



A Light for Science



European **S**ynchrotron **R**adiation **F**acility

**20 ans de Rayons X
Pour la Science**

Pascal ELLEAUME

European Synchrotron Radiation Facility



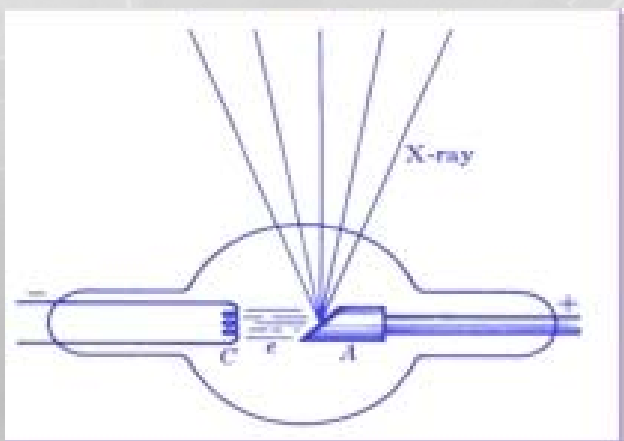
Plan de la Presentation

- Le Rayonnement Synchrotron
- L' ESRF
- Les Applications

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Sources de Rayons X

Electron dans un champ électrique :
Bremstrahlung, Fluorescence

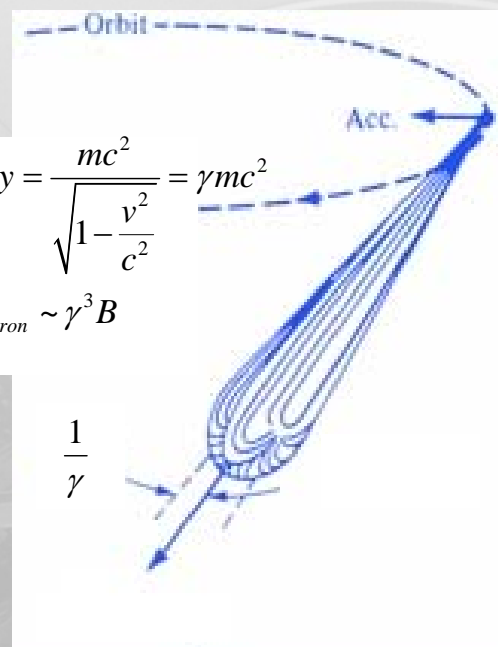


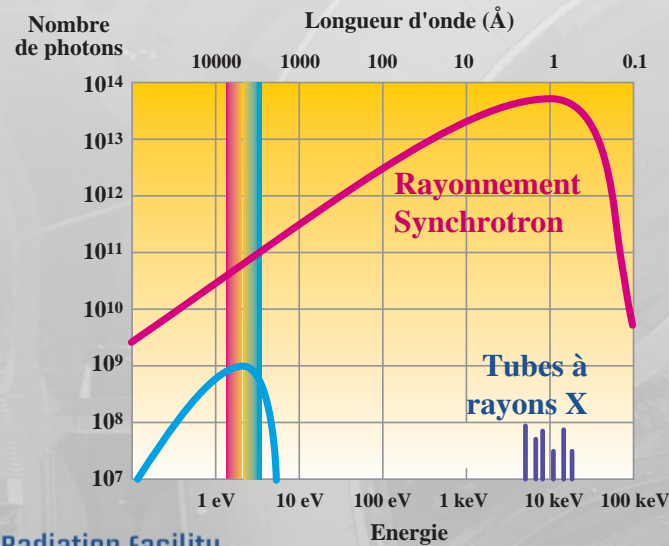
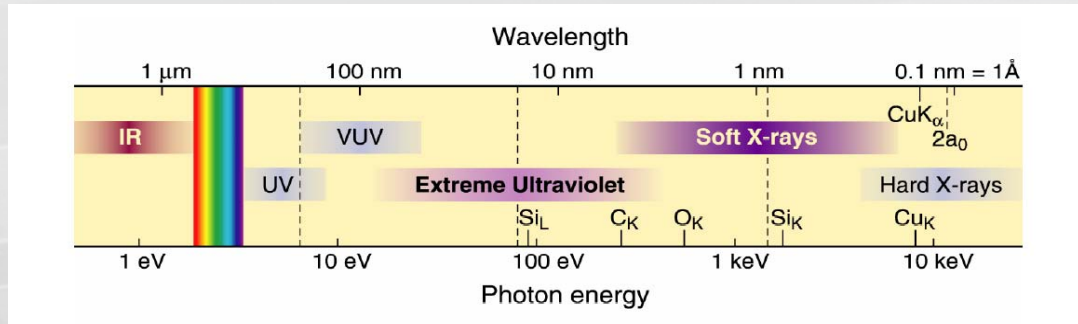
Electron Ultra-relativiste
dans un champ magnétique :
Rayonnement Synchrotron

$$Energy = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} = \gamma mc^2$$

$$P_{synchrotron} \sim \gamma^3 B$$

$$\frac{1}{\gamma}$$



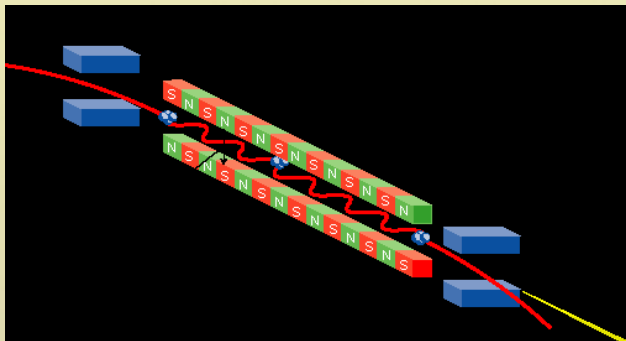
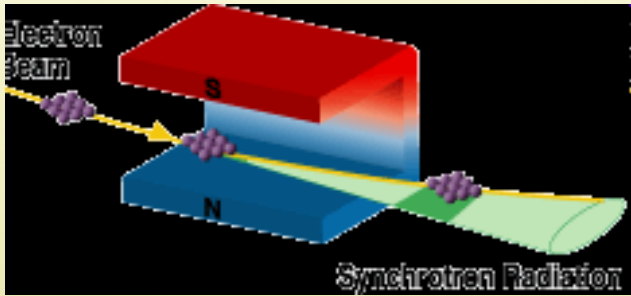


• **Brilliance Spectrale (Spectral Brightness)**

- Unité : Photons/sec /0.1 % /mm²/mrad²
- Se conserve lors de la propagation ou la focalisation par des optiques sans aberration (Liouville)
- Une forte brillance associe :
 - Un fort flux spectral (Photons/sec/0.1%)
 - Une faible étendue optique aussi appelée émittance

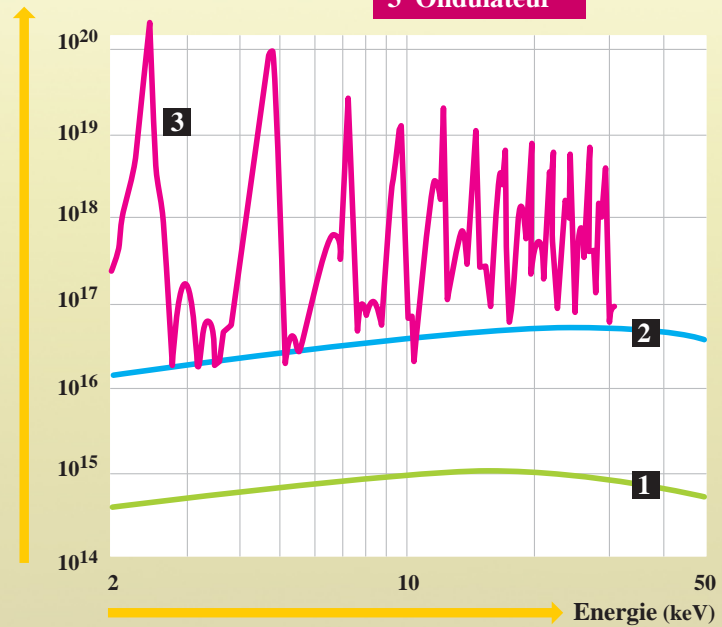


Sources de Rayonnement Synchrotron



- 1 Aimant de courbure
- 2 Wiggler
- 3 Ondulateur

Brillance
(photons/s/mm²/mrad²/0.1%B.F.)





Properties of Synchrotron Radiation

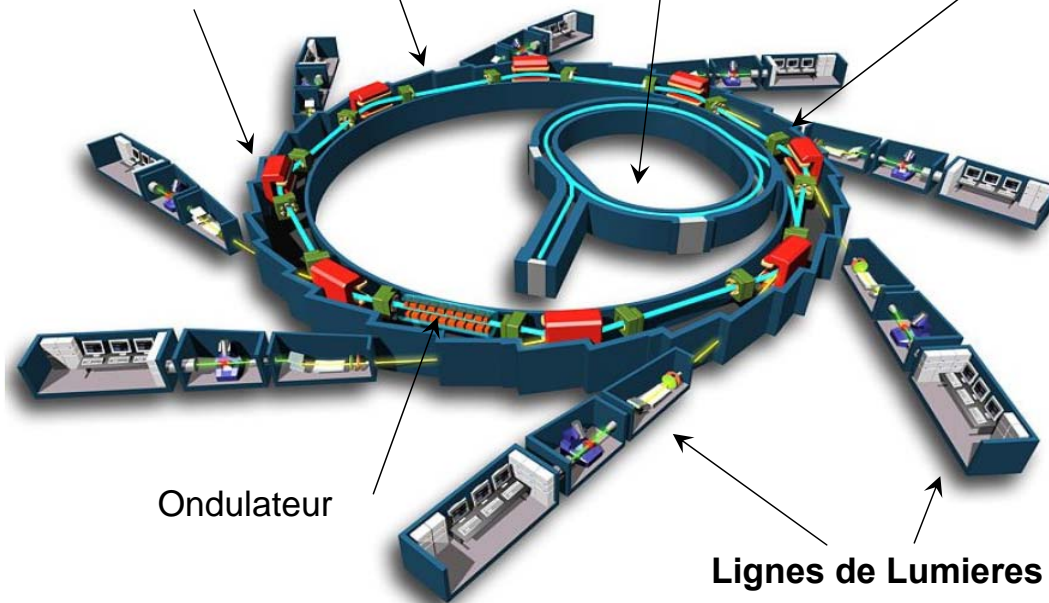
- Powerful
- Continuous spectrum from IR to Hard X-ray
- High Flux (Photons/sec/.1%)
- Highly collimated -> High Brightness (Photons/s/.1%/mm²/mr²)
- Well defined Polarization (linear or elliptical)

Anneau de stockage d'électrons

Injecteur

Quadrupole

Aimants de Deviation



Ondulateur

Lignes de Lumieres



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~ 50 Sources Synchrotron dans le Monde



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Parametres des Sources Synchrotrons

Name	Location	Energy [GeV]	Perimeter [m]	Number of Straights
SPRING-8	Japan	8	1436	48
APS	US	7	1060	40
ESRF	France	6	844	32
SSRF	China	3.5	396	20
SPEAR3	USA	3	240	18
DIAMOND	UK	3	560	24
Australian Synchrotron	Australia	3	216	14
CLS	Canada	2.9	171	12
SOLEIL	France	2.85	354	24
...				

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Synchrotrons Recents en Europe



Soleil, France



Diamond , UK

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Coopération de 19 pays



L'ESRF est une société civile de droit français dont le financement est assuré par 19 pays.

Budget 2008 : 87 MEuros.


Répartition du budget

France	27,5 %
Allemagne	25,5 %
Italie	15 %
Royaume-Uni	14 %
Espagne	4 %
Suisse	4 %
Benesync (Belgique, Pays-Bas)	6 %
Nordsync (Danemark, Finlande, Norvège, Suède)	4 %

Partenaires scientifiques :

Portugal	1 %
Israel	1 %
Autriche	1 %
Poland	1 %
Central Sync (Republique Tchèque, Hongrie, Slovaquie)	1 %

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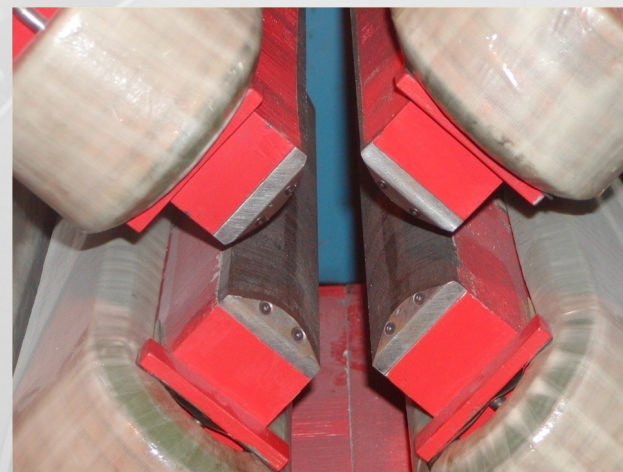
- **1975**  Project of a European third-generation synchrotron source
- **1988** Signature between the governments of 12 Member States.
- **1992** First electron beam in the storage ring. Commissioning phase.
- **1994** User operations with 15 beamlines
- **1998** 40 beamlines
- **2008** Upgrade Programme approved



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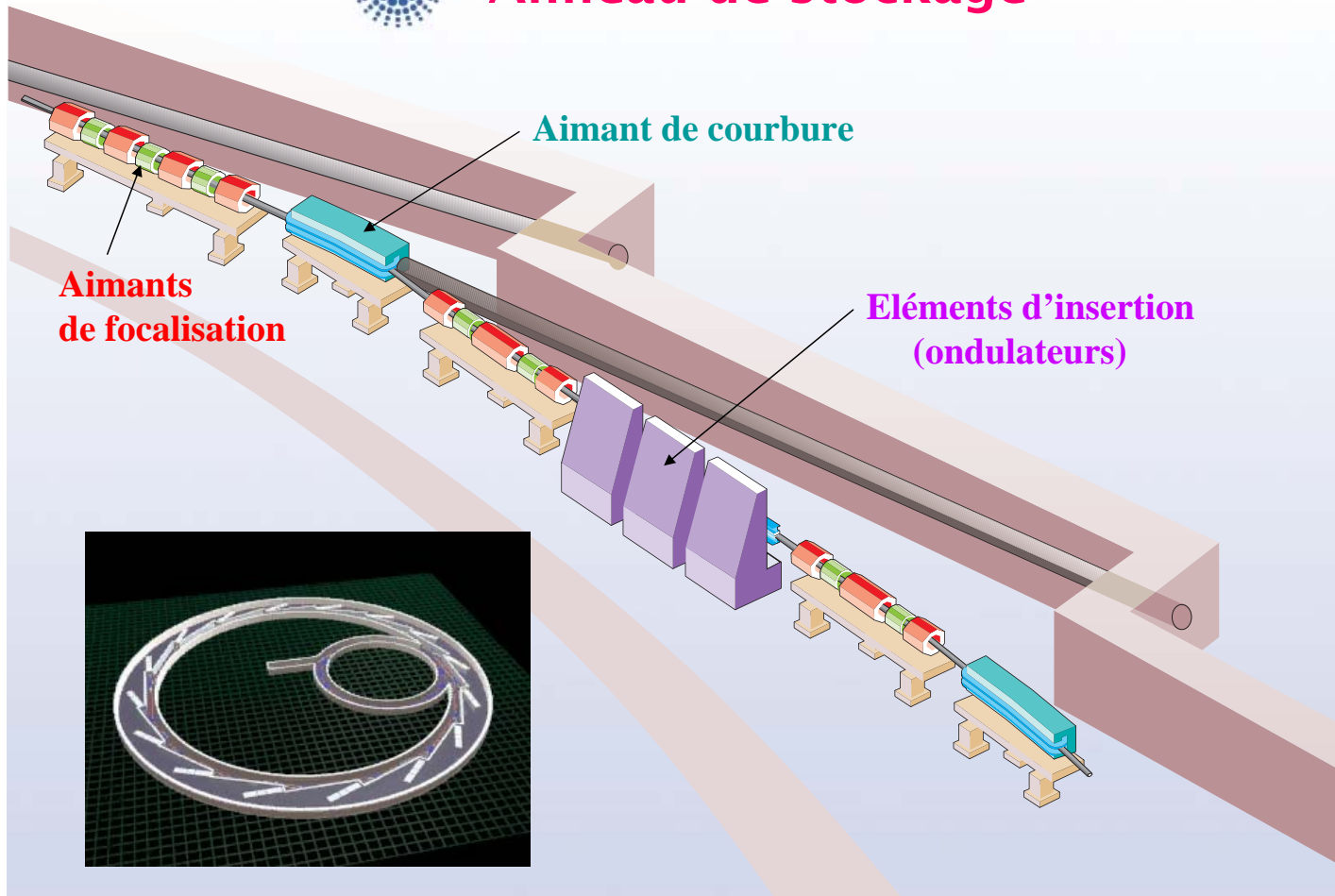
64 Aimants de deviations
Champ ~ 0.85 T
Longueur ~ 2.5 m

320 Quadrupoles (Focalisation)
Champ ~ 18 T/m
Longueur ~ 0.4 a 0.9 m





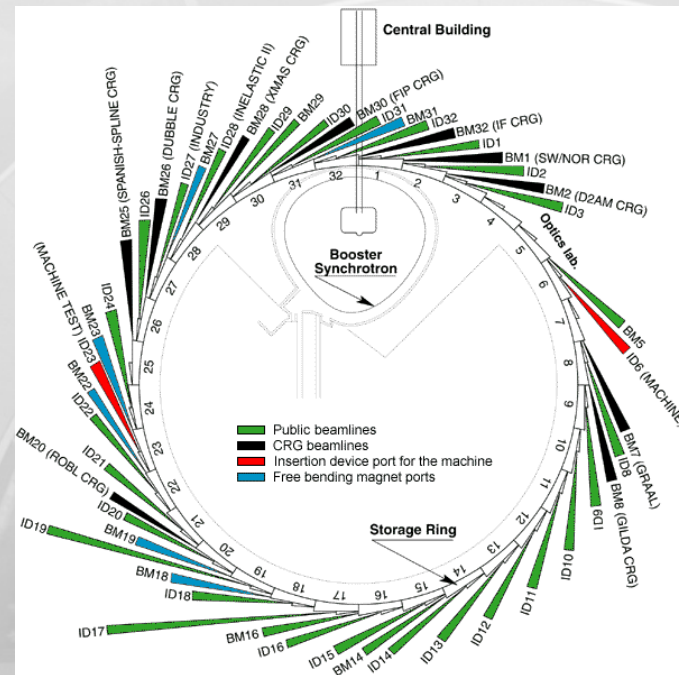
Anneau de stockage





ESRF

- Energy = 6 GeV
- Emittance = 4 nm-rad
- Perimeter = 844 m
- Psynchrotron = 1.2 MW
- 5500 hours of Beamline Operation /year
- 33 specialised beamlines – mainly on insertion devices
- 12 (national) Collaborating Research Group (CRG) beamlines on bending magnets



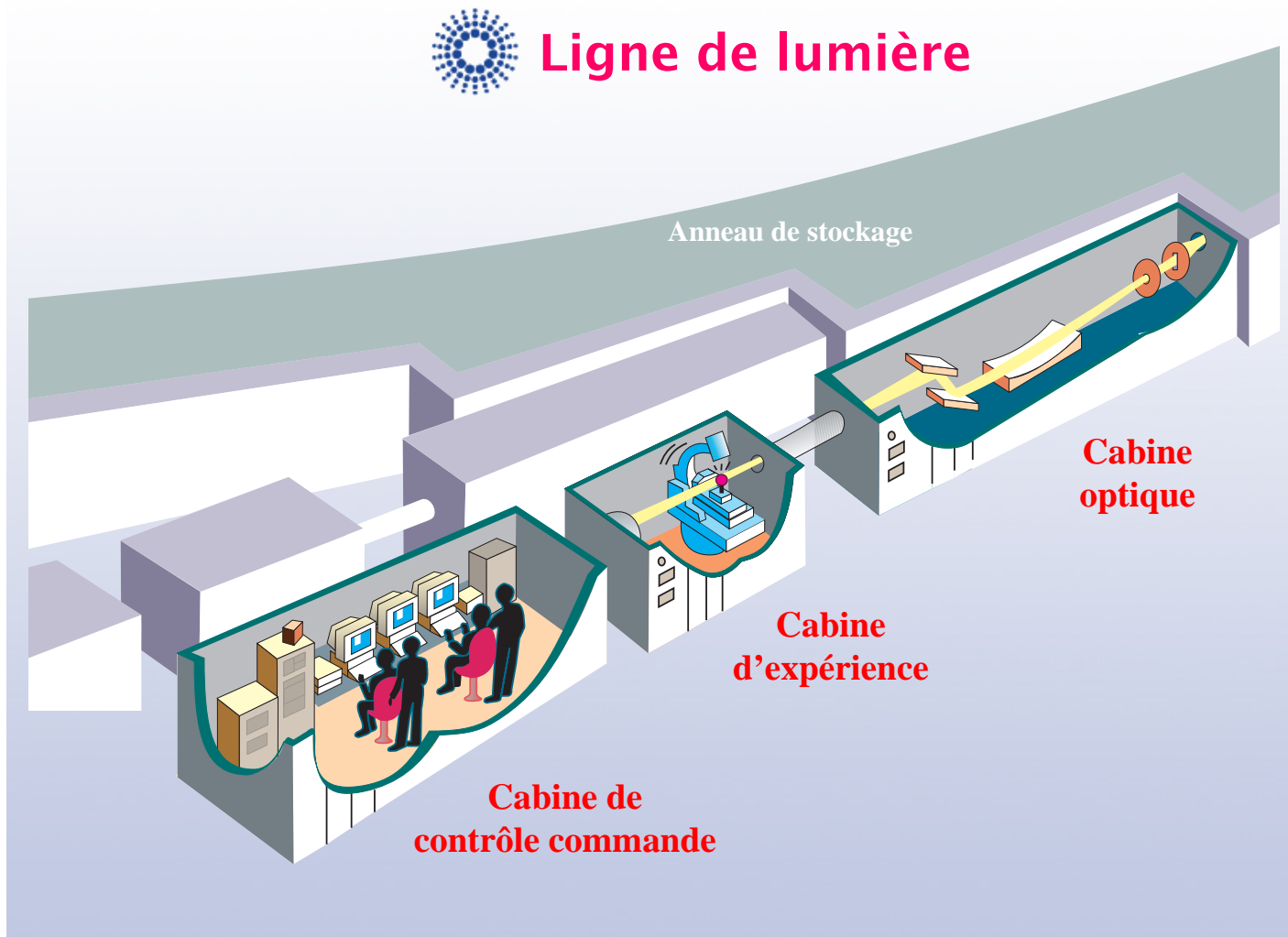
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Operation Statistics

	2006	2007	2008
Availability (%)	98.7	97.8	98.2
Mean time between failures (hrs)	61.5	56.8	63.2
Mean duration of a failure (hrs)	0.8	1.2	1.2



Ligne de lumière





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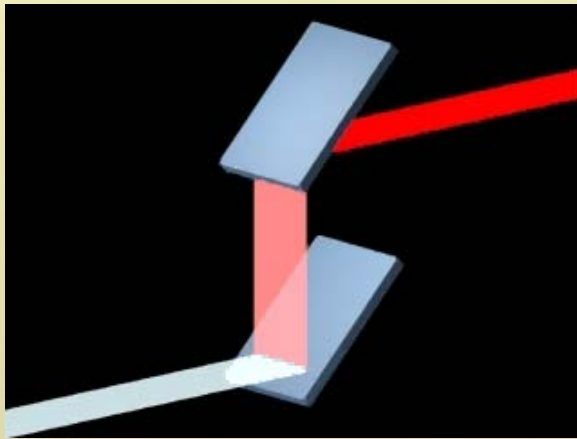


Optique

● Miroir



● Monochromateur

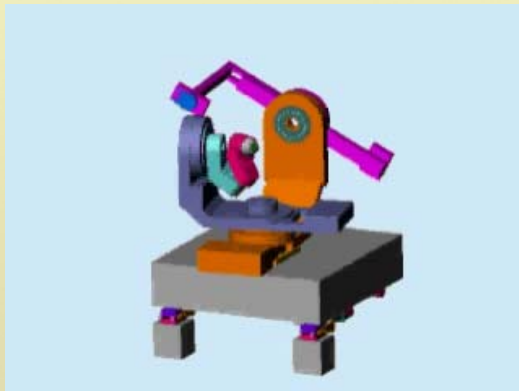




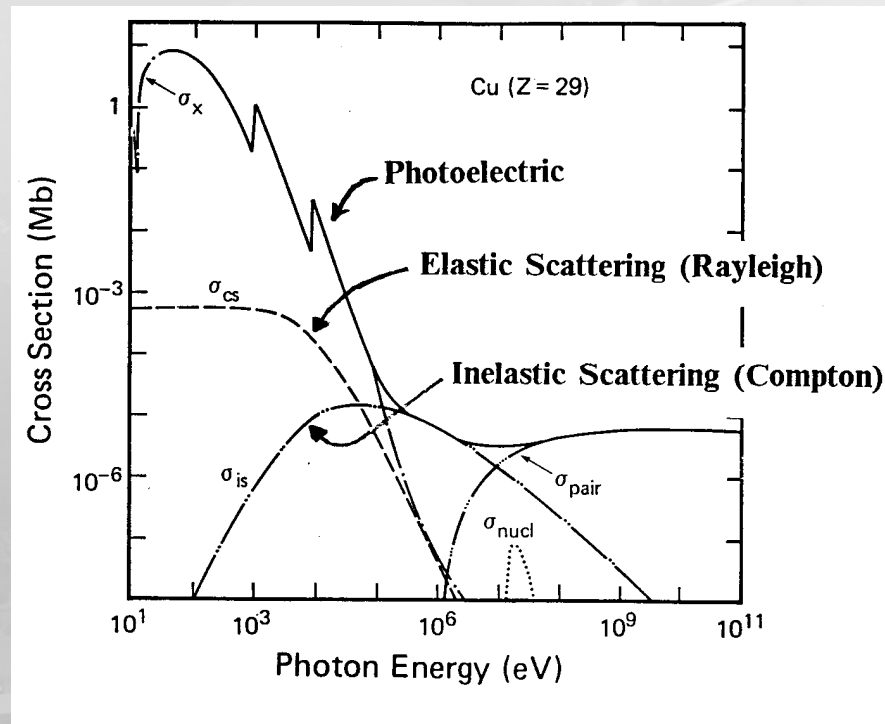
Expérience

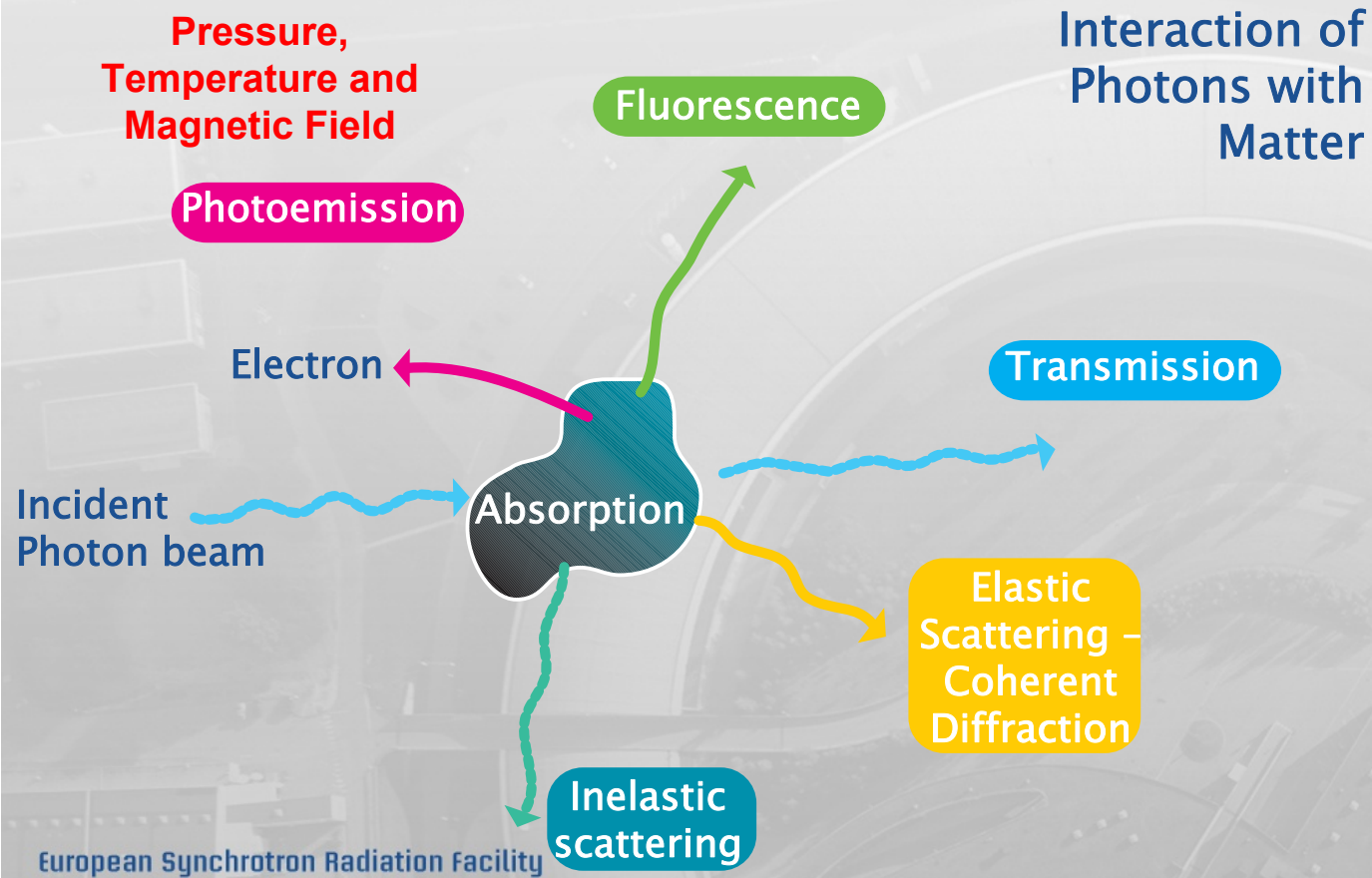
● **Diffractomètre**

● **Détecteur**



Cross Sections



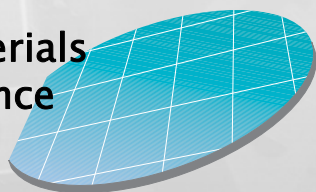


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Science at the ESRF

○ Materials science



○ Biology



○ Environment



○ Physics



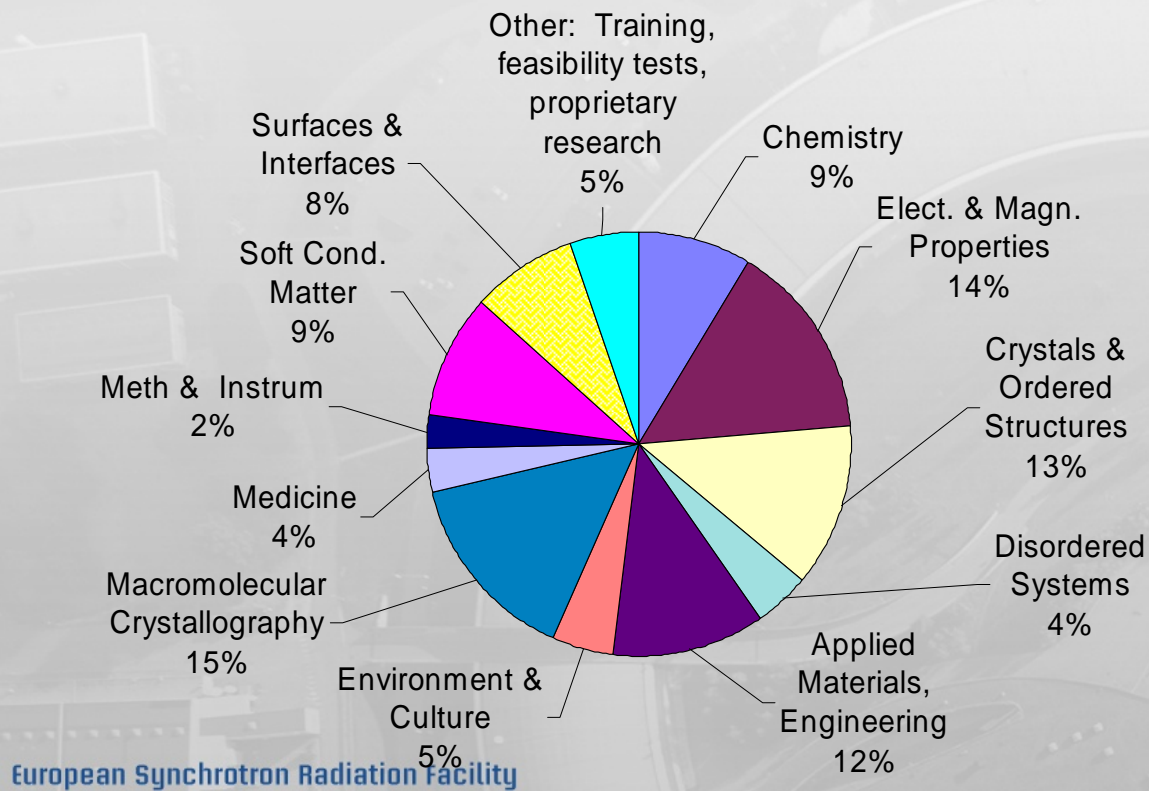
○ Chemistry

○ Medicine



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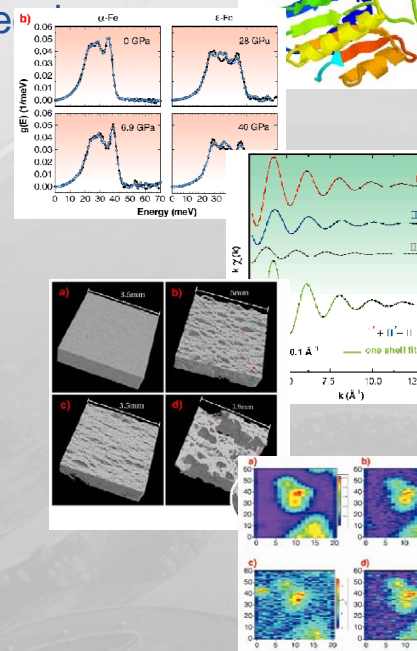
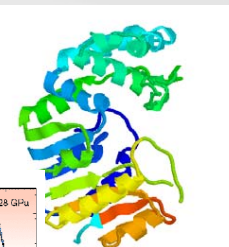
Distribution of time by scientific area

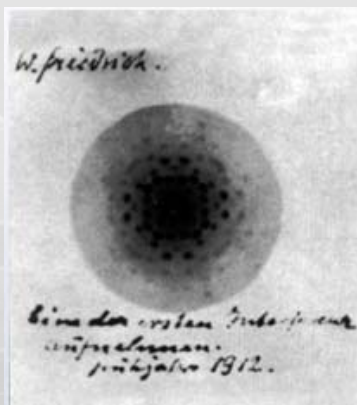


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Synchrotron Light Techniques

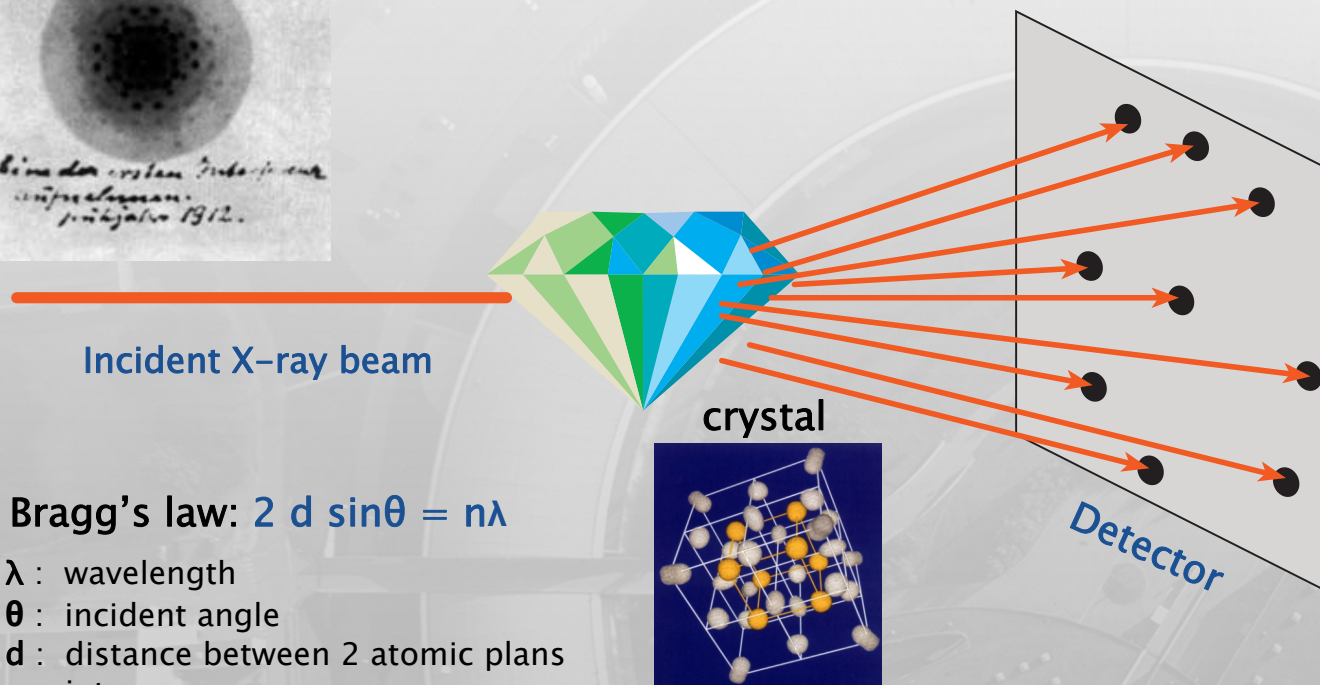
- **Diffraction:** powder, single-crystal, macro-mole
- **Scattering:** small-angle, inelastic...
- **Absorption:** XAFS, XMCD...
- **Imaging:** topography, phase-contrast
- **Microscopy:** x-ray, infra-red ...





First X-ray diagramme by Laue in 1912

X-ray Diffraction in a Crystal



Bragg's law: $2 d \sin\theta = n\lambda$

λ : wavelength

θ : incident angle

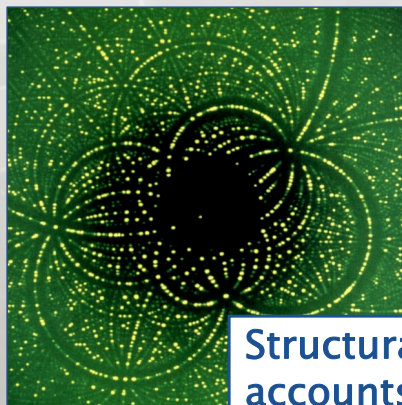
d : distance between 2 atomic plans

n : integer



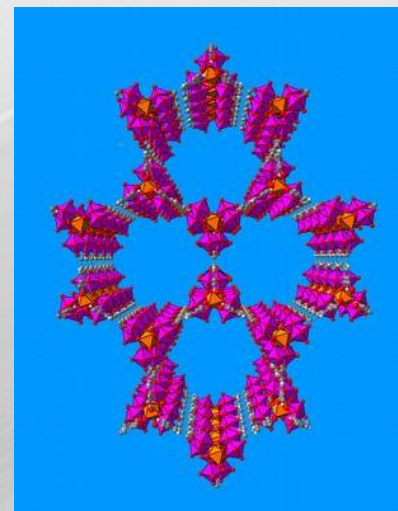
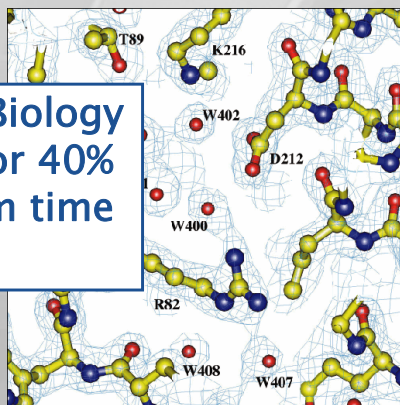
X-ray Diffraction of Microcrystals

Diffraction Pattern



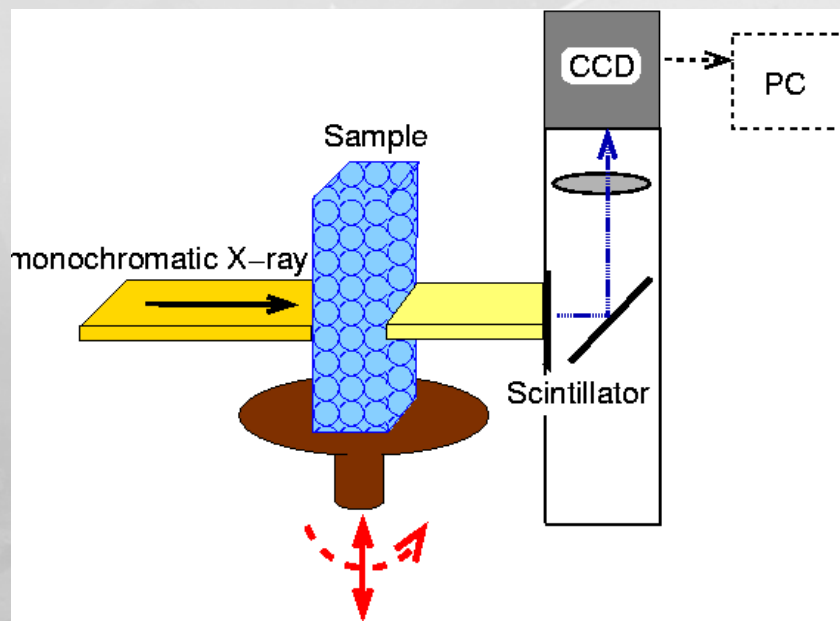
Crystals

Structural Biology
accounts for 40%
of the beam time
at the ESRF

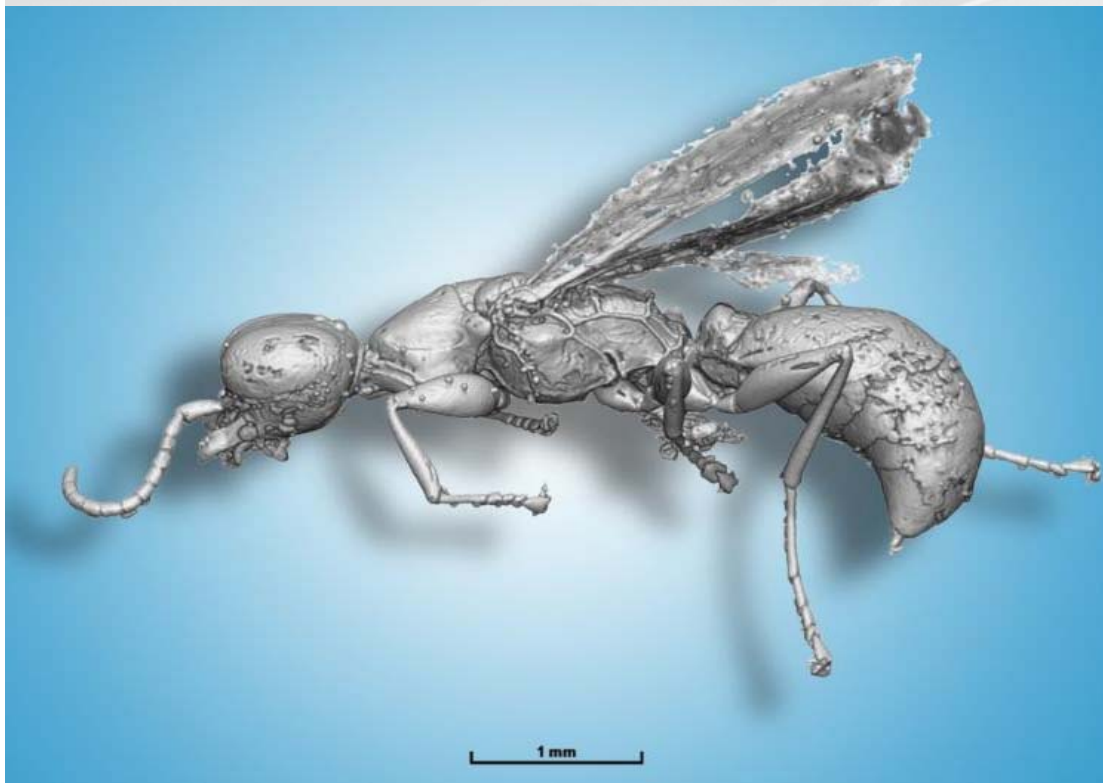


3D structure

Tomography



Tomographie par contraste de Phase



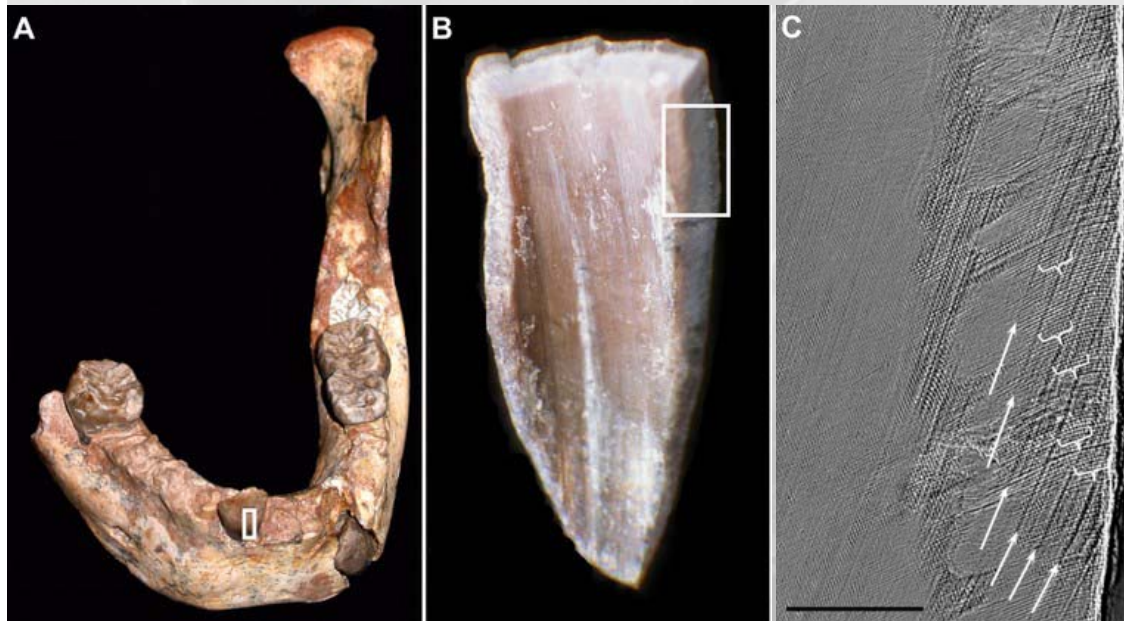
Guêpe
conservée
dans de
l'ambre
pendant 100
millions
d'Annees



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Fossil record of an eight year old child
living 160.000 years ago
Found in Jebel Irhoud, Morocco

Life History of a Fossil Human



Tomography
by phase
contrast

Mandril
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Area of interest

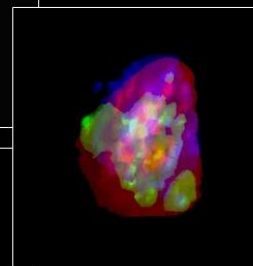
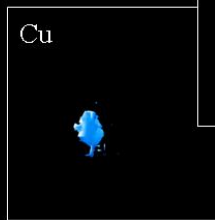
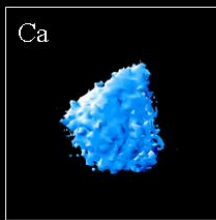
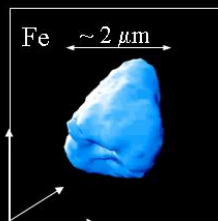
Daily growth lines ->
Determination of Age

Chemical Composition of a Comet Tail

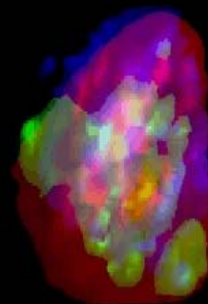
Stardust 0044-Track 3/terminal particle

Nano-fluorescence tomography: low intensity isosurfaces (envelopes) of the corresponding elements within the terminal particle

100 x 100 nm² voxels



reconstructed
composite image
corresponding to
Fe, Cr, Se.

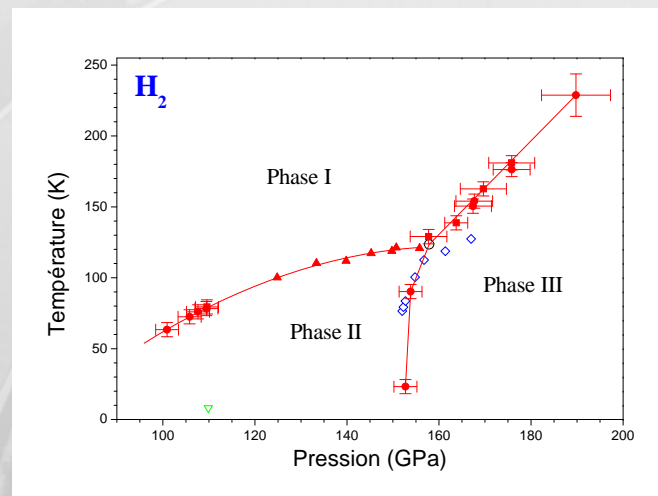


⇒ **heterogeneous on the submicron level**
main Fe-rich phase: olivine

Phase III of solid Hydrogen

3 Phases:

- I: FCC, H₂ molecules, free rotation
- II: determined recently (ID30 + ID09 + N/LLB). Incommensurate structure with local orientational order
- III: structure not known. First observations, ID27



100 GPa 200

1 GPa = 10 kbar

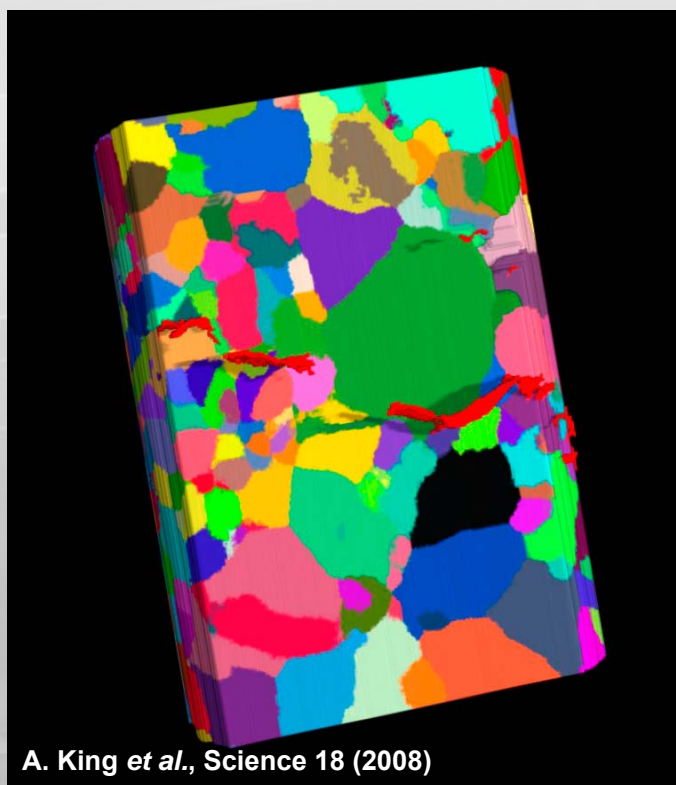
X-ray Imaging

How cracks grow in steel

Combination of stress and a corrosive environment

Cracks develop along 1600 boundaries of 360 grains

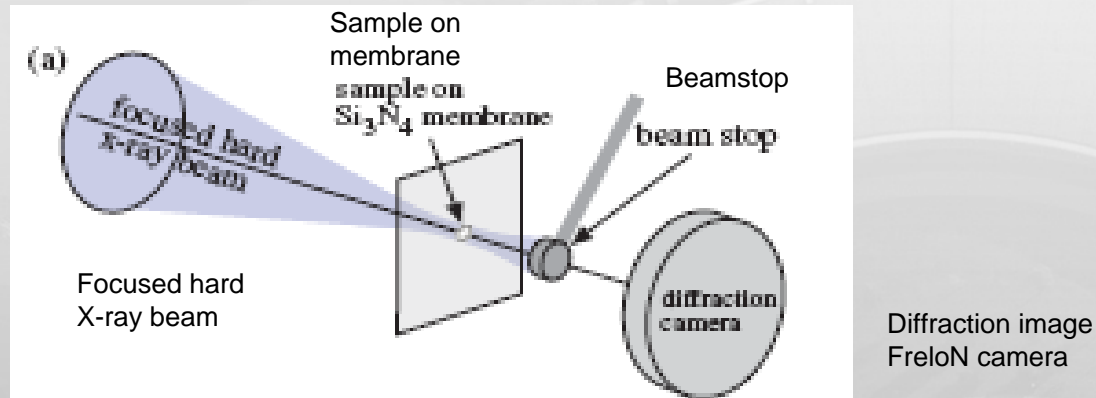
Visualisation *in situ* with the 3D grain mapping technique based on diffraction contrast tomography.



A. King *et al.*, Science 18 (2008)

European Synchrotron Radiation Facility

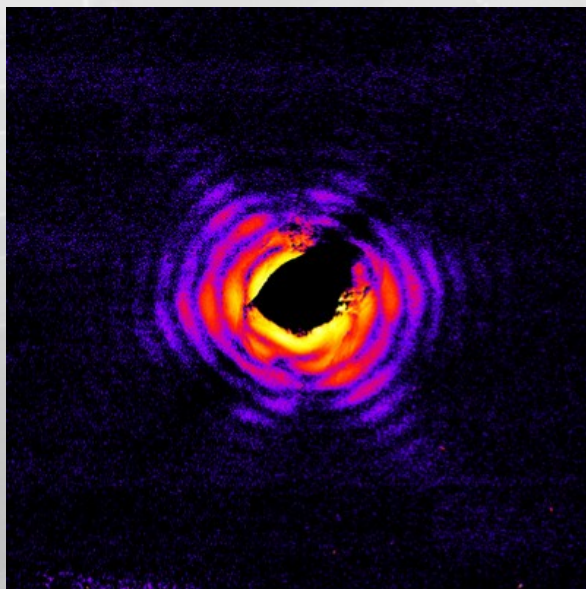
Very high resolution imaging – 100nm gold particle



- ID13, 15.25 keV
- Crossed refractive nanofocusing lenses → focal spot $\sim 100 \times 100 \text{ nm}^2$
- Coherent X-ray Diffraction Imaging (CXDI)

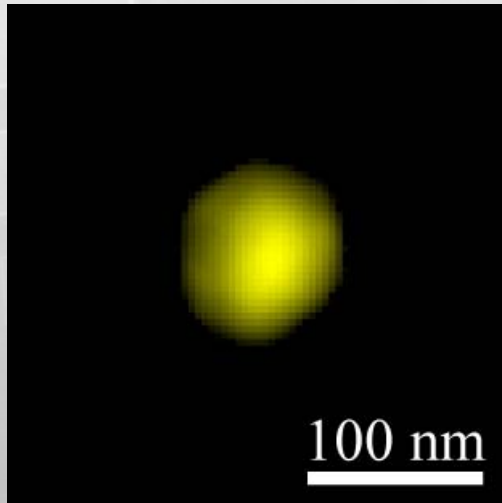
European Synchrotron Radiation Facility *Schroer et al, PRL 101, 090801, 2008*

Very high resolution imaging – 100nm gold particle



- CXDI: object illuminated with coherent beam
- Far-field diffraction image – no optics

Very high resolution imaging – 100nm gold particle

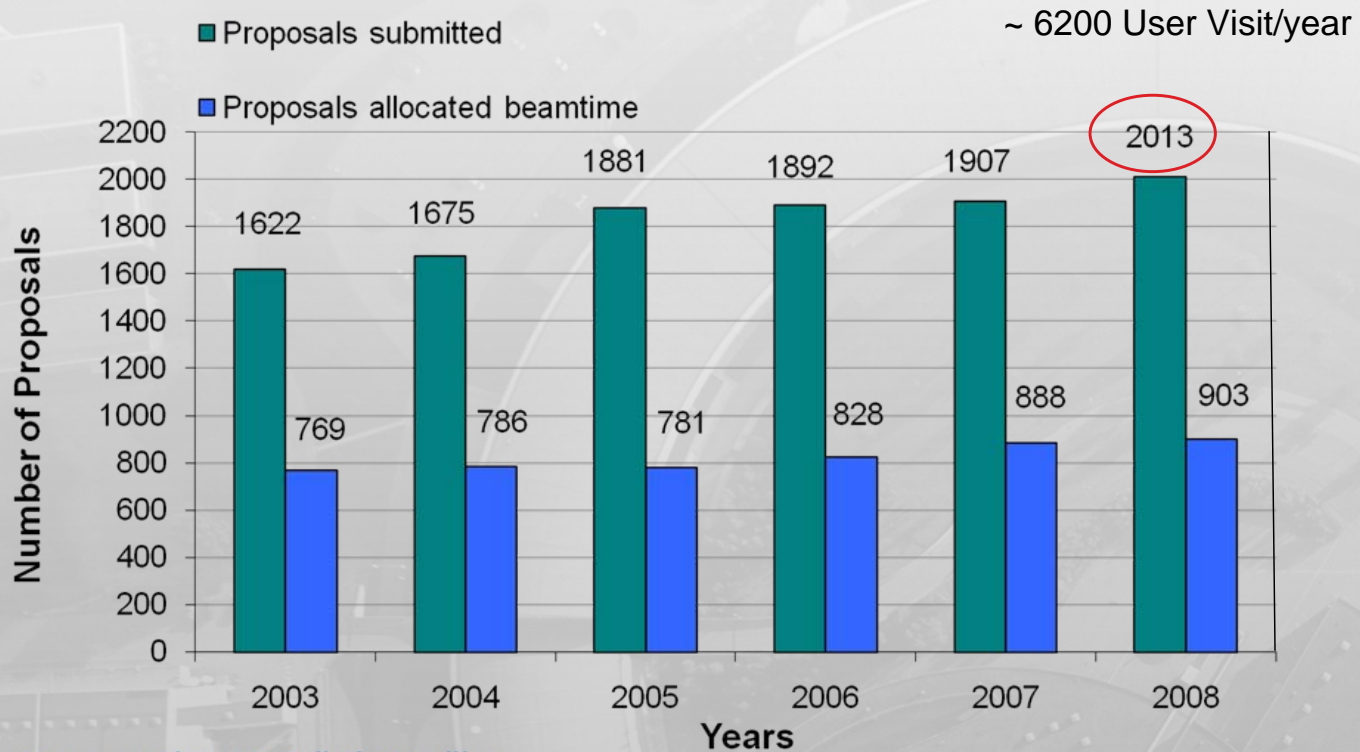


- Reconstructions used *hybrid input-output method*
- **Spatial resolution ~ 5 nm** from 600 sec exposure
- **Ultimate resolution possible: < 1 nm ?**

European Synchrotron Radiation Facility *Schroer et al, PRL 101, 090801, 2008*

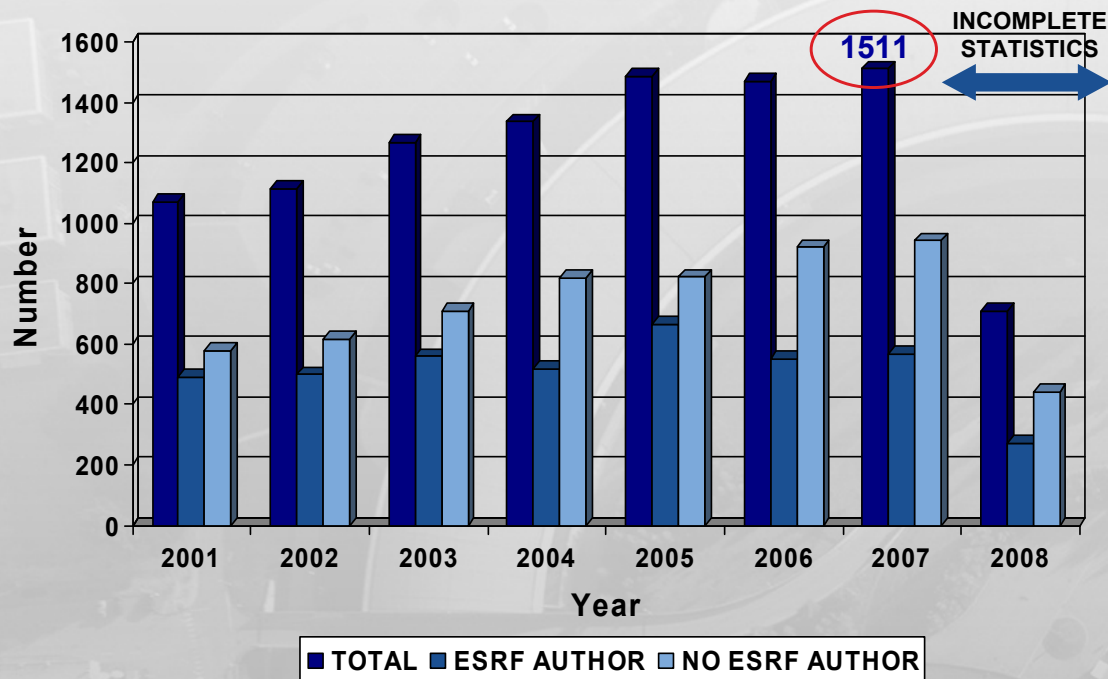


Proposals submitted and allocated beamtime

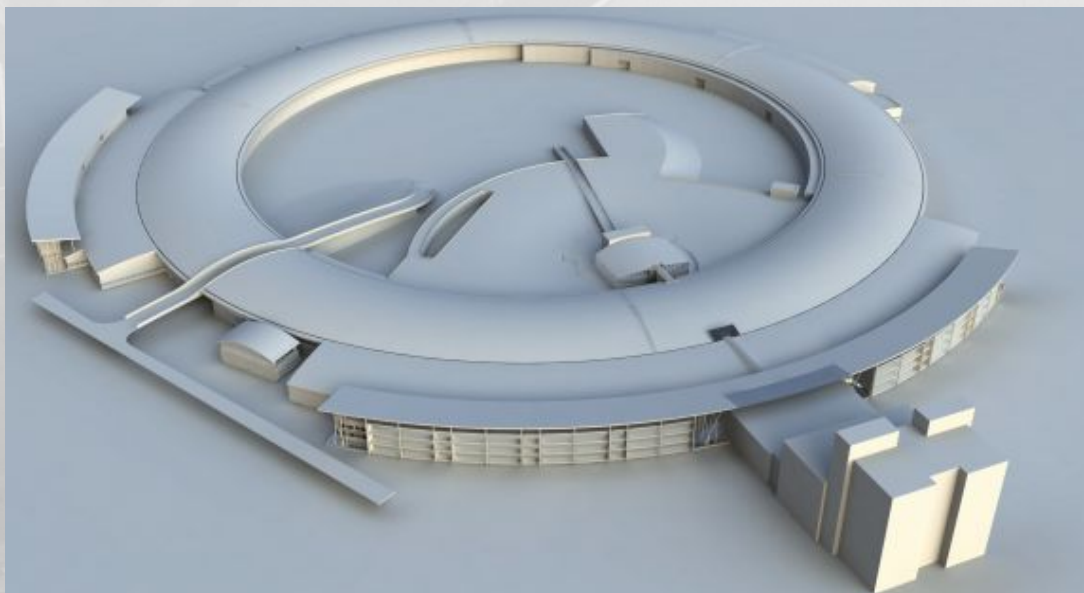




ESRF Refereed Publications



Upgrade Program 2009-2015



European Synchrotron Radiation Facility

Five Highlight Reference Areas

Nano-Science and
Nano-Technology

Structural/functional Biology
and Soft Matter

Pump-Probe Experiments
Time Resolved Studies

Science at
Extreme Conditions

X-ray Imaging



Merci de votre Attention !

**Pour en savoir plus :
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