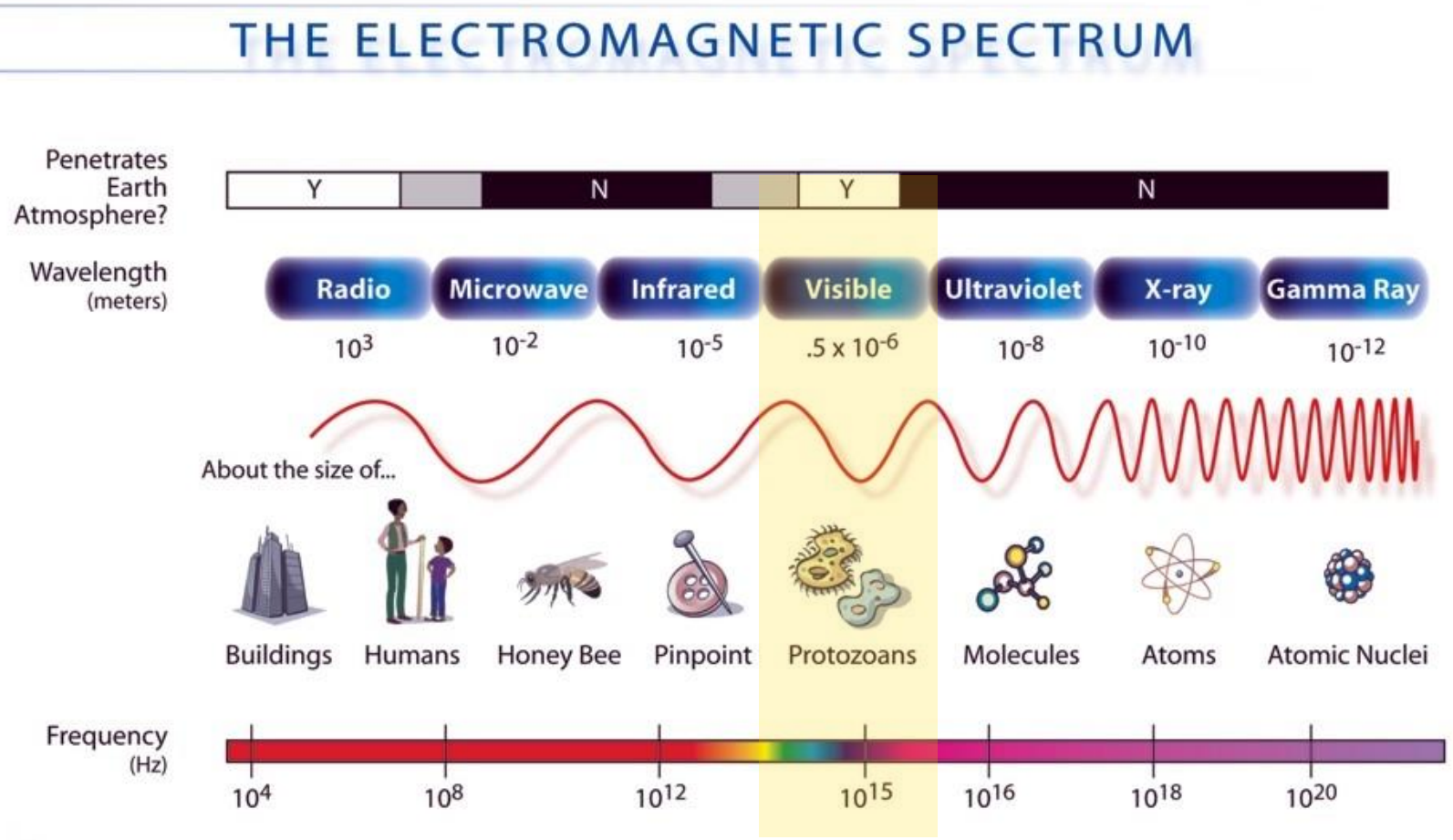
ESRF MISSIONS AND COMMITTMENTS

- Bring nations together through SCIENCE
- Pioneer science to serve the international community for the advancement of KNOWLEDGE and to tackle key global challenges: HEALTH, SUSTAINABILITY
- Design, construct, operate and develop state-of-the-art X-ray facilities and provide value to all partner countries: NEW SCIENTIFIC OPPORTUNITIES, NEW TECHNOLOGY
- Foster the use of X-RAYS FOR INDUSTRY from partner countries to strengthen EUROPE COMPETITIVENESS
- Train and inspire the YOUNG GENERATION OF SCIENTISTS, ENGINEERS AND TECHNICAL STAFF

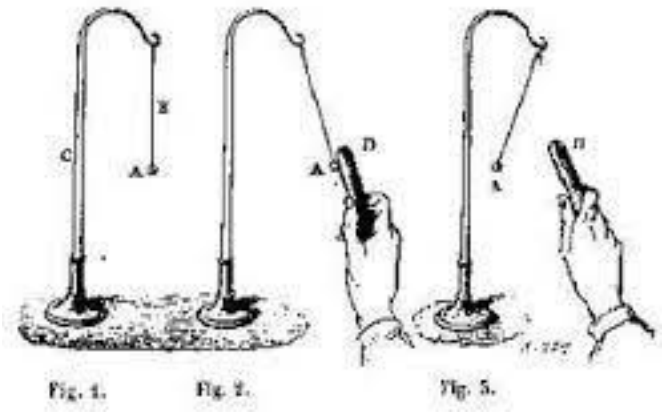
ESRF-Extremely Brilliant Source
Driving EU science and EU innovation to the benefit of society

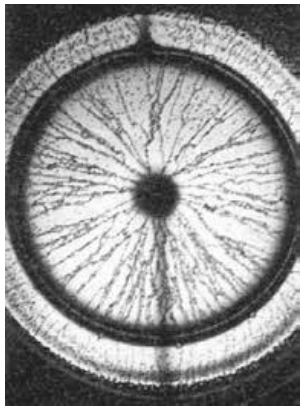
SYNCHROTRON LIGHT: ELECTROMAGNETIC WAVES



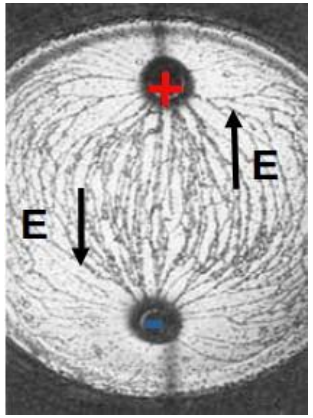


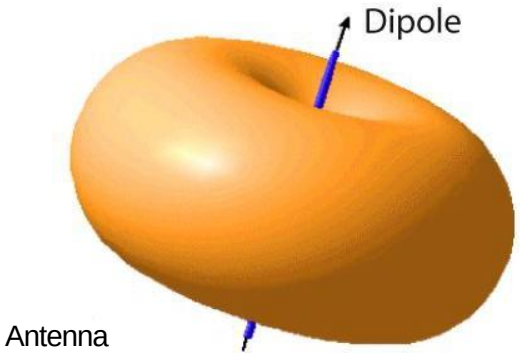
ELECTROMAGNETIC WAVES





F = *q***E**





SYNCHROTRON RADIATION

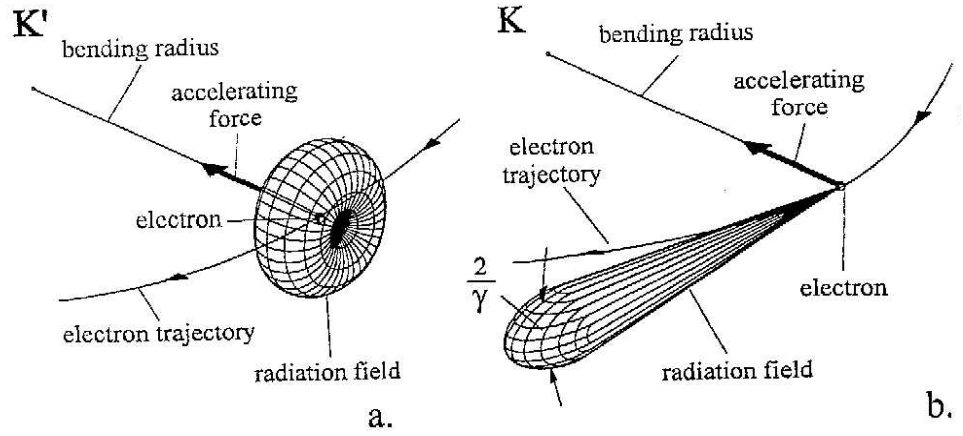
- **Lienart-Wiechert potential for an accelerated charge:**

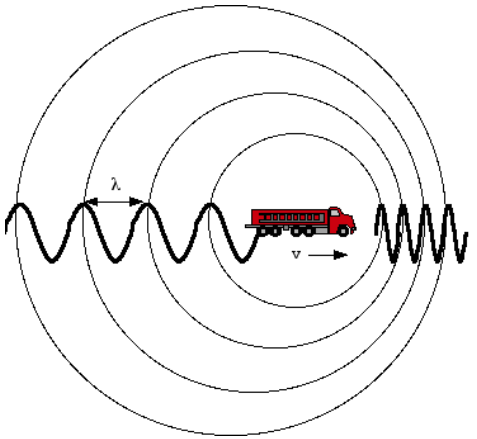
$$V = \frac{q}{4\pi\epsilon_0 c^2}\frac{1}{1-\mathbf{n}.\mathbf{v}/c}\frac{1}{R(t_0)};\ \mathbf{A} = \frac{q}{4\pi\epsilon_0 c^2}\frac{1}{1-\mathbf{n}.\mathbf{v}/c}\frac{\mathbf{v}}{R(t_0)}$$

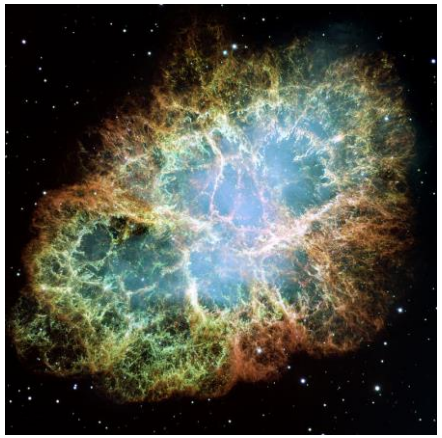
- **Electric field:**

$$\mathbf{E} = \frac{q}{4\pi\epsilon_0 c^2}\frac{1}{R}\frac{1}{(1-\mathbf{n}.\mathbf{v}/c)^3}\mathbf{n}\times[(\mathbf{n}-\mathbf{v}/c)\times\mathbf{a}]$$

- **Purely kinematic effect**, the retarted time of the particle is longer when it is moving (fast) towards the oberver. v/c = 0.999907
- **Doppler effect**, factor $m^2c^4/E^2 \approx 1.44\times10^7$ → X-rays.

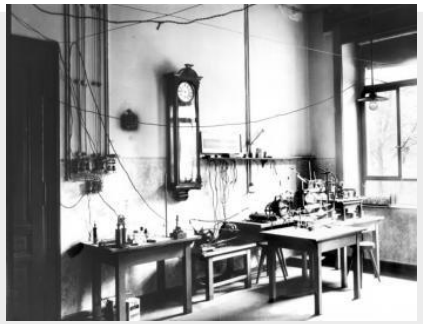






SYNCHROTRON STORAGE RINGS

1895



W.C. Röntgen

1947

General Electric

1975

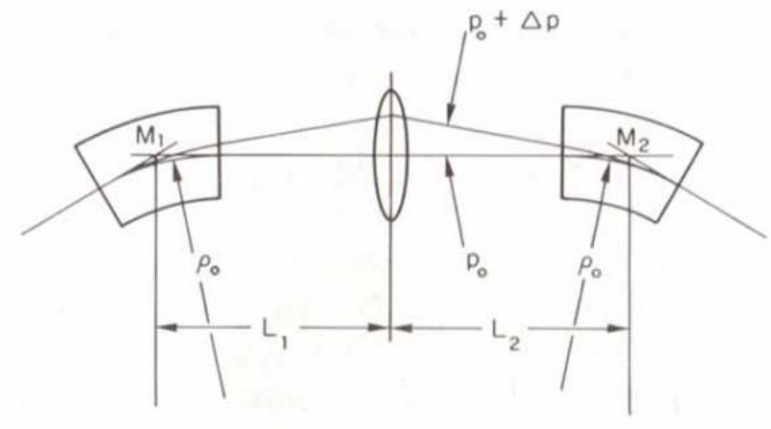
Double Bend Achromat
Chasman-Green Lattice

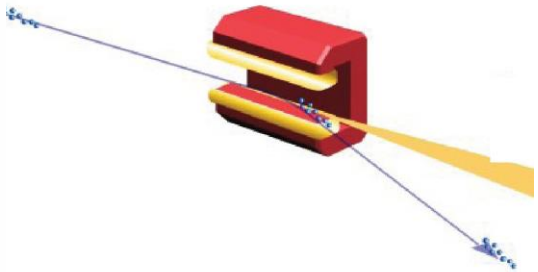
1988

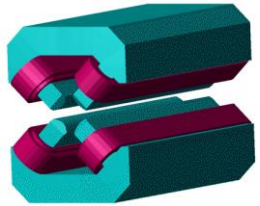
ESRF: 1st third-generation synchrotron light source

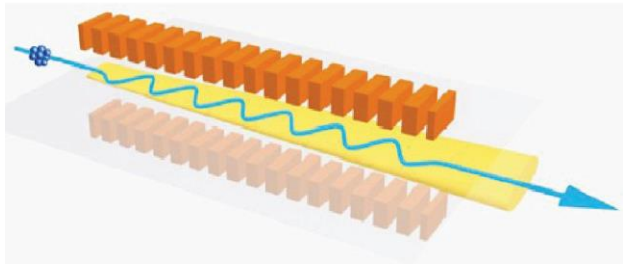
2020

ESRF-EBS: 1st high-energy 4th-generation synchrotron

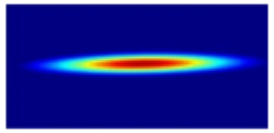
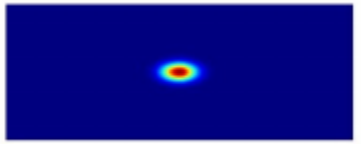








ESRF-EBS LATTICE VS. PREVIOUS ESRF-DBA LATTICE: DBA ❼H7BA

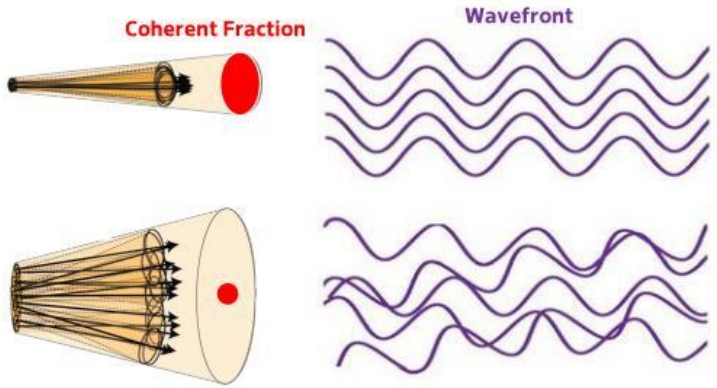
4000 pm.rad   133 pm.rad

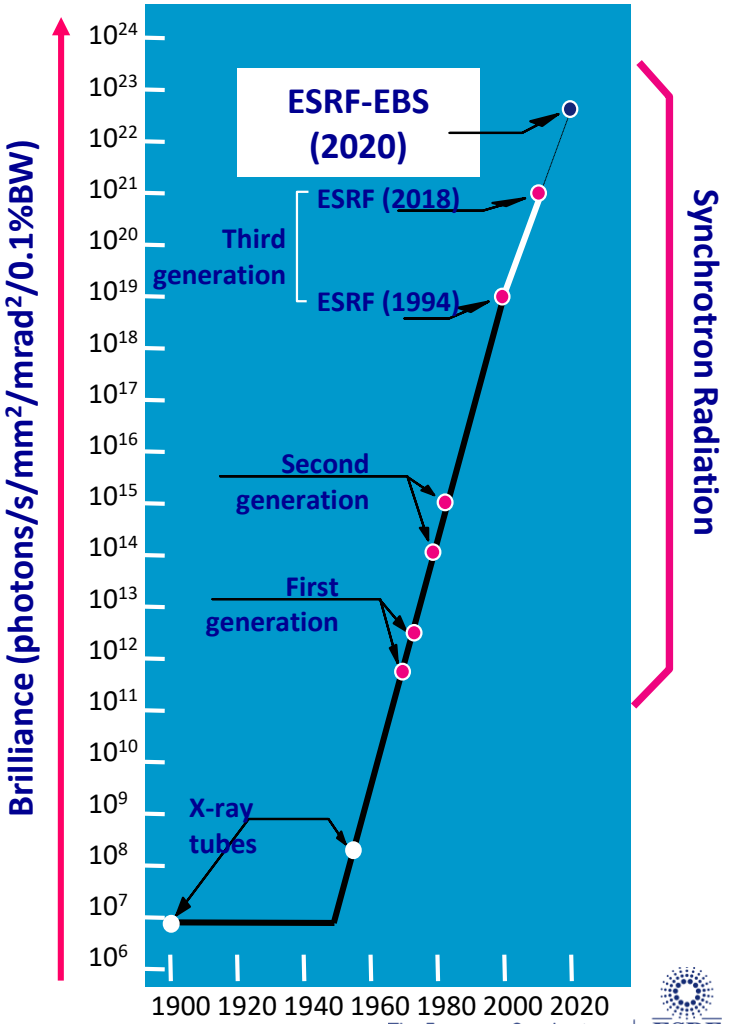
$$Brilliance = \frac{SpectralFlux}{4\pi^2\sigma_x\sigma'_x\sigma_y\sigma'_y} = \frac{SpectralFlux}{4\pi^2\epsilon_x\epsilon_y}\left[\frac{Photons/s}{mm^2mrad^2 0.1\%bandwidth}\right]$$

$$Emittance: \epsilon_{x,y} = \sigma_{x,y}\sigma'_{x,y}$$

$$Coherentfraction: f_{coh} = \frac{(\lambda/4\pi)^2}{\epsilon_x\epsilon_y}$$

$$\epsilon_x = C_L\frac{E^2}{N_d^2}$$

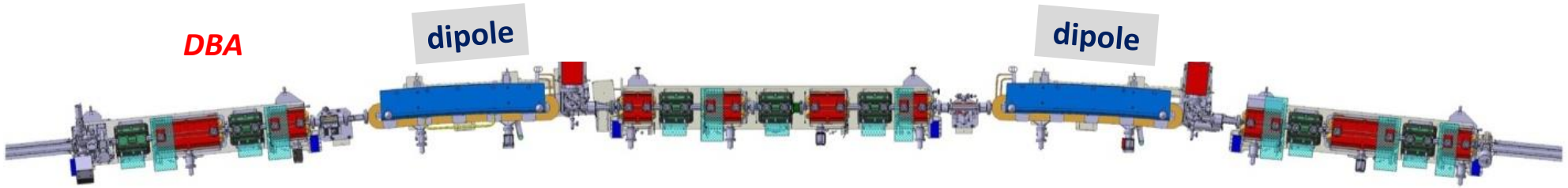


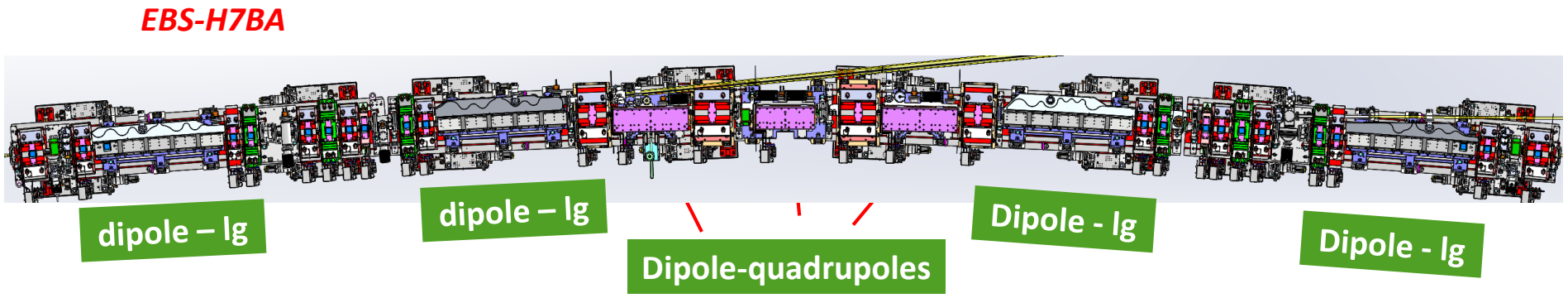


ESRF-EBS LATTICE VS. PREVIOUS ESRF-DBA LATTICE: DBA ➆H7BA

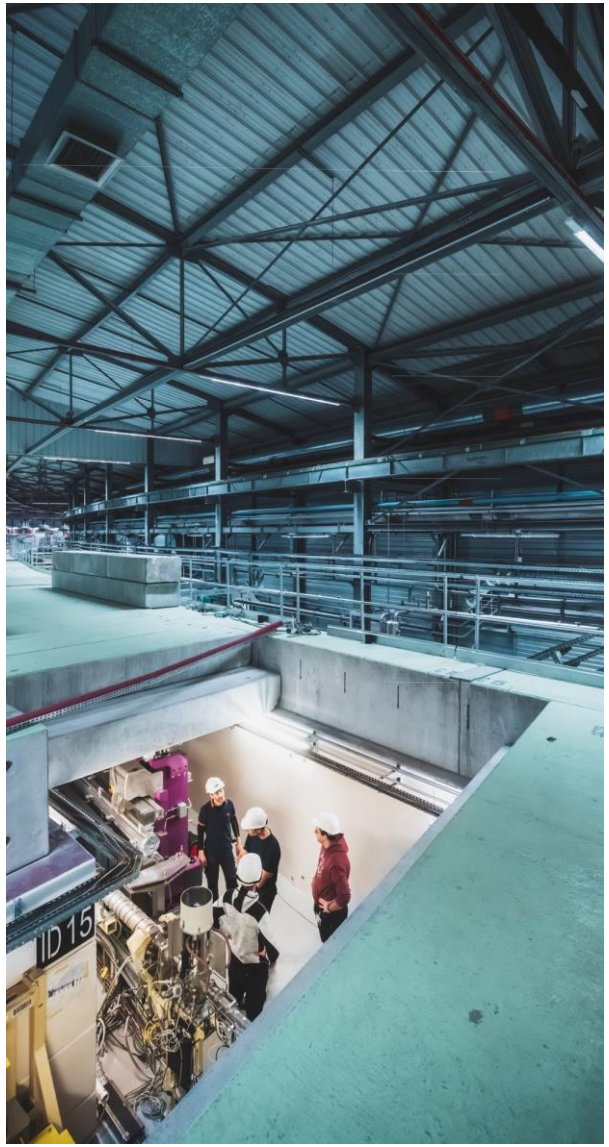
- **Previous ESRF lattice (cell)**
  Double Bend Achromat = **17 M** (2 dipoles + 8 quad. + 7 sext.) per cell
  ID length = 5 m (standard) / 6m / 7m
- **EBS lattice (cell)**
  Hybrid 7 Bend Achromat = **31 M** (4 dipoles-lg + 3 dipole-quad + 16 quad., 6 sext., 2 oct.)
  ID length = 5 m

31 magnets per cell instead of 17
32 cells (arcs) with 4 girders each
6 sextupoles instead of 7
Longer and weaker dipoles





ESRF-EBS NEW FEATURES



50
HORIZONTAL
EMITTANCE

X 100
BRILLIANCE

X 50
TRANSVERSAL
COHERENCE

ESRF UPGRADE PROGRAMME AND EBS ENABLED FEATURES

NEW Multiscale (mm → μm → nm)

NEW Pump-probe experiments

NEW Superior time resolution

NEW Conditions: extreme (T,P), in-situ, operando, in-vivo

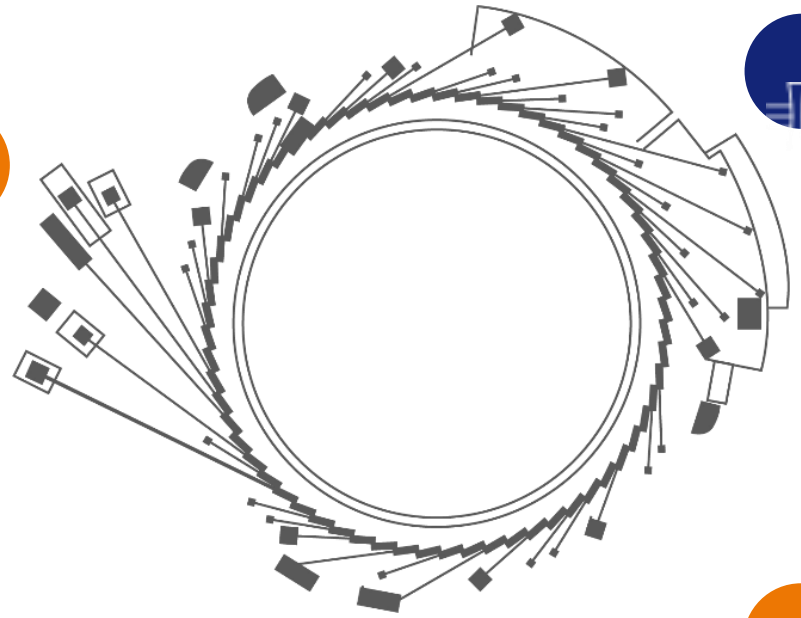
NEW Capabilities: energy resolution, sensitivity, throughput, selectivity…

NEW Operation Standards: ML for accelerators and beamlines, control, AI for data management and analyses

ESRF TECHNIQUES

SCATTERING

- Small angle scattering
- Resonant X-ray scattering
- Inelastic scattering
- Powder diffraction
- Surface diffraction
- Protein crystallography



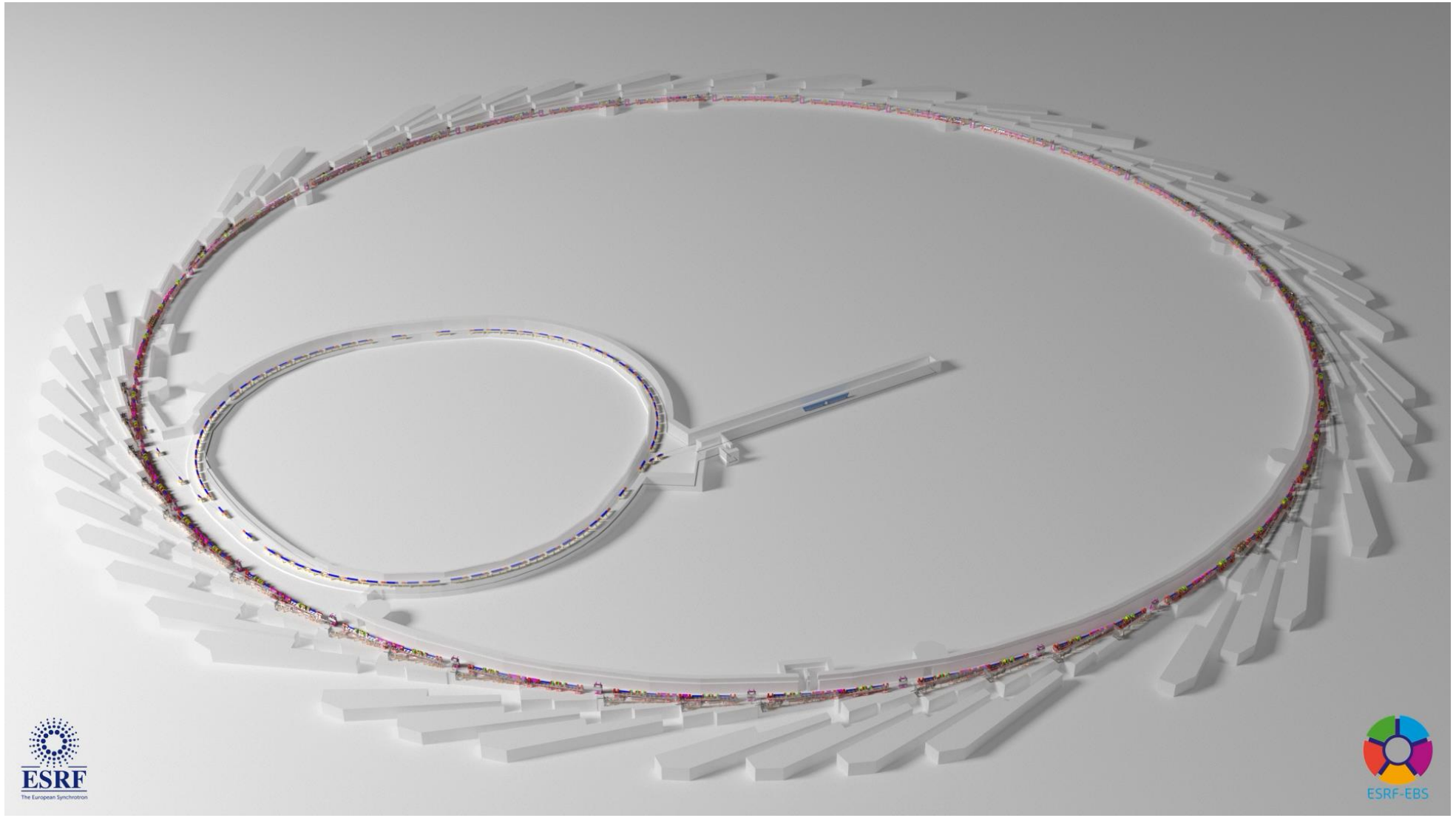
SPECTROSCOPY

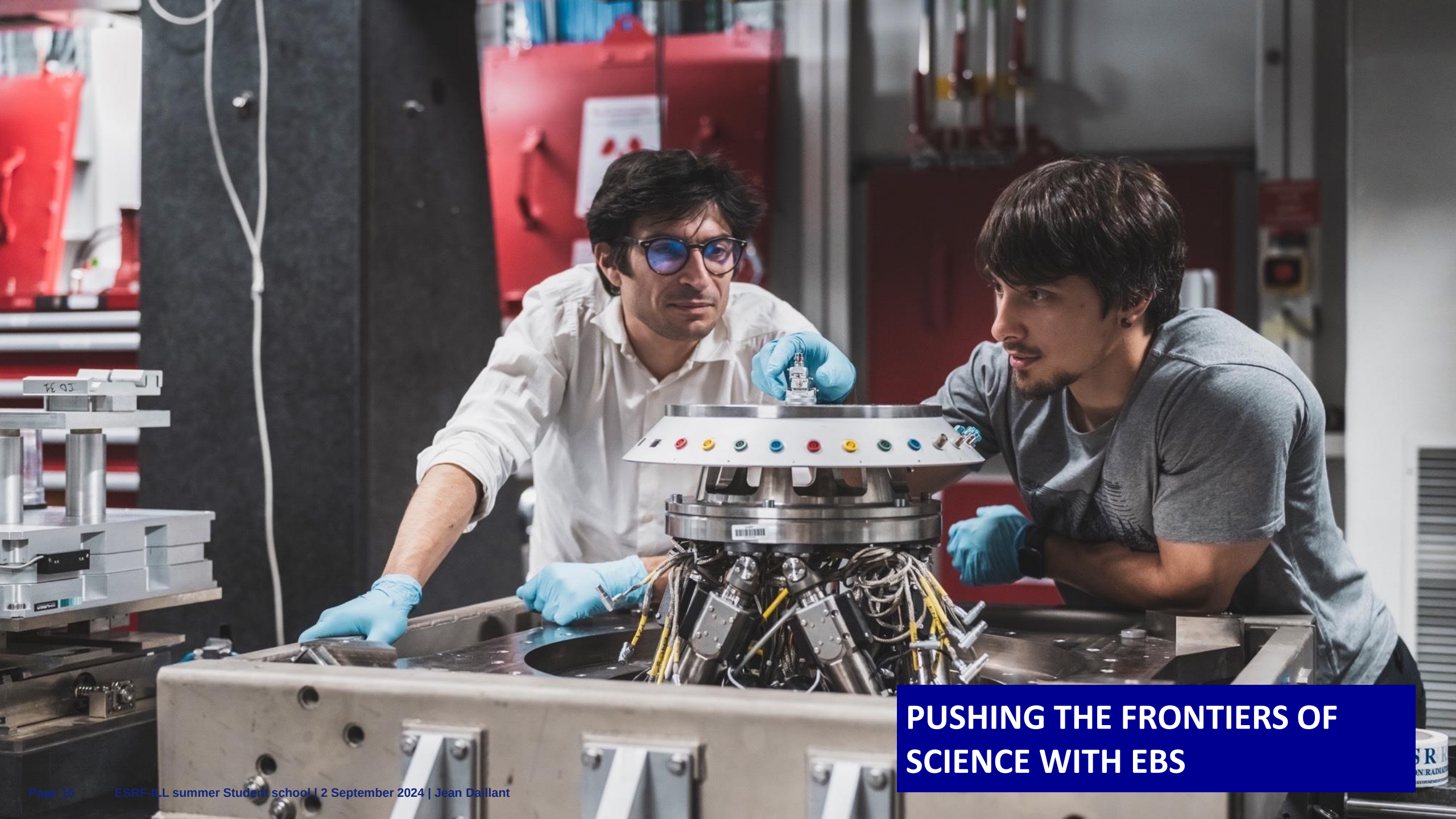
- X-ray fluorescence
- X-ray absorption near-edge structure
- Extended X-ray absorption fine structure

IMAGING

- Nano/micro tomography
- Phase-contrast tomography
- Hierarchical tomography
- Laminography

ESRF-EBS: HOW DOES IT WORK?



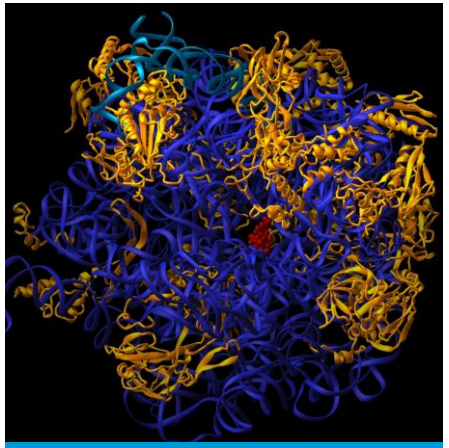


PUSHING THE FRONTIERS OF SCIENCE WITH EBS

THE ESRF: A GIANT MICROSCOPE FOR FUNDAMENTAL, APPLIED & INDUSTRIAL RESEARCH

ESRF- EBS
EXTREMELY BRILLIANT SOURCE

New insights into the complexity of matter from the atomic to the macroscopic scales

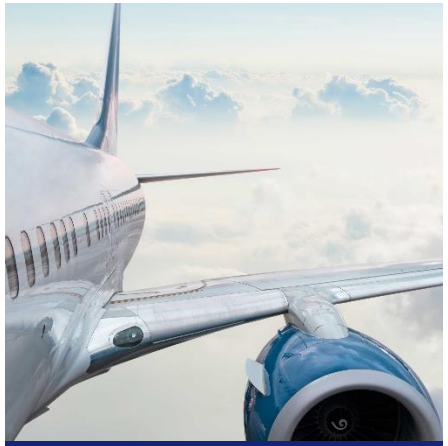


HEALTH & BIOLOGY

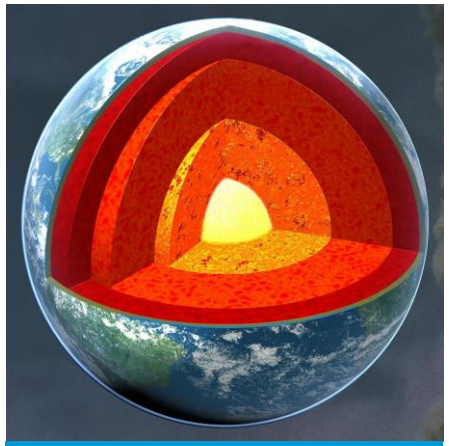
ENERGY & ENVIRONMENT

MICROELECTRONICS

CHEMISTRY & CATALYSIS

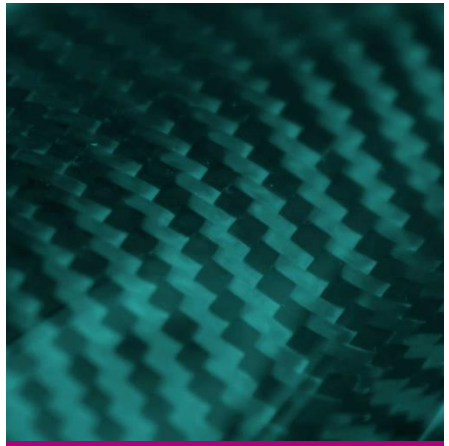


AEROSPACE

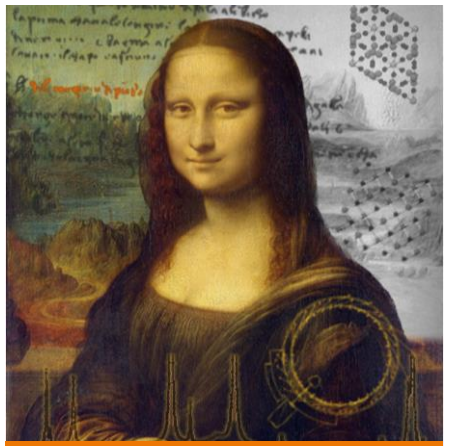


EXTREME CONDITIONS

FOOD SAFETY



ADVANCED MATERIALS



CULTURAL HERITAGE

ESRF-EBS: A NEW STANDARD FOR SYNCHROTRON LIGHT SOURCES

ESRF UPGRADE PROGRAMME 2009-2022

A « landmark » in the ESFRI roadmap
Great benefit also from dedicated EC calls

ESRF UPGRADE PROGRAMME

- 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

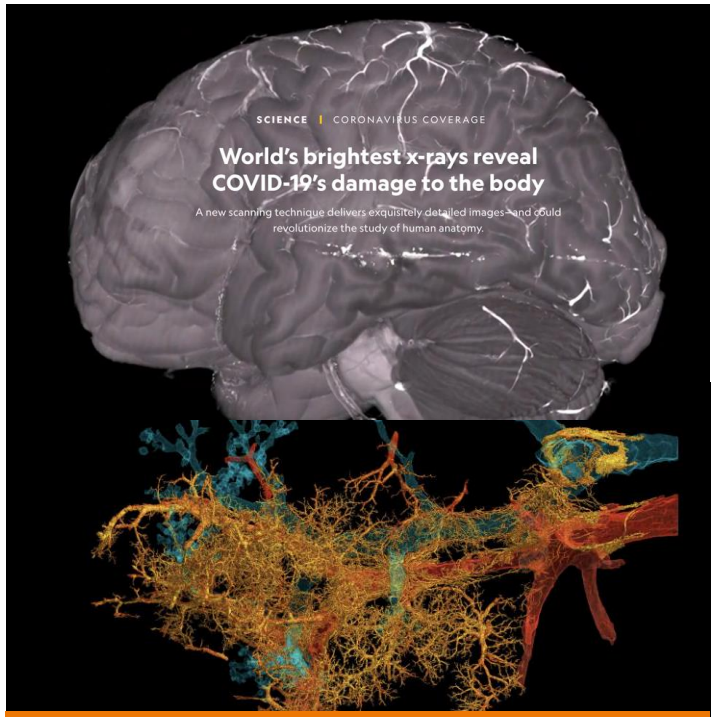
ESRF-EBS SCIENCE PROGRAMME

UNDERSTANDING COMPLEXITY IN MATTER ADDRESSING GLOBAL CHALLENGES

1. Health, Health Innovation, overcoming diseases and pandemics
2. Material for tomorrow, circular economy and sustainable industry
3. Clean Energy transition, sustainable energy storage and technologies
4. Planetary research, Environmental and climatic challenges
5. Bio-based economy and food safety
6. Humanity and world cultural heritage

ESRF-EBS: 4 YEARS OF IMPACTFUL OPERATION

10 on-going ERC GRANTS based on the EBS capabilities



New scientific projects such as the HUMAN ORGAN ATLAS PROJECT A game changer for bio-imaging

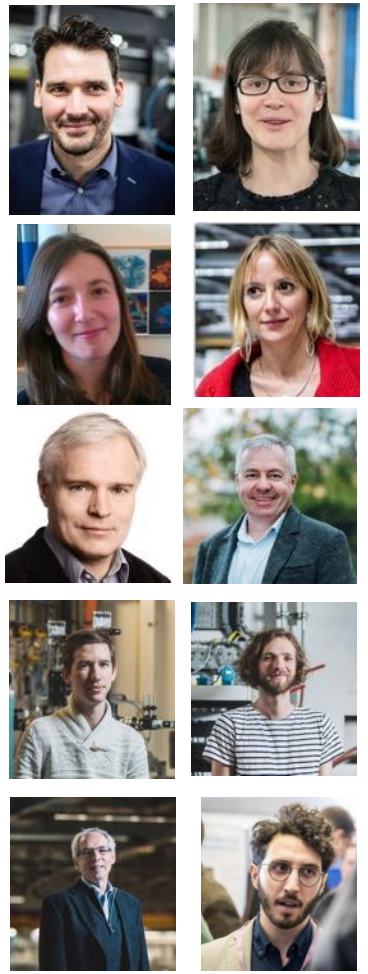
New services for industry to facilitate the use of EBS capabilities

erc European Research Council
Established by the European Commission

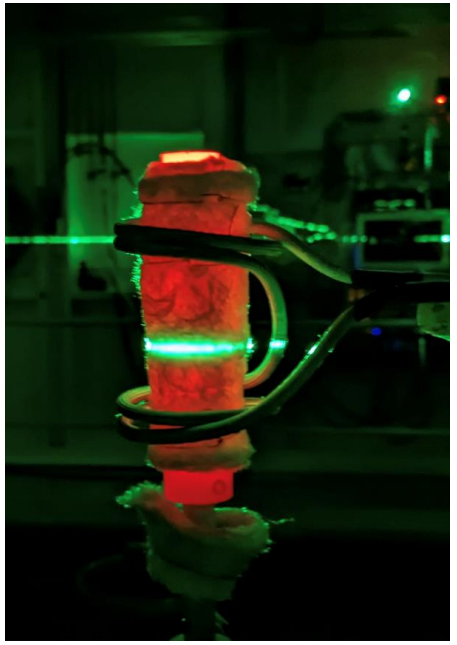
NEW SCIENCE: 10 ERC GRANTS BASED ON ESRF-EBS CAPABILITIES

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 Core (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 Sequestration and Enrichment of metals in DEEP marine deposits with novel micro X-ray emission spectroscopy (DEEP-SEE)	2022-2027
Can YILDIRIM, ESRF, ID03	**Starting**	Deformation and Recrystallization Mechanisms in Metals (D-REX)	2023-2028

European Research Council
Established by the European Commission



A DRIVER FOR EU SCIENCE: ON-GOING ERC GRANTS BASED ON THE EBS CAPABILITIES



"With EBS, the ESRF has the world-leading capabilities needed to perform this experimental programme. The new beamline BM18 provides the world's largest high-energy and high-coherence synchrotron beam for hierarchical imaging and high throughput tomography."
François Renard

François RENARD
ERC Advanced Grant
ESRF long-term user

- **His ERC project: BREAK -** Break-Through Rocks

- **The aim**: to study the origins and precursors of earthquakes. At the new EBS beamline BM18, Renard has installed a rock-deformation apparatus, ZEUS, to study the mechanisms that control the transition from slow, aseismic slip to rapid seismic rupture in rock samples.

erc European Research Council
Established by the European Commission

A DRIVER FOR EU SCIENCE: ON-GOING ERC GRANTS BASED ON THE EBS CAPABILITIES

“My ERC grant would not exist if it wasn’t for the new Extremely Brilliant Source at the ESRF.
`The EBS, with its brilliance and high coherence, enables the study of small nanoparticles, as small as 20 nanometres.” Marie-Ingrid Richard

Marie-Ingrid RICHARD
ERC Consolidator
ESRF user

- **Her ERC project: CARINE** - Coherent diffrAction foR a look Inside Nanostructures towards atomic rEsolution: catalysis and interface

- **The aim**: to study, at one nanoparticule level, the chemical structure of catalysts changes while in action. From creating fertilizers to converting toxic gases into harmless ones, catalysis plays a key role.

European Research Council
Established by the European Commission

A DRIVER FOR EU SCIENCE: ON-GOING ERC GRANTS BASED ON THE EBS CAPABILITIES

"Thanks to the EBS, I have access to an extremely small beam to study my samples, which are several microns in size. This makes the ESRF one of the few, if not the only place in the world where I can do my research"
Ilya Kupenko

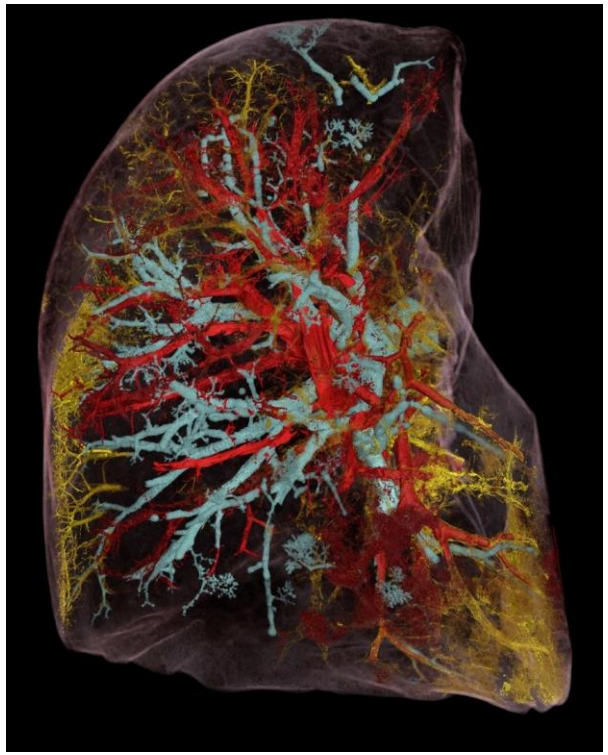
Ilya KUPENKO
ERC Starting
ESRF researcher

- **His ERC project: LECOR –** Light Elements in the Core

- **The aim:** to study the sound velocities and plastic deformation mechanisms of candidate iron alloys and compounds in situ at extreme pressure-temperature conditions using a combination of state-of-the-art synchrotron X-ray techniques, with the aim of solving the question of the composition of the Earth's core.

erc European Research Council
Established by the European Commission

EBS SCIENCE: THE HUMAN ORGAN ATLAS PROJECT



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.

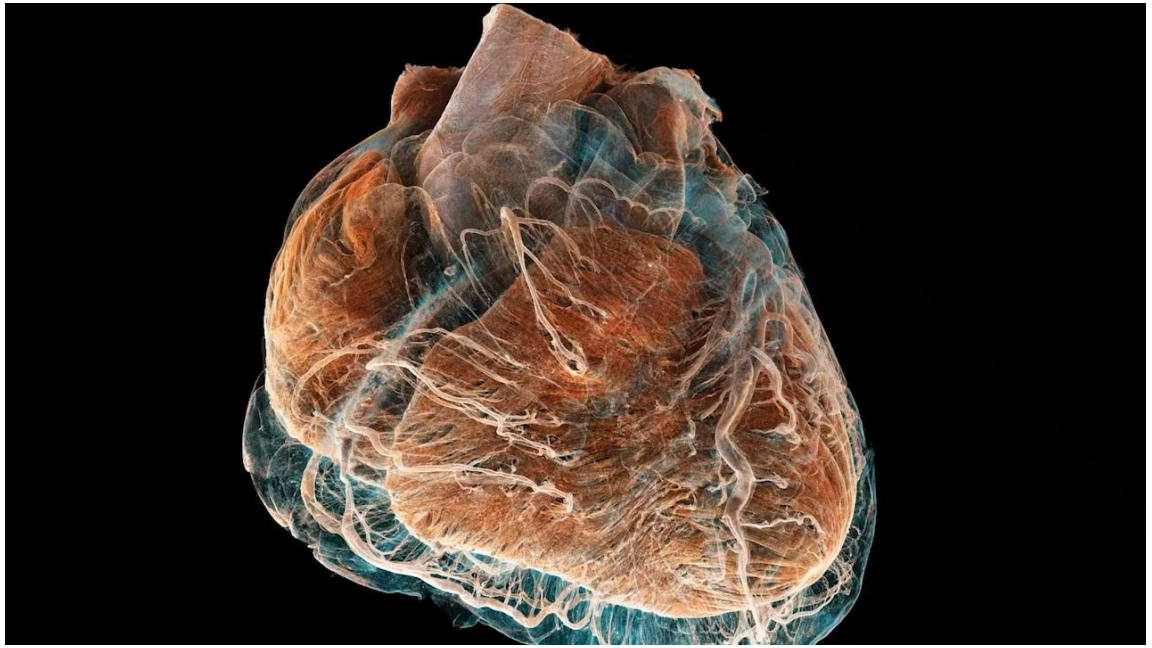
A REVOLUTION FOR BIO-IMAGING UNDERSTANDING HUMAN DISEASES THANKS TO A NEW INSIGHT INTO OUR BODY

https://human-organ-atlas.esrf.eu/

An **open-access database** developed as part of the **EU project PaNOSC**

Already **over 40 groups worldwide** collaborating to provide samples and utilise/share the results

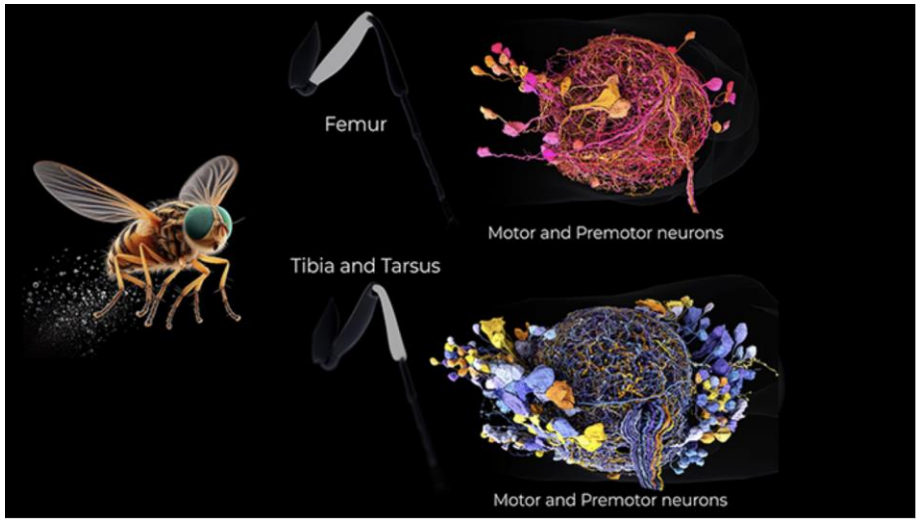
NEW SCIENCE: THE HUMAN ORGAN ATLAS PROJECT



FIRST 3D IMAGING OF A WHOLE ADULT HUMAN HEART DOWN TO CELLULAR LEVEL

- Scientists have, for the first time, mapped 2 whole human hearts in unprecedented 3D detail using Hierarchical Phase contrast Computed Tomography (HiP-CT).
- ESRF's HiP-CT new technique demonstrates its capacity for high spatial resolution, multi-scale, cardiac imaging ex-vivo, revealing histologic-level detail of the myocardium, valves, coronary arteries, and cardiac conduction system across length-scales.
- Virtual sectioning of the cardiac conduction system provides new information on fatty infiltration, vascular supply, and pathways between the cardiac nodes and adjacent structures.
- Published IN *RADIOLOGY, 17 July 2024*

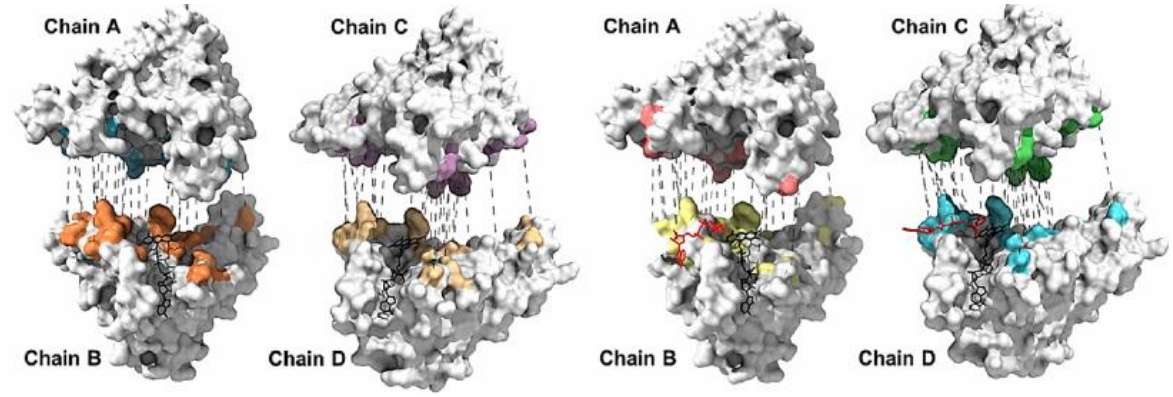
EBS SCIENTIFIC HIGHLIGHTS



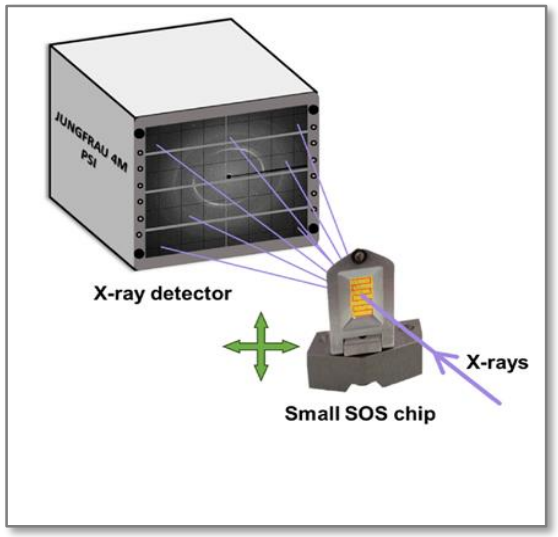
NEW INSIGHT ON HOW THE CENTRAL NERVOUS SYSTEM OF THE FLY CONTROLS THE BODY

- Neural circuits that coordinate leg and wing movements during take-off and landing discovered by a team from University of Washington, Harvard Medical School, and ERC SG grantee ESRF scientist Alexandra Pacureanu.
- Determining which motor neurons control individual muscles, they found that some muscle fibres are innervated by multiple motor neurons. This **poly-neuronal innervation** may explain how insect legs achieve precision in complex functions.
- The team combined X-ray nano-tomography at ID16A, electron microscopy and sparse genetic labelling.
- Azevedo et al., *Nature,* June 2024

EBS SCIENCE: SERIAL MACROMOLECULAR CRYSTALLOGRAPHY



A. Grieco, et al., *Protein Science* **33**, e4957 (2024)



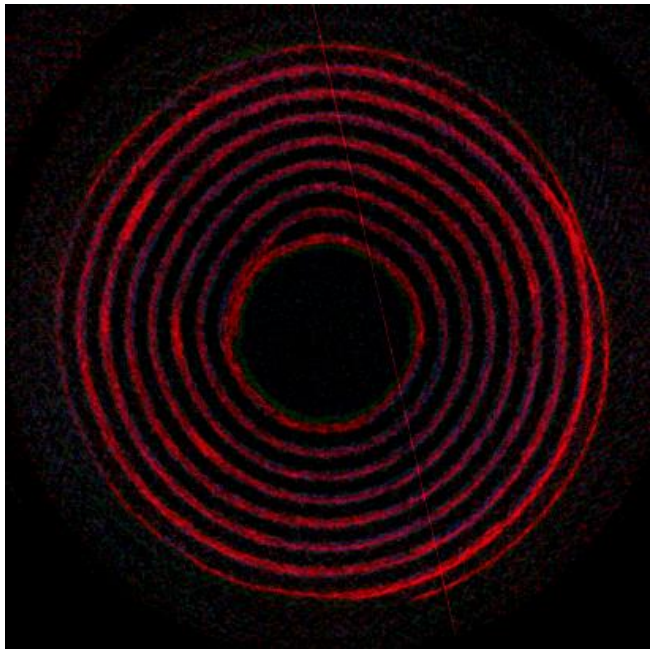
Setup: 1% bandwidth x-ray beam, pulse length 90 µs, repetition rate 231.25 Hz. SOS chip moves from left to right in a zig-zag pattern across the X–Y axes

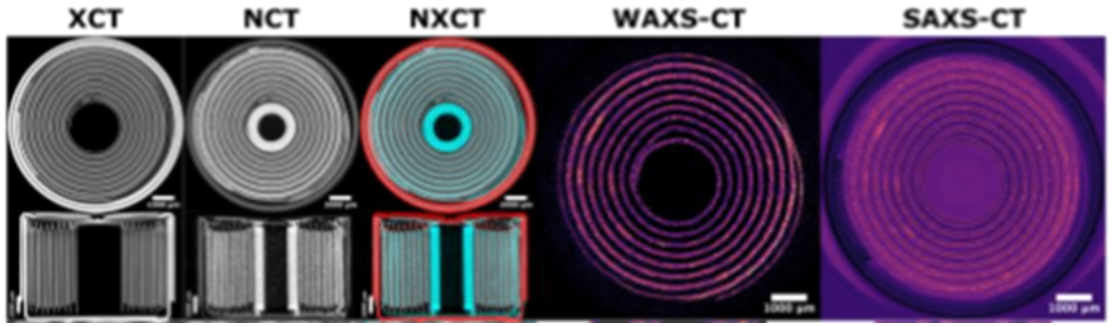
COMPLEX REDOX MECHANISM OF NQO1 (ENZYME PROTECTING CELLS FROM DAMAGE)

- The human NAD(P)H NQO1 catalyzes the two-electron reduction of quinones to hydroquinones, being essential for the antioxidant defense system, stabilization of tumor suppressors, and activation of quinone-based chemotherapeutics. It is also overexpressed in several tumors, which makes it an attractive cancer drug target.
- Understanding the complex redox mechanism of NQO1 is key for the development of new treatments for both cancer and Alzheimer's disease
- Ambient temperature serial crystallography at ID29 revealed:
  - First structure of the hNQO1 in complex with NADH
  - First evidence that functional cooperativity is driven by long-propagation contacts between two active sites
- These results are key to demonstrate interplay between protein flexibility & kinetic function critical to advance in the design of new, more effective inhibitors of this enzyme

- A.Grieco, et al., Protein Science 33, *19 March 2024*

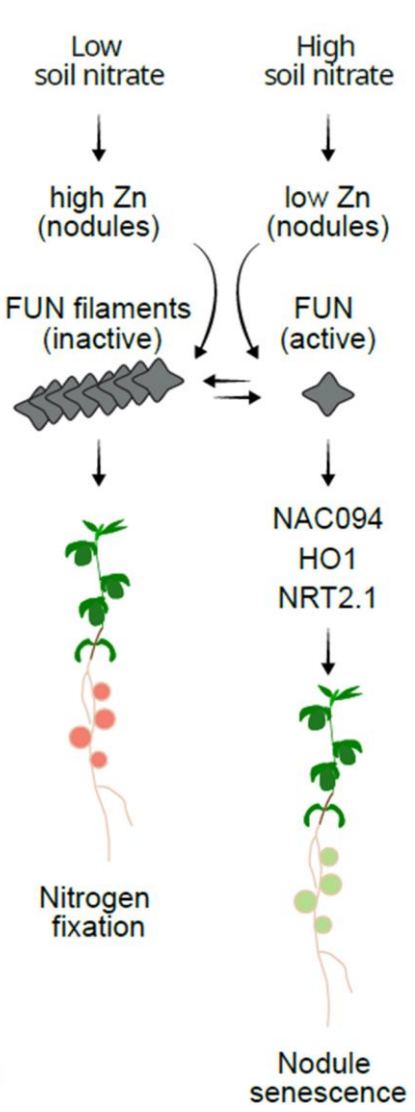
ESRF-EBS SCIENCE HIGHLIGHTS

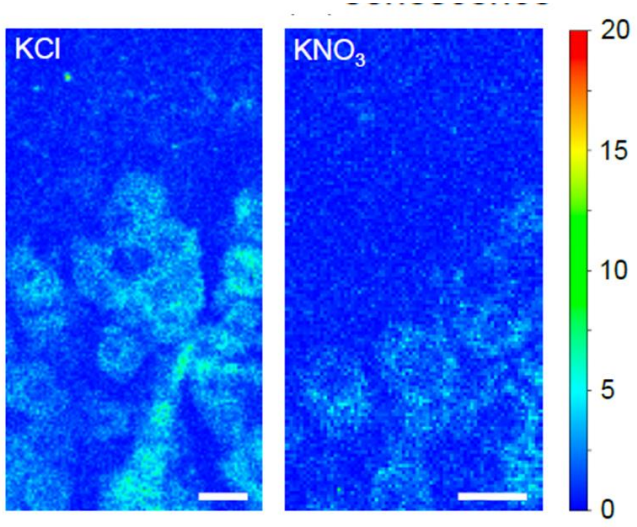




BETTER UNDERSTANDING DEGRADATION/FAILURE IN SILICON-BASED LI-ION BATTERIES

- EBS performances has enabled new methodologies to study battery operation at extreme conditions
- Scientists found the key origin of ageing of silicon-based Li-ion batteries in the electrode processing during the manufacturing by combining X-ray and neutron imaging techniques at ESRF/ILL
- They identified macroscopic deformations in the wound structure of the copper current collector and demonstrated that these defects are due to local silicon enrichments occurring during the electrode wet process manufacturing → new opportunities to better predict & mitigate unwanted aging and failure modes
- Lübke E. *et al*, *Energy and Environmental Science*, 2024
- **Futures perspectives:** to study post-lithium cells within the European Battery HUB, with the implementation of new and faster XRD detectors to better exploit the EBS flux



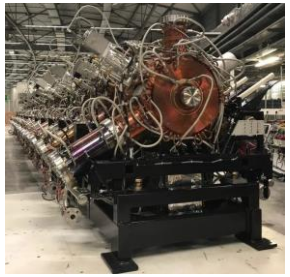


FINDING WAYS OF SECURING CROPS WITHOUT DAMAGING THE ENVIRONMENT

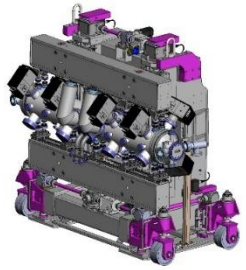
- A team from La Trobe University (Australia), Aarhus University (Denmark), the Universidad Politécnica de Madrid (Spain) and the ESRF has shown that zinc, an essential plant micronutrient, acts as an intracellular second messenger that connects environmental changes to transcription factor control of metabolic activity in root nodules.
- This opens new avenues for fine-tuning to enhance tolerance of legumes to soil nitrate, It could be key to understanding how to increase the crop's capacity to convert nitrogen from the air and improve soil quality.
- The team used X-ray fluorescence on ID21 to track the distribution of zinc in the root nodules of Lotus plants in low-nitrate soils and in nitrate-rich soils.
- Lin et al., *Nature* 2024, *26 June 2024*

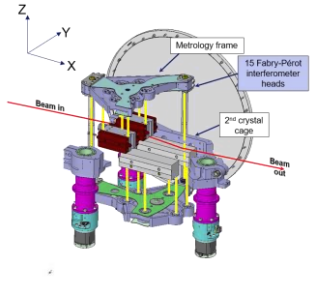
PROMOTING SCIENTIFIC EXCELLENCE THROUGH THE OPTIMUM EXPLOITATION OF ESRF-EBS

Beamline & Accelerator upgrades



Beamline & Accelerator enabling technologies





New access modes

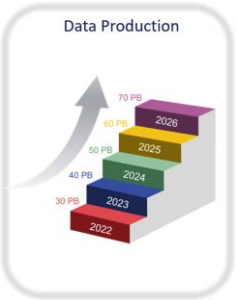
BAG

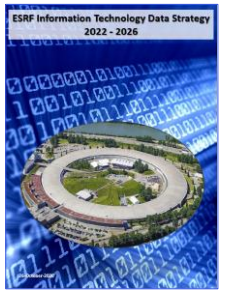
HUB

Rapid Access

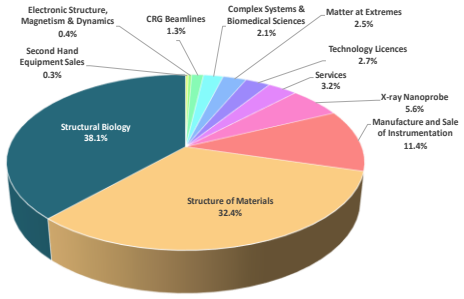
Coordinated Access

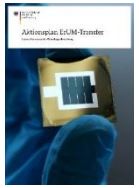
Data Strategy Implementation Plan





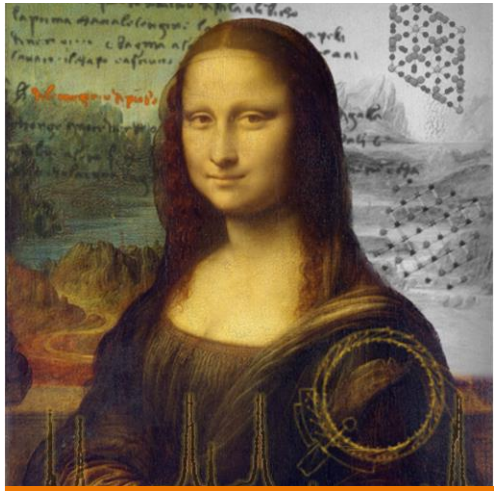
Commercial use





User Outreach & Training

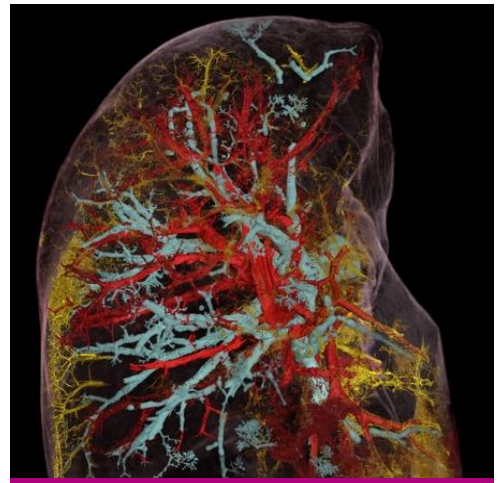
NEW ACCESS MODE TO EXPLOIT EBS, TO ENLARGE & STRENGTHEN THE USER COMMUNITY



HISTORICAL MATERIALS BAG
Launched in 2021

BATTERY HUB
Launched in 2021

SHOCK BAG
Launched in 2022



HUMAN ORGAN ATLAS HUB
Launched in 2023

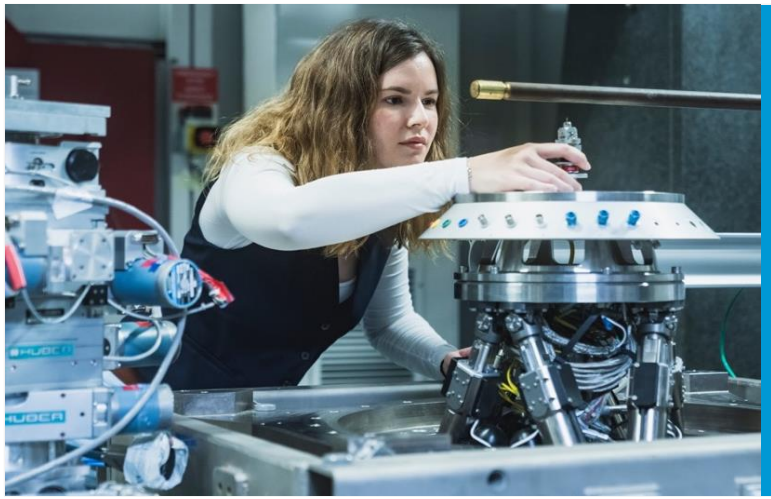
RAPID ACCESS

COORDINATED ACCESS

TO THE BENEFIT OF THE SCIENTIFIC COMMUNITY
A DRIVER FOR EU SCIENTIFIC COLLABORATIONS

STREAMLINE

INSPIRING AND TRAINING THE NEXT GENERATIONS OF SCIENTISTS



EUROPEAN PROGRAMMES TOWARDS POSTDOCS AND PHDS WITH ACADEMIA AND INDUSTRY

MARIE SKŁODOWSKA-CURIE ACTIONS
Research Fellowship Programme

HERCULES EU SCHOOL
ESRF-ILL INTERNATIONAL UNDERGRADUATE STUDENT SUMMER SCHOOL
SYNCHROTRON@SCHOOL

HERCULES
European School

SYNCHROTRON @SCHOOL

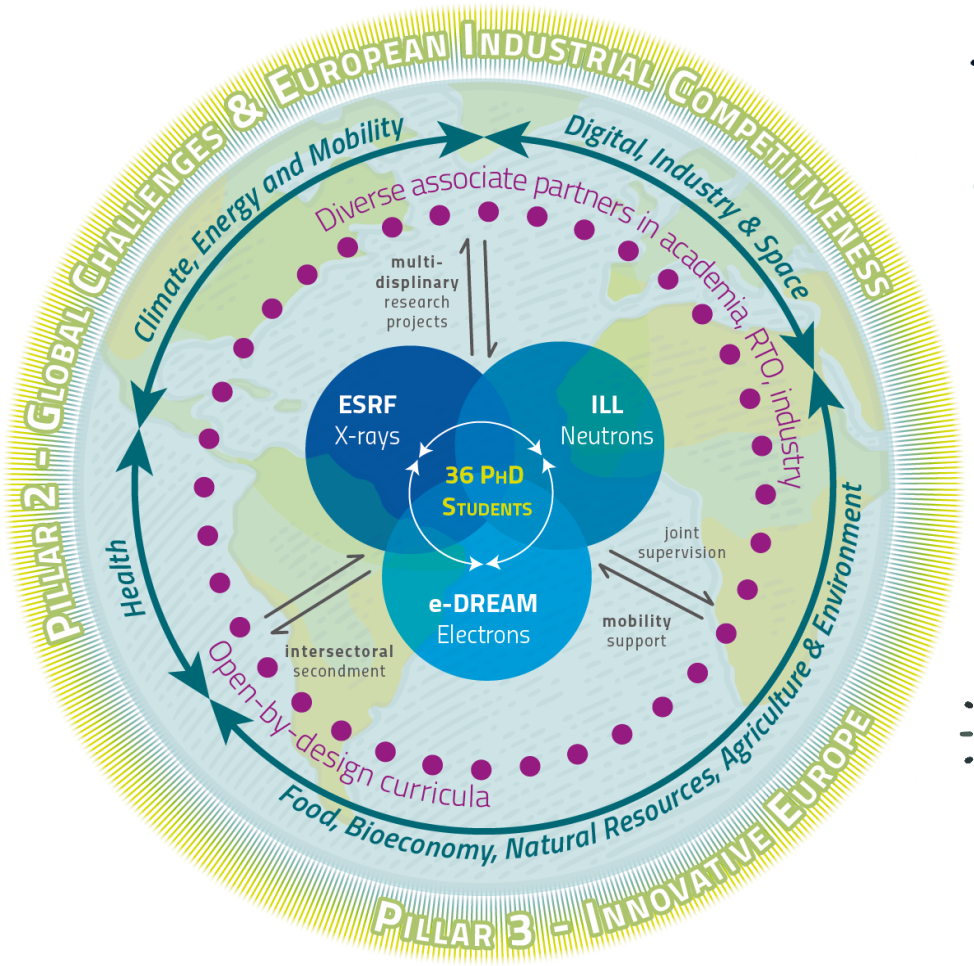
académie Grenoble

MINISTÈRE DE L'ÉDUCATION NATIONALE

MINISTÈRE DE L'ENSEIGNEMENT SUPÉRIEUR ET DE LA RECHERCHE

NEXTSTEP: a new Marie Skłodowska Curie COFUND PhD programme just accepted by the EC

*Three e-DREAM nodes: FZJ (G), Norwegian University of Science and Technology (N) and AREA Science Park (I)



- **NEXTSTEP will be 36 PhD students at ESRF, ILL & e-DREAM* from Sept 2025**
- - ESRF Coordinator
- - 3.7MEuro EC contribution

- **Each PhD project in collaboration with an Academic, Industrial or Research and Technology Organisation (RTO) Associate**
- - EMBL and other RTO are already identified as Associates

PhD topics on sustainable development and innovation challenges in four Horizon Europe Pillars

- Health; Digital, Industry & Space; Food, Bioeconomy, Natural Resources, Agriculture & Environment; Climate, Energy & Mobility

INTERNATIONAL COLLABORATIONS AT THE HEART OF ESRF VALUES AND MISSIONS

EUROPEAN OPEN SCIENCE CLOUD

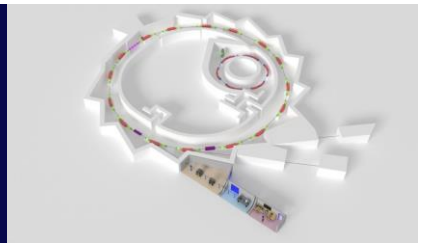
panosc

Member of the **European Open Science Cloud Association**

Active actor of **SESAME**

especially as coordinator of the **BEATS EU project**

BEATS
BEAmline for Tomography at SESAME



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serving european science

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which brings together eight of **Europe's Big Science facilities**

Member of LEAPS

the League of European Accelerator-based Photon Sources

Member of the African Lightsource Foundation
executive and international advisory committees

THE AFRICAN LIGHTSOURCE
Towards a Lightsource for the African Continent


ESRF
The European Synchrotron
THANKS FOR YOUR ATTENTION