ESRF | The European Synchrotron

PIONEERING SYNCHROTRON SCIENCE

ESRF
The European Synchrotron

30 years of science

2019

BEST WISHES FOR THE NEW YEAR

The Pan African Conference on Crystallography (PCCR2)
and
The African Light Source Conference (AfLS2)

The Extremely Brilliant Source at the ESRF

31 January 2019

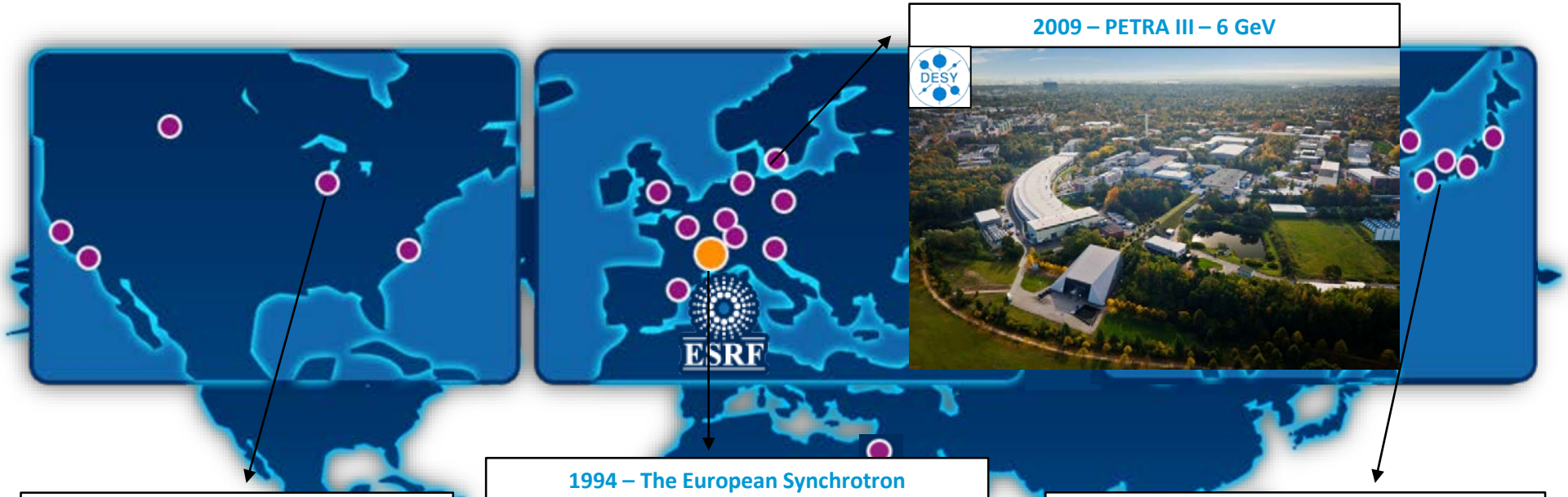
F. Sette, Director General of the ESRF

SYNCHROTRON X-RAY SCIENCE AND APPLICATIONS

Fundamental, applied and industrial research

Large variety of a applications for a common goal: link Function to Atomic Structure

Major synchrotrons in the world



2009 – PETRA III – 6 GeV

1996 – Advanced Photon Source - 7 GeV

1994 – The European Synchrotron Radiation Facility – 6 GeV

FIRST THIRD-GENERATION SYNCHROTRON

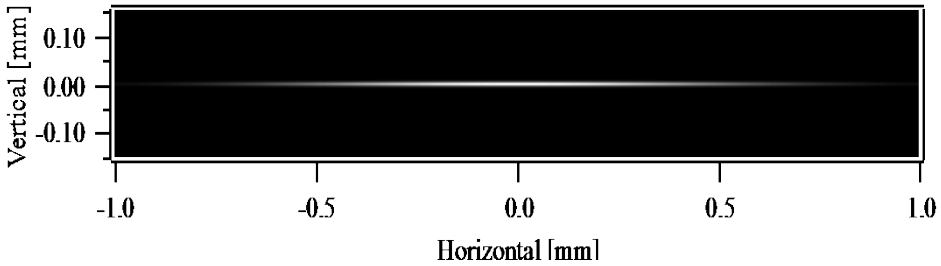
1997 – Super Photon RING 8 GeV

ELECTRON BEAM SIZE AT THE ESRF AND AT THIRD GENERATION SYNCHROTRON SOURCES

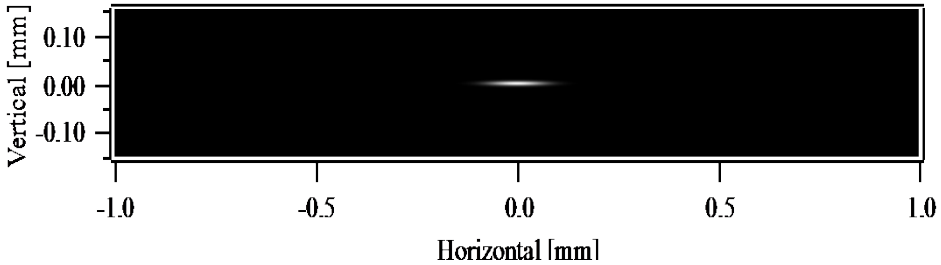
Present

Middle of ID straight

High Beta ~ parallel beam and large source size



Low Beta : large horizontal divergence and small source size



ESRF: A LANDMARK FOR SCIENCE

A world landmark for Science

- 44 beamlines
- Leader in scientific output: almost 2 000 publications/year and more than 32 500 publications since 1994
- Leader in number of users: ~7 000 user visits/year, more than 10 000 individual users in the last three years
- 4 Nobel Prizes for 5 ESRF users

Brian Kobilka,
Shared 2012 GPCR

ESRF today: the world's most performing and brilliant "third-generation" light source

EPN SCIENCE CAMPUS : A UNIQUE SITE FOR RESEARCH AND INNOVATION

- +500 scientists in the Campus
- 3 European Organisations, Members of EIROFORUM, and IBS – a French Institute for Structural Biology (CEA-CNRS-University Grenoble-Alpes)

european photon & neutron science campus

ESRF The European Synchrotron

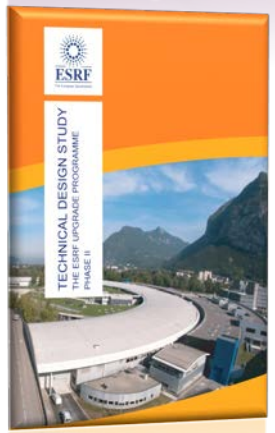
NEUTRONS FOR SOCIETY

EMBL

ibs Institut de Biologie Structurale

ESRF SCIENCE Programme: New and better Science

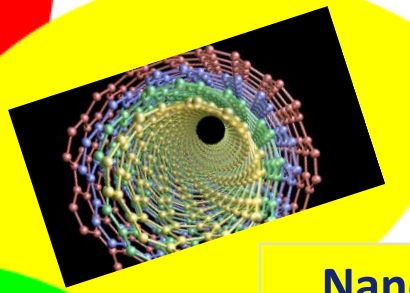
Purple Book January 2008



Orange Book January 2015

Pump-and-Probe Experiments and Time-resolved Science

X-ray Imaging Science



Nano-Science And Nano-Technology

Science at Extreme Conditions

Structural and Functional Biology And Soft Matter

New and innovative materials

Health & life sciences

Energy and Environment

ESRF UPGRADE PROGRAMME PHASE I

Purple Book January 2008

ESRF UPGRADE PHASE I
180 M€ (2009-2015):
ESFRI ROADMAP 2006-2016

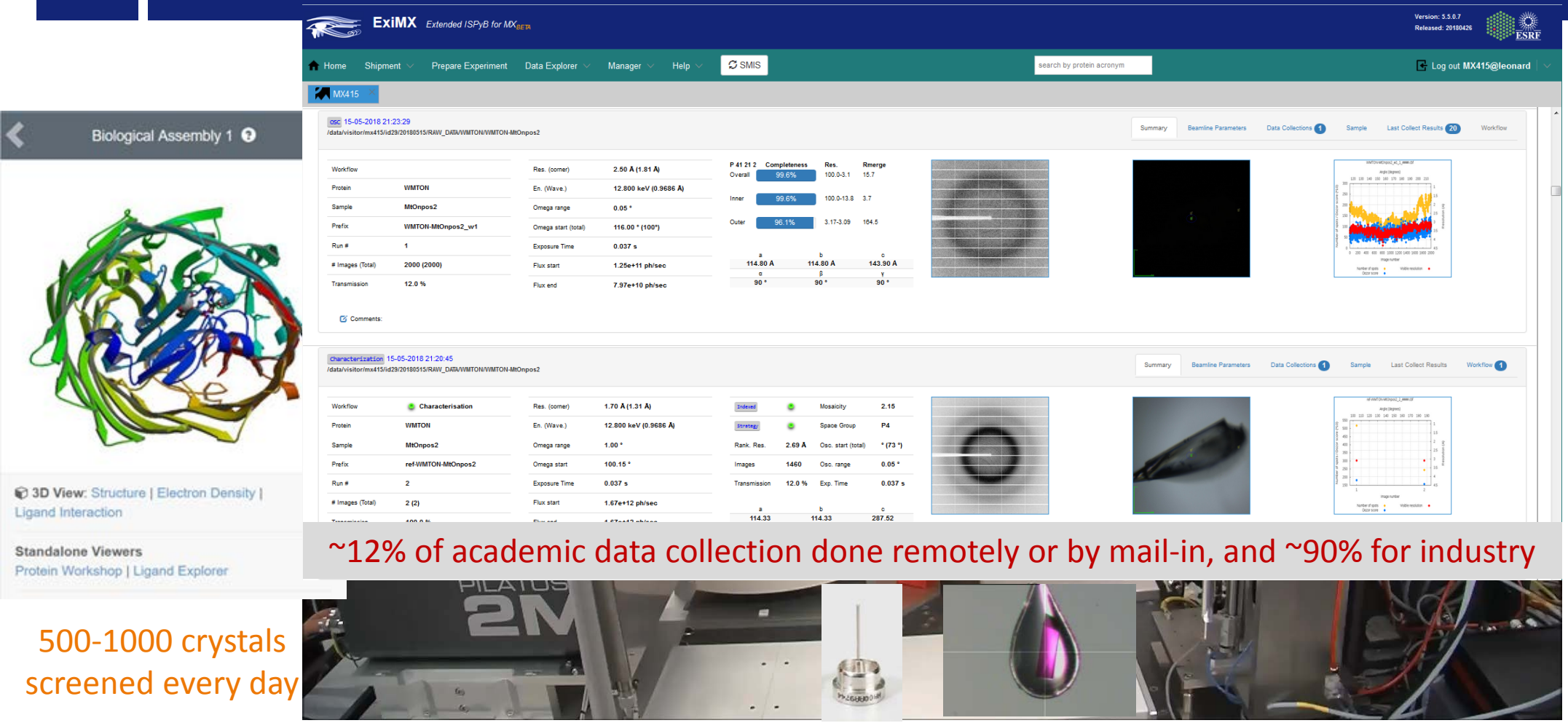
- 19 new beamlines, many specialised on *nano*-science
- New user support facilities
- Study for a revolutionary new storage ring

➢ **Constructing a suite of new and upgraded instruments dedidcate to explore matter with nanometric resolution**

ESFRI

European Commission

THE NEW HIGH THROUGHPUT MX BEAMLINES – A NEW LEVEL OF AUTOMATION

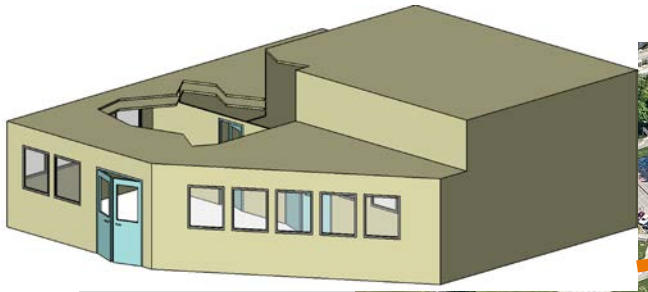


500-1000 crystals screened every day

Over the last ~3 years, structural biology activity at the ESRF has seen:

- > 8300 users (>800 proprietary research)
- > 500 high impact factor (IF > 9) peer-review publications
- > 2600 PDB depositions

THE MX BEAMLINES AND NEW HIGH CRYO-ELECTRON MICROSCOPY PLATFORM AT THE ESRF



CM01
cryoEM

BM30

ID30

BM29

ID29

ID23

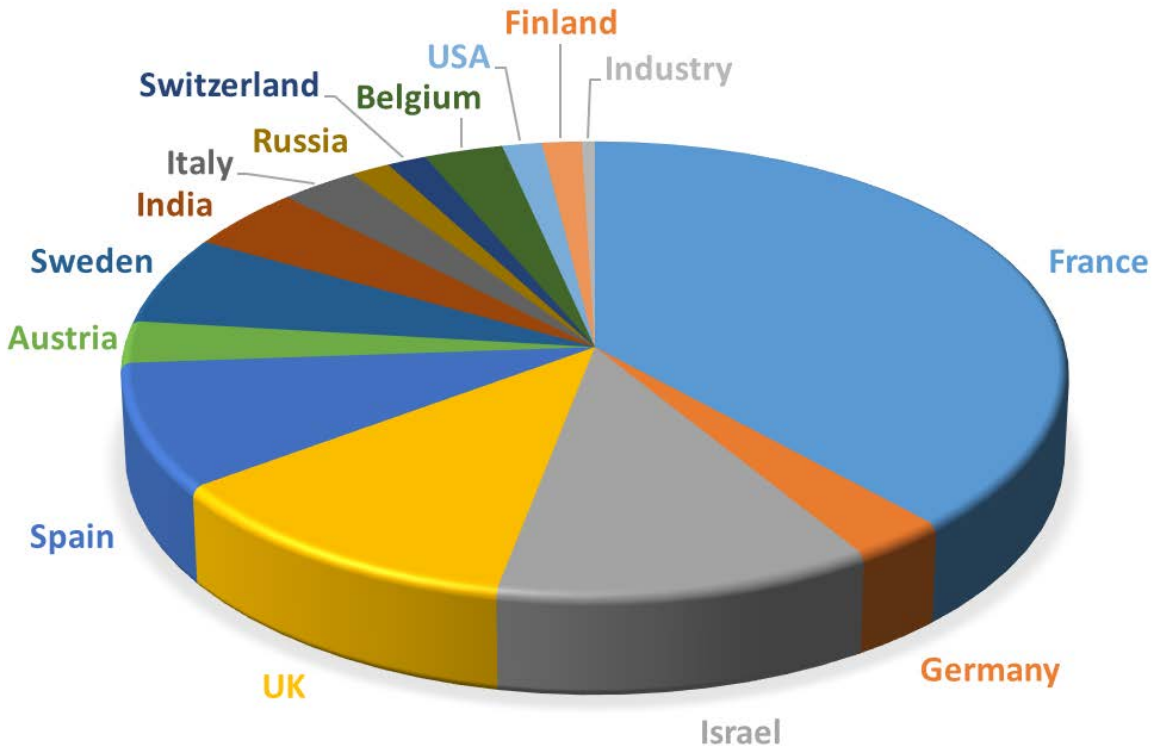
Titan Krios G2 – Open to users since November 2017

Cryo-EM at the ESRF

Excellent science being published

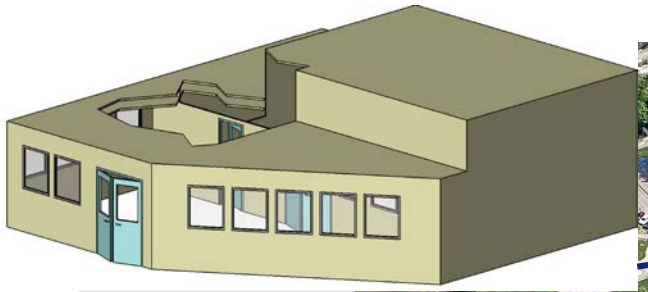
66 user experiments (602 shifts – 200 days – 3 day/exp)
1 industrial mail-in experiment

- A state-of-the-art cryo-EM platform open to structural biology scientists from all over the world
- Time provided on *Scientific Excellence* basis by the ESRF Peer-Review System
- **~5 000 hours/year**
- **Full ESRF access programme applies: OPEN TO USERS SINCE 11 – 2017**



24/11/2017 – 09/12/2018

THE MX BEAMLINES AND NEW HIGH CRYO-ELECTRON MICROSCOPY PLATFORM AT THE ESRF



CM01
cryoEM

BM07

FIP – French CRG for Macromolecular Crystallography

BM30

ID30

BM29

ID29

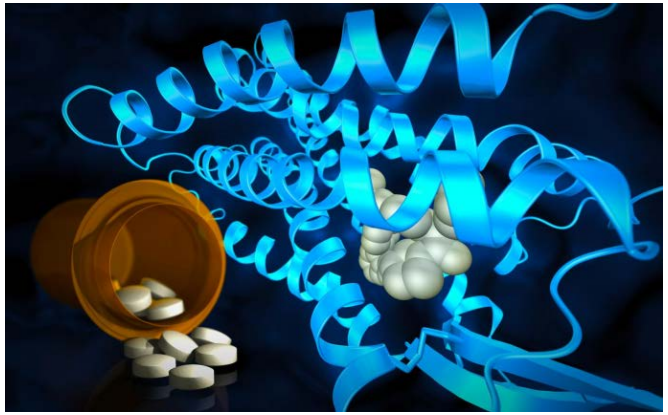
ID29

EBSL8 – Beamline for Serial Macromolecular Crystallography

ID23

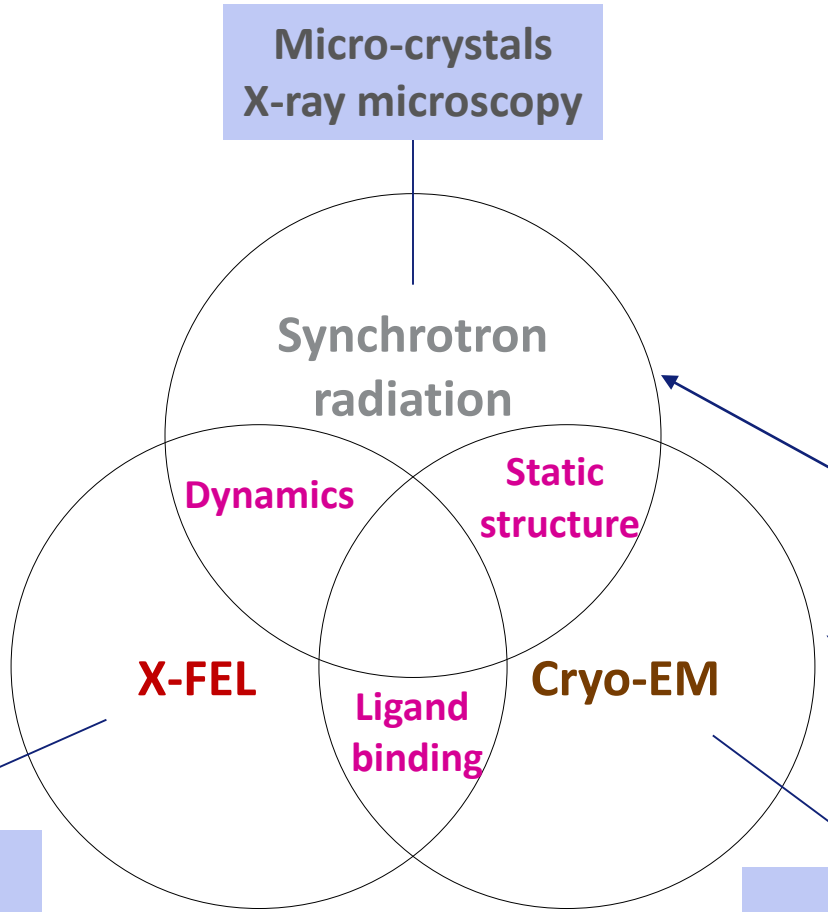
Titan Krios G2 – Open to users since November 2017

Structural Biology with X-rays and electrons

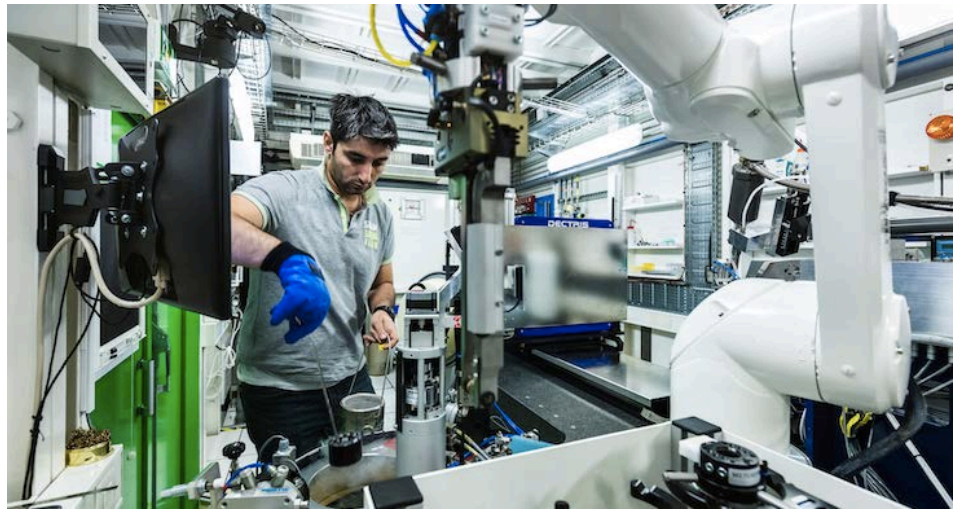


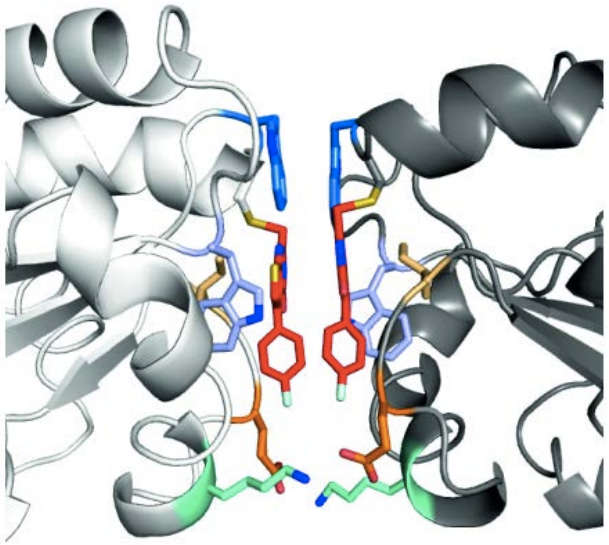
"Revealing molecular structures can show where drugs interact with receptors. These help in designing medicines of the future."
Greg Stewart/SLAC National Accelerator Laboratory; https://phys.org/news/2017-04-x-ray-reveals-long-sought-insights-potential.html

From molecules to drugs



ESRF Strategy:
State-of-the-art Facilities for
High throughput and serial-crystallography
Cryo-microscopy User Platform





The perfect dimer: Crystallographically observed inhibitor-mediated dimerization interface.
Credits: Wagner, A.

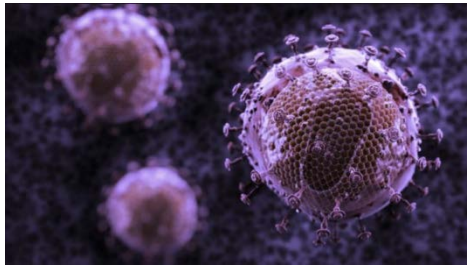
MX + bioSAXS

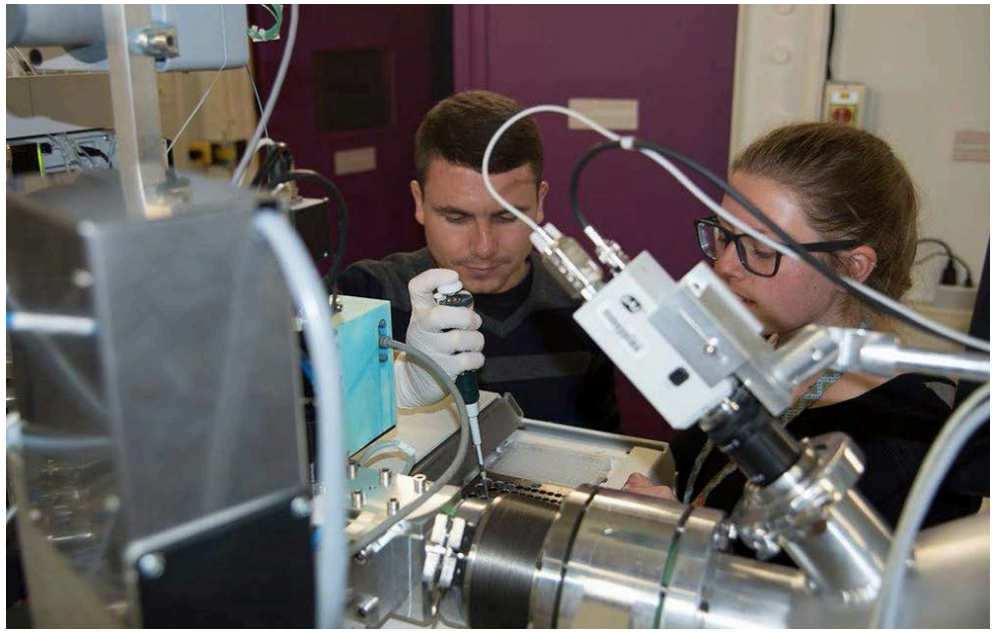
Structural biology: how synchrotron techniques help to address health diseases

- **As an example: studies on sleeping sickness**
- Human African trypanosomiasis (HAT), also known as sleeping sickness, is a major cause of mortality in Africa. Current therapy has unacceptable side-effects with an overall mortality of 5%.
- **Several teams of scientists have used ESRF MX beamlines** to discover how inhibitors against essential proteins of the parasite which causes African sleeping sickness works.
- **These studies could help in the future design of drugs combatting this disease.**
- *Inhibitor-induced dimerization of an essential oxidoreductase from African Trypanosomes, Angew. Chem. Int. Ed. Engl. (2019) (ESRF ID29).*
- *Inhibitors of PEX14 disrupt protein import into glycosomes and kill Trypanosoma parasites, Science (2017) (ID30B)*

ESRF HIGHLIGHTS WITH AFRICAN SCIENTISTS

PROTEA support





2015-2016: a fruitful collaboration on Health through the PROTEA grant

- **The South Africa/France Protea joint call** were created to develop relationship between French and South African scientific communities through joint research.
- **Topic: "Structural characterisation of macromolecular protein and DNA complexes in Malaria and HIV"**
  - **Malaria: research on life cycle and infection**
  - **HIV: research on infection mechanisms**
- 20k€ dedicated to researcher mobility between ESRF, ILL and Wits University
- **The results:** the mobility of 7 young researchers (3 from France, 4 from South Africa) and 5 senior staff

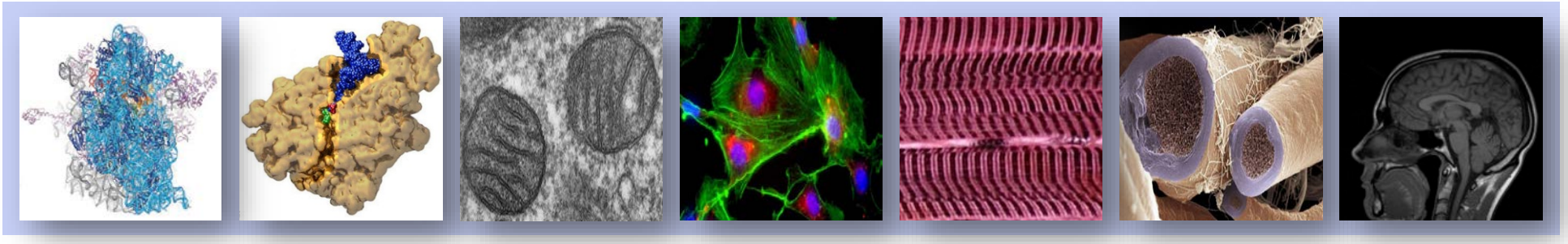
LIFE SCIENCE AT THE ESRF

Structure

Biological / Physiological Functions

Interactions with the local environment

Increasing complexity

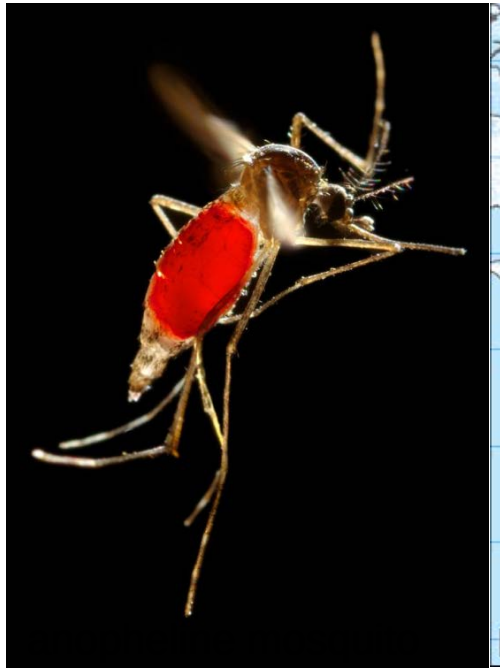


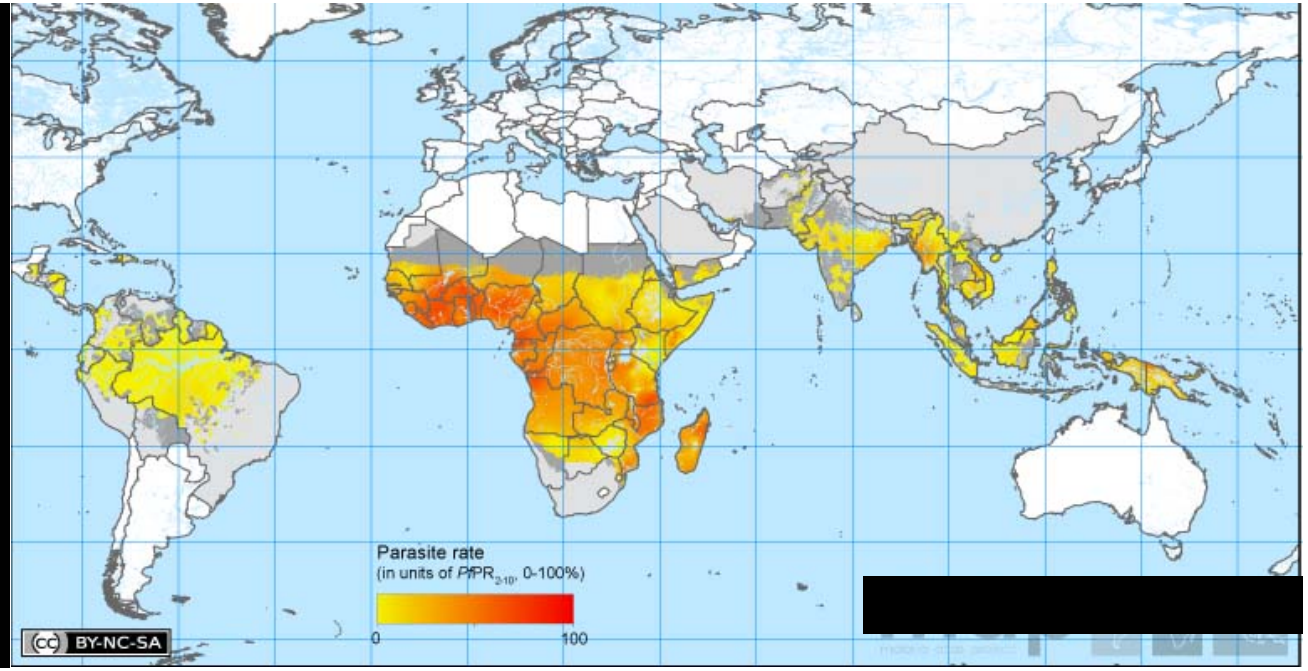
Å — nm — µm — mm

Increasing spatial resolution

- Structure & morphology
- Elemental & chemical composition
- Dynamics

Sub-cellular label-free localisation of anti-malarian drugs





Malaria:

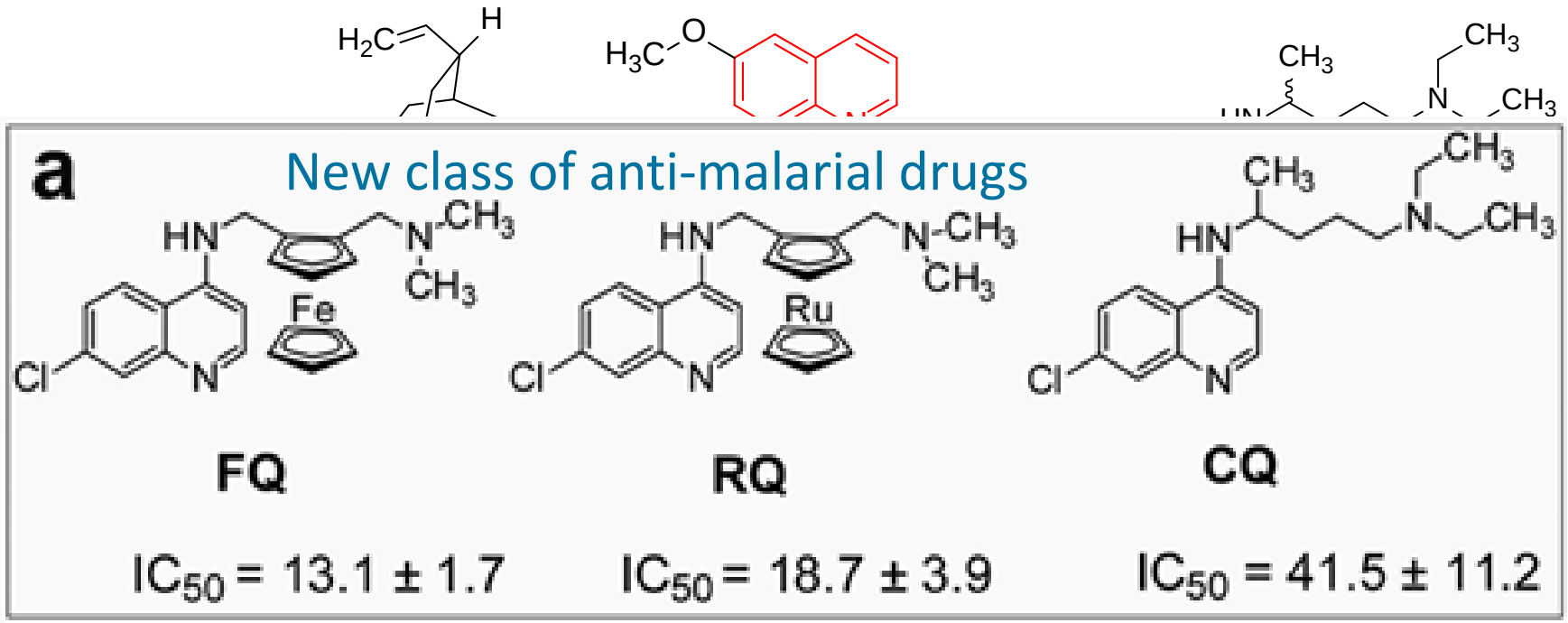
CJL Murray et al., Lancet 2012; 379: 413

- ~ 400 million clinical cases per year
- ~ 1.2 million deaths (mostly children under five)

- Resistance of main parasite to existing drugs
- Essential to constantly develop new anti-malarial drugs

ANTI-MALARIAL DRUGS

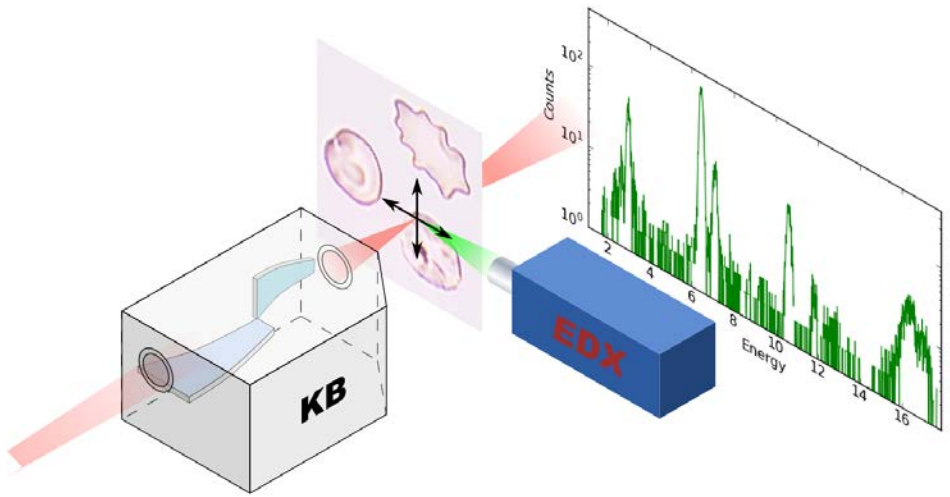
Quinine **Primaquine** **Chloroquine**



1948-1980 1977-1982

NANOCHEMICAL IMAGING: SUB-CELLULAR LABEL-FREE LOCALISATION OF ANTI-MALARIAL DRUGS

Synchrotron *nano*-probe techniques contribute to the localisation of new drugs and to the elucidation of their action mechanisms.



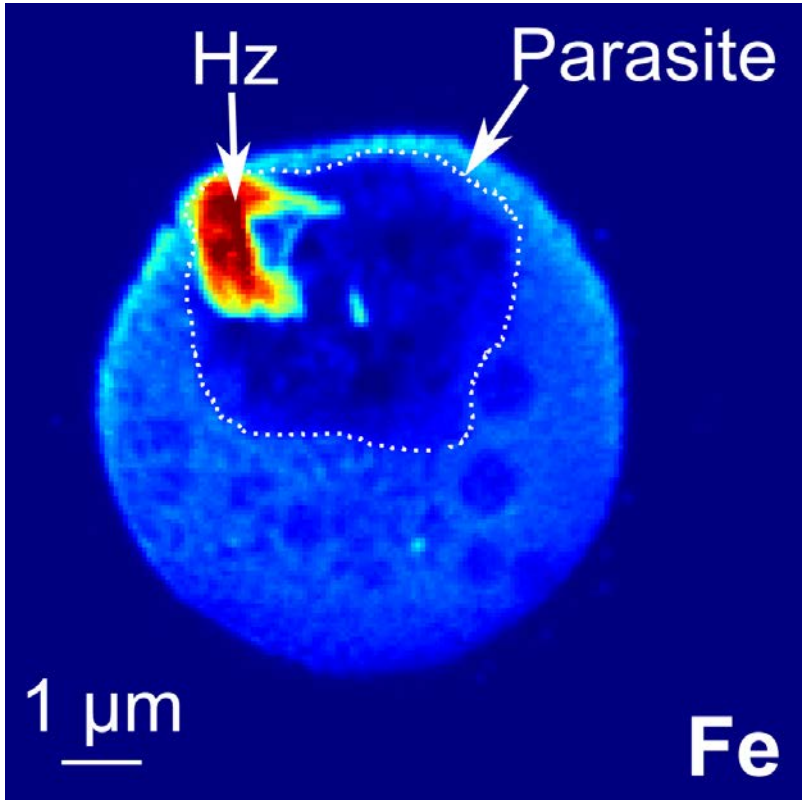
ESRF *nano*-probe ID16B

50 nm pixel, flux ~ 5 10^{11} ph/s, E_0 = 17 keV,

Simultaneous acquisition of the **fluorescence signature of most elements of biological interest**

Iron from haem groups sequestrated as an in-vivo Haemozoin (Hz) crystal

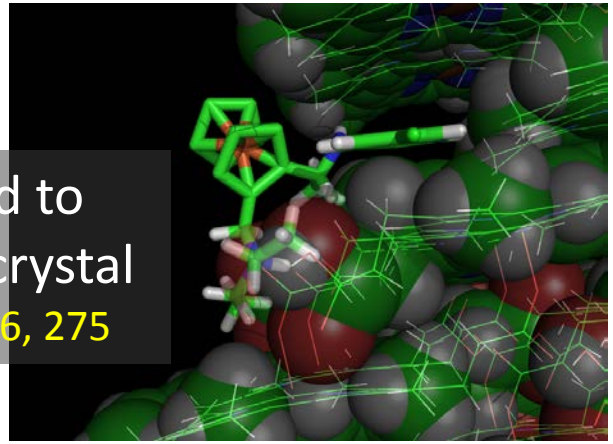
Fe fluorescence in malaria infected red blood cell



F Dubar et al., Chem. Comm. 48, 910 (2012)

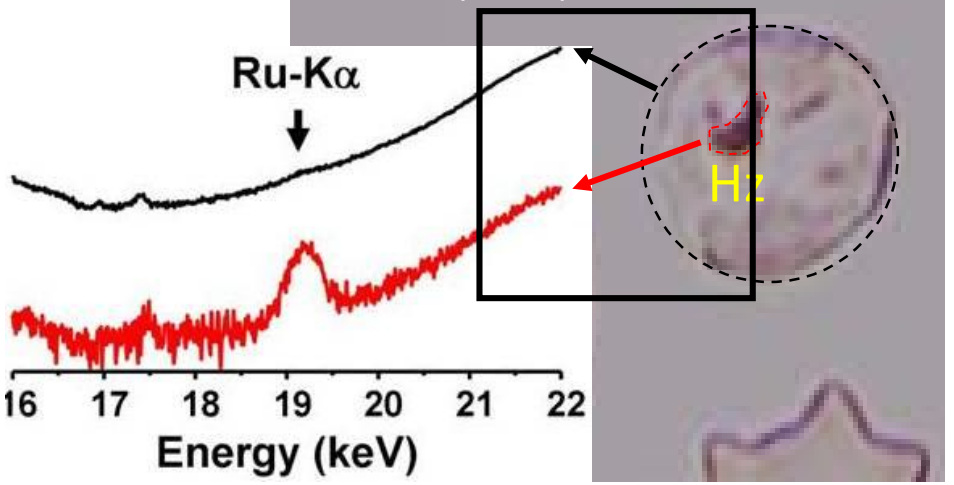
NANOCHEMICAL IMAGING: SUB-CELLULAR LABEL-FREE LOCALISATION OF ANTI-MALARIAL DRUGS

Localisation of a new drug candidate
Ruthenoquine (Ferroquine equivalent)

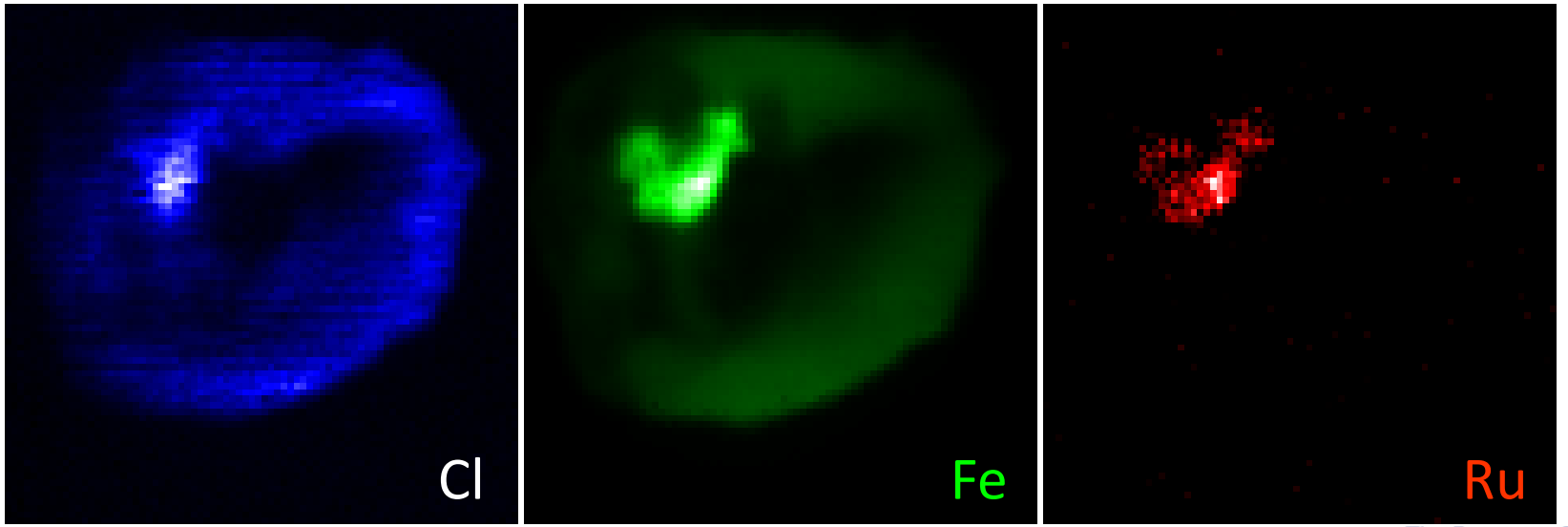


Ferroquine bound to Haemozoin (Hz) crystal
ACS Chem Biol, 2011, 6, 275

F Dubar et al., Chem. Commun. 48, 910 (2012)



E_0=29 keV



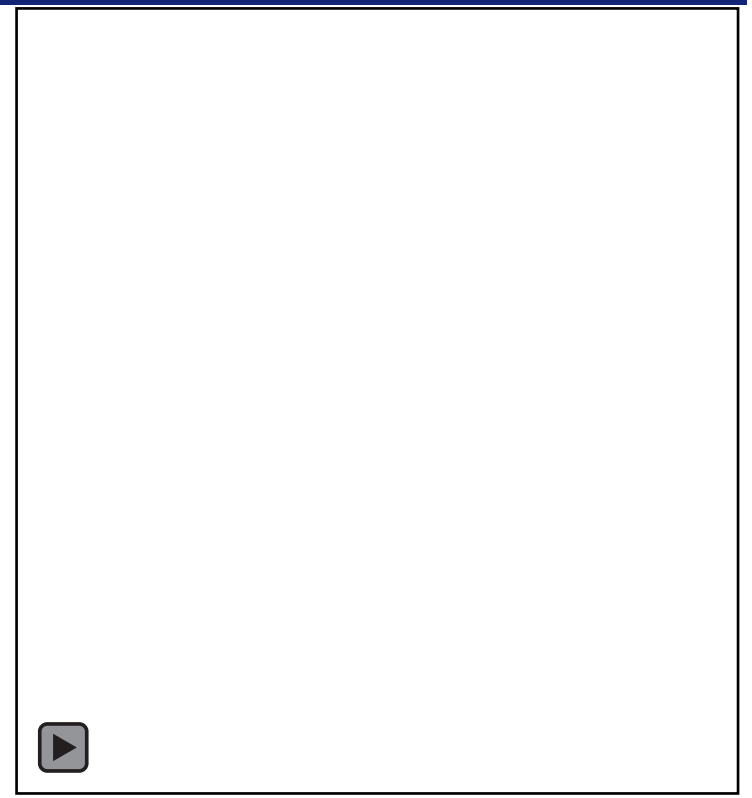
X-RAY IMAGING AND MATERIAL SCIENCE: TAKING ADDITIVE MANUFACTURING'S HEARTBEAT

AM processes are poorly understood and simulation models are limited

Manufacture of complex, high value added components:

- **AM built Ti-alloy aerofoils in a aircraft engine XWB-97k test bed engine**
- **knee replacements**

Simulation courtesy H. Basalto, U.Birm.



ultra-fast (<10ms) process

optimisation (Ti64 at 50,000fps)

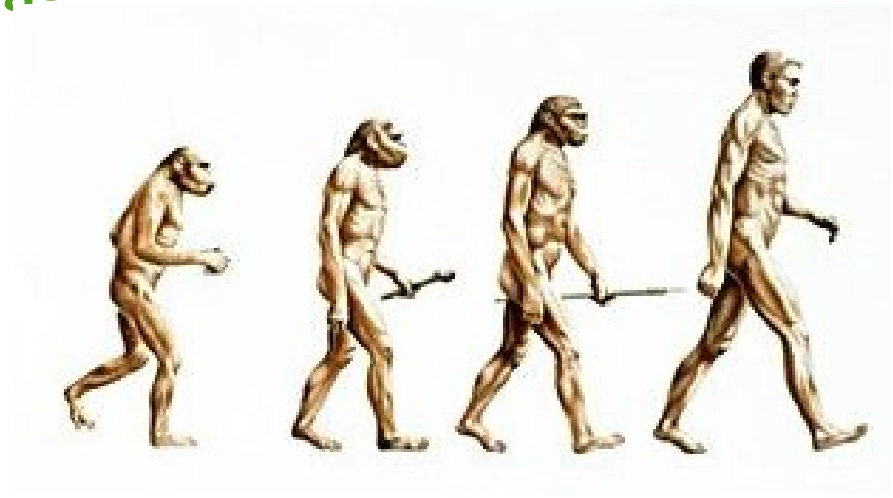
Peter D. Lee et al.
(*peter.lee@ucl.ac.uk*)

X-RAY IMAGING AND PALAEONTOLOGY: THE MALAPA SYNCHROTRON PROJECT AND SEDIBA

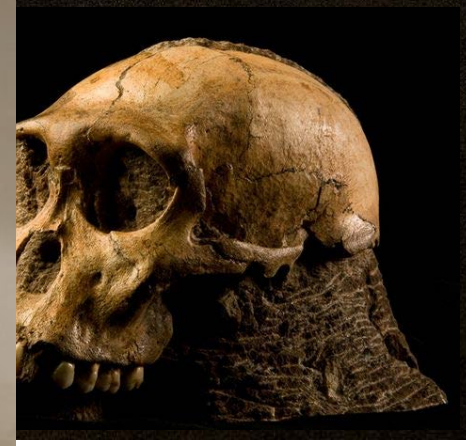
New hominid species (age 1.9 million years) have been discovered in August 2008 in South Africa by Pr. Lee Berger and colleagues.

"Transition" species showing intermediate character between *Australopithecus* and *Homo-Genus*.

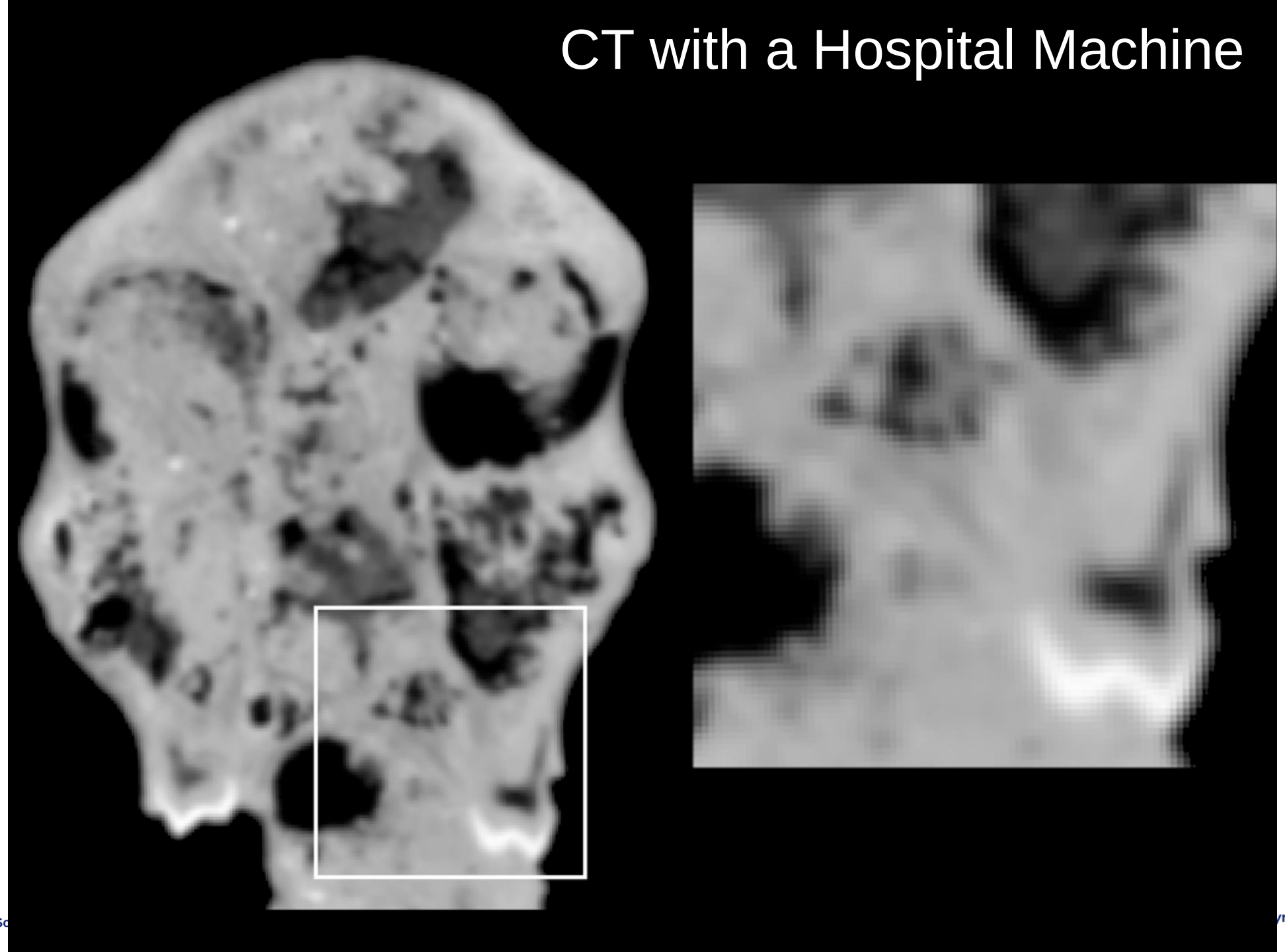
Sediba means "natural spring" or "well" in the Sotho language



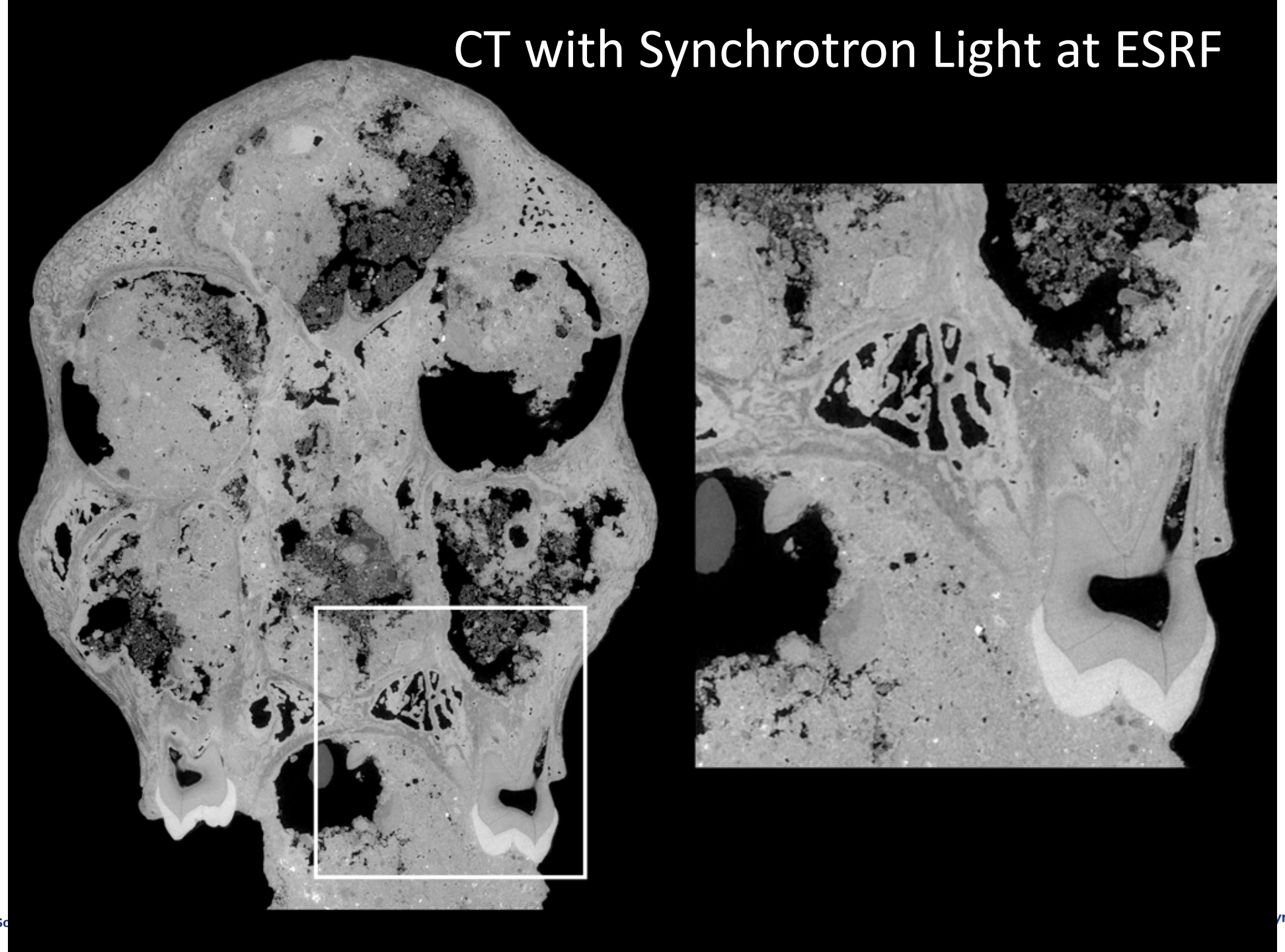
9 April 2010: Four papers in SCIENCE describe the discovery of a new hominid species



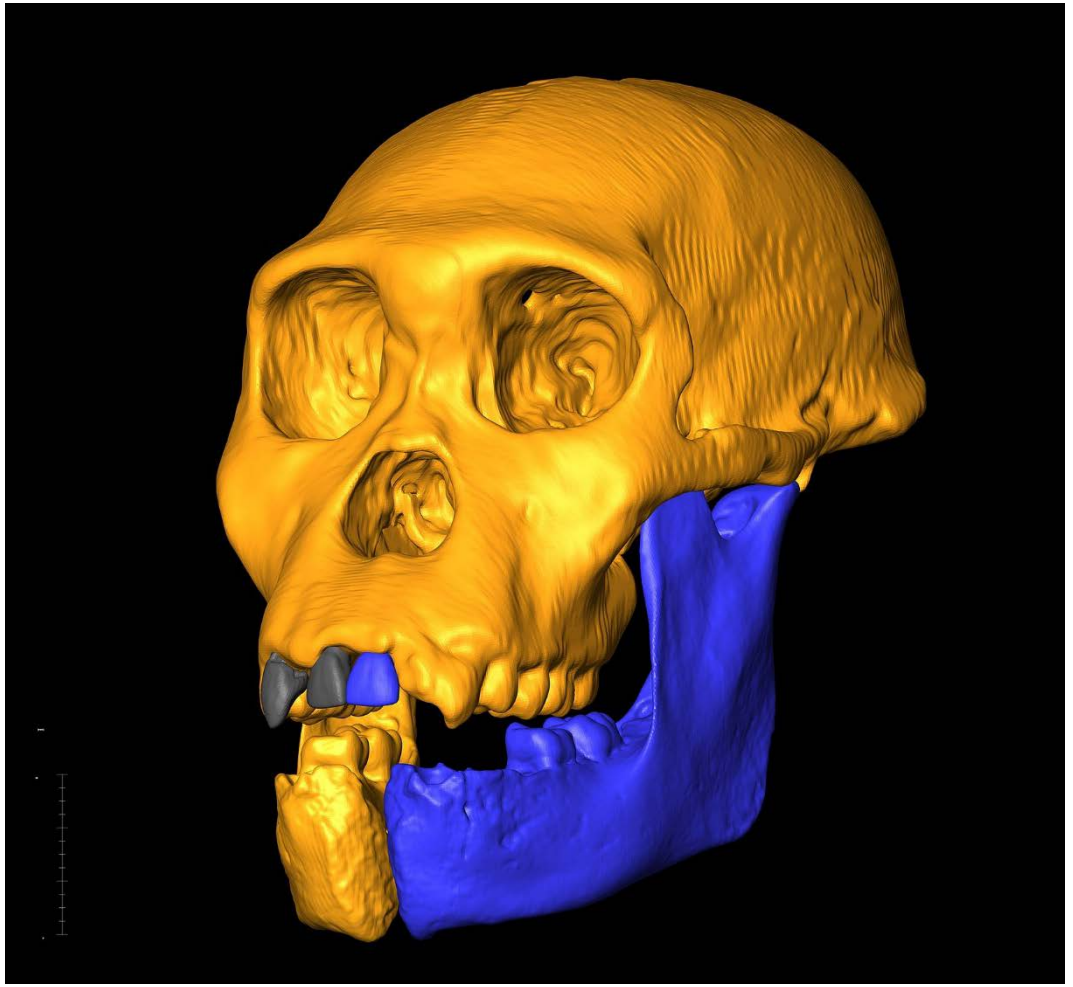
CT with a Hospital Machine



CT with Synchrotron Light at ESRF

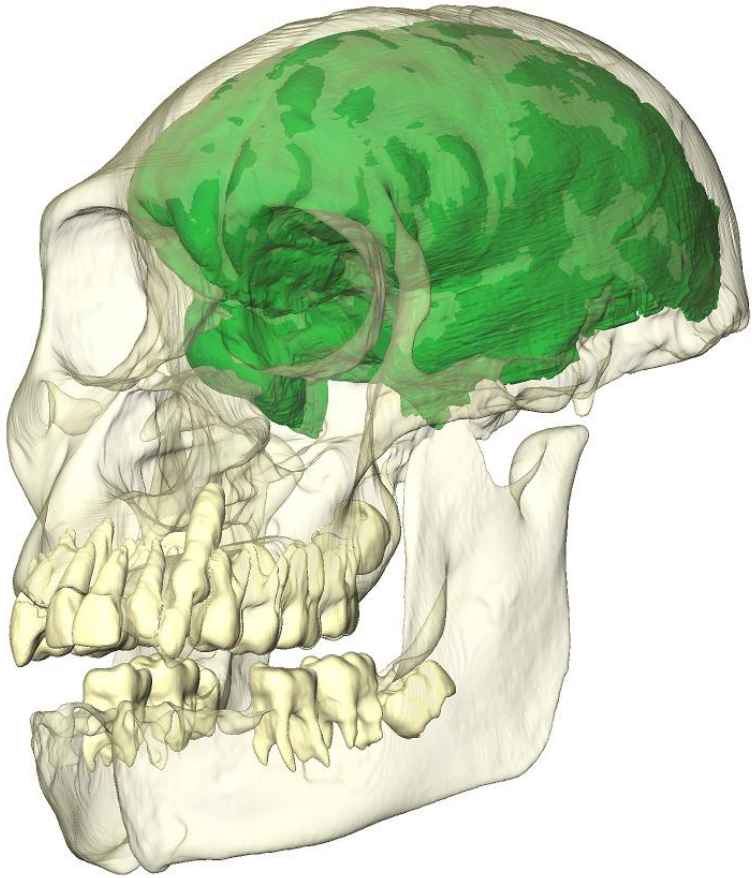


X-RAY IMAGING AND PALAEONTOLOGY: THE MALAPA SYNCHROTRON PROJECT AND SEDIBA



Among many interesting results from a 3D-virtual rendering of the precious fossil: a quantitative measure of brain dimensions and features and a precise reconstruction of missing parts (in blue)

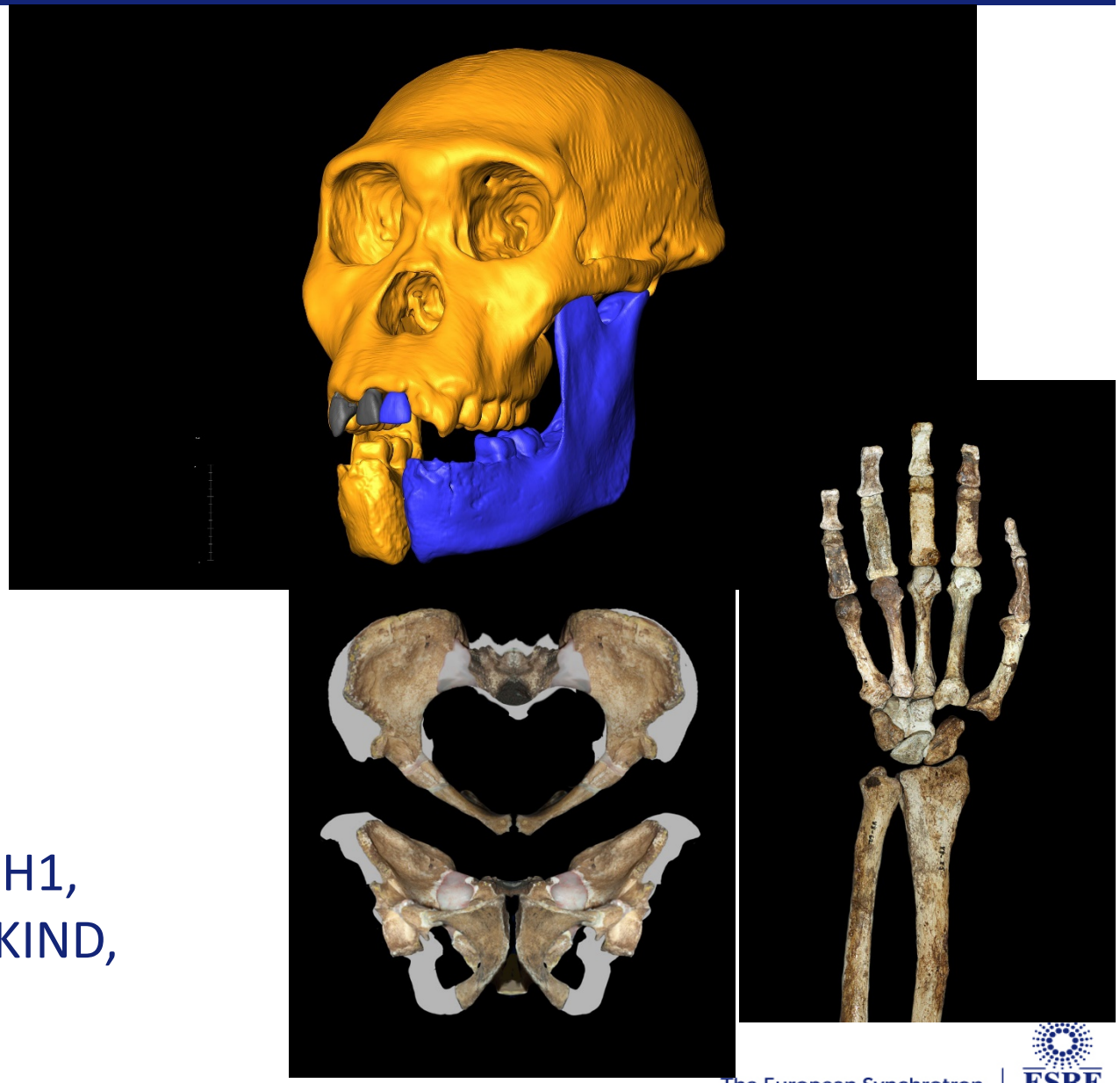
Australopithecus Sediba at the ESRF



http://www.esrf.eu/UsersAndScience/Publications/Highlights/2011/imaging/ima7

9 Sept 2011
Five papers on:
Brain (ESRF)
Hand
Hip bone (pelvis)
Foot and ankle
Exact age

"The many very advanced features found in the brain and body ...make it possibly the best candidate ancestor for our genus, the genus Homo."
Lee Berger, Wits U, Johannesburg



Original skeleton of the *A. sediba* holotype MH1, on display at Maropeng, CRADLE OF HUMANKIND, South Africa

ESRF UPGRADE PROGRAMME PHASE I

Purple Book January 2008

ESRF UPGRADE PHASE I
180 M€ (2009-2015):
ESFRI LANDMARK (2016)
IN TIME – WITHIN BUDGET

- 19 new beamlines, many specialised on *nano*-science
- New user support facilities
- Study for a revolutionary new storage ring

- Studying the possibility to construct a new X-ray source with qualitatively increased performances:
- Discovery of a new revolutionary storage ring

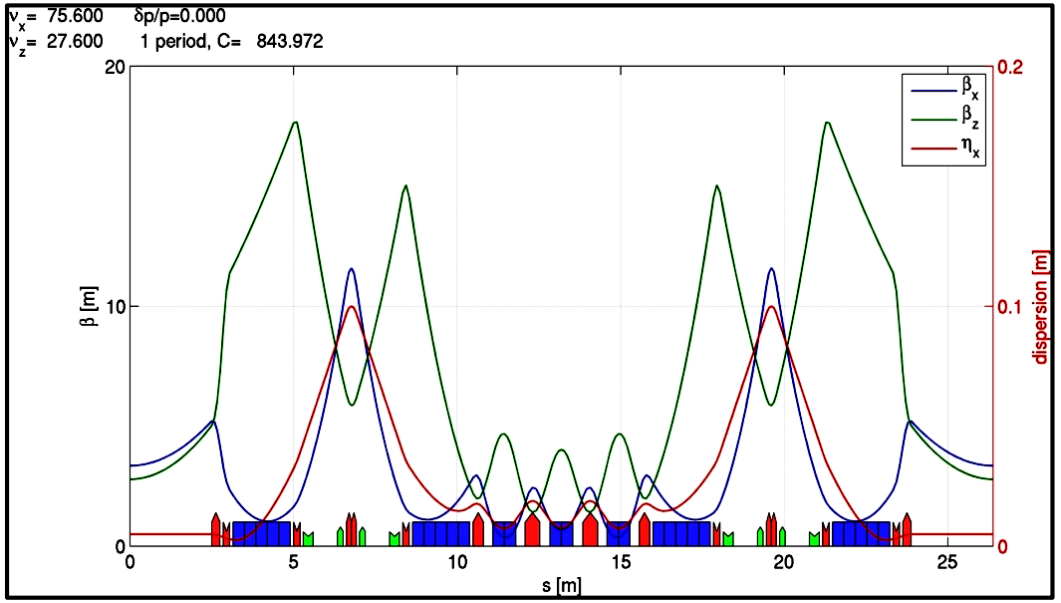
ESFRI

European Commission

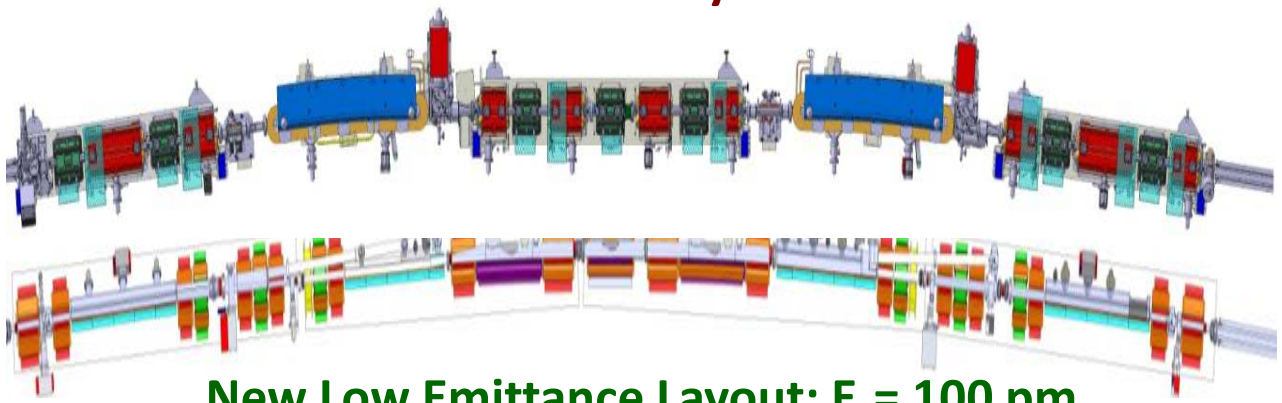
A QUEST FOR A NEW AMBITIOUS STANDARD FOR X-RAY SYNCHRTRON SOURCES

Key Parameters

H7BA lattice
Energy 6 GeV
Current 200 mA
ε_x 100 pm rad
ε_z 4 pm rad



Present ESRF Arc Layout: Ex=4nm



New Low Emittance Layout: E_x= 100 pm

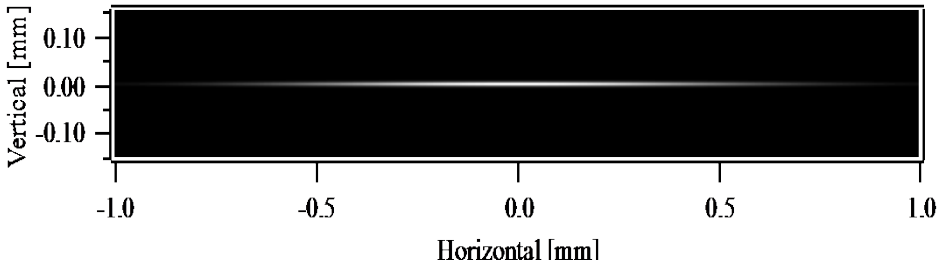
- **Drastic reduction of the horizontal equilibrium emittance**
- Maintain the existing ID straights for the beamlines
- Maintain the existing bending magnet beamline ports
- Preserve time-structure and multibunch - 200 mA Operation Modes
- Keep the present injector complex
- Reuse, as much as possible, the existing hardware (~80%)
- Minimise the energy lost in synchrotron radiation
- Minimise operation costs, particularly wall-plug power
- Limit downtime for installation and commissioning to 20 months

ELECTRON BEAM SIZE AT THE ESRF AND THIRD GENERATION SYNCHROTRON SOURCES

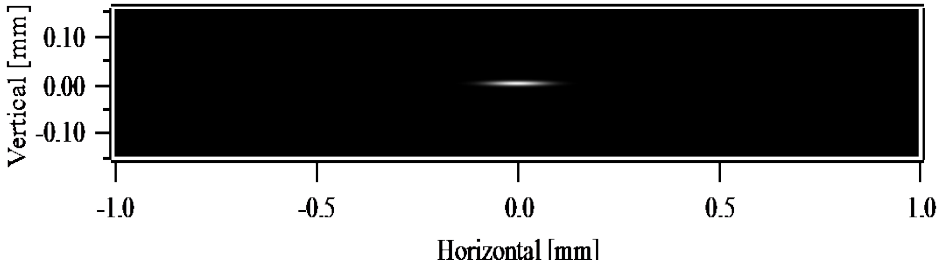
Present

Middle of ID straight

High Beta ~ parallel beam and large source size

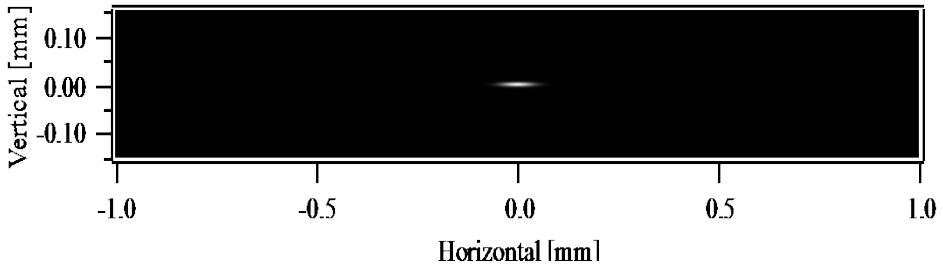


Low Beta : large horizontal divergence and small source size



Future

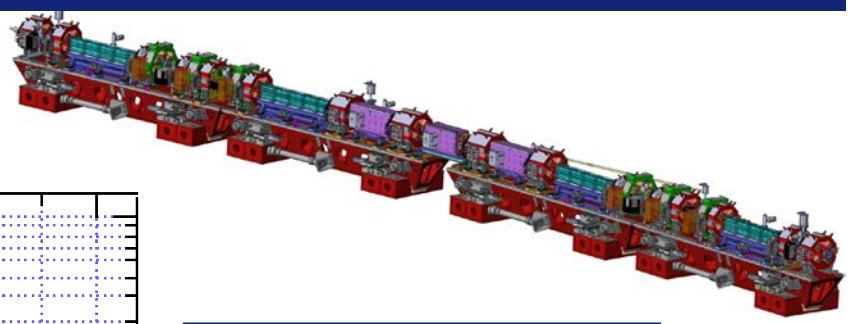
ESRF EBS ~ an even more parallel beam and smaller source size

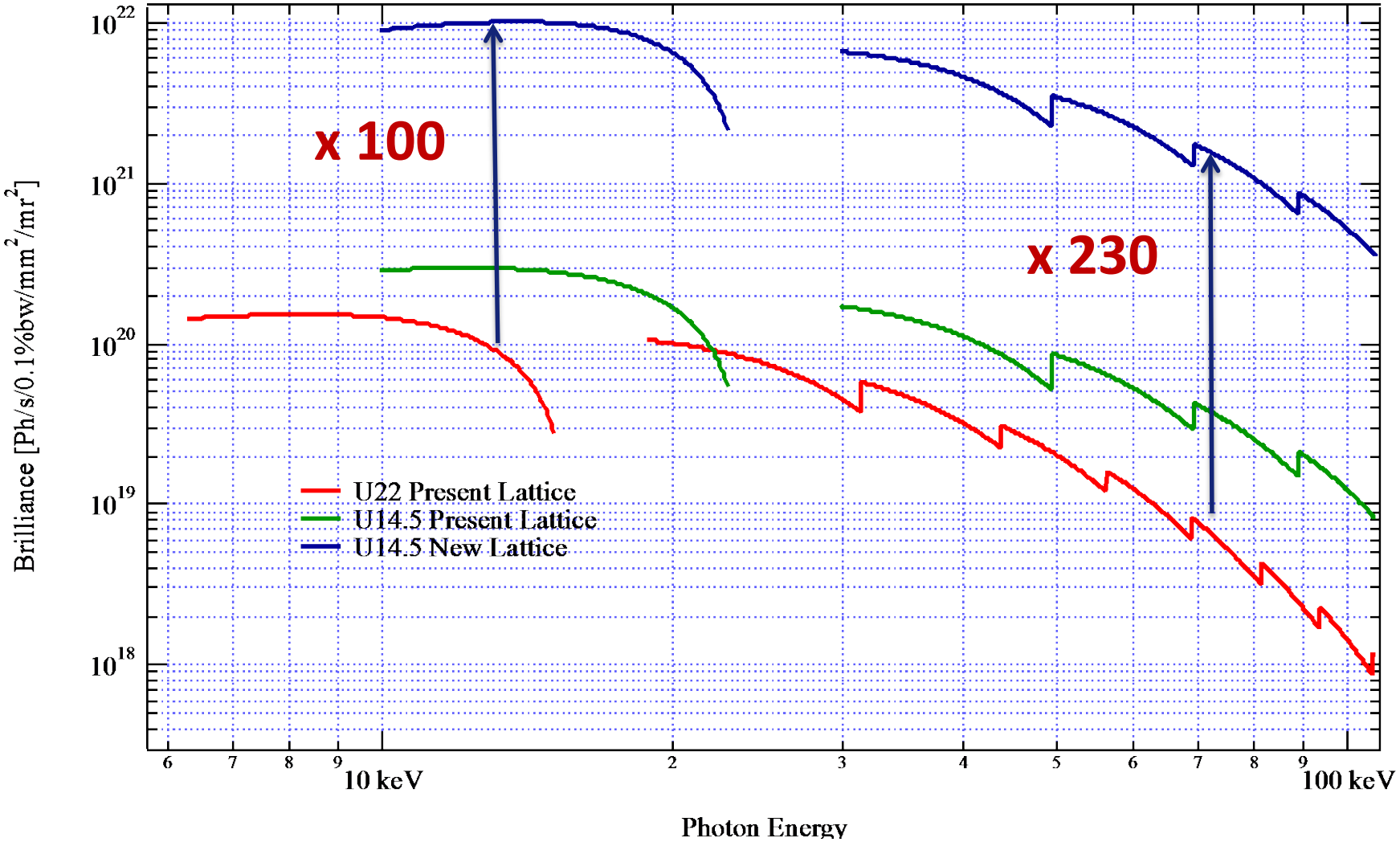


H7BA LATTICE – SOURCE BRILLIANCE

IVUN22 min. gap 6 mm, K_{max}=1.7

CPMU14.5 min. gap 4 mm, K_{max}=1.7





Key Parameters

H7BA lattice

Energy 6 GeV

Current 200 mA

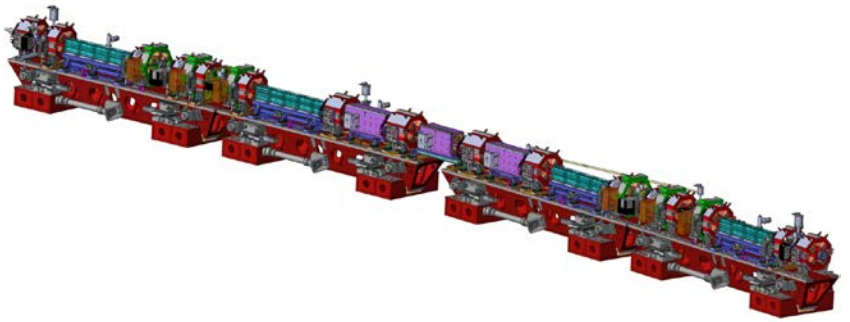
ε_x 100 pm rad

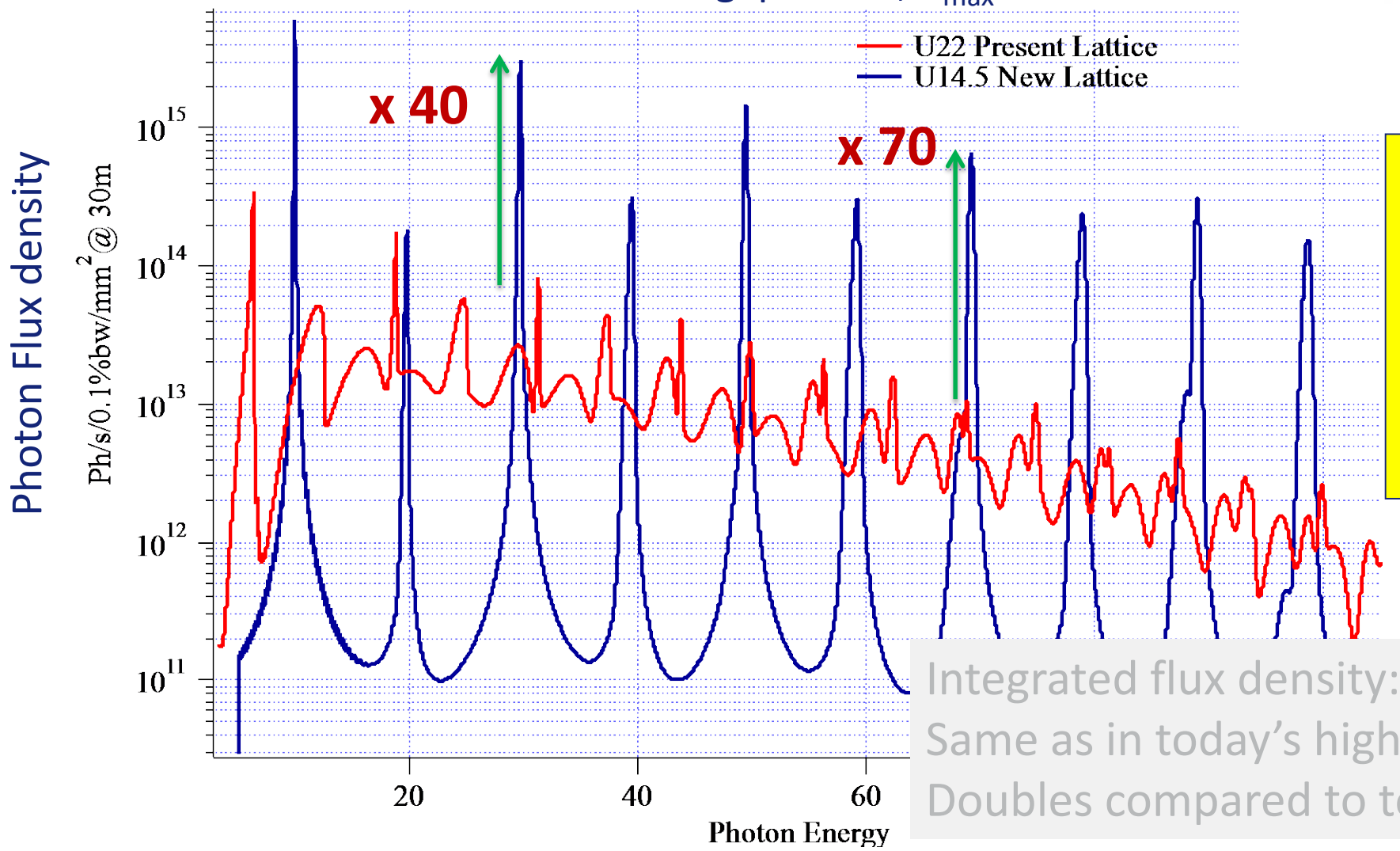
ε_z 4 pm rad

H7BA LATTICE – SOURCE PHOTON FLUX DENSITY

IVUN22 min. gap 6 mm, K_{max}=1.7

CPMU14.5 min. gap 4 mm, K_{max}=1.7





Key Parameters

H7BA lattice

Energy 6 GeV

Current 200 mA

ε_x 100 pm rad

ε_z 4 pm rad

Integrated flux density:

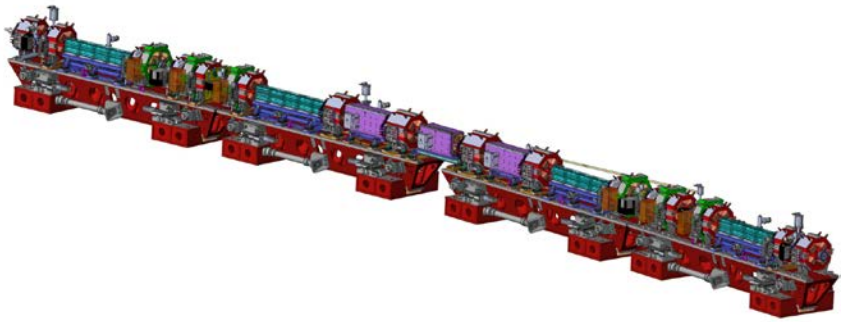
Same as in today's high-beta sections

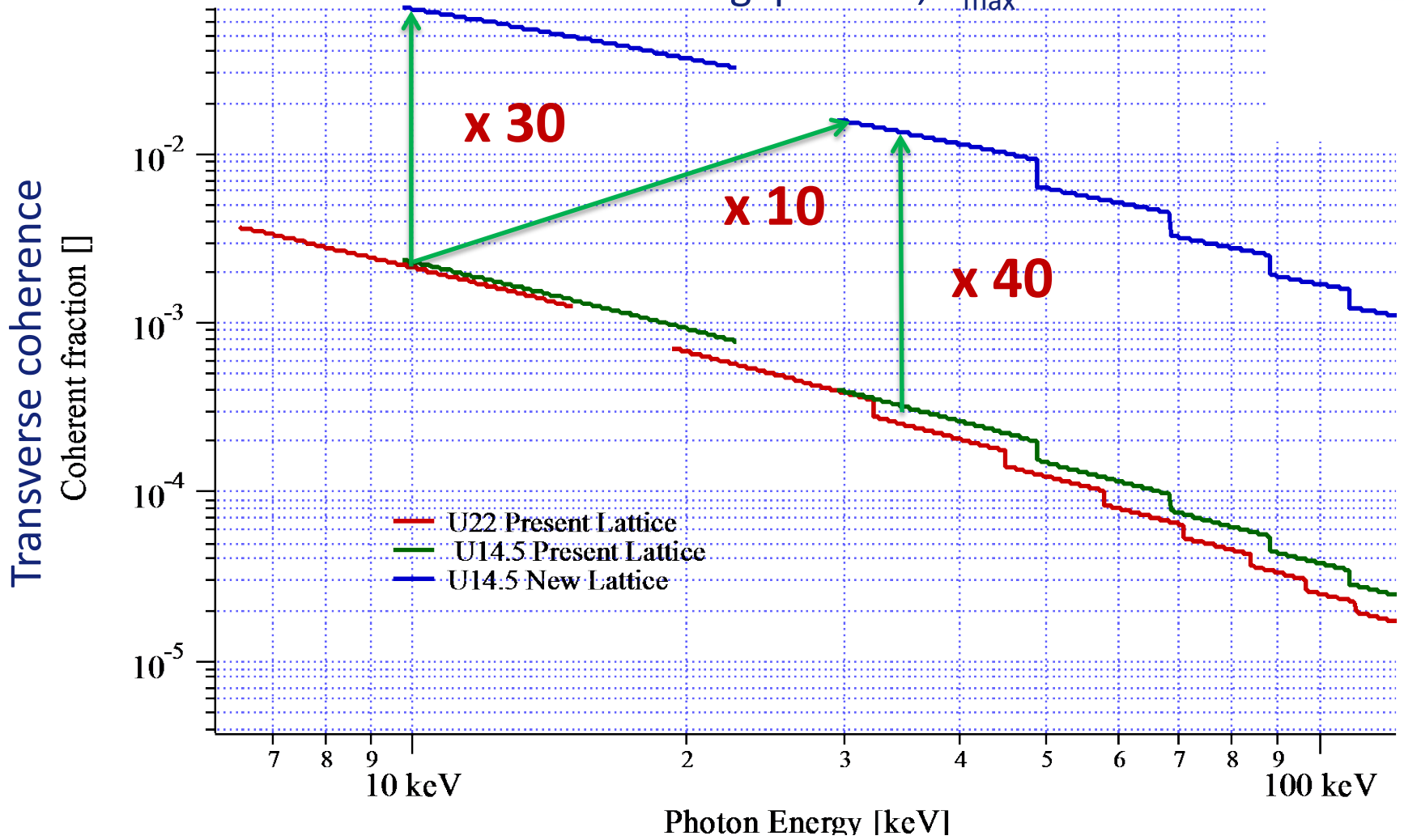
Doubles compared to todays low beta sections

H7BA LATTICE – SOURCE PHOTON COHERENT FLUX FRACTION

IVUN22 min. gap 6 mm, K_{max}=1.7

CPMU14.5 min. gap 4 mm, K_{max}=1.7





Key Parameters

H7BA lattice

Energy 6 GeV

Current 200 mA

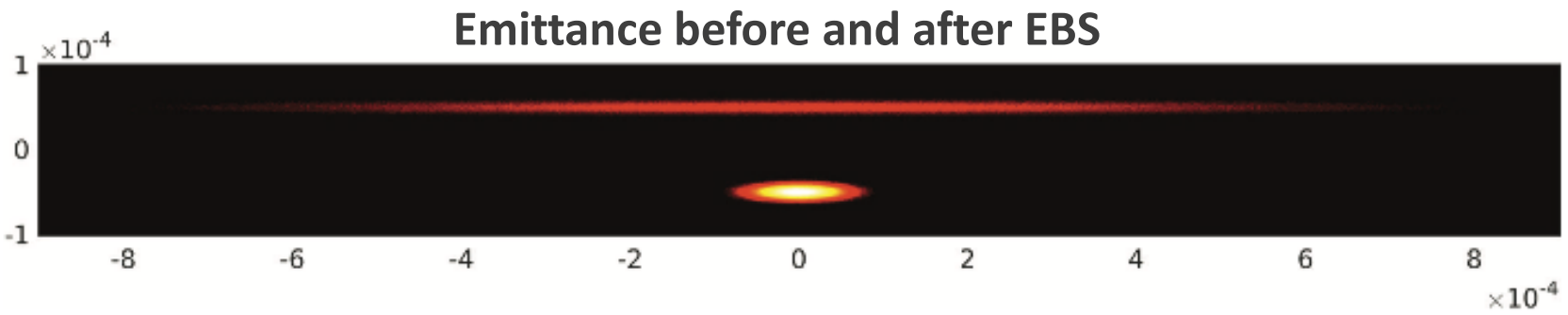
ε_x 100 pm rad

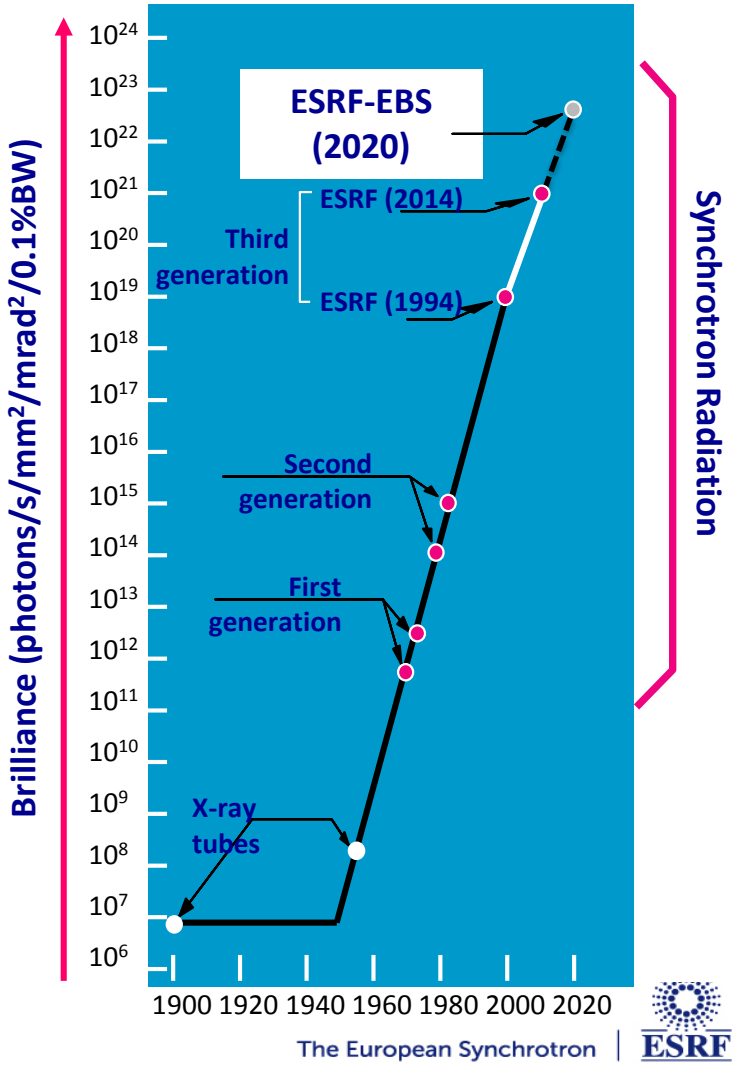
ε_z 4 pm rad

ESRF Extremely Brilliant Source
The 1st high-energy 4th-generation synchrotron light source

Pantaleo Raimondi wins the Gersch Budker IPAC17 Prize

For his invention of the “Hybrid Multi Bend Achromat” (HMBA) lattice, which has become the design basis of most future “fourth generation” synchrotron sources in the world

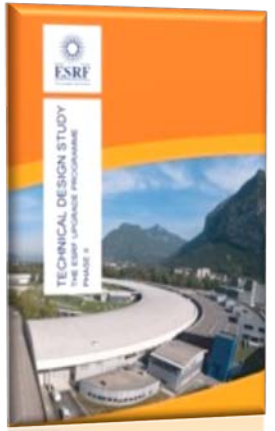




The European Synchrotron | ESRF

ESRF EBS: AN AMBITIOUS NEW STANDARD FOR SYNCHROTRON STORAGE RINGS

Purple Book January 2008



Orange Book January 2015

ESRF UPGRADE PHASE I
180 M€ (2009-2015):
ESFRI ROADMAP 2006-2016
ESFRI LANDMARK (2016)
In time – within the budget
- **19 new beamlines specialised on nano-science**
- **Study for a revolutionary storage ring**

ESRF-EBS
Extremely Brilliant Source
150M€ (2015-2022)
ESFRI LANDMARK (2016):
- **The 1st high-energy fourth-generation synchrotron**
- **4 new flagship beamlines**
- **Detectors, Instrumentation and Data As A Service**

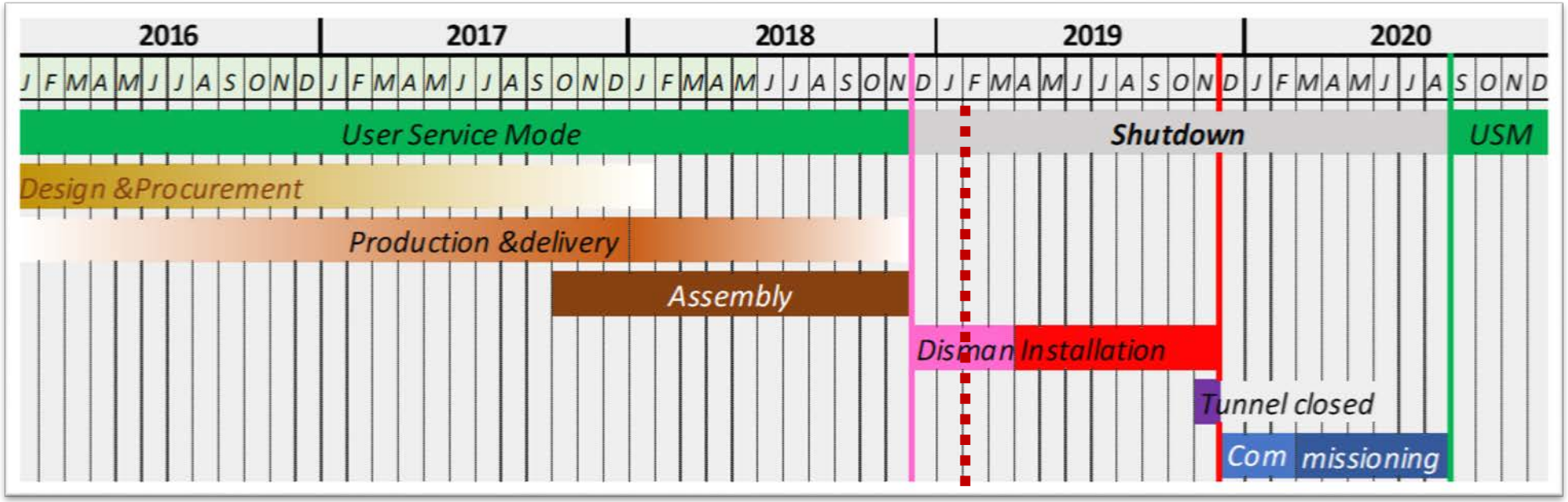
ESFRI

European Commission

AN EXTREMELY BRILLIANT SOURCE, EBS, TO PIONEER SYNCHROTRON SCIENCE

EBS STORAGE RING: CONSTRUCTION MASTER SCHEDULE

EBS storage ring implementation schedule and beamlines restart



20 October	2017	Start girder assembly *(12 months)*
10 December	2018	End of USM and Start of Shutdown (*20 months*)
		Dismantling *(3 months)* and Installation *(8 months)*
8 November	2019	Tunnel closed
2 December	2019	Accelerator commissioning *(4 months)*
March	2020	Beamlines and Accelerator commissioning *(5 months)*
25 August	2020	Back to USM

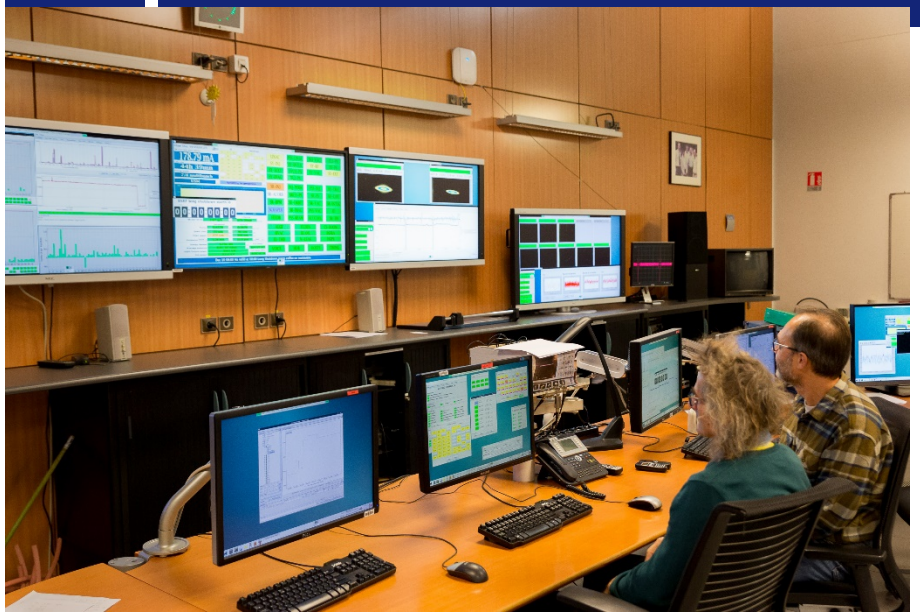
EBS STORAGE RING: GIRDER ASSEMBLY IN THE ESRF-01 BUILDING

BINP and ESRF colleagues working together in the ESRF-01 building: BINP contract ended 31-10-2018

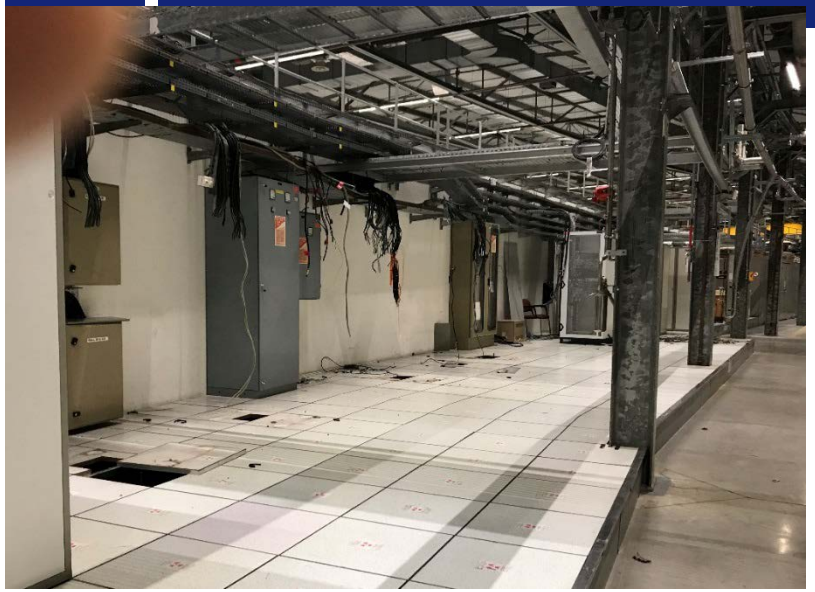
Assembly of the 129 girders composing the 32 arcs of the new EBS storage ring started in Autumn 2017

GIRDERS ARE NOW ASSEMBLED AND READY TO BE INSTALLED IN THE TUNNEL

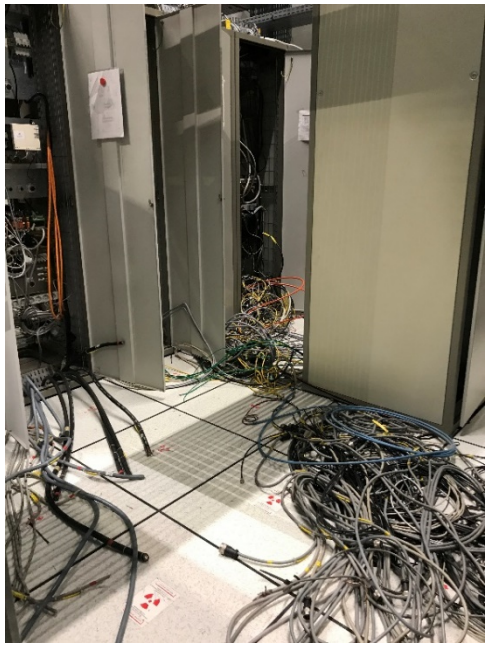
LAST BEAM AT 8.00 AM ON 7 DECEMBER 2018



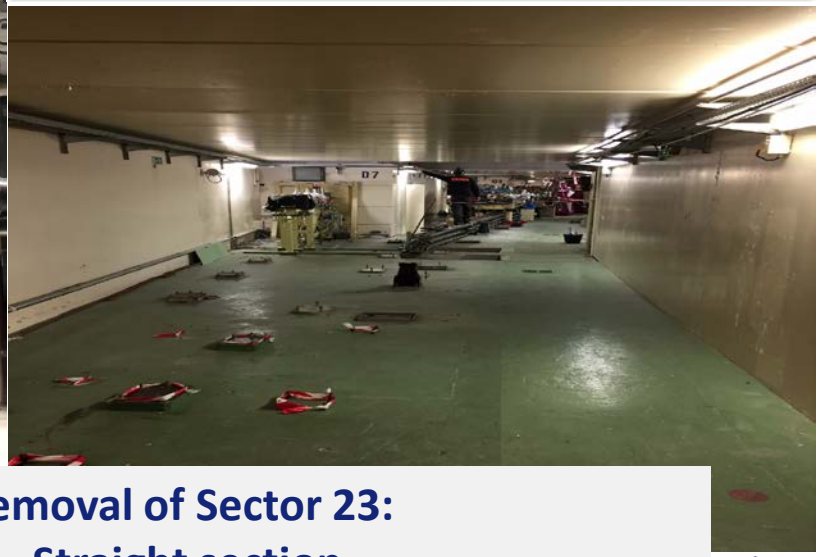
WORKS IN PROGRESS



Technical Gallery



RF Zone



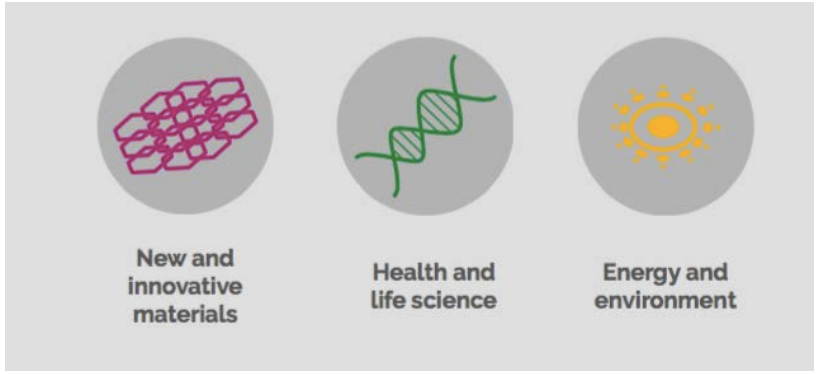
Removal of Sector 23:

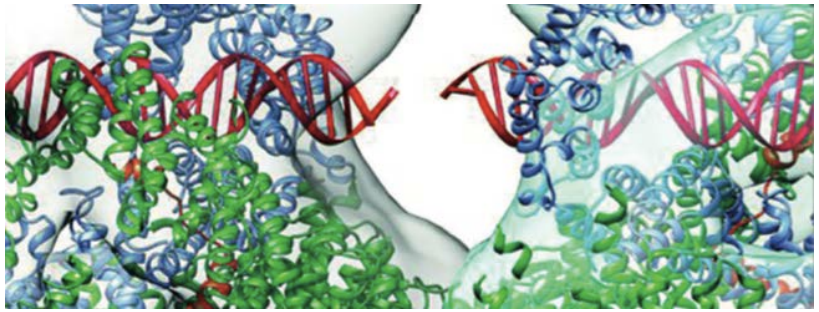
- **Straight section**
- **Girder G10, G15, G20 $ VLM Chs.**

EBS STORAGE RING INSTALLATION IS BEING PREPARED IN ALL ITS *"INFINITE"* DETAILS TO START IN APRIL 2019

- ✓ Material for the installation of the EBS storage ring is continuously arriving on site, or stored in adapted areas close to the ESRF
- ✓ The vast majority (+95%) of the new storage ring components have been procured
- ✓ Gantry assembly tests and vacuum system preparation activities
- ✓ Alignment of thousands of components on the girders with ~ 20μm tolerances on a 1 km length scale (~20 ppb)
- ✓ New timing system commissioned
- ✓ Etc.

THE EXTREMELY BRILLIANT SOURCE: A QUANTUM LEAP IN RESEARCH





EBS will enable scientists to write a new chapter in X-ray science by providing new tools for the investigation of materials and living matter

ESRF-EBS
EXTREMELY BRILLIANT SOURCE

Construction of 4 flagships beamlines: ESRF Council on 26-27 June 2017

- **EBSL1 – Beamline for Coherent X-rays Dynamics and Imaging Applications**
- **EBSL2 – Beamline for Hard X-ray Diffraction Microscopy**
- **EBSL3 – Beamline for High throughput Large Field Phase-Contrast Tomography**
- **EBSL8 – Beamline for Serial Macromolecular Crystallography**

New and better science unveiling the secrets of nature

Down to the single atom

Go to extreme conditions

Detect new phenomena

Higher throughput and faster dynamics

IMPACT OF SYNCHROTRON LIGHT SOURCES IN EUROPE AND WORLDWIDE

- 1963: Europe – Pioneer of synchrotron science with the invention of the storage ring electron accelerator in Frascati: learning on particle physics machines – **1st generation**
- 1970s to 90s: Powerful programme at **2nd generation** synchrotrons: BESSY – Berlin, HASYLab – Hamburg, LURE – Paris, MAX – Lund; NINA – Daresbury; PULS – Frascati
- **1994: Inauguration of the ESRF, the first 3rd generation synchrotron, and opening of a new page in X-ray science**
- 1990s to nowadays: the ESRF success and technology drives the construction of eleven very performing synchrotron facilities in Europe, and the building up of a European Users Community of 24 000 scientists
- **2013: ESRF-EBS storage ring lattice concept opens a new horizon for future 4th generation synchrotron sources, which mobilizes the SR world**
- 2016: Inauguration of MAX IV, the first multi-bend synchrotron source
- **2020: The ESRF will open a new page in X-ray science with the inauguration of the EBS storage ring, fulfilling its mission of pioneering synchrotron science worldwide**

B. Touschek
INFN-Frascati

R. Chasman, G.K.Green
Brookhaven National Laboratories

P. Raimondi
INFN-Frascati and ESRF

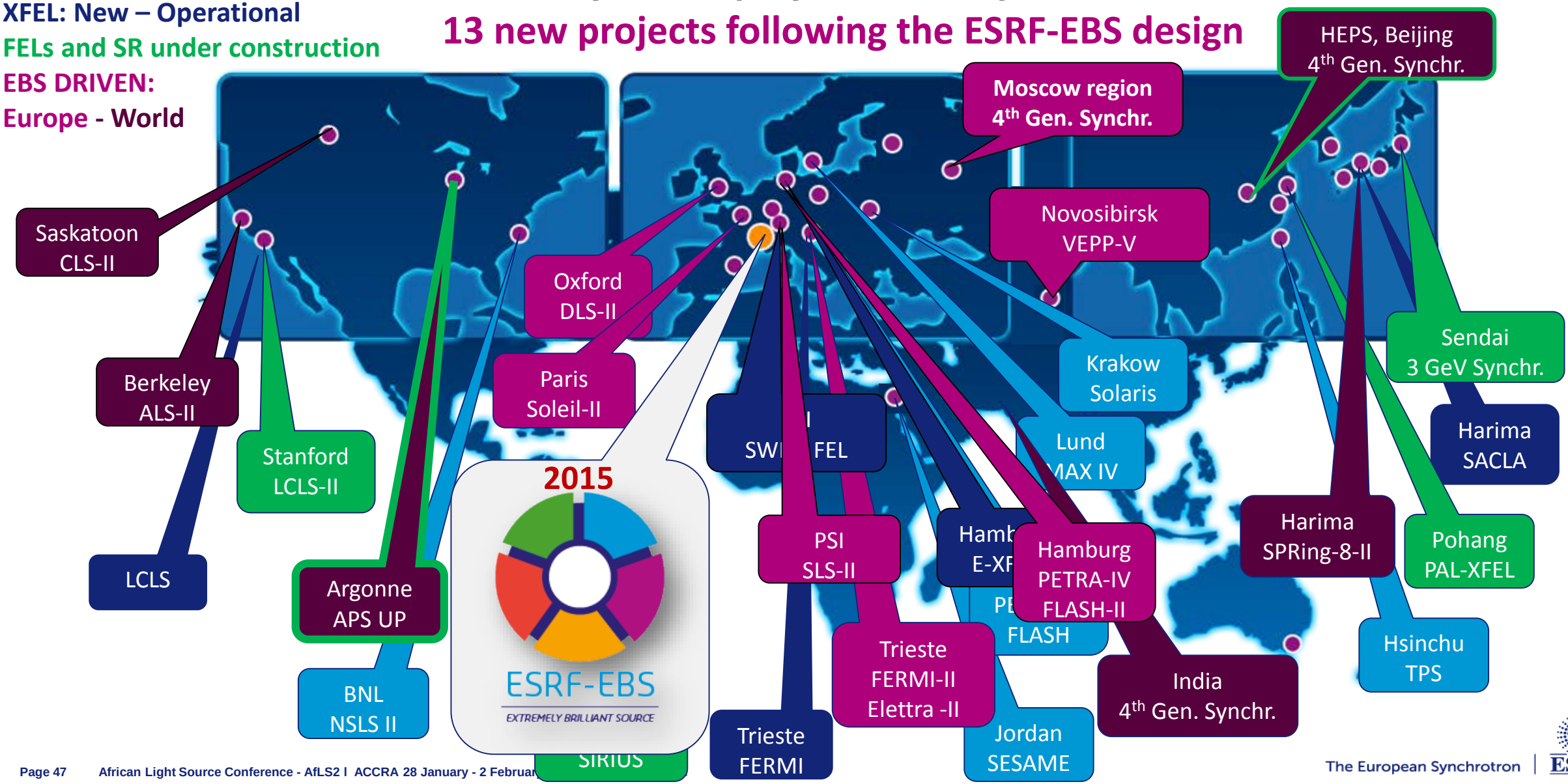
The European Synchrotron | ESRF

ESRF EBS IN THE INTERNATIONAL CONTEXT

SR: New – Operational
XFEL: New – Operational
FELs and SR under construction
EBS DRIVEN:
Europe - World

Major new projects in X-ray science

13 new projects following the ESRF-EBS design



ESRF objective is enabling scientific excellence in the the domain of synchrotron science:

- To serve advancement of knowledge
- To address global societal challenges, enabling key research in areas as: health – energy – food – environment
- To support education and training programmes for the next generation
- To foster innovation
- To contribute shaping a sustainable future
- To support the European strategy for: open-science – open-data – open to the world
- **Ready to discuss cooperation and association programmes with African Countries in the context of building up the African Light Source**


Thanks for your attention! @esrfsynchrotron