

ESRF – Extremely Brilliant Souce (EBS): a European effort to pioneer synchrotron X-ray science

5th LEAPS Plenary Meeting

PSI, 25 - 28 October 2022

Michael Krisch on behalf of the ESRF staff





OUTLINE OF THE PRESENTATION



- > History
- ESRF-EBS: a European effort to pioneer synchrotron science
- EBS scientific highlights
- Conclusions



HISTORY OF THE ESRF: 13 YEARS PRE-HISTORY AND 28 YEARS OF OPERATION





ESRF impact – facts and figures – industry use and procurement





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

Purple Book January 2008

2009





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



2015

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



Page 5 5th LEAPS Plenary Meeting | PSI 25 - 28 Oct 2022 | Michael Krisch on behalf of the ESRF staff



90% existing infrastructure re-used



~20% reduction in power consumption



Home office











Drastically reduced travel for users (& staff)



ESRF: 2021 OPERATION FIGURES







experimental sessions

experiments carried out remotely



proposals accepted (out of 1920 submitted)

runs of beam time





machine availability



operation modes

42/44

beamlines hosted experiments



hours of beam delivered to users (out of 4648 scheduled)

11 711

shifts delivered to users (out of 27 371 requested)



1219

ESRF publications in peer-reviewed journals



ESRF-EBS IMPACT ON THE EXPERIMENTAL PROGRAMME





ESRF-EBS, AN EXTREMELY BRILLIANT SOURCE TO TACKLE GLOBAL CHALLENGES

- **1. Health, Health Innovation**, overcoming diseases and pandemics
- **2. Material for tomorrow,** and innovative and sustainable industry
- **3. Clean Energy transition**, sustainable energy storage and clean hydrogen technologies
- **4. Planetary research** (terrestrial and extra-terrestrial)
- 5. Environmental and climatic challenges
- 6. Bio-based economy and food security
- 7. Humanity and world cultural heritage





BATTERIES RESEARCH





		Cell generation	Cell chemistry	7	
Energy and power density		Post-Lithium	Sodium-ion, multivalent metal-ion, metal-air, redox flow, etc.		
		Generation 5	Lithium-Sulphur, Lithium-air		
		Generation 4	All-solid-state with Li-ion or Li-metal		
		Generation 3b	Cathode: HE-NMC, HVS (high voltage spinel) Anode: Silicon/Carbon		
		Generation 3a	Cathode: NMC622 to NMC811 Anode: 100% Carbon (graphite) + Si (5-10%)		
		Generation 2b	Cathode: NMC523 to NMC622 Anode: 100% Carbon	- current	
		Generation 2a	Cathode: NMC111 Anode: 100% Carbon		
		Generation 1	Cathode: LFP, NCA Anode: 100% Carbon		

https://battery2030.eu/research/roadmap/

Goals of future battery R & D

- higher energy density (longer range)
- higher power density (fast charge/discharge)
- longer cycles
- lower costs
- greater safety

Batteries are multi length-scale objects \rightarrow analytical Research Infrastructures play a crucial role



ESRF

INVESTIGATION OF COMMERCIAL LITHIUM-ION BATTERIES BY X-RAY HOLOGRAPHIC NANOTOMOGRAPHY

X-ray Holographic Nanotomography on ID16A



- Cathode crack detection and effect of particle density on damage
- Cathode stabilization with additive engineering

Courtesy of P. Cloetens



The European Synchrotron

INVESTIGATION OF COMMERCIAL LITHIUM-ION BATTERIES BY X-RAY HOLOGRAPHIC NANOTOMOGRAPHY



T. Fu, Y. Liu, et al., Advanced Functional Materials (2022)

Cathode crack detection: Particle density plays a role on the damaging which varies as a function of electrode depth



G. Zan, Y. Liu, et al., Journal of Material Chemistry A (2021)

Cathode stability: Link between the cathode electrode delamination and the degree of pulverization of the active material



THERMOMECHANICAL PROCESSING OF HEAVILY DEFORMED IRON ALLOY

Dark field X-ray Microscopy on ID06 (future ID03)





Detailed quantitative insight in the dynamics of recrystallisation and grain growth during annealing

Significant industrial importance because these processes strongly influence the microstructure & texture, hence the properties of materials.

C. Yildirim et al, Scripta Materialia; IOP Conf. Ser.: Mater. Sci. Eng. (2022)



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, C₆N₄) in N₂ 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



CHEMICAL COMPOSITION AND PROCESSES OF EARTH'S INTERIOR

para

1000

500

α-Fe

5

T (K)



3D seismic tomography



Abundance of light elements at extreme conditions



Sound velocities in single crystal of ε-Fe



S(q, w) [arb. units]

A. Dewaele et al, submitted

Explanation of 3-4% seismic anisotropy in the core Partitioning of C between the core and the mantle Better understanding of the deep carbon cycle

Tetracarbonate formation at lower mantle pressures



V. Cerantola et al, submitted



The European Synchrotron

Cd IN CACAO BEANS: KEEPING CHOCOLATE SAFE



Everyone has a right to safe, healthy and nutritious food

World Health Organization Food safety, everyone's business





New EU and CODEX legal limit (2019): 0.8 mg kg⁻¹ Cd in dark chocolate (50% cacao) 0.1 mg kg⁻¹ in milk chocolate (30% cacao)

Use of 2 cultivars

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



μXRF

ISTerre



µXRF at ID21 Cryo-analysis \checkmark Elemental + chemical information ~ Resolution (EBS) 0.7x0.4µm² step size 1 µm \checkmark Acquisition time: \checkmark **Before EBS** EBS + new XRF detectors 13.3 h 20 min Courtesy of H. Michel-Castillo lcbm



INAUGURATION OF BM18



25-10-2022

Share

On 25 October 2022, Mario Brandenburg, the Parliamentary State Secretary to the German Federal Minister of Education and Research (Bundesministerium für Bildung und Forschung, or BMBF) inaugurated the new EBS flagship beamline for tomography, BM18.



BM18: HIERARCHICAL PHASE-CONTRAST TOMOGRAPHY



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





Industrial applications



Material sciences



 Non-destructive control of large devices (batteries, complex mechanical parts)

 Additive manufacturing (in-situ and ex-situ)



🗾 Fraunhofer EZRT



HIERARCHICAL IMAGING OF COMPLETE HUMAN ORGANS



Medizinische Hochschule Hannover Jeden Tag für das Leben.



HEIDELBERG UNIVERSITY HOSPITAL

















- 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)





Jeden Tag für das Leben.



HEIDELBERG UNIVERSITY HOSPITAL





National Geographic's favorite science photos of 2021
How COVID-19 affects the lungs' airways
NATIONAL GEOGRAPHIC



The lang of a 54-year-old main who died of COVID-IP means its internal structure under the behavior any glasm of the Languest Systemation Rediation Facility is Consolid, Hance, These high-resultation cores are pair up blood classing within the langs smallest acrossys. *Without to Colors 4*(1),65

Deutsches **Ärzteblatt**

25 | 2022

24. Juni | Ausgabe A www.aerzteblatt.de UG Université Grenoble Alpes

Die Zeitschrift der Ärzteschaft | Gegründet 1872



école de Chirurgie

> Deutsches Zentrum für Lungenforschung



Ersteinschätzungsverfahren Vier Konzepte liegen vor Seite 1120

> Zertifizierte Fortbildung Substanzabhängigkeit bei Kindern Seite 440





The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Pulmonary Vascular Endothelialitis, Thrombosis, and Angiogenesis in Covid-19

Maximilian Ackermann, M.D., Stijn E. Verleden, Ph.D., Mark Kuehnel, Ph.D., Axel Haverich, M.D., Tobias Welte, M.D., Florian Laenger, M.D.,
Arno Vanstapel, Ph.D., Christopher Werlein, M.D., Helge Stark, Ph.D., Alexandar Tzankov, M.D., William W. Li, M.D., Vincent W. Li, M.D., Steven J. Mentzer, M.D., and Danny Jonigk, M.D.

N ENGL J MED 383;2 NEJM.ORG JULY 9, 2020

Check for updates

IMAGES IN PULMONARY, CRITICAL CARE, SLEEP MEDICINE AND THE SCIENCES

The Bronchial Circulation in COVID-19 Pneumonia

8 Maximilian Ackermann^{1,2}, Paul Tafforeau³, Willi L. Wagner⁴, Claire L. Walsh⁵, Christopher Werlein^{6,7}, Mark P. Kühnel^{6,7}, Florian P. Länger^{6,7}, Catherine Disney⁸, Andrew J. Bodey⁹, Alexandre Bellier¹⁰, Stijn E. Verleden¹¹, Peter D. Lee⁸, Steven J. Mentzer¹², and Danny D. Jonigk^{6,7}

Am J Respir Crit Care Med Vol 205, Iss 1, pp 121-125, Jan 1, 2022

ARTICLES

https://doi.org/10.1038/s41592-021-01317-x

nature methods

Check for update:

OPEN

Imaging intact human organs with local resolution of cellular structures using hierarchical phase-contrast tomography

C. L. Walsh[©]^{1,2,17}, P. Tafforeau[©]^{3,17}, W. L. Wagner^{4,5,17}, D. J. Jafree^{6,7}, A. Bellier[®]⁸, C. Werlein[®]⁹, M. P. Kühnel^{9,10}, E. Boller³, S. Walker-Samuel[®]², J. L. Robertus^{11,12}, D. A. Long[®]⁶, J. Jacob^{13,14}, S. Marussi¹, E. Brown², N. Holroyd[®]², D. D. Jonigk^{9,10}, M. Ackermann[®]^{15,16} and P. D. Lee[®]¹

NATURE METHODS | VOL 18 | DECEMBER 2021 | 1532-1541 | www.nature.com/naturemethods

The fatal trajectory of pulmonary COVID-19 is driven by lobular ischemia and fibrotic remodelling

Maximilian Ackermann,^{a,b,1} Jan C. Kamp,^{c,d,1} Christopher Werlein,^{d,e} Claire L. Walsh,^f Helge Stark,^{d,e} Verena Prade,^g Rambabu Surabattula,^h Willi L. Wagner,^{Lj} Catherine Disney,^k Andrew J. Bodey,¹ Thomas Illig,^{d,m} Diana J. Leeming,^m Morten A. Karsdal,ⁿ Alexandar Tzankov,^o Peter Boor,^p Mark P. Kühnel,^{d,e} Florian P. Länger,^{d,e} Stijn E. Verleden,^q Hans M. Kvasnicka,^a Hans H. Kreipe,^e Axel Haverich,^{d,r} Stephen M. Black,^s Axel Walch,ⁿ Paul Tafforeau,^t Peter D. Lee,^m Marius M. Hoeper,^{c,d,*} Tobias Welte,^{c,d} Benjamin Seeliger,^{c,d} Sascha David,^u Detlef Schuppan,^{h,v,2} Steven J. Mentzer,^{w,2,*} and Danny D. Jonigk^{d,e,2}



eBioMedicine 2022:85:

104296



UCL-ESRF HUMAN ORGAN ATLAS PROJECT

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.

Human Organ Atlas	EXPLORE SEARCH
Patients	A FO-20.129 male 54 yo died from COVID-19 21 days after hospitalisation, mechanical ventilation, pulmonary failure, renal failure,bacterial pneumonia with Klebsiella aerogenes, general brain edema, subarachnoidal and intracranial bleeding
	우 LADAF-2020-31 우 GLR-163
	type 2 diabetes, pelvic radiation to treat cancer of the uterus, right colectomy (benign lesion on histopathology), bilateral nephrostomy for acute obstructive renal failure, cystectomy, omentectomy and peritoneal carcinoma with occlusive syndrome resection of the lower lobe segment 6 due to small pulmonary adenocarcinoma (1.4), coronary heart disease, arterial hypertension, chronic rheumatic disease (polymyalgia rheumatica)
Organs	kidneyheartlungImage: Comparison of the sector o
Datasets	2.45um_VOI-01_upper-lobe-apical Vertical column in local tomography at 2.45um pixe size performed by HIP-CT on the beamline BM05 of the left lung from the body donor LADAF-2020-27 using half-acquisition protocol.

ESRF

HIERARCHICAL STRUCTURE OF MUSCLE



4. generation SR

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



H2020 project aiming for sustainable scientific exploitation of the ESRF-EBS

Duration: November 2019 – May 2024; Funding: 5 M€; https://streamline.esrf.fr/



- New source
- Brighter X-ray beams
- New beamlines
- New infrastructure

New science



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870313.



NEW ACCESS MODES: PILOT PROJECTS

Historical Materials BAG



The Courtauld	supérieu paris-sa	clay PARIS-SACLAY		
So SCITCC		RUKS MUSEUM		
UNIVERSITAT POLITŘO DE GATALUNYA BARCELONATECH	Concepto Nazaona delle Barrelor	e CP de Chimie Paris	MINISTÈRE DE LA CULTURE	ORDERED UCHNON INSTRUCTION INSTRUCTION INSTRUCTION

🖄 molecules

Article

The "Historical Materials BAG": A New Facilitated Access to Synchrotron X-ray Diffraction Analyses for Cultural Heritage Materials at the European Synchrotron Radiation Facility

Marine Cotte ^{1,2,*}^(D), Victor Gonzalez ^{3,*}, Frederik Vanmeert ^{4,5,*}^(D), Letizia Monico ^{4,6,7,*}^(D), Catherine Dejoie ¹, Manfred Burghammer ¹, Loïc Huder ¹, Wout de Nolf ¹, Stuart Fisher ¹, Ida Fazlic ^{1,8}, Christelle Chauffeton ^{9,10,11}, Gilles Wallez ^{9,11,12}, Núria Jiménez ¹³^(D), Francesc Albert-Tortosa ¹³^(D), Nati Salvadó ¹³^(D), Elena Possenti ¹⁴^(D), Chiara Colombo ¹⁴, Marta Ghirardello ¹⁵^(D), Daniela Comelli ¹⁵^(D), Ermanno Avranovich Clerici ^{4,16}^(D), Riccardo Vivani ¹⁷^(D), Aldo Romani ^{6,7}, Claudio Costantino ^{6,70}, Koen Janssens ^{4,8}^(D), Yoko Taniguchi ¹⁸^(D), Joanne McCarthy ¹⁰, Harald Reichert ¹ and Jean Susini ^{1,†}

Shock BAG



William Proud, Simon Bland







Nick Hawker, Hugo Doyle

Daniel Eakins, David Chapman, Clive Siviour



MDPI

Southampton

Amitay Cohen, Arno Joshef-Hai, David Levi-H



Collapse dynamics of spherical cavities in a solid under shock loading Escauriza et al., Sci. Rep. May 2021 Time resolved radiography ID19 - ESRF

Battery HUB

Grenoble Battery HUB ESRF – ILL - CEA







HIGH THROUGHPUT POWDER DIFFRACTION SERVICE AT ID31

Service in place Jan 2023

- time to change Sample holder: ~2s
- time to change sample & read QR-code with sample descriptor: 0.095s
- measuring time: 1s
- shaker for better powder averaging -
- max. capacity 66 sample holders = 1056 samples
- measurement time for **1056 samples**: ~22 minutes







First prototype, tests with different acquisition times (here <1s) Johannes Frey, Sample Environment Support





ID27: High flux nano-XRD beamline for extreme conditions. *Refurbishment finished*

ID24-ED: Facility for dynamic compression studies *Construction finished*

ID21: X-ray Microscopy beamline Nearly finished **ID24-DCM:** High brilliance XAS beamline (XAS/XES) *Construction in progress* 2022

EBSL8 (ID29) : (Time-

resolved) Serial Crystallography Beamline *Nearly finished* 2022

EBSL3 (BM18): High

throughput large field phasecontrast tomography beamline *Nearly finished* 2022

EBSL2 (ID03):

Beamline for Hard X-Ray Microscopy *Construction in progress 2024*

ID18 (move to ID14):

Nuclear Resonant Scattering *Construction in progress 2024*

EBSL1 (ID18):

Beamline for Coherence Applications *finished*

ID26: XES beamline DCM finished



LEAPS collaborations 2015 - 2021



PUMA (Publication and User experiment Metadata Analyser); courtesy R. Duyme



CONCLUSIONS & TAKE-HOME MESSAGES



We need a global **joint effort** for a world facing **Societal Challenges** at a planetary scale.





(European) Research Infrastructures are a key element for **co-innovation**





Co-innovation We all make the best fishing gear and then each one decides what to fish...

Inspired by Sergio Bertolucci & the ATTRACT vision



THANK YOU FOR YOUR ATTENTION





