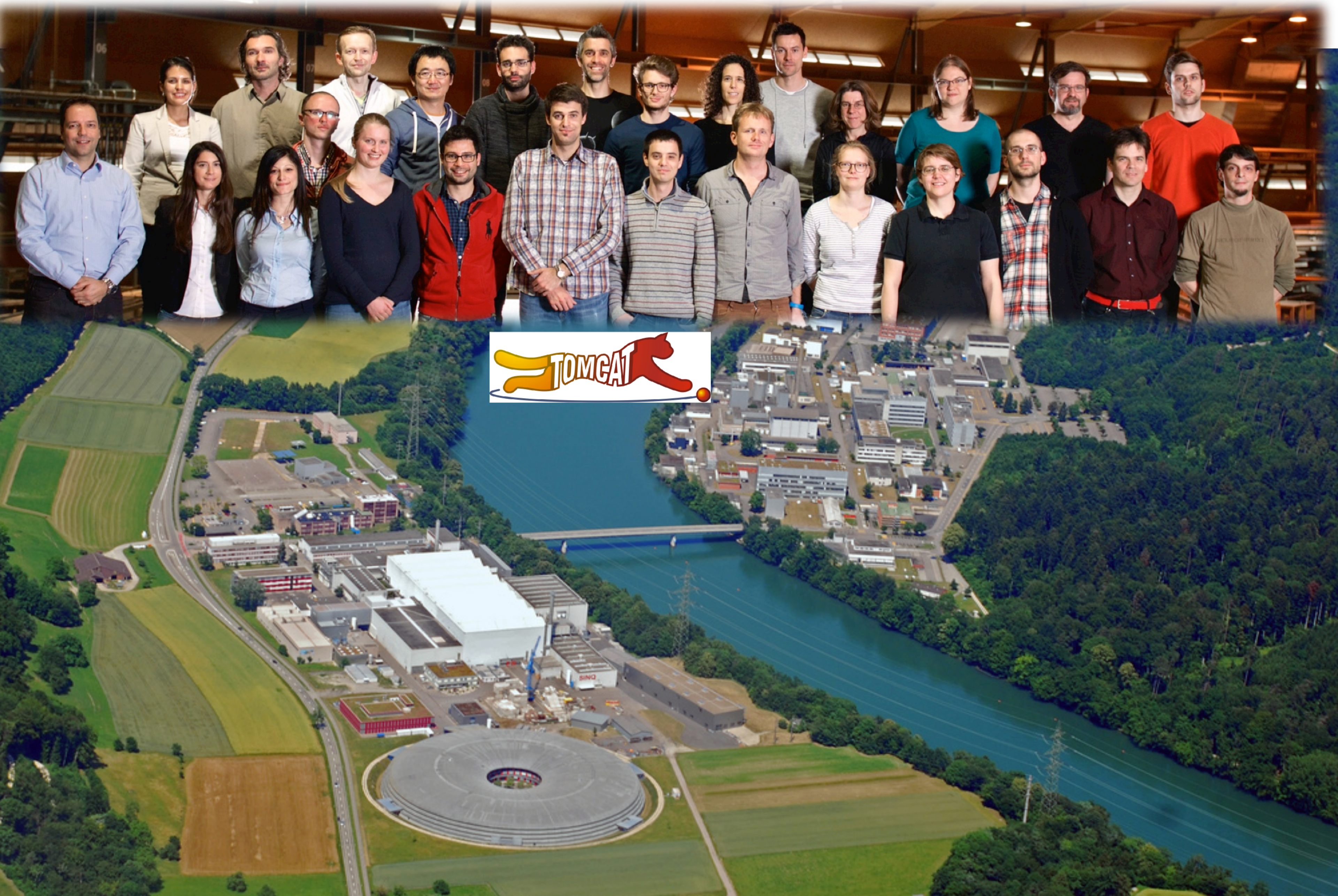
Fast and ultrafast imaging

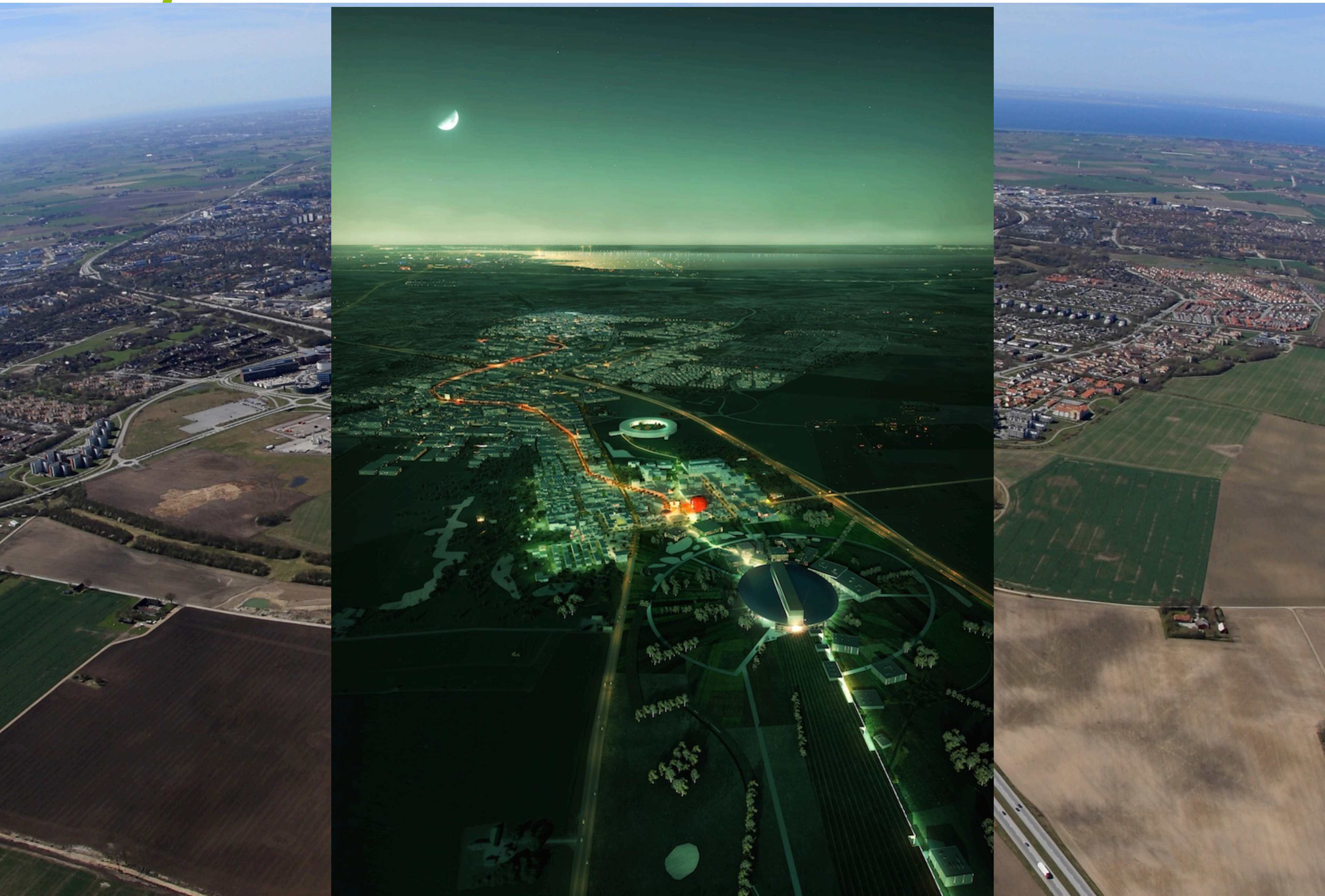
Rajmund Mokso

Max IV Laboratory

Synchrotron Facilities: Swiss Light Source



Synchrotron facilities: Max IV

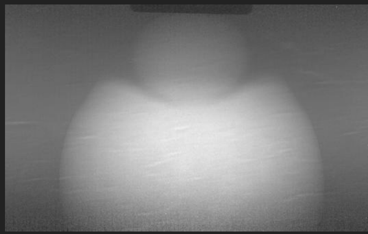


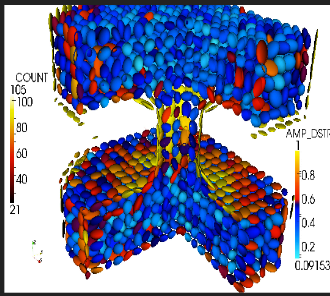
Outline

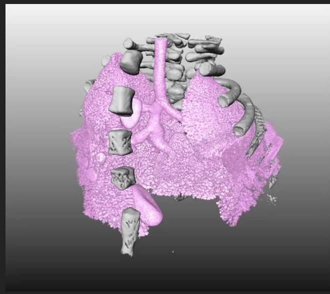
I. Ultrafast 2D imaging
   I. Dynamic processes

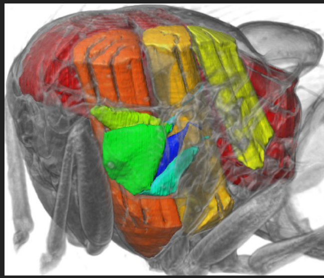
II. Fast 3D imaging
   I. The ingredients

III. Examples
   I. Lungs, fly, foams









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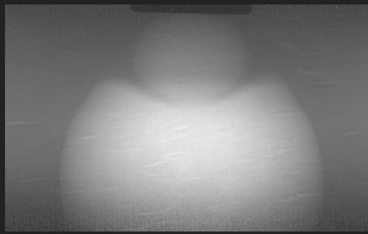

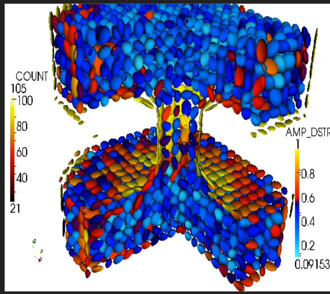

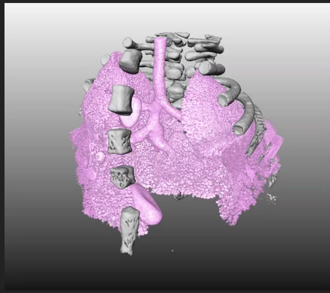

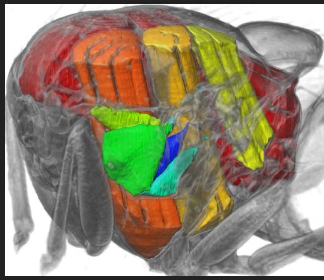

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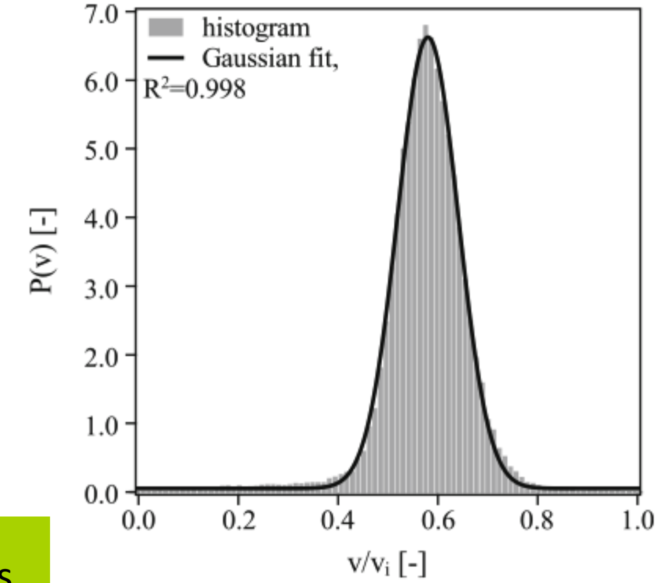
Abrasive water jet

Exp Fluids (2013) 54:1476
DOI 10.1007/s00348-013-1476-8

RESEARCH ARTICLE

Ultra-fast X-ray particle velocimetry measurements within an abrasive water jet

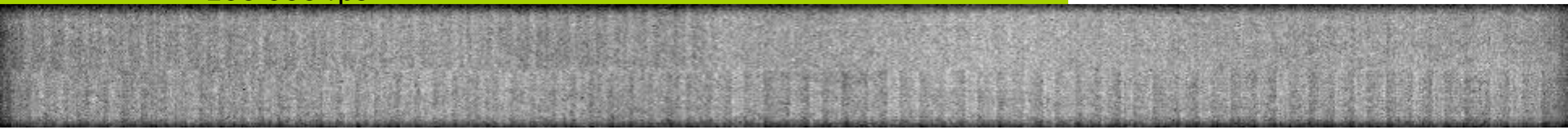
R. Balz · R. Mokso · C. Narayanan · D. A. Weiss · K. C. Heiniger

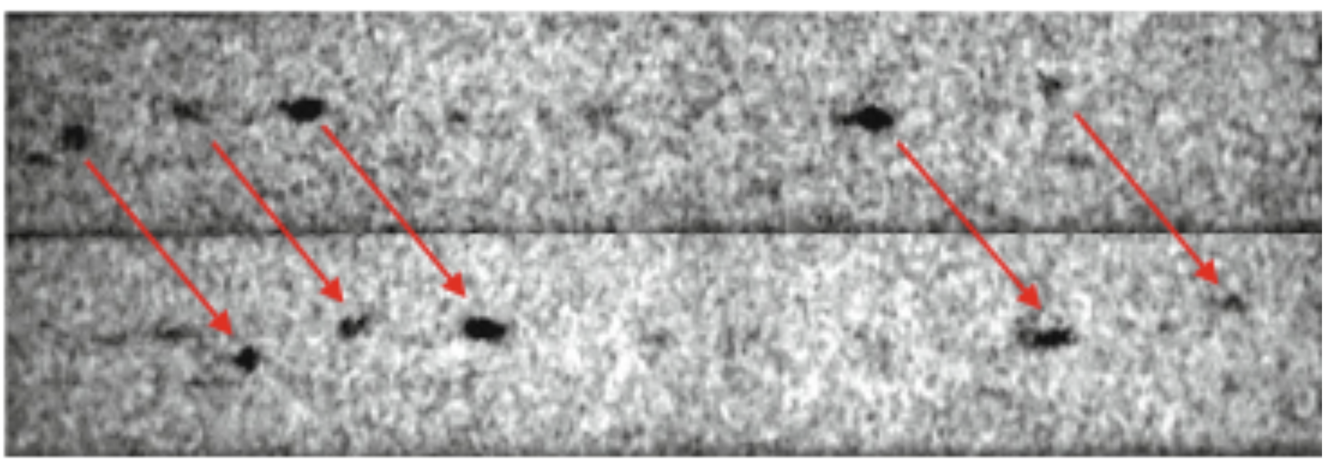


ultra-fast micro radiology

100 000 fps

1 μs and 5 μs





particle speed: 435 m/s

Balz, Mokso et al., Exp. Fluids, 2013

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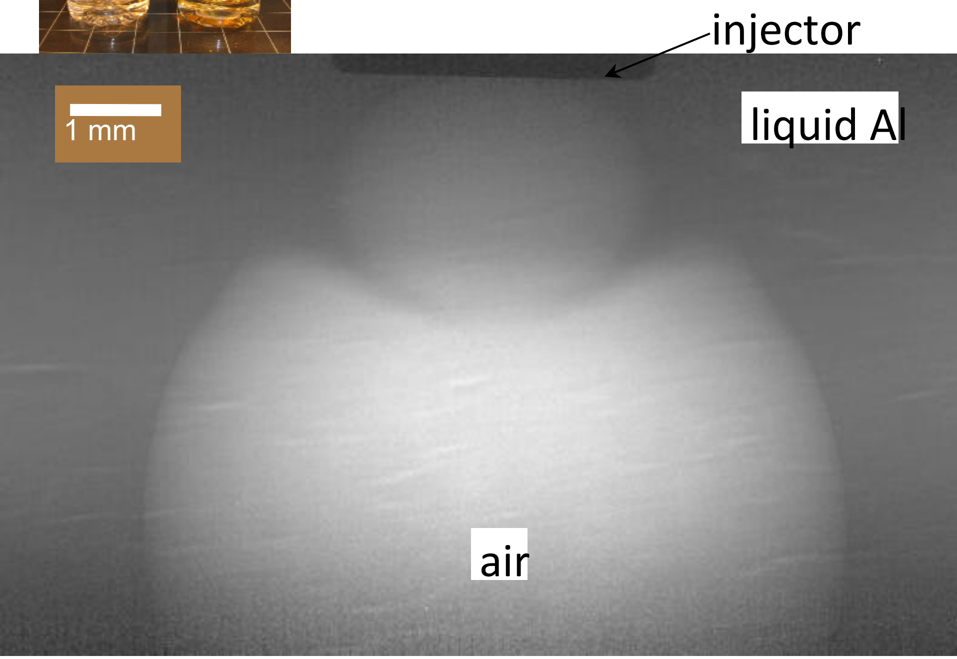
Creating superior metallic foams

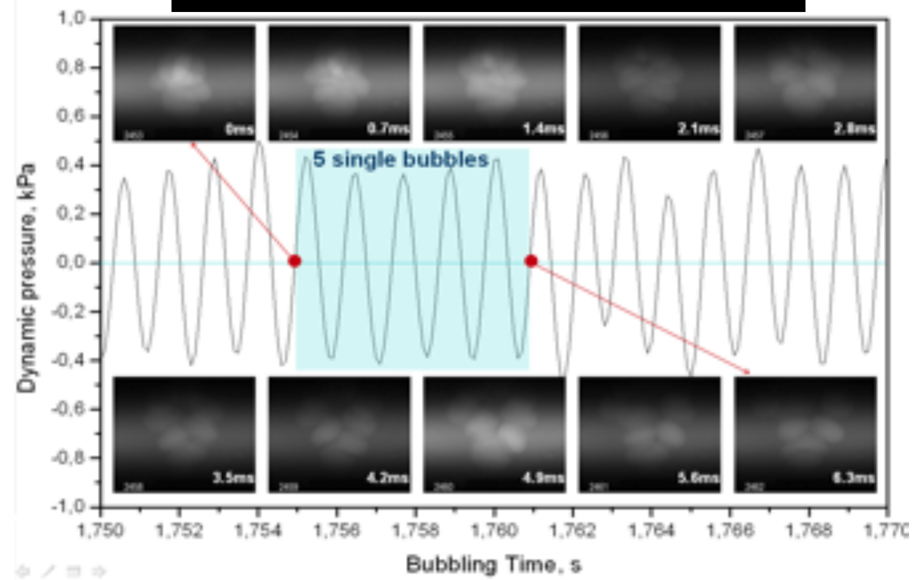
controlling the bubble sizes in metallic foams
big bubbles vs. small bubbles



Alu. melting temperature conditions

10.000 fps - total observation time ~ 20 s

correlation with gas pressure



New properties:

- mashinable
- weldable
- fire proof
- castable

Babcsan, Mokso et al., TMS, 2012

Fast dynamics in 2D

Metals **2012**, *2*, 10-21; doi:10.3390/met2010010

OPEN ACCESS

metals

ISSN 2075-4701

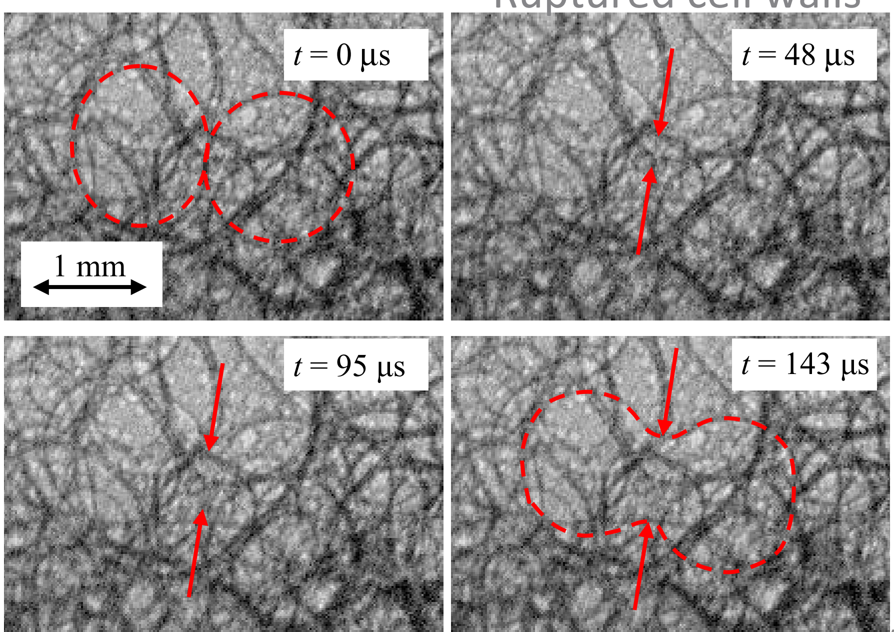
www.mdpi.com/journal/metals/

Review

Metal Foaming Investigated by X-ray Radioscopy

Francisco Garcia-Moreno [1,2,*], Manas Mukherjee [1,2], Catalina Jiménez [1,2], Alexander Rack [3] and John Banhart [1,2]

Ruptured cell walls



Frame rate: 105 kHz
Pixel size: 20 µm

Al foam nucleation

Liquid Aluminum, nanoparticle stabilisation

projections of tomographic acquisitions
scan time = 100 ms, pix. size = 3 μm
Acquisition time= 10 s

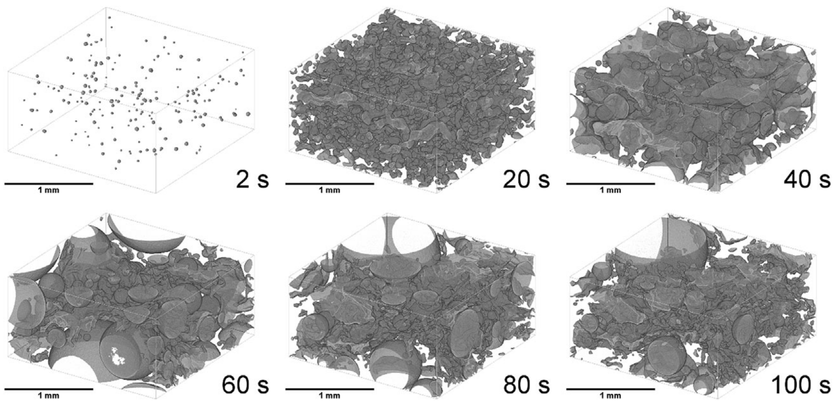
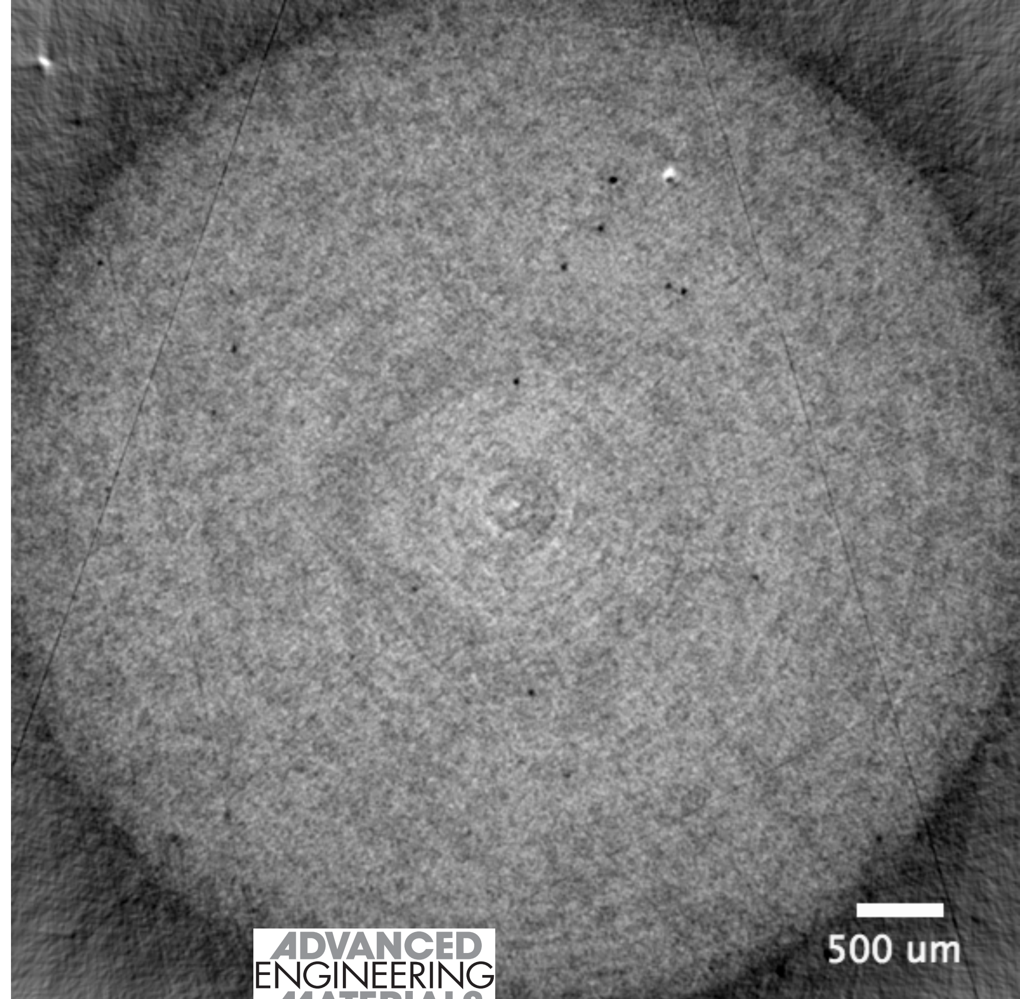


Fig. 2. Tomographic reconstructions (subset of entire volume) of the bubble structure of AlMg17.5 alloy foamed at 650 °C. Specific times are selected, namely t = 2, 20, 40, 60, 80, and 100 s after the onset of foaming. Bubble evolution is clearly observable.



ADVANCED ENGINEERING MATERIALS

DOI: 10.1002/adem.201600550

Fast Synchrotron X-Ray Tomography of Dynamic Processes in Liquid Aluminium Alloy Foam**

By *Paul Hans Kamm, Francisco García-Moreno,** *Tillmann Robert Neu, Korbinian Heim, Rajmund Mokso* and *John Banhart*

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MAX IV

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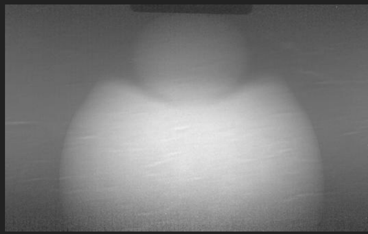
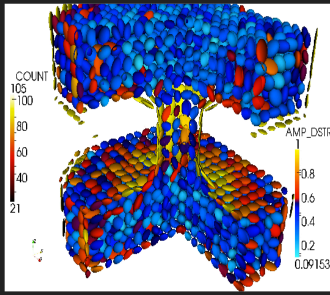
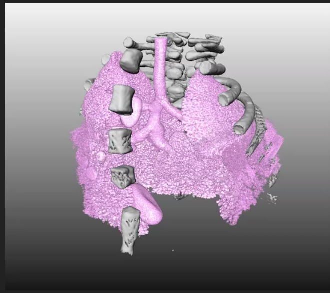
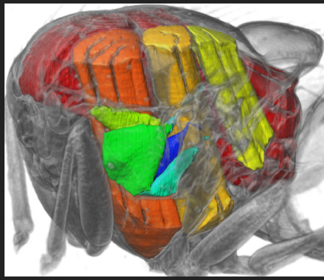
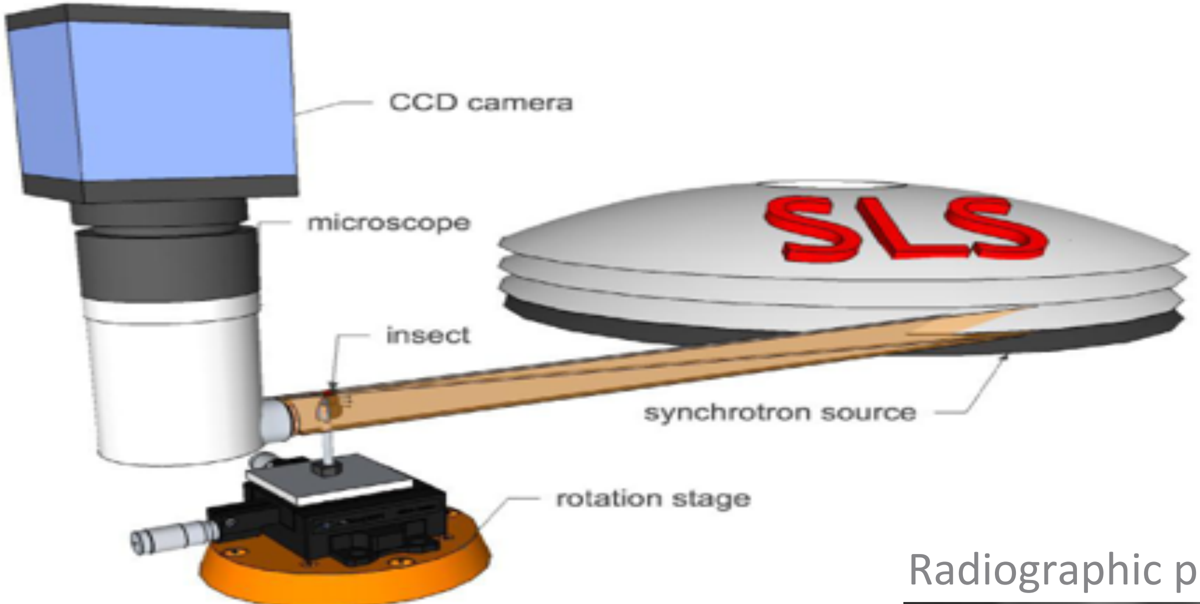








Tomographic microscopy at synchrotron



Pixel size: 11 -> 0.3 µm

FOV: 22 x 22 -> 1 x 1 mm^2

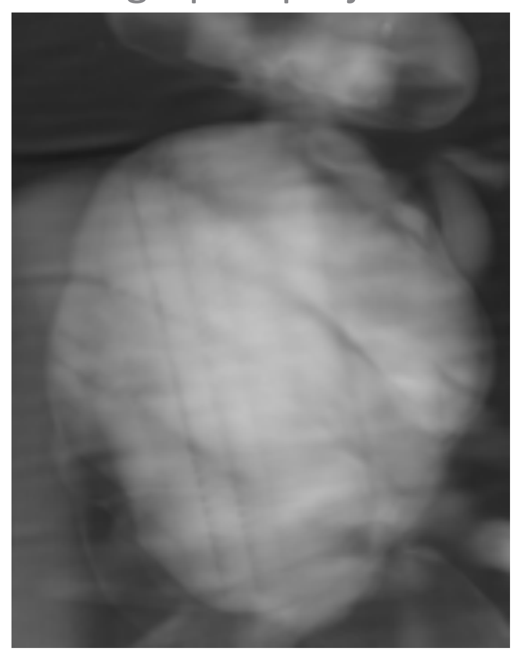
Projections: 300–2000

Exposure times: 0.1–300 ms

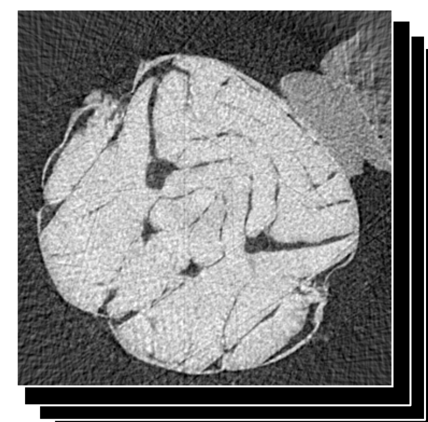
Total scan time: 0.05 to 500 s

sample rotation over 180 deg

Radiographic projections



Tomographic slices



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Scan time improvements over time

What is the rate of acquisition speed increase of synchrotron microtomography?

(a) 1 order of magnitude every 3 years
(b) Two fold every year
(c) Five fold every year
(d) exponential

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Imaging at XFELs

SCIENTIFIC REPORTS

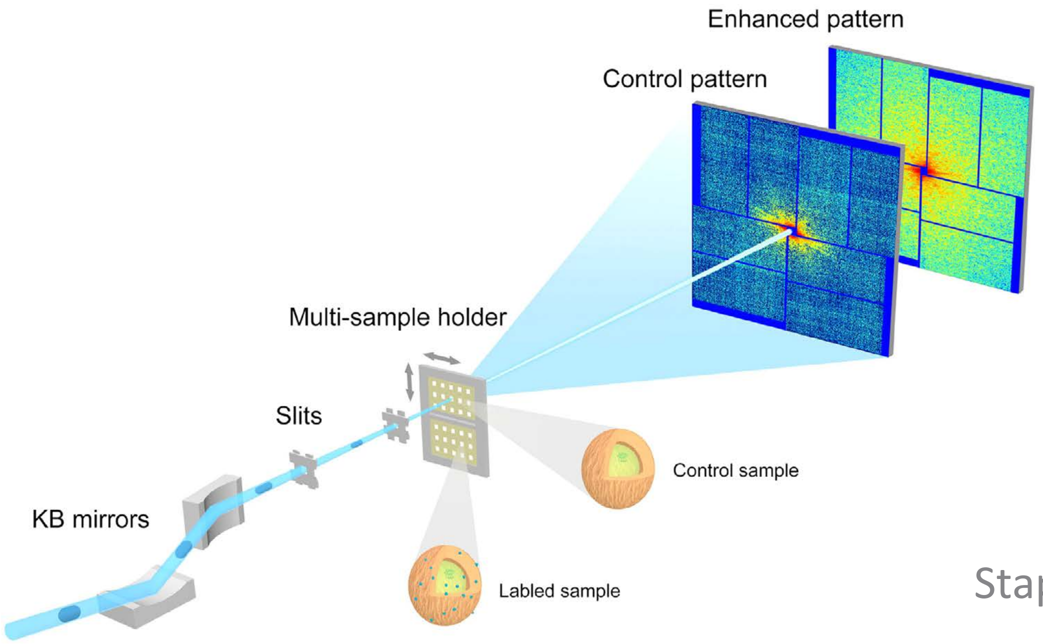
OPEN

Single-pulse enhanced coherent diffraction imaging of bacteria with an X-ray free-electron laser

Received: 25 March 2015
Accepted: 06 September 2016
Published: 23 September 2016

Jiadong Fan[1], Zhibin Sun[1], Yaling Wang[2], Jaehyun Park[3], Sunam Kim[3], Marcus Gallagher-Jones[4], Yoonhee Kim[5], Changyong Song[6], Shengkun Yao[1], Jian Zhang[1], Jianhua Zhang[1], Xiulan Duan[1], Kensuke Tono[7], Makina Yabashi[3], Tetsuya Ishikawa[3], Chunhai Fan[8], Yuliang Zhao[2], Zhifang Chai[2], Xueyun Gao[2], Thomas Earnest[8,9] & Huaidong Jiang[1,10]

Imaging at XFELs



Staphylococus aureus

Figure 1. Schematic layout of the enhanced single-pulse coherent diffraction imaging experiment. In front of the sample chamber, a pair of Kirkpatrick-Baez mirrors was used to focus the X-ray pulse to $\sim 2 \times 2\,\mu m^2$.

Imaging at XFELs

Resolution 60-150 nm

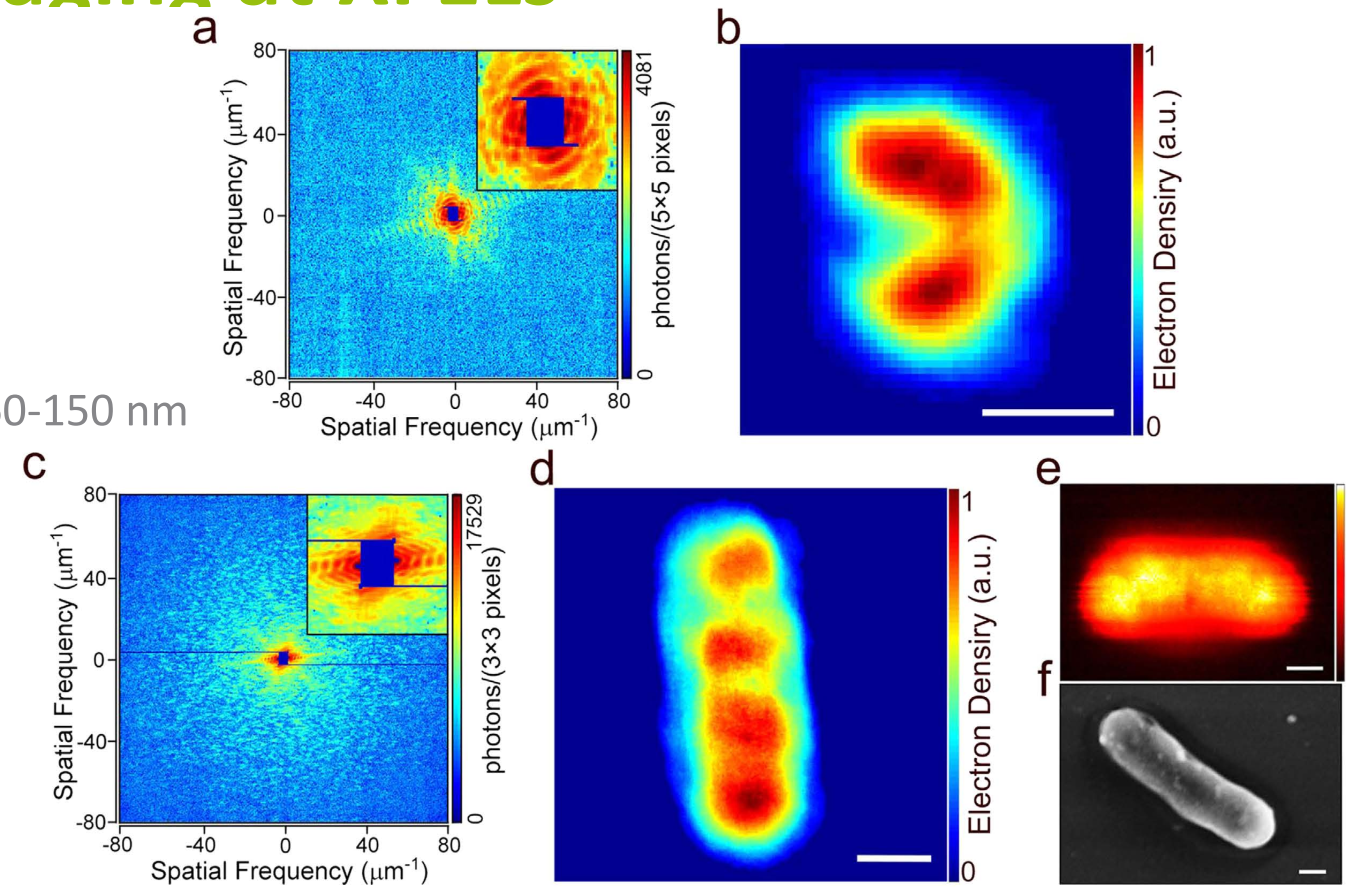


Figure 3. Reconstructions of *S. aureus* strains. (**a**) A representative diffraction pattern of control *S. aureus*. (**b**) A reconstructed image of an *S. aureus* cell from the diffraction pattern (**a**) shows two tightly connected daughter cells. (**c**) A representative diffraction pattern of labeled *S. aureus* cells, in which the diffracted signals extend to the edge of the MPCCD. (**d**) Four tightly connected daughter cells; a reconstruction result from (**c**) showing the diffraction pattern. (**e**) SEM image of another labeled *S. aureus* strain on the same membrane. (**f**) Scanning transmission X-ray microscopy image showing the morphology and density contrast of the labeled *S. aureus* cells. Scale bars, 300 nm.

Imaging at XFELs

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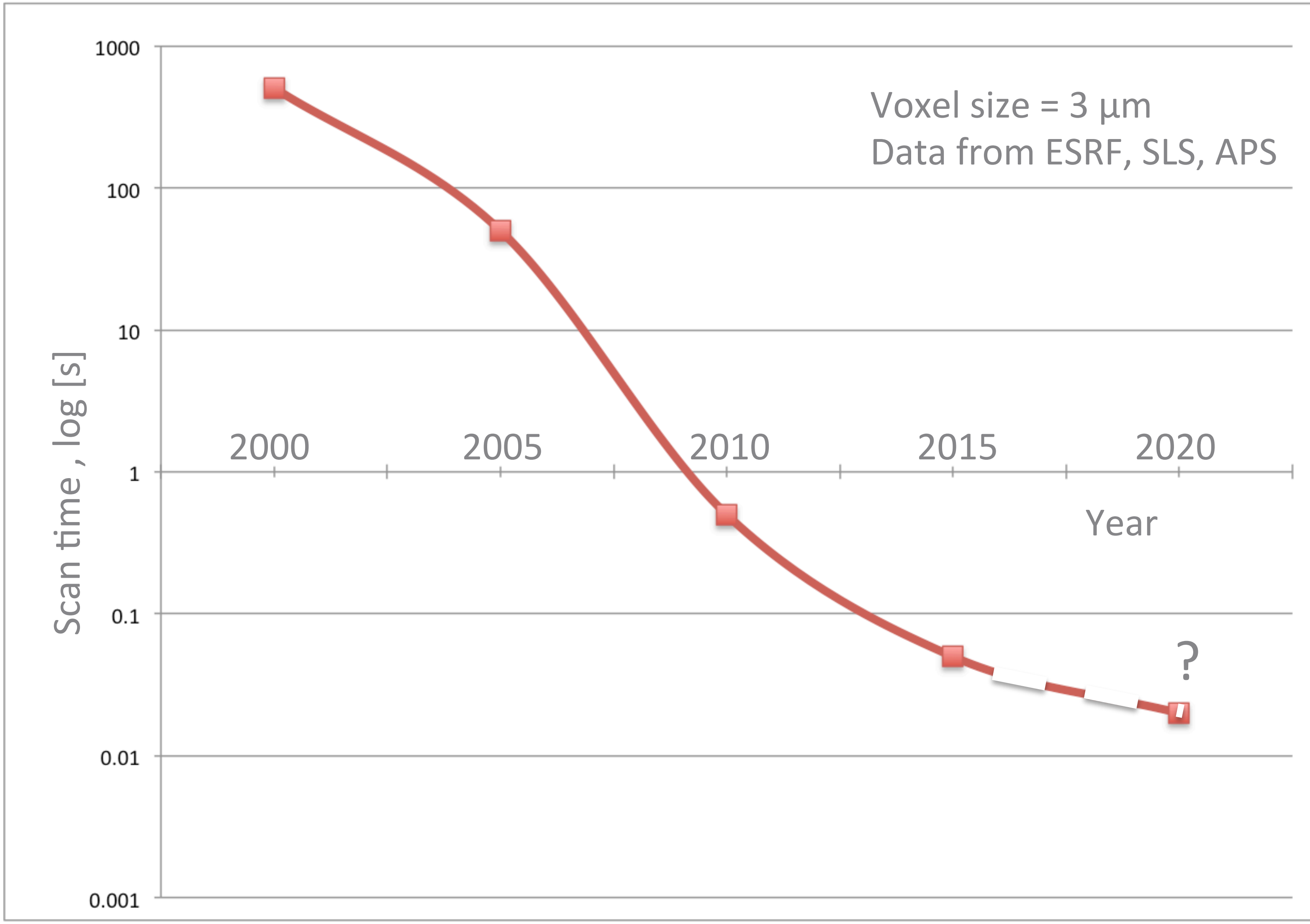
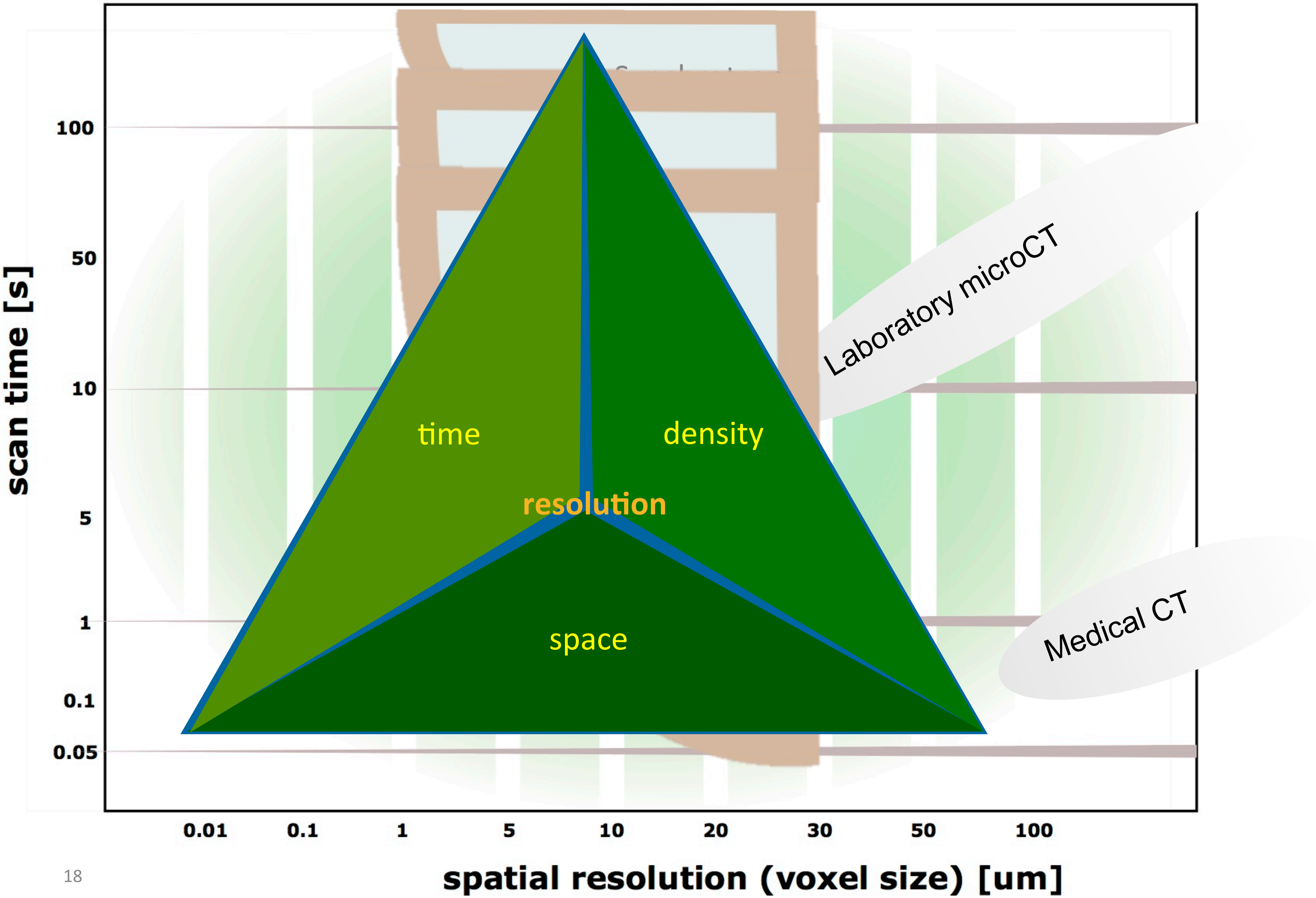
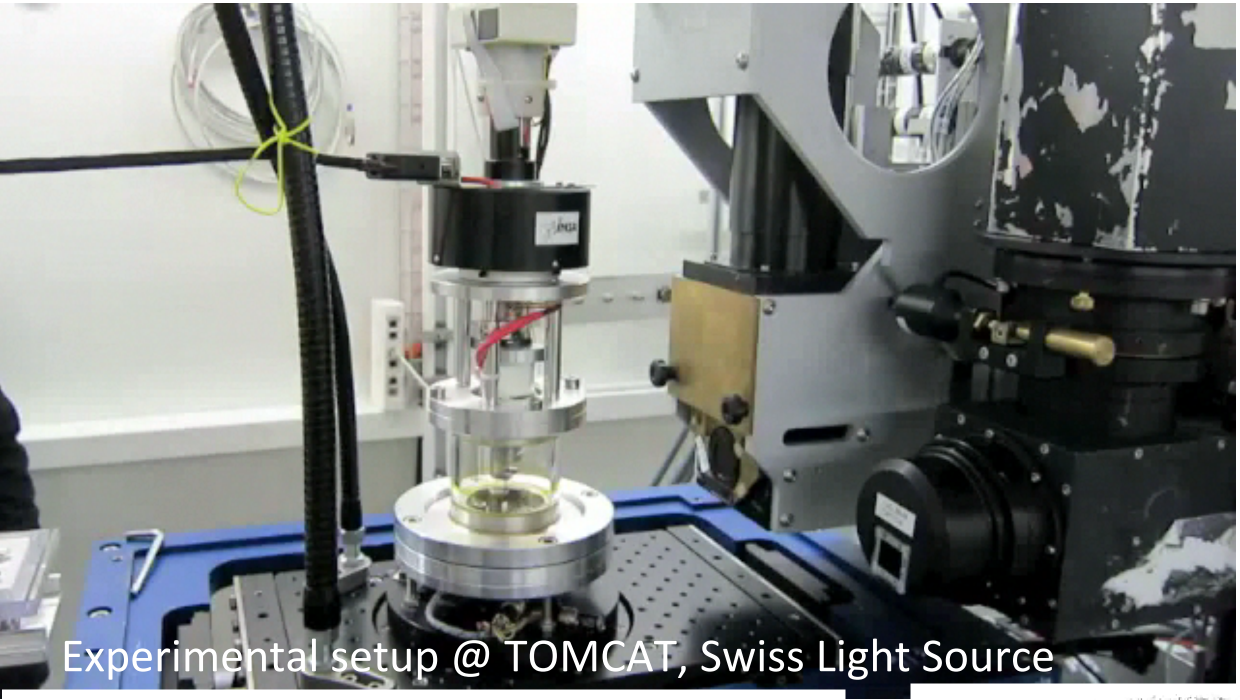
Foam scan time improvements over time



Fast tomographic microscopy: 3D

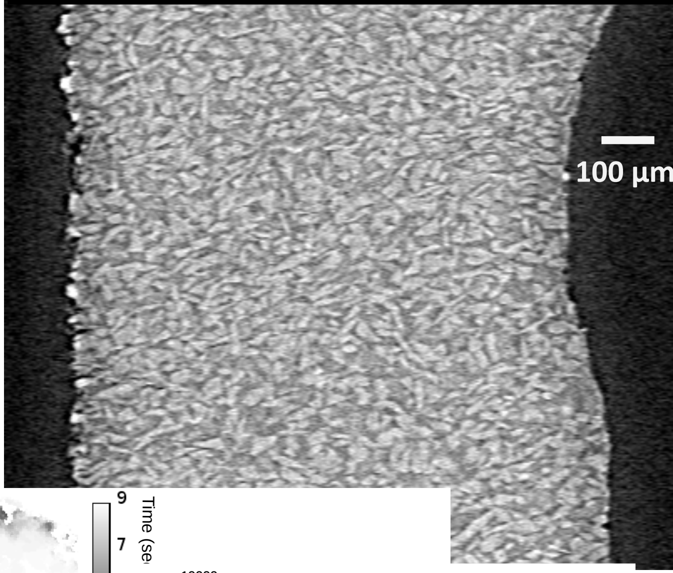


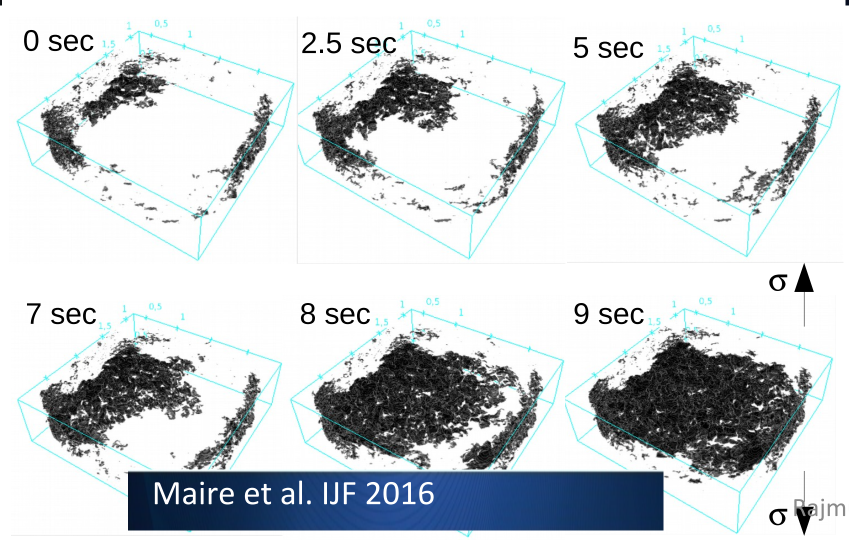
Crack visualization in 3D at 20Hz

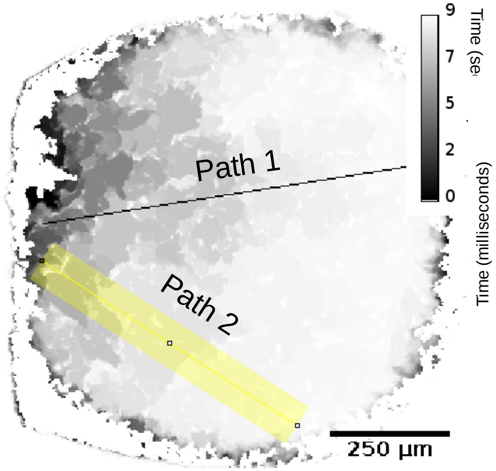


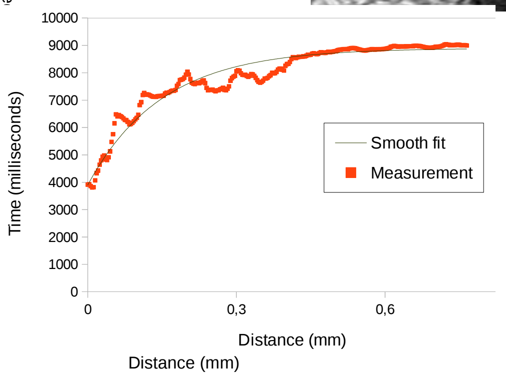
Al – Alumina (Eric Maire, INSA Lyon)

Vertical tomographic slice, time separation ~ 50 ms, voxel = 3µm









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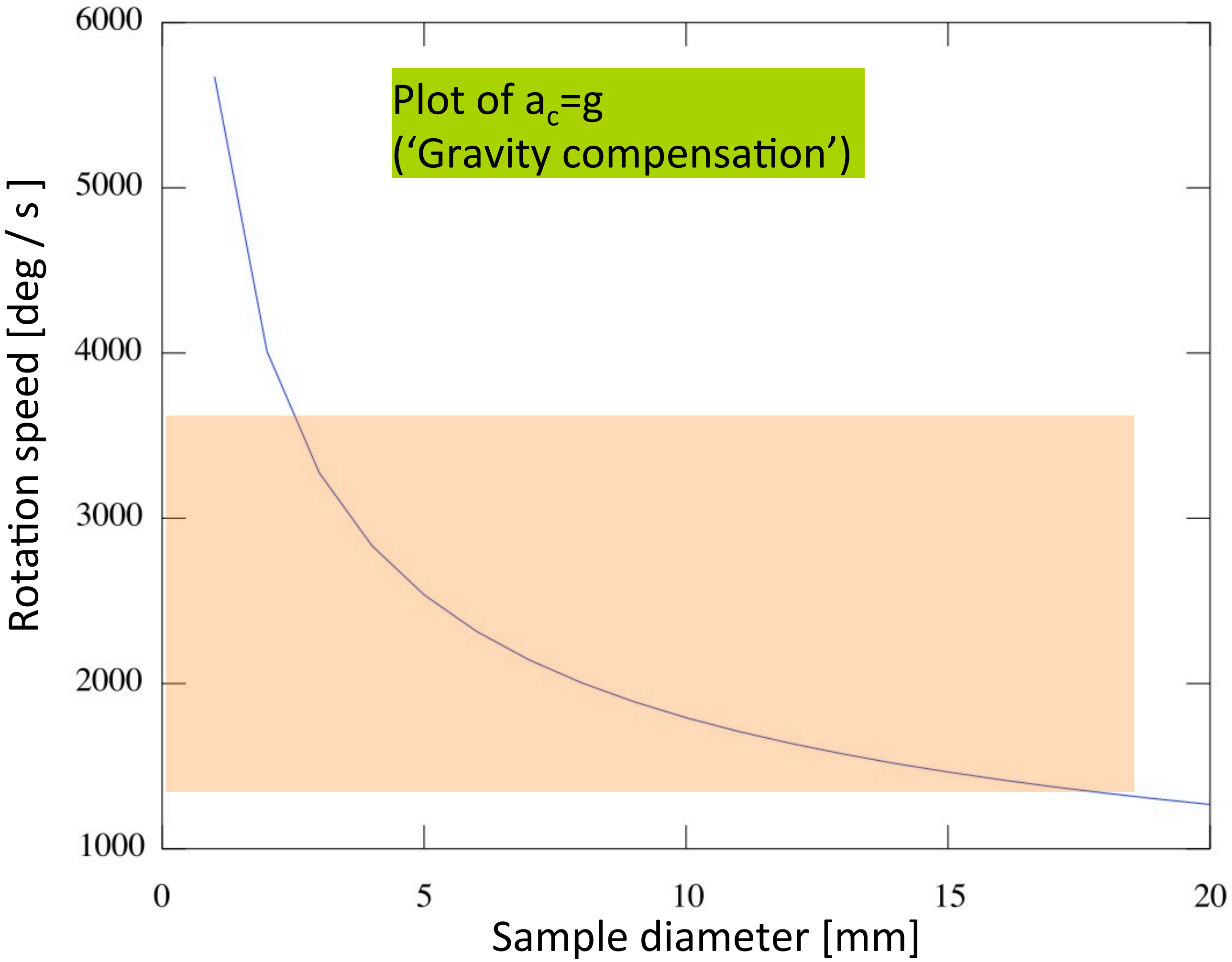
Mechanical requirements



I. Sample holder balancing (with precision)

The ingredients of fast tomography

- The brilliance of the synchrotron sources
- Fast detectors
- Sensing the phase
- Advanced tomographic reconstruction algorithms
- Image analysis with physical priors

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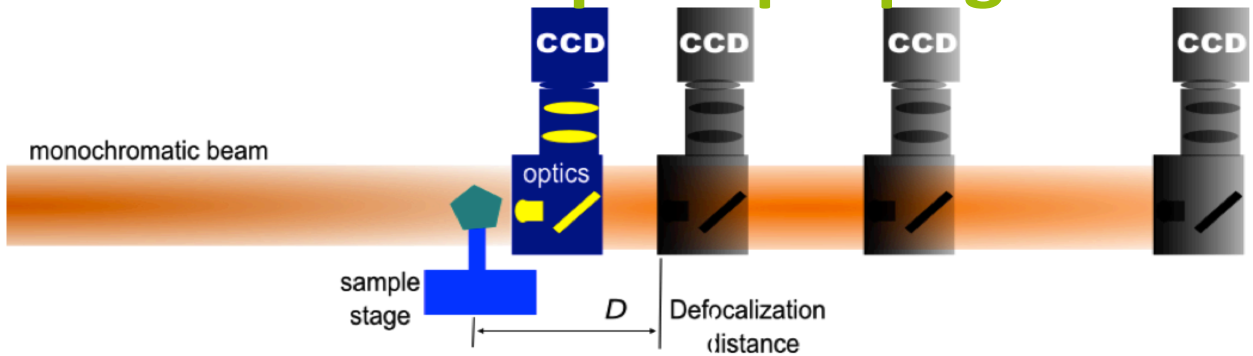
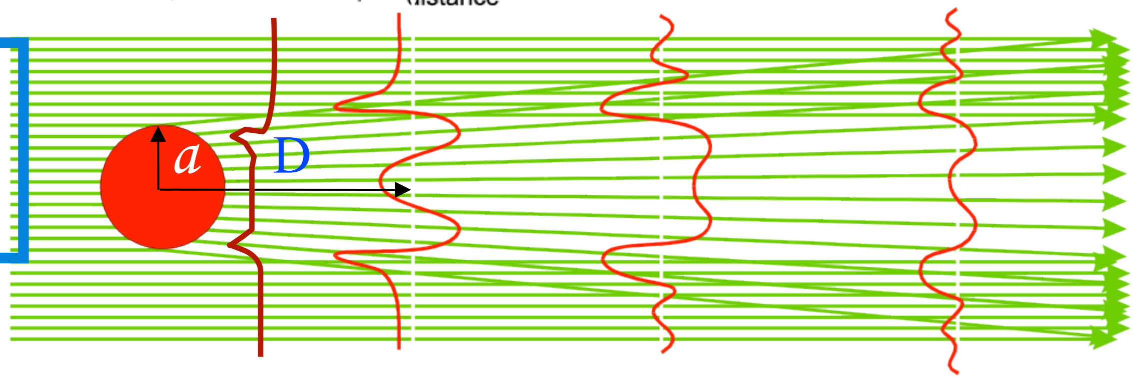
Phase contrast in free space propagation



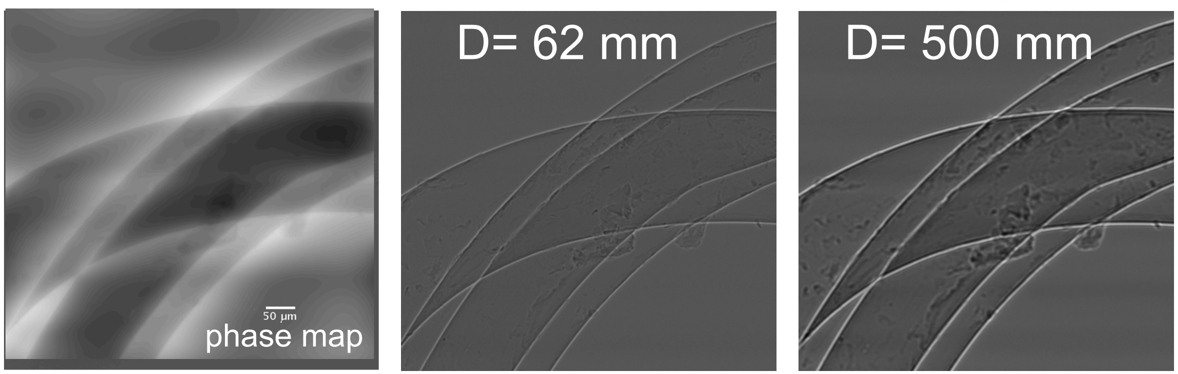
Fresnel transform:

$$U_D(x) = U_0(x) \otimes \sqrt{\frac{-i\pi}{\lambda.D}}.e^{\frac{i\pi}{\lambda.D}.x^2}$$

propagator



Born, M., and E. Wolf, 1990, Principles of Optics



Three phase fibers

Fresnel diffraction
Partially coherent illumination

$$\varphi(f) = \frac{\sum_m \sin(\pi\lambda D_m f^2) I_m(f)}{\sum_m 2\sin^2(\pi\lambda D_m f^2)}$$

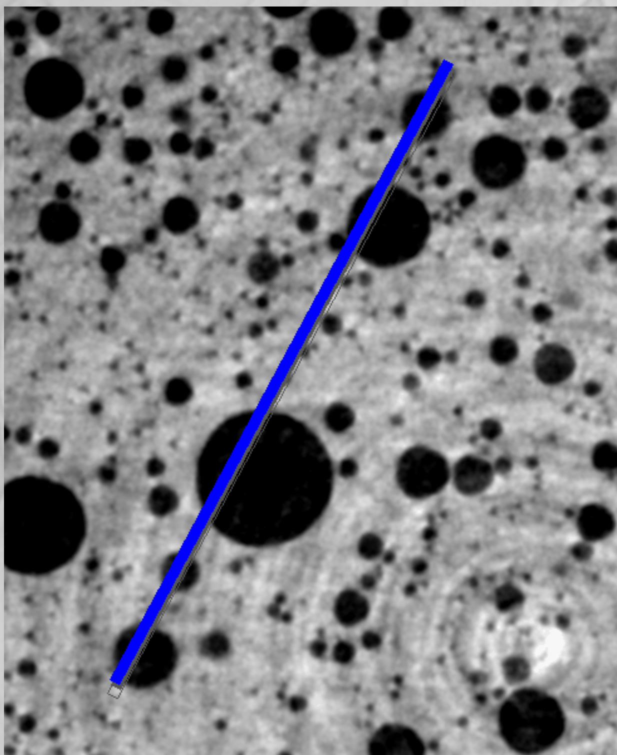
Cloetens et al. J. Phys. 1999

Why phase tomography?

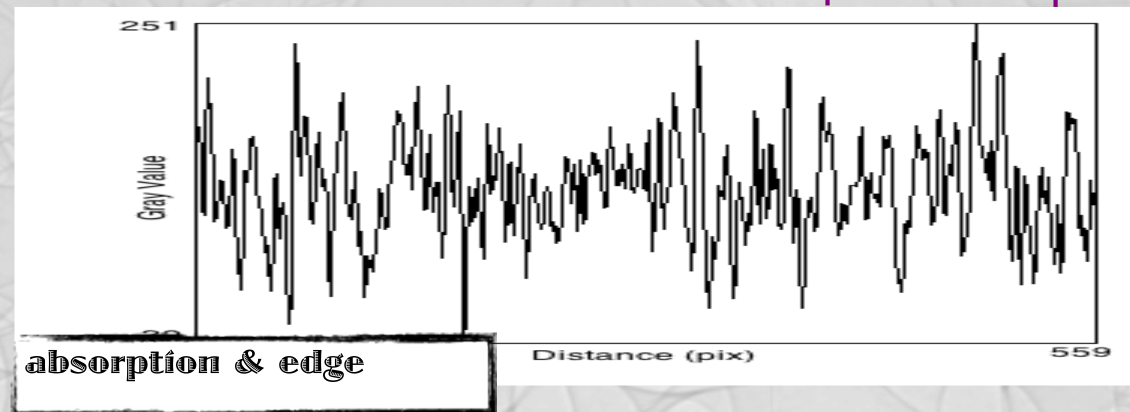
liquid foam, 20 Hz tomography

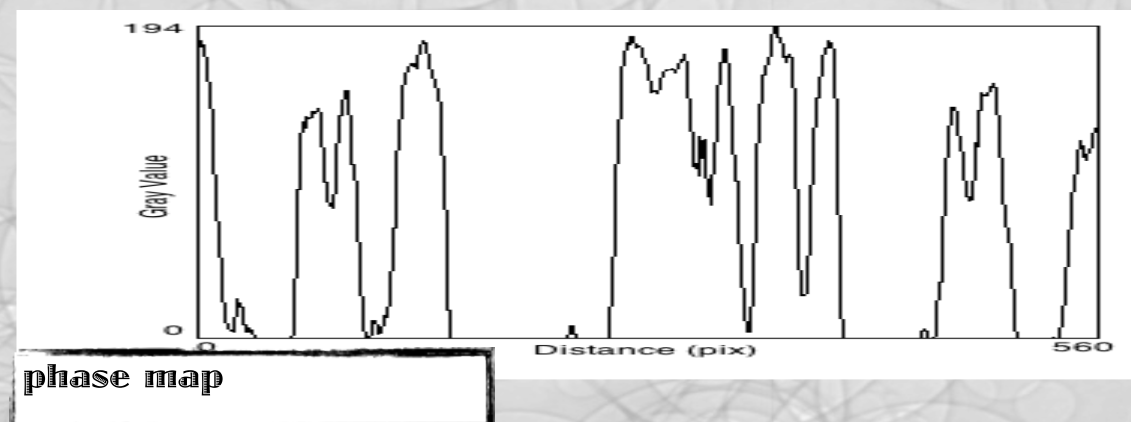
- Refractive index n

$$n = 1 - \delta + i\beta \qquad \delta \gg \beta$$



Windhab, SLS experiment, May 2014

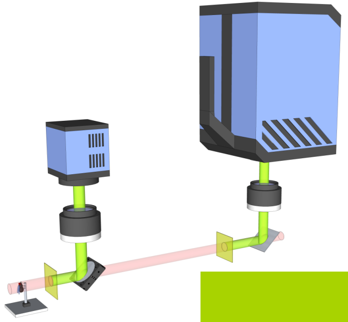


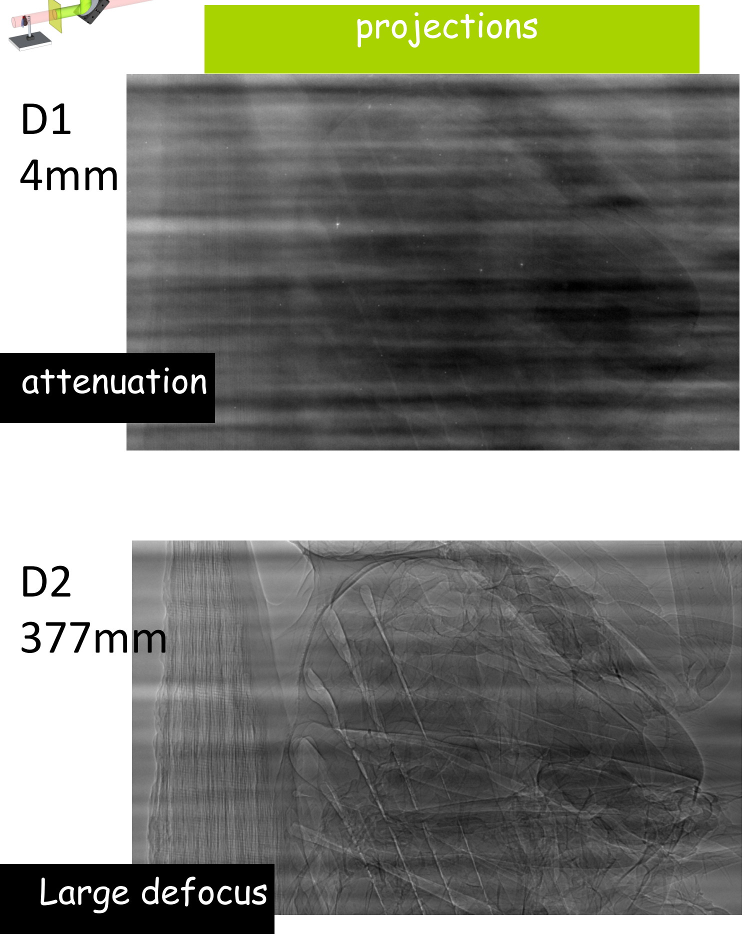


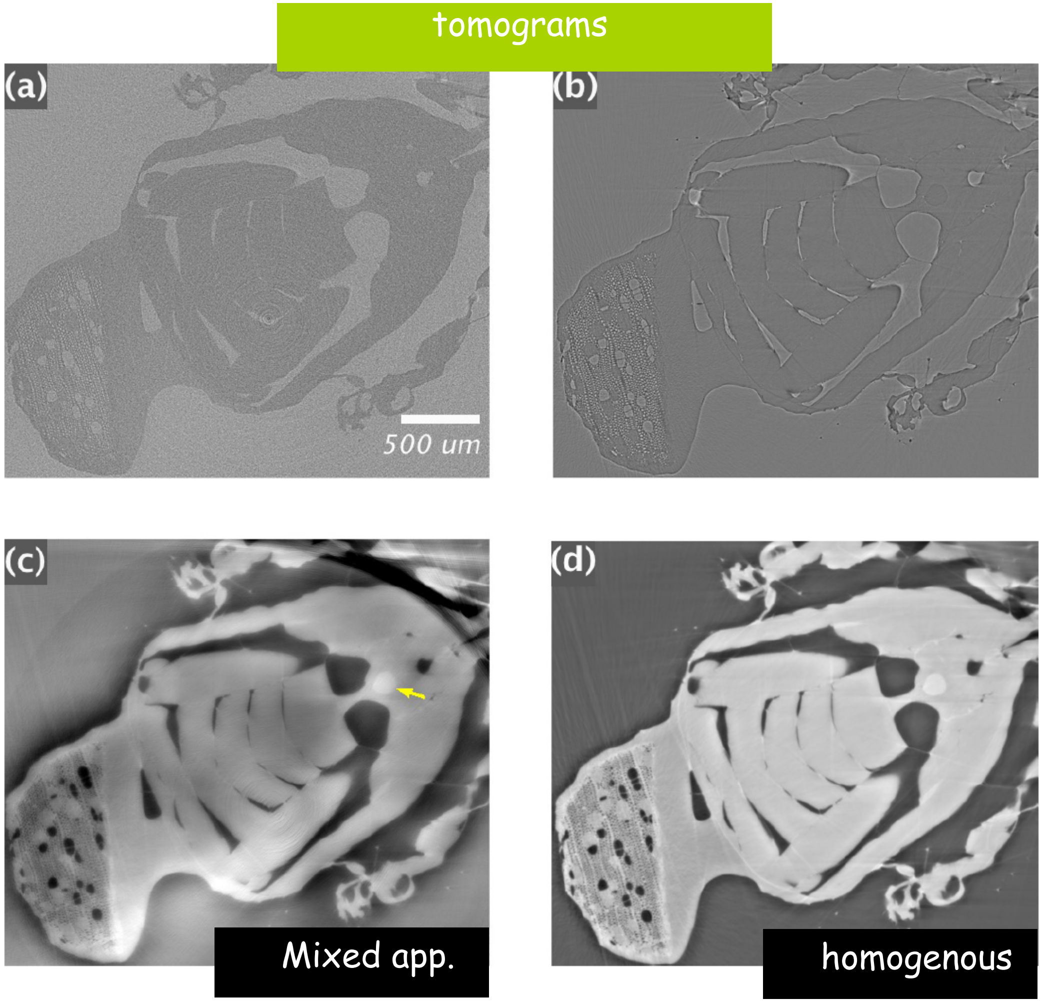
Phase contrast tomography

Mokso et al., J. Phys. D, 2013

Simultaneous two-image tomography







Projections and tomographic slice of a domestic fly: (a) D1; (b) D2; (c) "Mixed approach"; (d) "Paganin"

Mokso et al. J. Phys. D (2013)

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- Image analysis with physical priors

The GigaFrost fast detector system

Fast off-line data processing

On-the-fly reconstruction

Streaming real-time image analysis

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Advanced tomographic techniques

Inverse Problems and Imaging
doi:10.3934/ipi.2015.9.447
Volume 9, No. 2, 2015, 447–467

4D-CT RECONSTRUCTION WITH UNIFIED SPATIAL-TEMPORAL PATCH-BASED REGULARIZATION

Daniil Kazantsev

The Manchester X-ray Imaging Facility, School of Materials

7th Conference on Industrial Computed Tomography, Leuven, Belgium (iCT 2017)

Registration Based SIRT: A reconstruction algorithm for 4D CT

Vincent Van Nieuwenhove[1], Jan De Beenhouwer[1], Jelle Vlassenbroeck[2], Maarten Moesen[3], Mark Brennan[3], Jan Sijbers[1]

[1]University of Antwerp, Universiteitsplein 1, Wilrijk, Belgium, e-mail: Vincent.VanNieuwenhove@uantwerpen.be, Jan.DeBeenhouwer@Uantwerpen.be, Jan.Sijbers@uantwerpen.be

[2]Inside Matters, Meet District bus 502, Ottergemsesteenweg Zuid 808, Ghent, Belgium, e-mail: jelle@insidematters.eu

Four dimensional material movies: High speed phase contrast tomography by backprojection along dynamically curved paths

A. Ruhlandt, M. Töpperwien, M. Krenkel, and T. Salditt*
Institut für Röntgenphysik, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, Göttingen, Germany

R. Mokso
Paul Scherrer Institut, Villigen, Switzerland
Max IV Laboratory, Lund, Sweden