Imaging at Elettra and FERMI

Elettra
Sincrotrone
Trieste

www.elettra.eu

Main difference

✓ SR recirculate beam multi bunch	FEL single pass machine
✓ SR High pulse rate (~100 MHz)	FEL Low pulse rate (10 – 1000 Hz)
✓ SR High average current (~100 300 mA)	FEL High peak current
✓ Temporal pulse length 15 – 30 ps	100 fs
✓ Flux 10^{11} -10^{12} ph/sec	Flux 10^{12} -10^{13} ph/pulse
✓ Peak power 10^{3} W	Peak power 10^{9} W !!!!
✓ Partially coherent source	Coherent source

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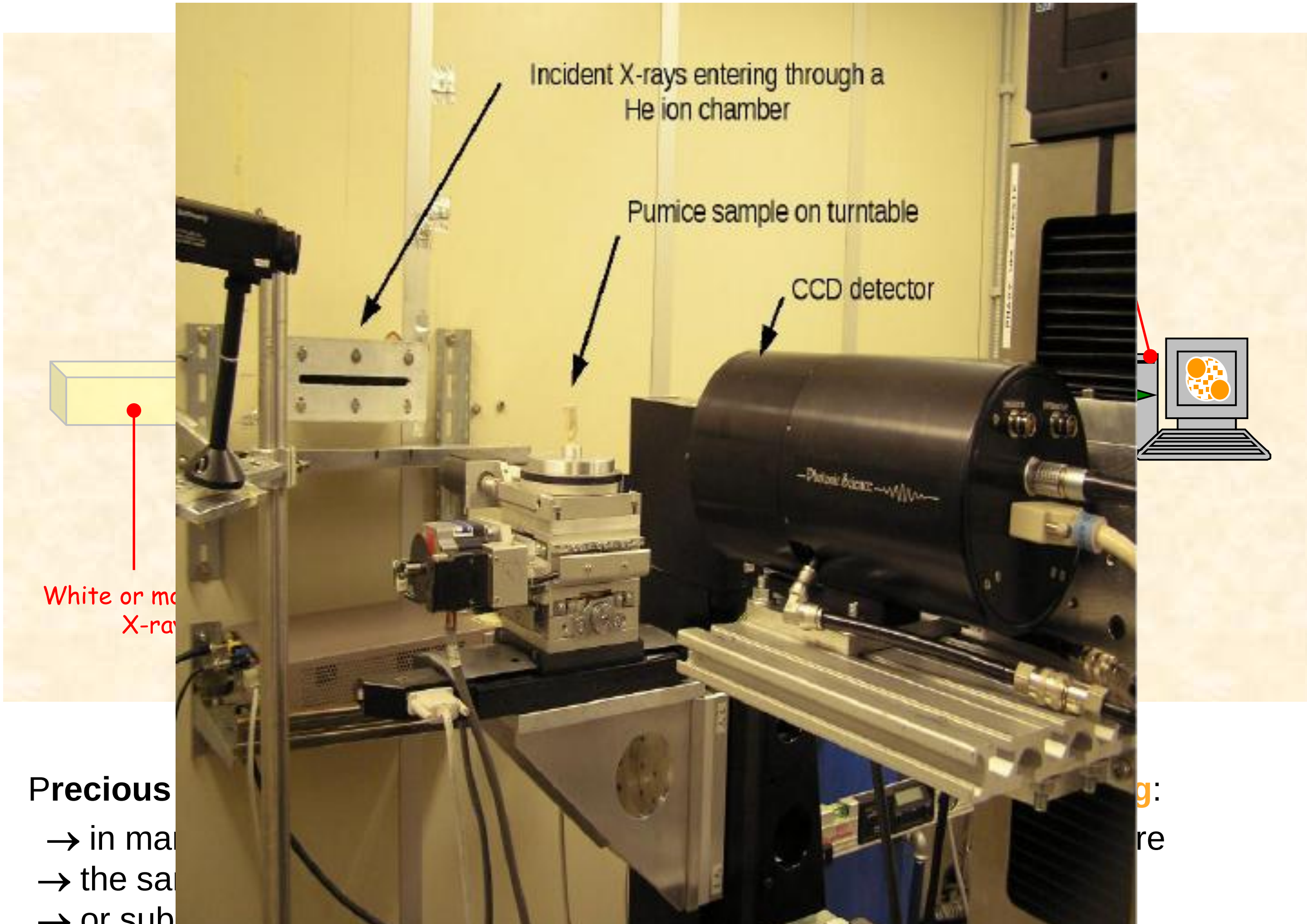
Part 1 : ***Synchrotron X-ray computed microtomography (μ -CT)***

and some earth-science examples

Thanks to Lucia Mancini

Synchrotron X-ray computed microtomography (μ -CT)



- **Precious** … g:
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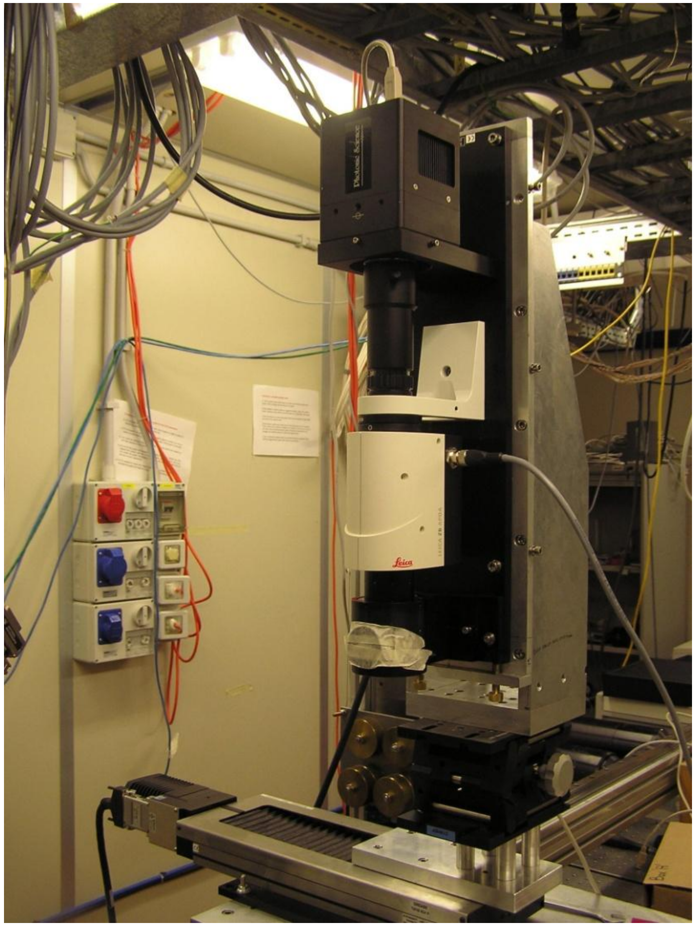
CCD detectors & optics

- Photonic Science HYSTAR
  - **16 bit**, **2048 x 2048** pixels^2
  - pixel size: (3.85) 14 x (3.85) 14 μm^2
  - **FOV**: (8) 28 mm x (8) 28 mm
- Photonic Science VHR
  - **12 bit**, **4008 x 2672** pixels^2
  - effective pixel size: 4.5x4.5 μm^2
  - **FOV**: 18 mm x 12 mm



- Photonic Science Lens-coupled
  - **16 bit**, **2048 x 2048** pixels^2
  - pixel size: 7.4x7.4 μm^2
  - **FOV**: continuously adjustable

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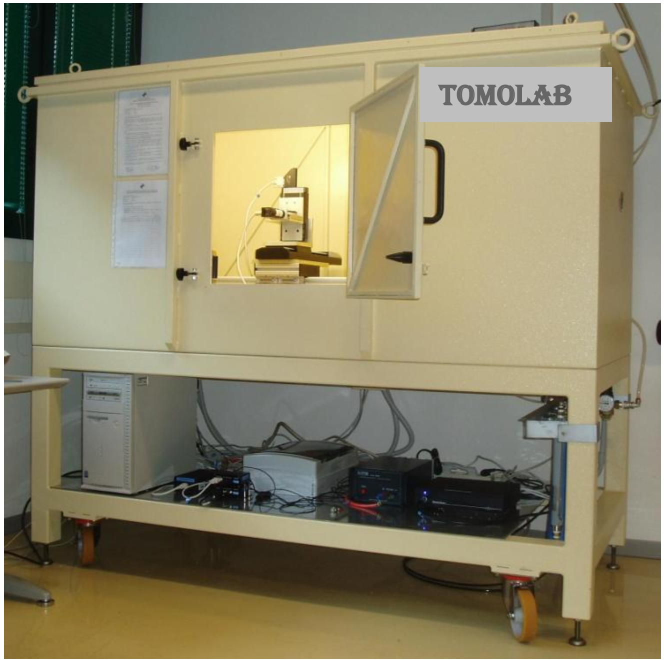
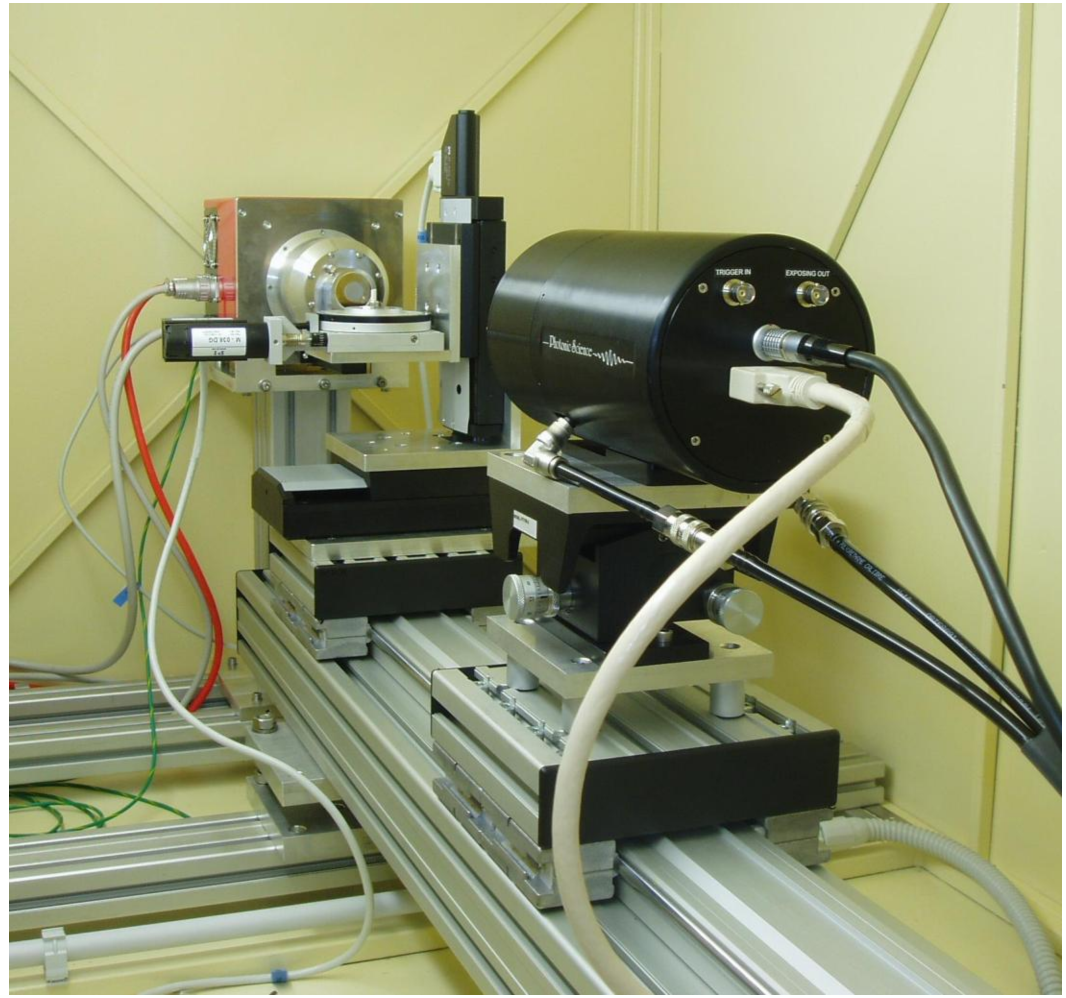
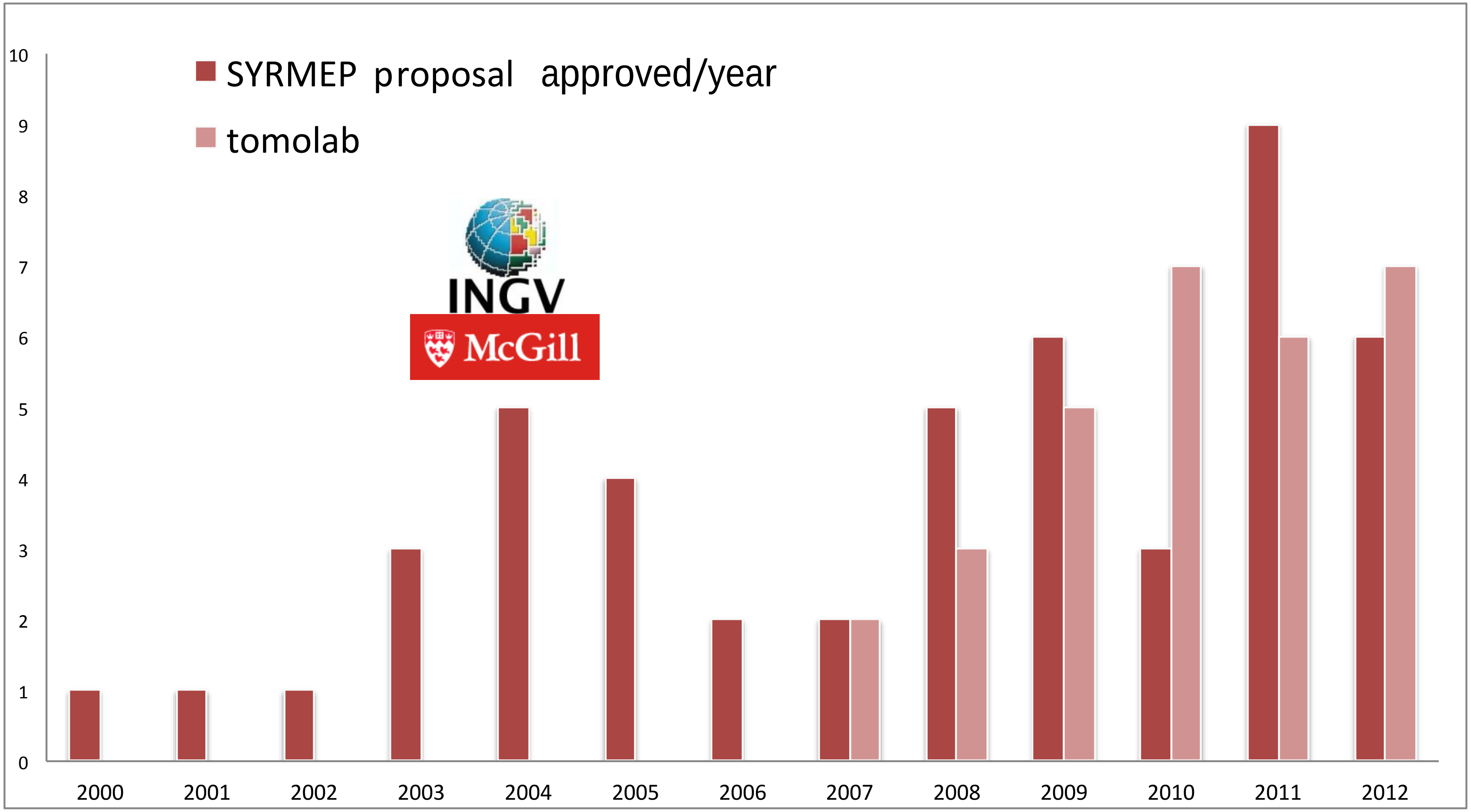
The TOMOLAB station @ Elettra



Designed at *Elettra* and constructed in collaboration with Georesources Dept. and Corso di Laurea in Odontoiatria e Protesi Dentaria - Facoltà Medicina e Chirurgia of the ***Università di Trieste***.



V = **40÷130 kV**, P_{max} = **39 W**, focal spot_{min} = **5 μm**



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SYRMEP proposal approved/year
tomolab
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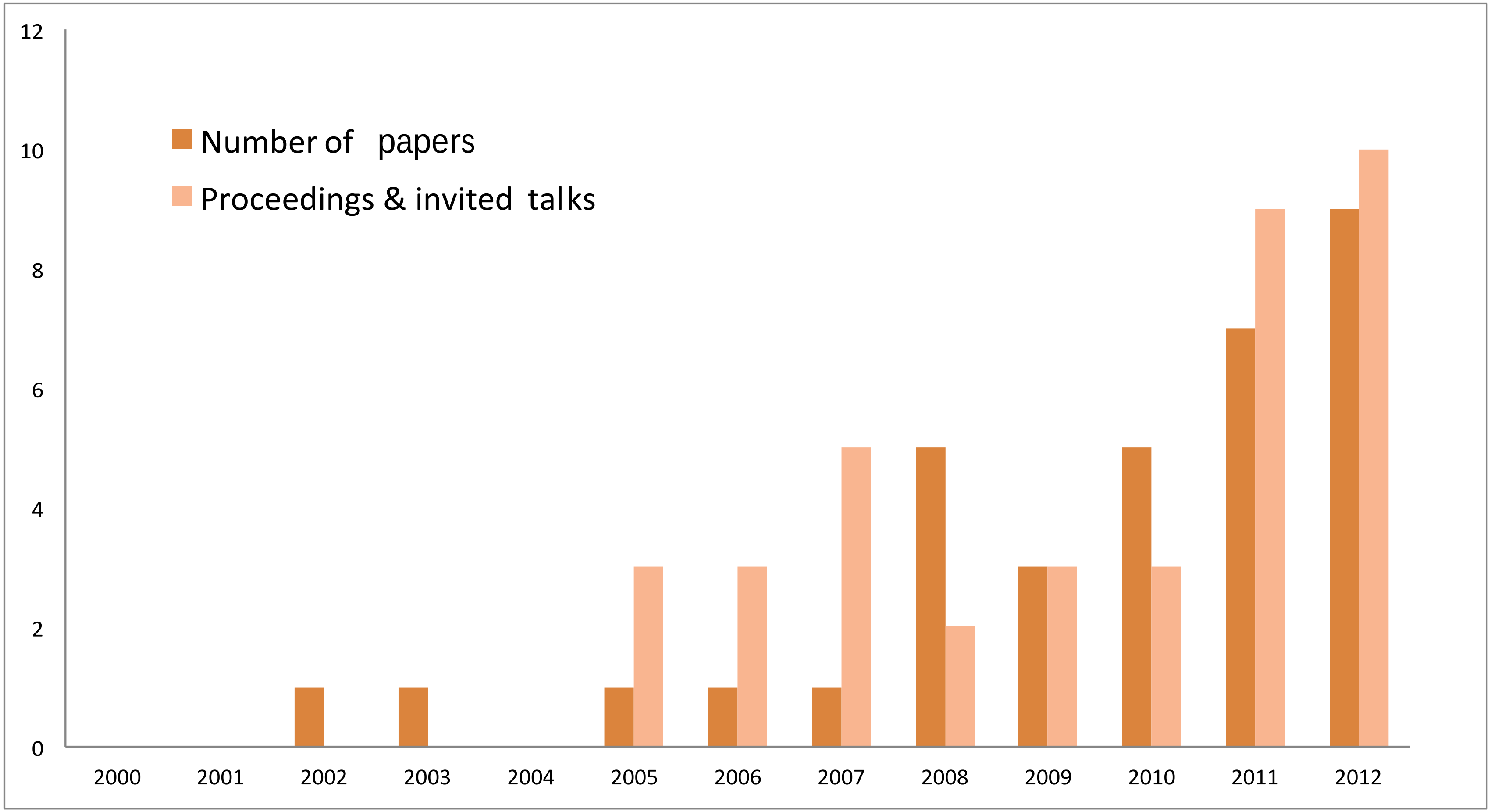

12
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Number of papers
Proceedings & invited talks
2000
2001
2002
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2004
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2010
2011
2012

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The Pore3D project: why?

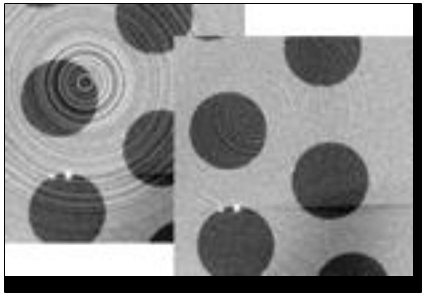
- A sw library specifically designed for ***X-ray μ-CT images*** of porous media and multiphase systems, Manipulation of ***huge datasets*** with ***common hw***.

- ***Different strategies of analysis*** as a function of the scientific application: *Pore3D* implements ***several algorithms for each step*** of the analysis, having ***a full control of the parameters*** of the algorithm and of the intermediate results.

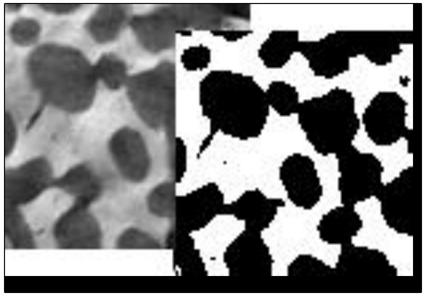
- On the basis of ***specific know-how*** of the ***SYRMEP collaboration*** the main aim was to merge many of features implemented in existing software, in some cases customizing it or adding new tools.

Elettra Sincrotrone Trieste **http://ulisse.elettra.trieste.it/uos/pore3d**

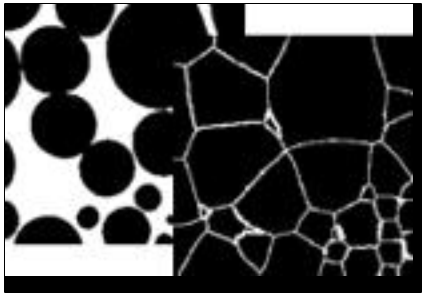
Pore3D is a software tool for **3D image processing** and **analysis**



Filters
Basic (mean, median, gaussian, ...)
Anisotropic diffusion
Bilateral
Ring artifacts reduction
Binary (median, clear border, ...)



Segmentation
Automatic thresholding (Otsu, Kittler, ...)
Adaptive thresholding
Region growing
Multiphase thresholding
Clustering (*k*-means, *k*-medians, ...)



Morphological processing
Dilation and erosion
Morphological reconstruction
Watershed segmentation
Distance transform
H-Minima filter

Skeleton extraction
Thinning
Medial axis (LKC)
DOHT
Gradient Vector Flow
Skeleton pruning
Skeleton labeling

Analysis
Minkowski functionals
Morphometric analysis
Anisotropy analysis
Blob analysis
Skeleton analysis
Textural analysis (fractal dimension, ...)

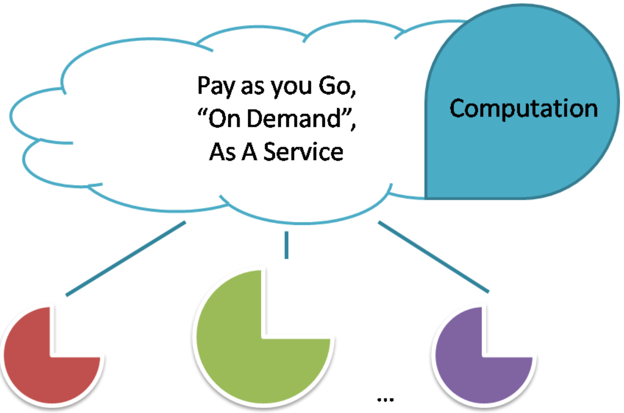
Brun F. et al., NIM A, 615 (2010) 326–332
Brun F. et al, IFMBE proc., 25 (2010) 926-929
Brun F. et al. Proc. IEEE CIP (2011) 405-408

The Software-As-A-Service concept

The classical approach consists in building a dedicated computing centre (software + hardware) for each laboratory:
- financially inconvenient
- sometime impracticable
- geographically distributed groups integration harder

The SAAS model:

- delivered through the Internet
- no installation client side
- remote storage and computation
- exploiting remote supercomputers
- "pay as you go" policy



- The current release:

  deals only with computation by ***integration with IDL®***

  GUI available only for internal users

  special hardware (***40 CPUs, 192 GB RAM***)

  leading edge technologies such as ***VirtualGL***

- It is free for ***Elettra users***

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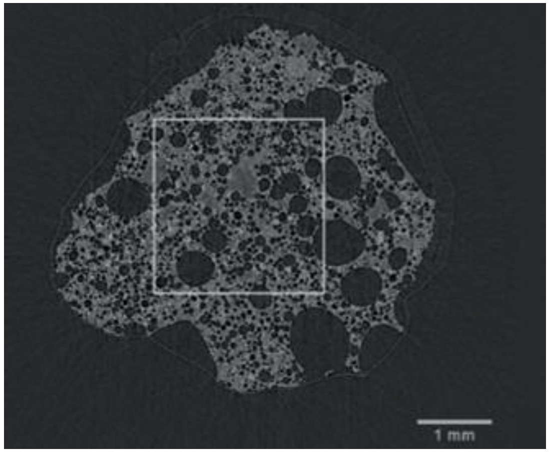
3D quantitative analysis of geomaterials: application to volcanic rocks

Formation of a volcanic rock: a complex process with many steps involved, from magma ascent in the conduit to fragmentation and emplacement beyond the crater's rim. All these ***processes*** are somehow ***recorded in the texture of the rock***.

Products of explosive eruptions, such as ***pumices*** and ***scoriae***, feature an arrangement of crystals and vesicles within a glassy framework. This arrangement represents the status of the magma prior to the fragmentation process; then a great deal of information about the ***history of the rock formation*** can be obtained by the study of its ***morphology*** and ***texture***.

Scoria from Ambryn, vesiculated, low crystallized

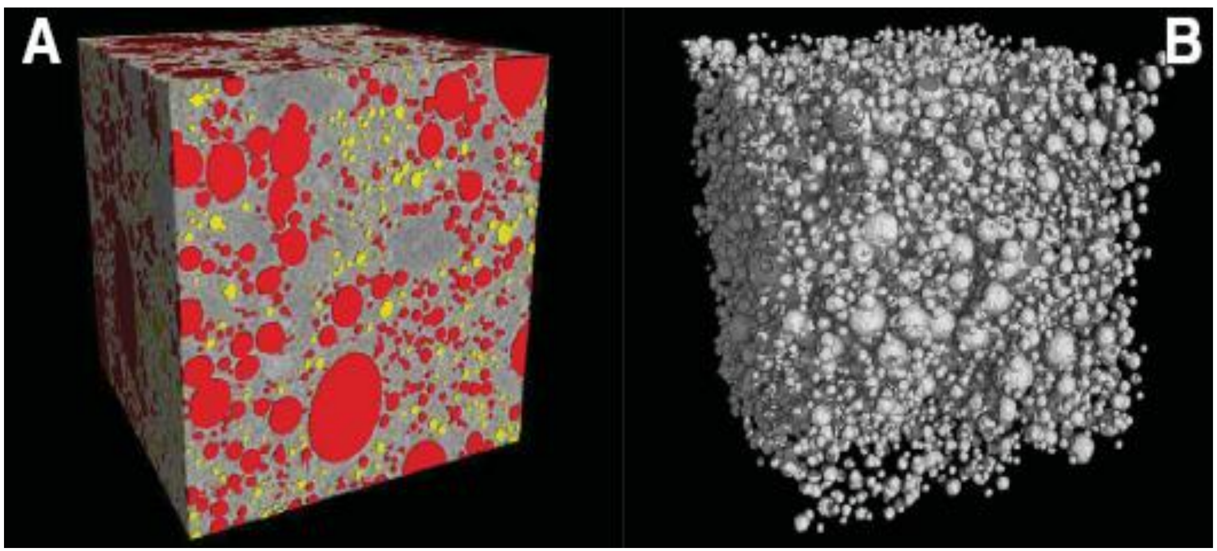


Vesicles colored after connected component analysis.

Red: connected component

Yellow: the others

Vesicles isolated after watershed segmentation and border cleaning.

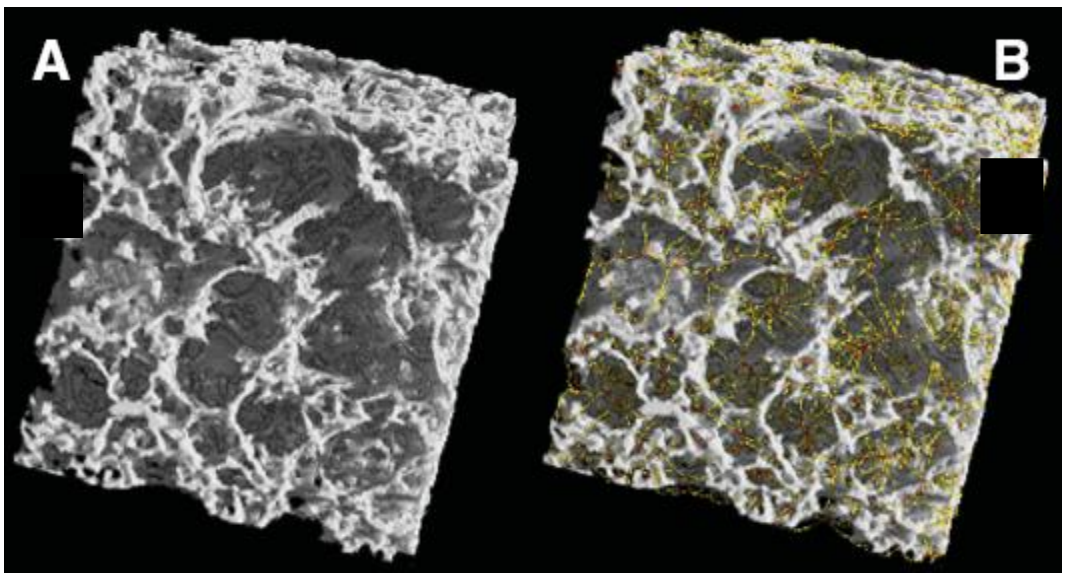


D. Zandomeneghi et al., Geosphere, 6 (2010) 793-804

Pumice from Stromboli, highly vesiculated, low crystallized

Skeletonization of the porous phase

Red dots: skeleton nodes
Yellow lines: node-to-node branches

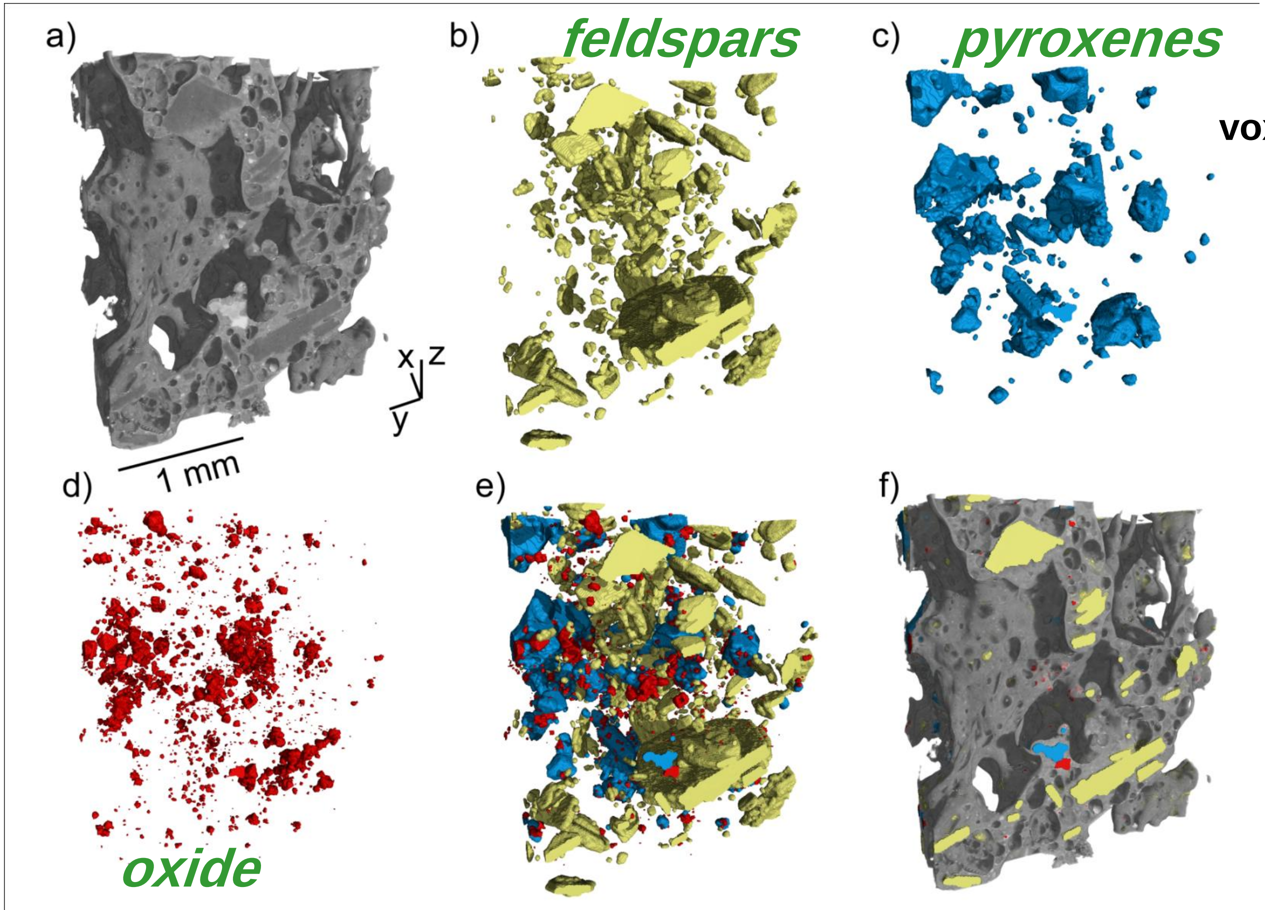


Quantification of degree of vesicle interconnectivity

D. Zandomeneghi et al., Geosphere, 6 (2010) 793-804

Elettra Sincrotrone Trieste

Scoria from Etna (experiments performed at the TOMCAT beamline at the Swiss Synchrotron Light Source, PSI)



voxel size: 1.85 µm

vesicles -> 68.9%, pyroxenes -> 3.2%, "oxides" -> 0.7%, glass -> 22.9%

M. Voltolini et al., J. of Volc. and Geothermal Res., 202 (2011) 83-95

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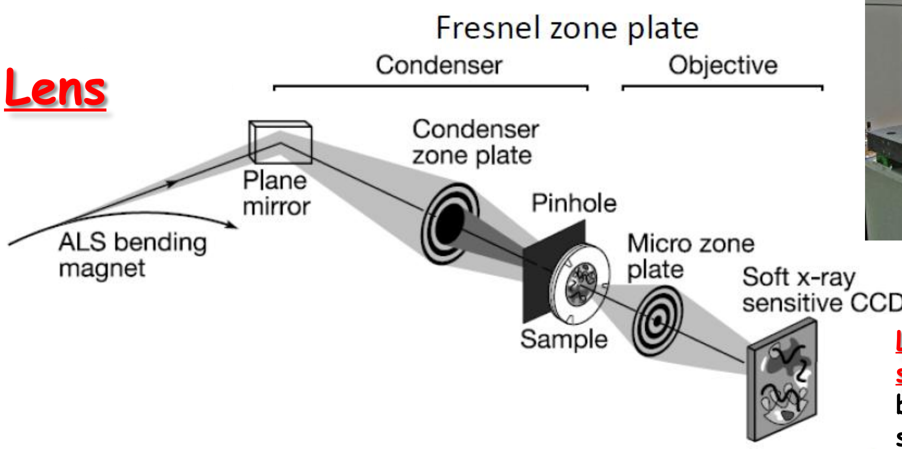
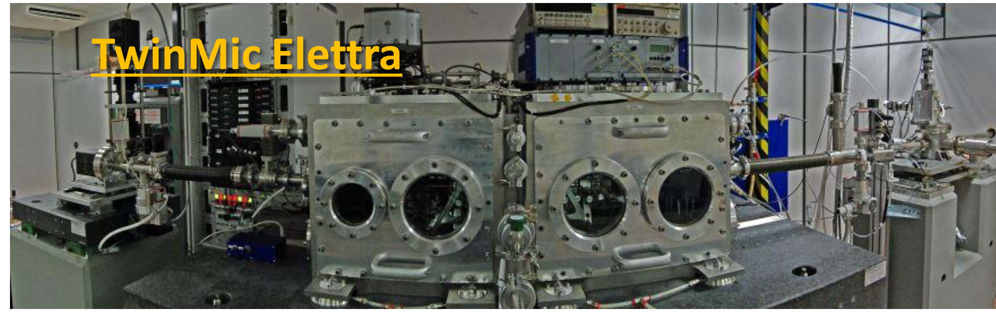
Coherent Diffraction Imaging
(basic principles)
and some time-resolved experiments with FEL

Thanks to Flavio Capotondi

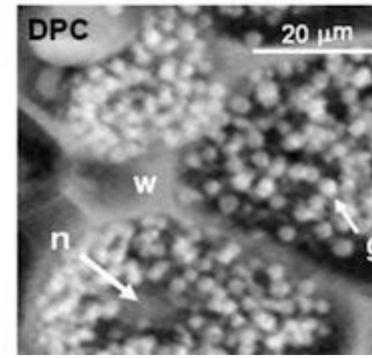
Lens vs Lensless imaging

Lens

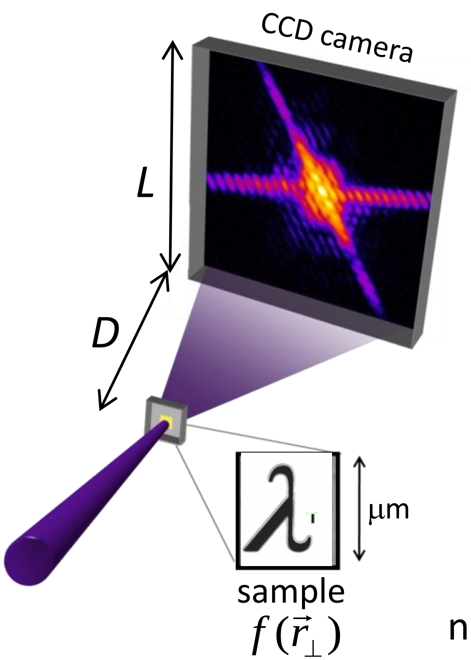




Lenses directly acquire information in real space, inverting the Fourier transformation by recombining at a given distance the scattered x-rays with correct phases making them interfere to form a replica of the object



Lensless



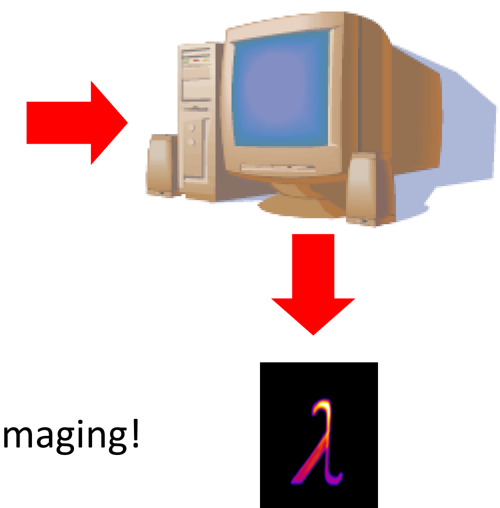
Measured diffracted intensity

$$\left|TF\{f\}(\vec{k}_\perp)\right|^2$$

Phase lost

$$\cancel{\varphi(\vec{k}_\perp)}$$

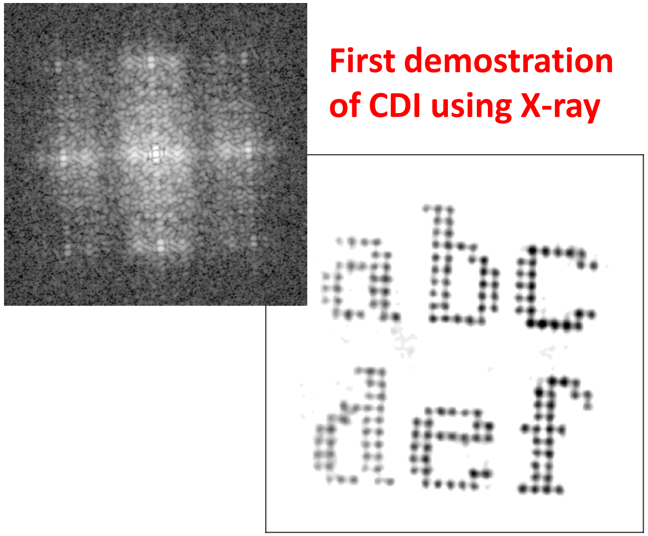
no high quality optics for imaging!



CDI acquire data in reciprocal space. In Fraunhofer approximation Diffraction pattern is related to the real-space object through a Fourier transformation, which encodes the image in propagation directions and phases of the electromagnetic field.

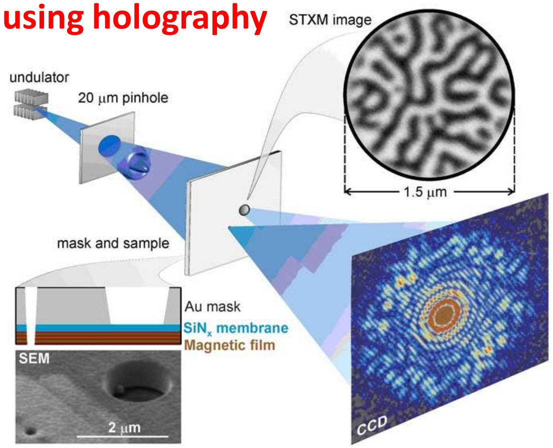
Some examples of lensless imaging

First demostration of CDI using X-ray



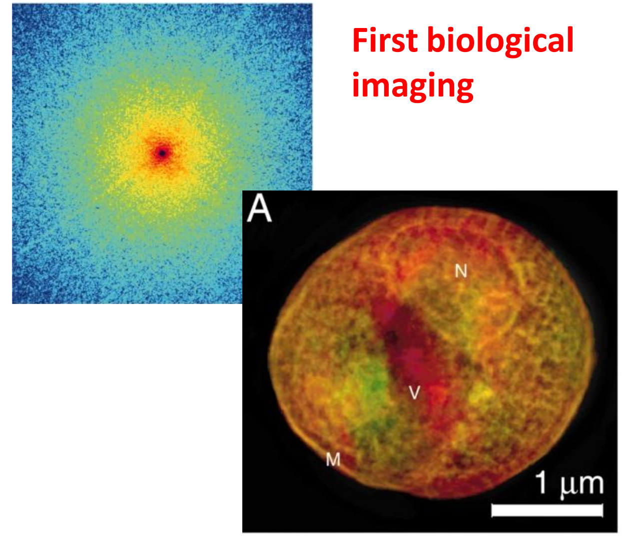
Miao J., et al. Nature 1999

First magnetic imaging using holography

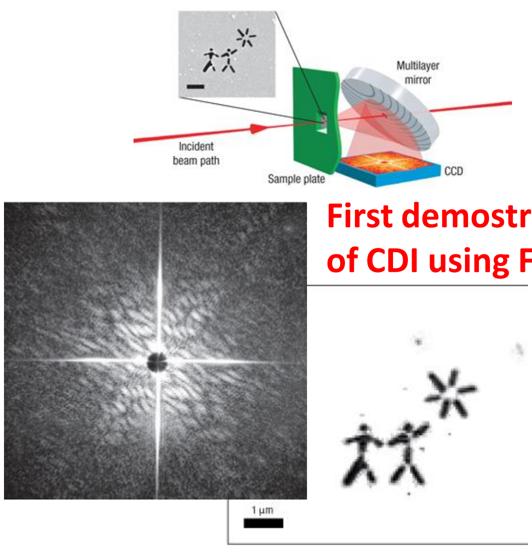


Eisebitt S., et al. Nature 2004

First biological imaging



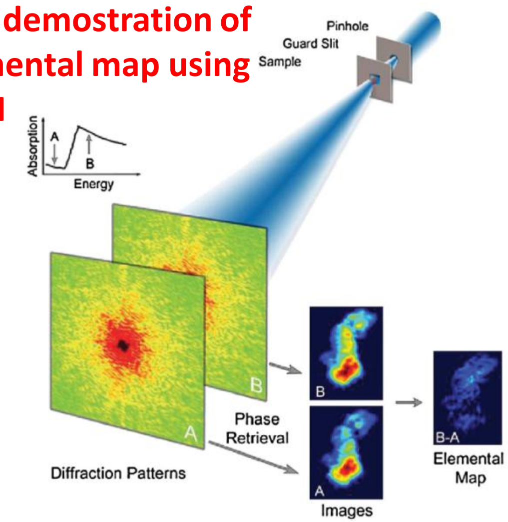
Shapiro D et al. PNAS 2005



First demostration of CDI using FEL

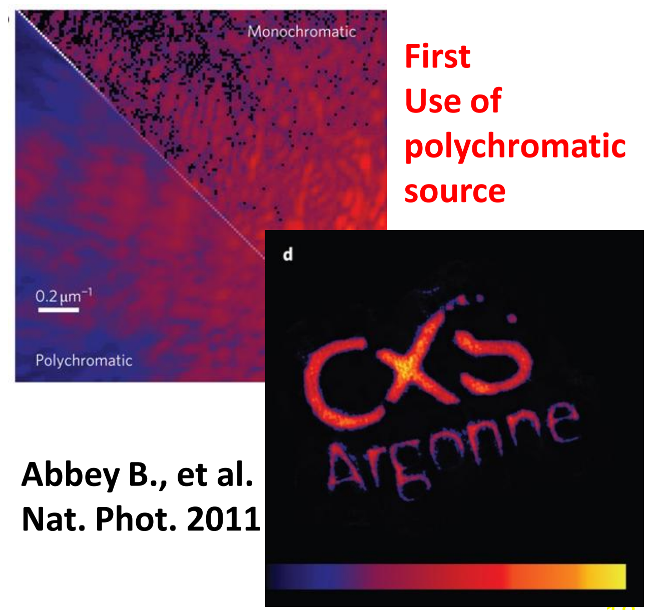
Chapman H.N., et al. Nat. Phot. 2006

First demostration of elemental map using r-CDI



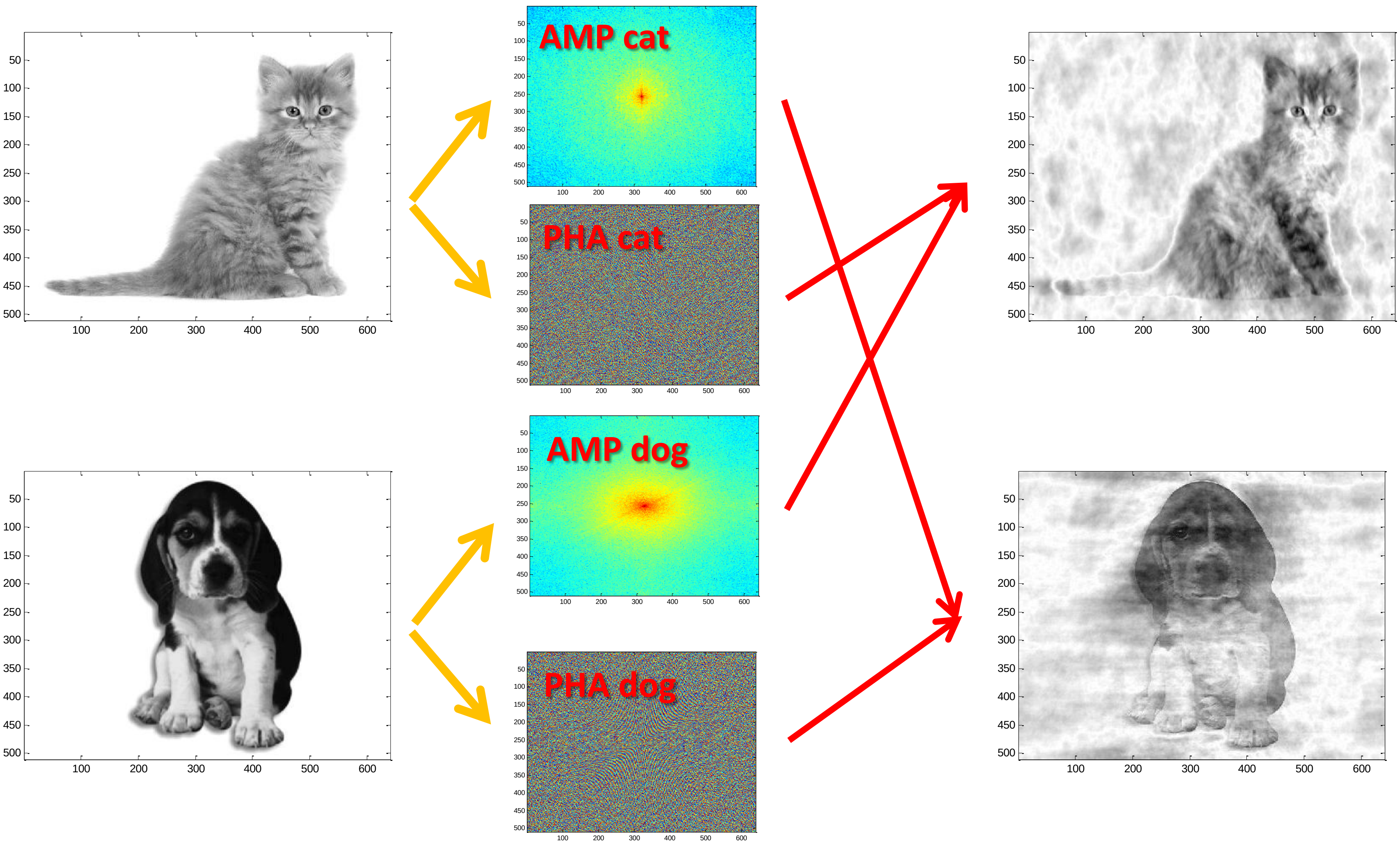
Song C., et al. PRL 2008

First Use of polychromatic source

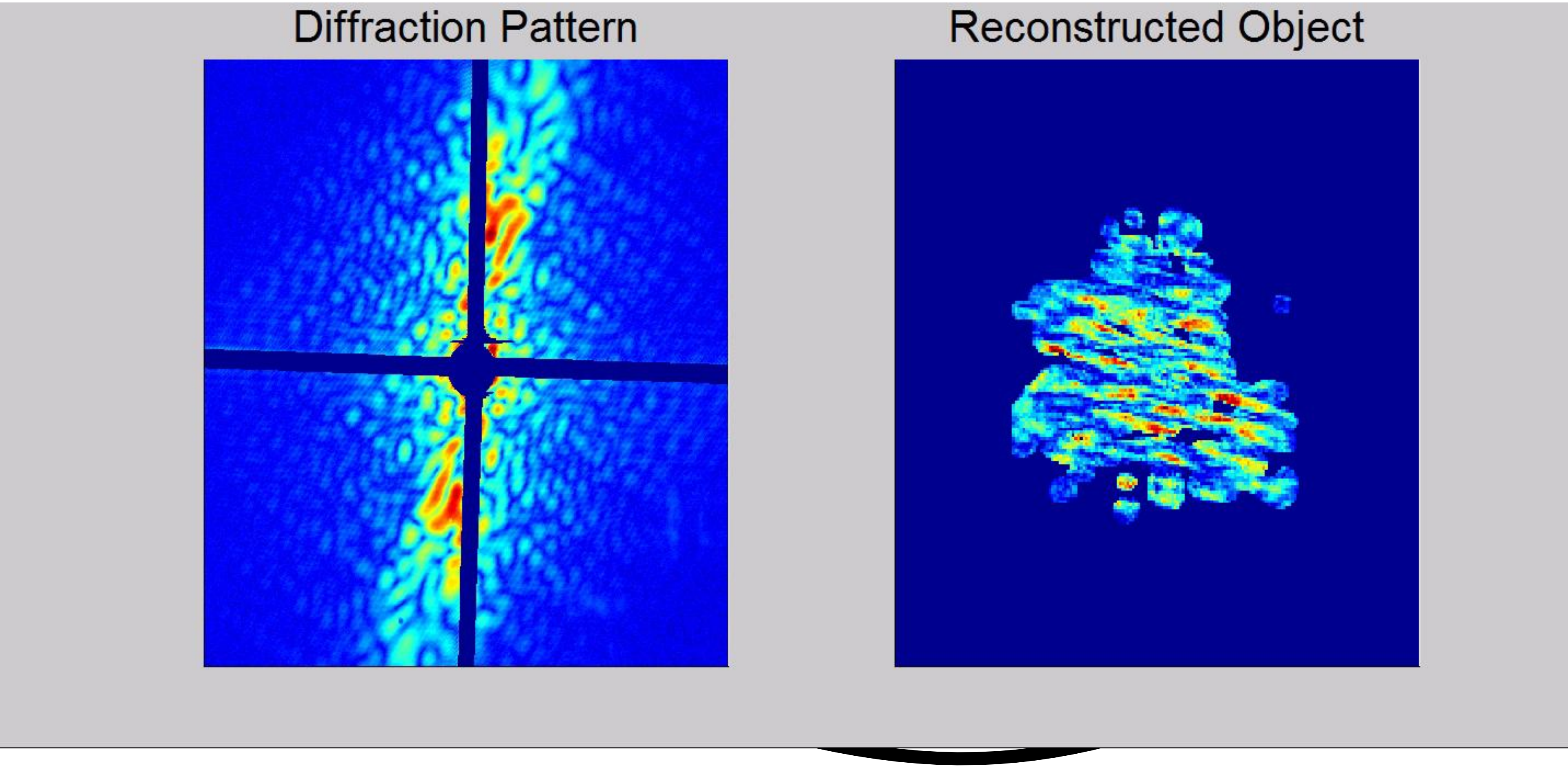


Abbey B., et al. Nat. Phot. 2011

For imaging phase is important !!!



How CDI works



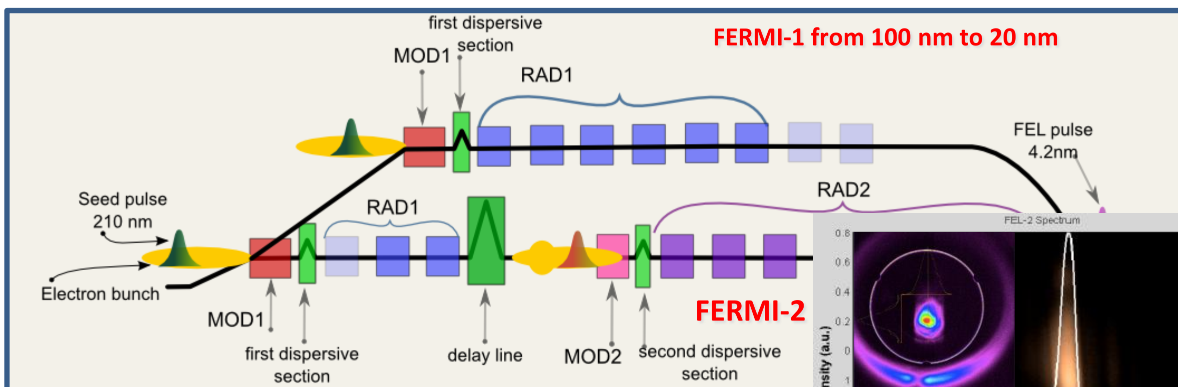
Impose "support" **Guess Phase**

FERMI source

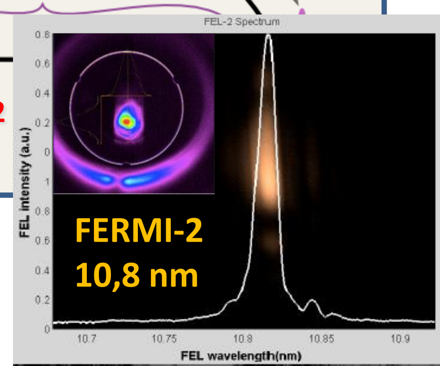
FERMI@Elettra is a single-pass seeded FEL user-facility.

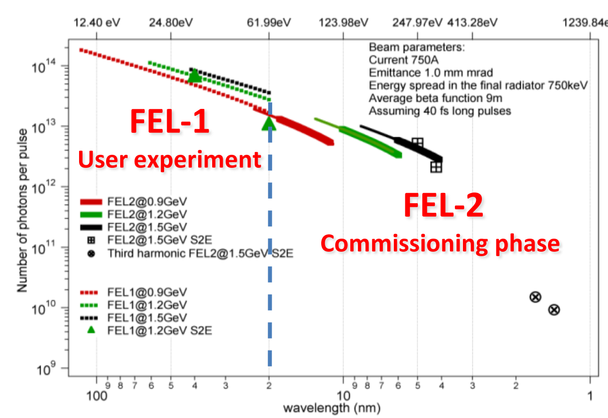
- ✓ Two separate FEL amplifier will cover the spectral range from 100 nm (12 eV) to 4 nm (320 eV).
- ✓ Based on the high gain harmonic generation scheme FERMI provides pulses of <100 fs with unique characteristics:

- ❑ ***high peak power***
- ❑ ***short temporal structure***
- ❑ ***tunable wavelength***
- ❑ ***variable polarization***
- ❑ ***seeded harmonic cascade***



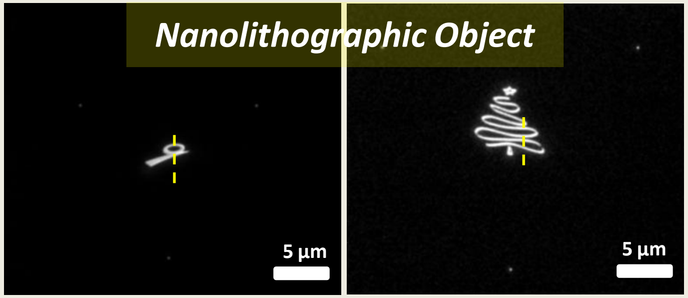
Ref: E.Allaria et al. Nature Photonics (2012)

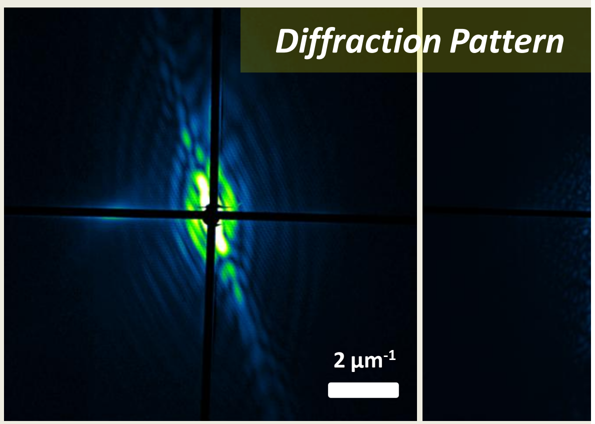


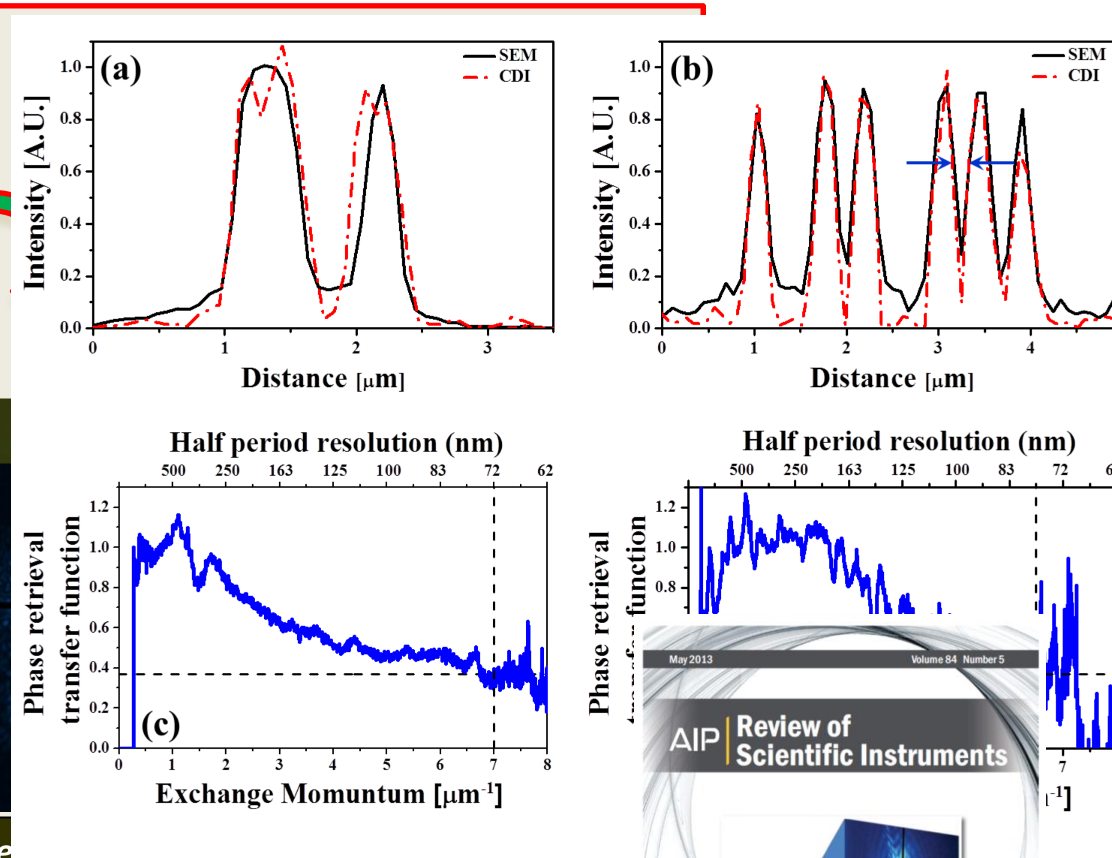


DiProI – CDI experiments

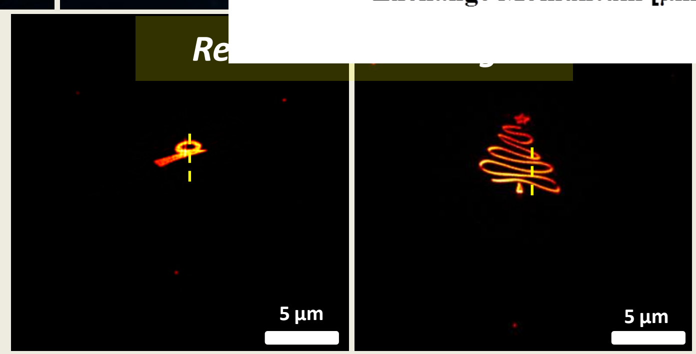
CDI From reciprocal to

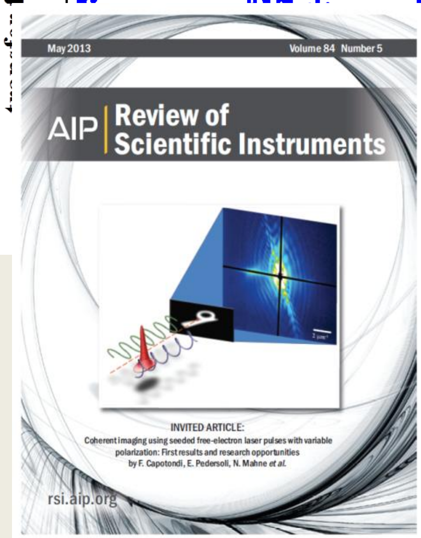






Phase retrieval algorithm



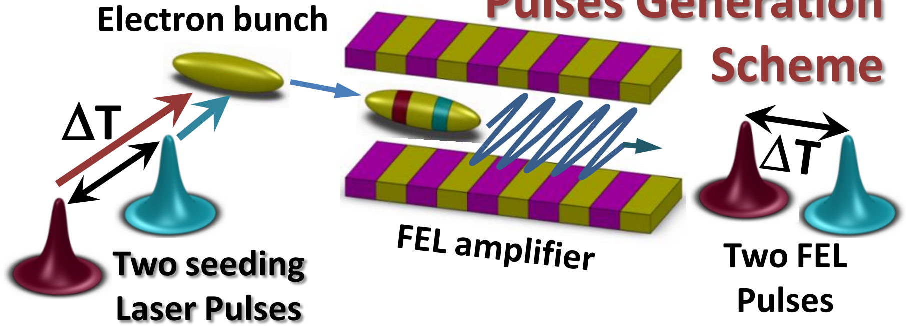


In collaboration with:
H.N.Chapman, S.Bait, M. Barthelmess

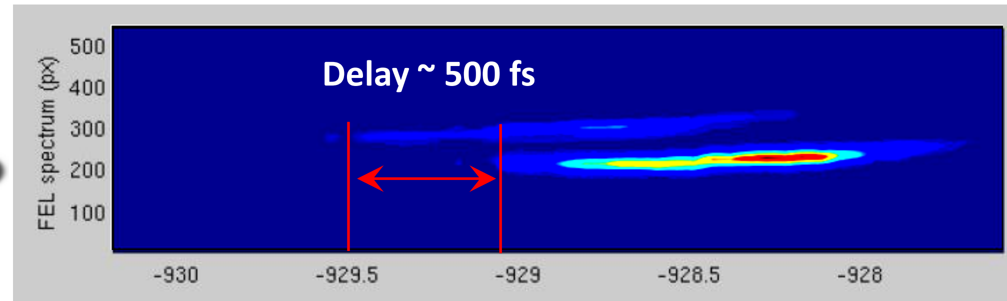
Further info on DiProI end station:
Rev. Sci. Instrum. 84, 051301 (2013)

Two Color Pump and Probe

Pulses Generation Scheme



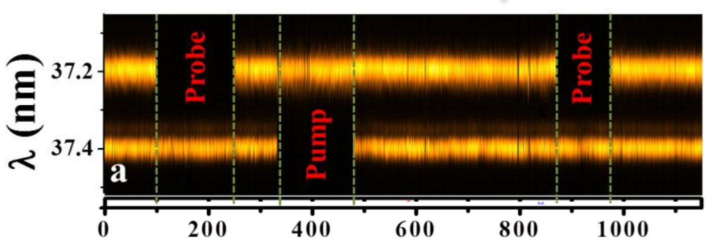
Pulses Delay

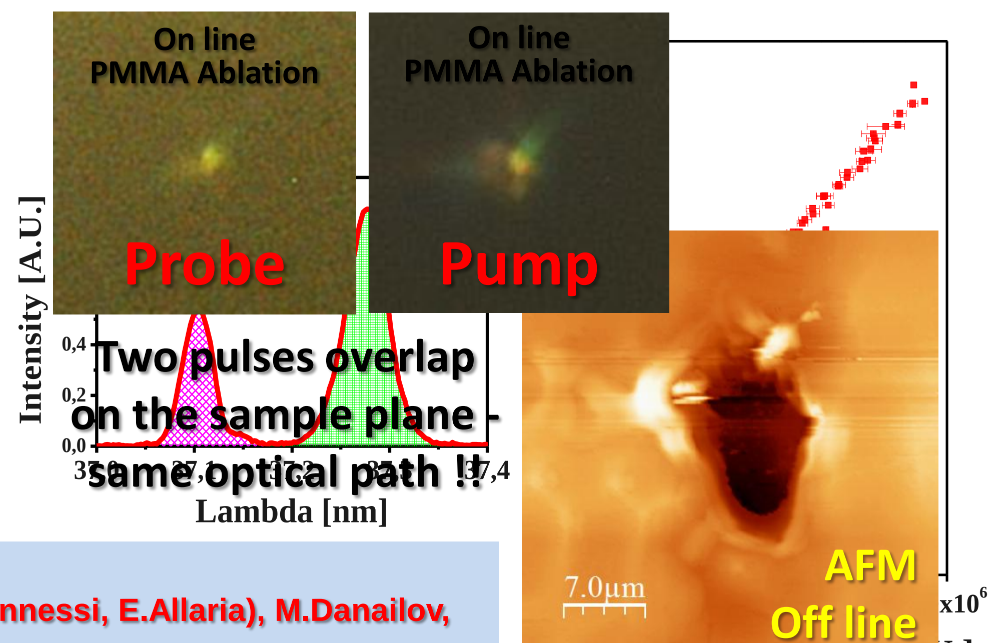


Spectrometer gives information of energy distribution among pulses

Pulses Overlapping on Sample Plane

FEL stability





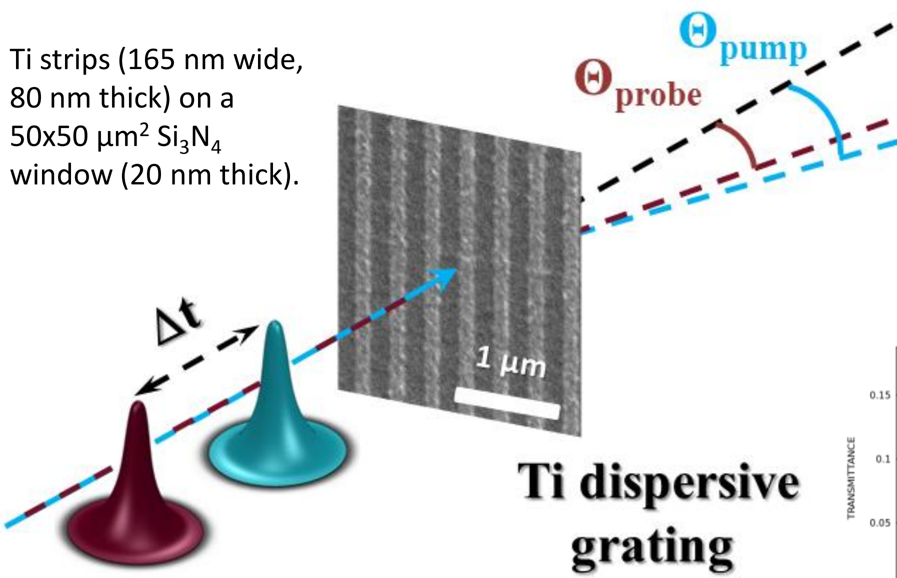
In collaboration with:
F.Bencivenca, D.Fausti, Fermi Commissioning Team (L.Giannessi, E.Allaria), M.Danailov, Padres Team (L.Raimondi, M.Zangrando).

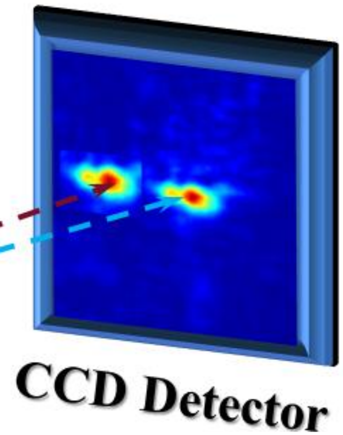
Nature Communication accepted for pubblication

Two Color Pump and Probe *(Experiment)*

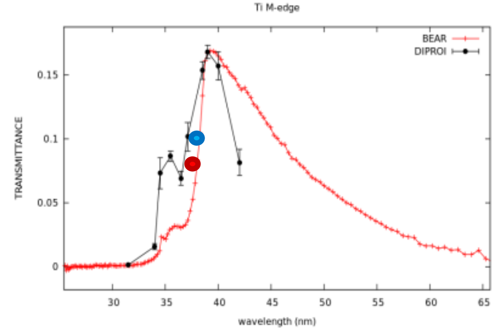
Two pulses tuned to wavelengths across the Ti- M edge

Ti strips (165 nm wide, 80 nm thick) on a 50x50 μm^2 Si_3N_4 window (20 nm thick).

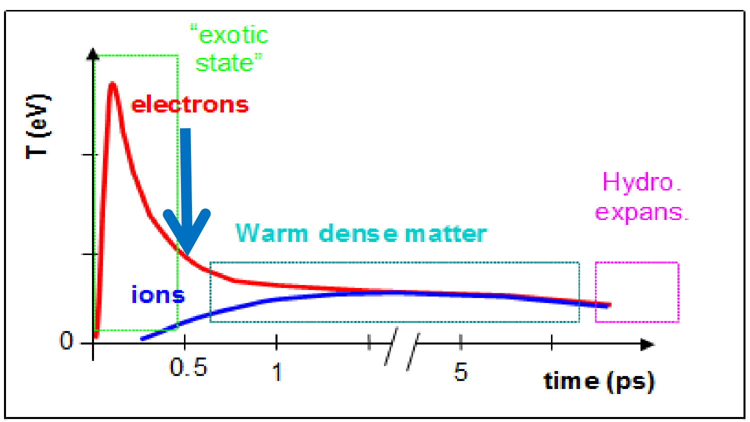




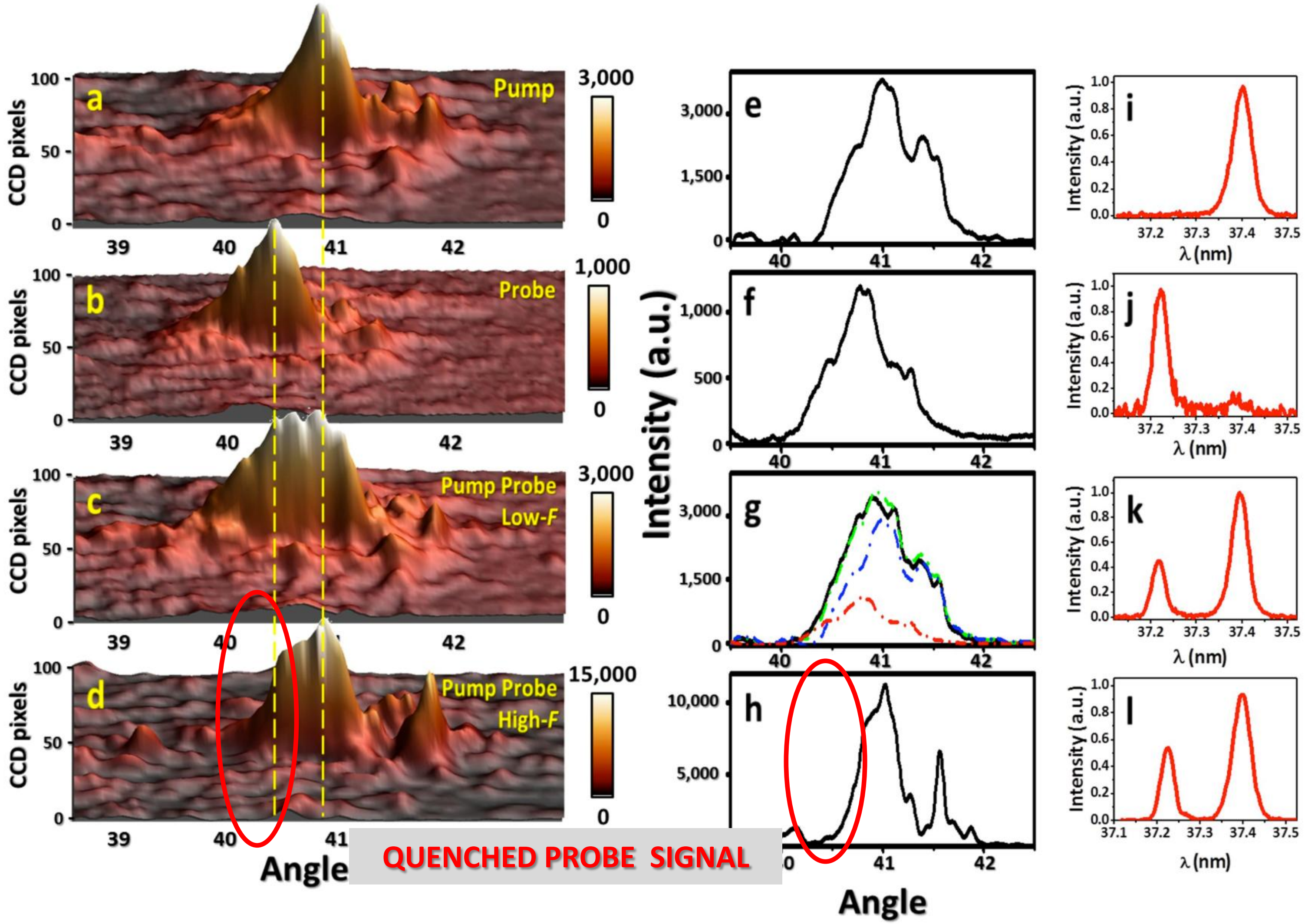
Time delay 500 fs



Line grating expansion is negligible before a few ps => no change in sample morphology is expected before the arrival of the probe

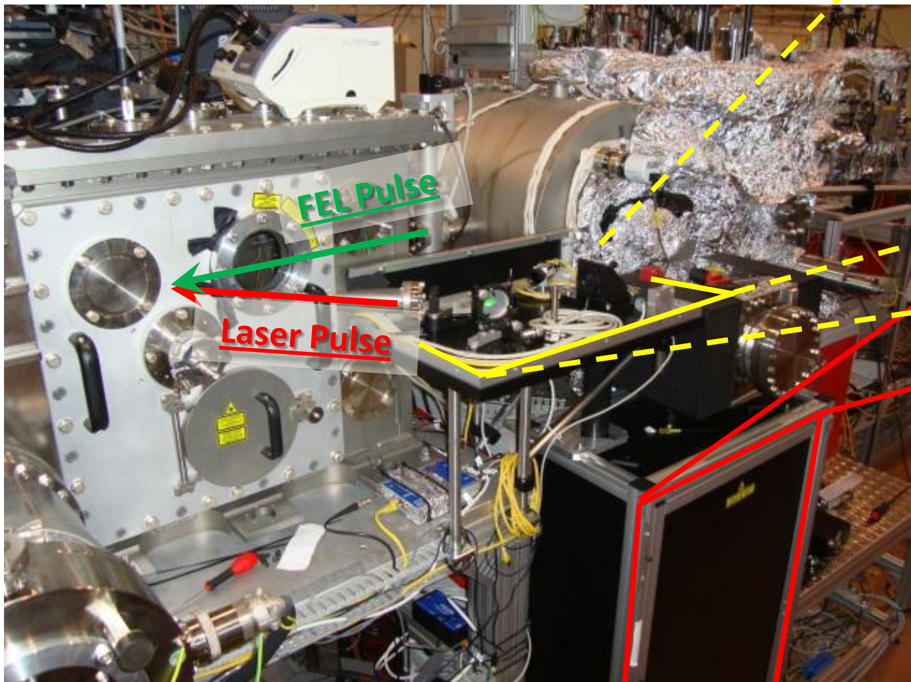


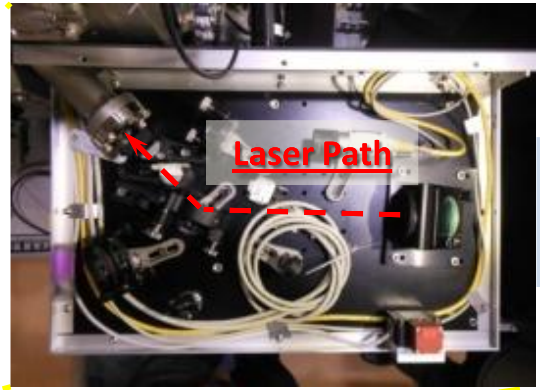
Two Color Pump and Probe *(Results)*



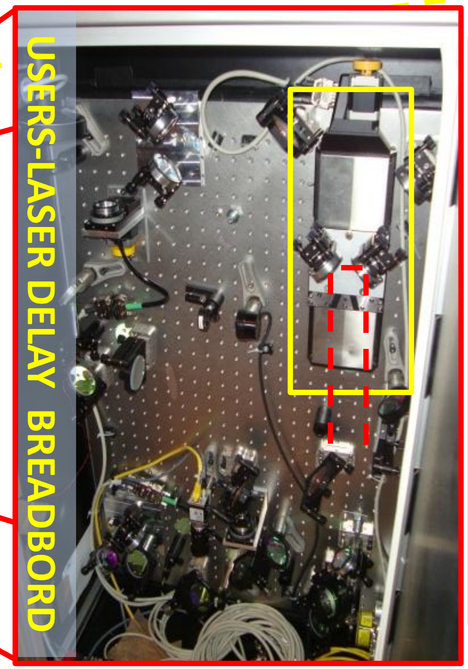
At high fluence → evidence for dramatic changes in the Ti electronic structure: high degree of ionization that makes the grating 'transparent'.
The pulse length (~90 fs) and the delay (500 fs) are shorter than the time scales of hydrodynamic expansion 1 - 10 ps

DiProI – user laser





USERS-LASER COUPLING BREADBORD



Two pass optical Delay line +/- 330 ps
(to be extended to +/- 660 ps)

Automatic attenuator plate and vertical horizontal polarizer

Laser shot-by-shot Intensity monitor

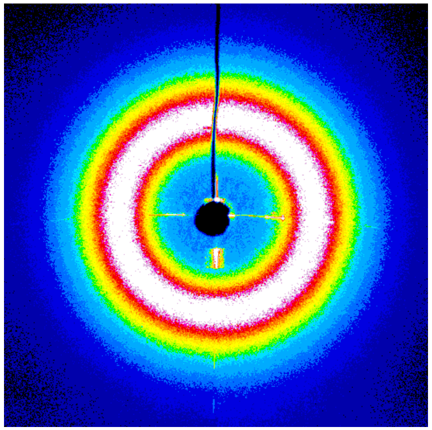
Pulse selector shutter

Since FEB-2013 DiProI end station equipped with external user laser

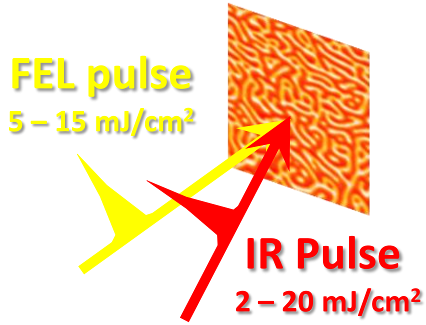
In collaboration with: M.Danailov, A.Demidovich, K.Gabor, I.Nikolov, P.Cinquegrana, P.Sigalotti

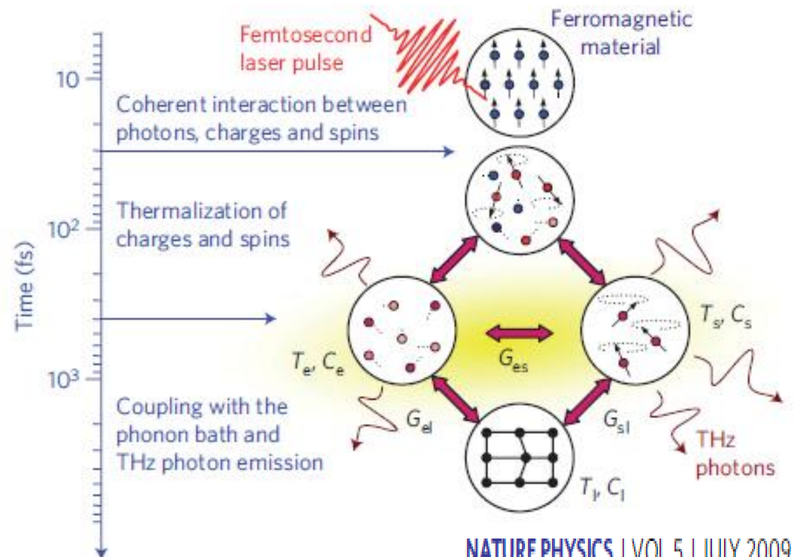
Fast Demagnetisation with FERMI

Maze domain



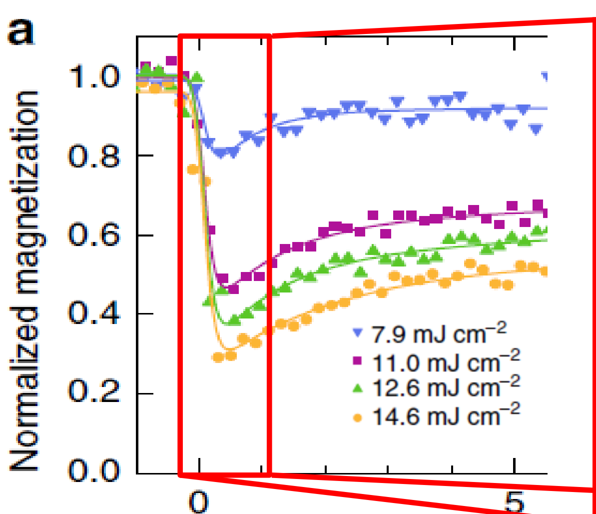
Co/Pt ML SASX ring at 20.8 nm

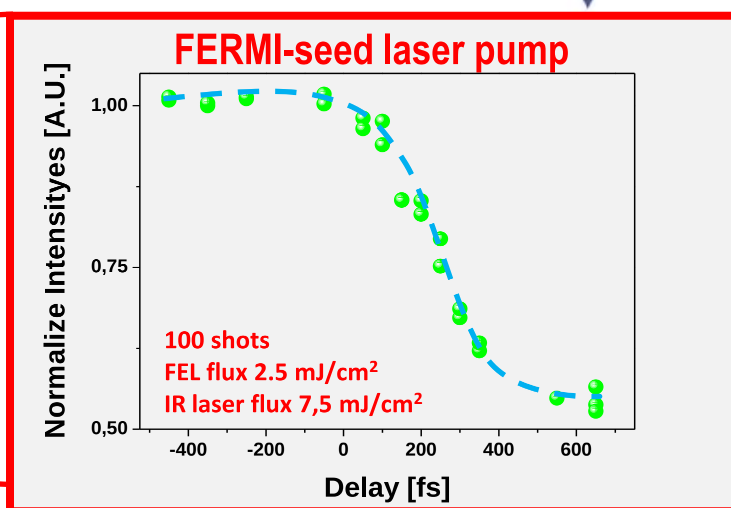




NATURE PHYSICS | VOL 5 | JULY 2009

B. Pfau et al Nature Com. (2012): time resolution 250 fs





...st magnetism induced by
...er pulses

and Eric Beaurepaire

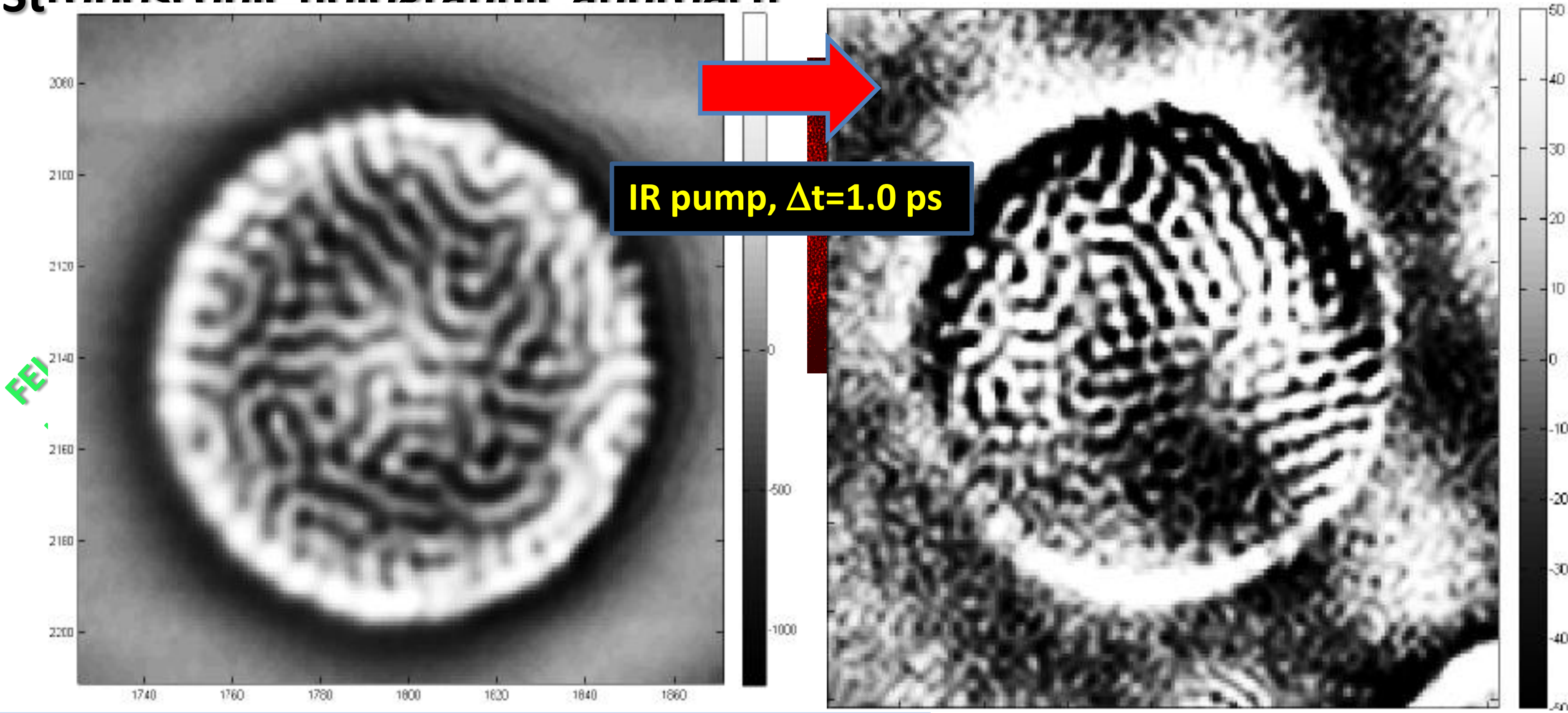
G.Grübel, C. Gutt, L. Müller, J. Lüning, B.Vodungbo, S.Eisebitt , B.Pfau ...

Fast Demagnetisation with FERMI

<u>Question:</u> is it possible to observe the domain walls evolution during fast demagnetization processes?

IR pump 15 μJ (~10-20 mJ/cm2), Time delay 1 ps, 1 μJ FEL shot
Sum of 6000 images, Difference between Left and right circular

Stroboscopi



G.Grübel, C. Gutt, L. Müller, J. Lüning, B.Vodungbo, S.Eisebitt , B.Pfau …

COLLABORATORS

Internal and external

Elettra Sincrotrone Trieste

DiProI: M. Kiskinova (coordinator),F. Capotondi (BL scientist), E. Pedersoli (post-doc)
Lasers: M. Danailov, A. Demidovich, I. Nikolov (pump&probe laser)
Others: R. Menk (consulting for detectors), R. Borges (software),
C. Spezzani, F. Bencivenga, C. Masciovecchio, D. Fausti, and all the FERMI TEAM
(collaboration for instrumentation and experiments)

PADReS: M. Zangrando, N. Mahne, L. Raimondi, C. Svetina (beamlines, optics)

Photon Analysis Delivery & REduction System

CFEL SCIENCE – DESY – UHH: H. Chapman, S. Bajt, A. Barty et al.

PULSE STANFORD: M. Bogan et al.

Lawrence Livermore National Laboratory: A. Nelson, M. Frank et al.

UPPSALA UNIVERSITET: J. Hajdu et al.

TU berlin: S. Eisebitt et al.

DESY: G.Grübel, C. Gutt, L. Müller, B. Keitel,K. Tiedtke,E. Plönjes-Palm et al.

Laser-Laboratorium Göttingen e.V.: K. Mann, T. Mey

UPMC SORBONNE UNIVERSITÉS: J. Luning et al.

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THANK YOU FOR YOUR ATTENTION

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