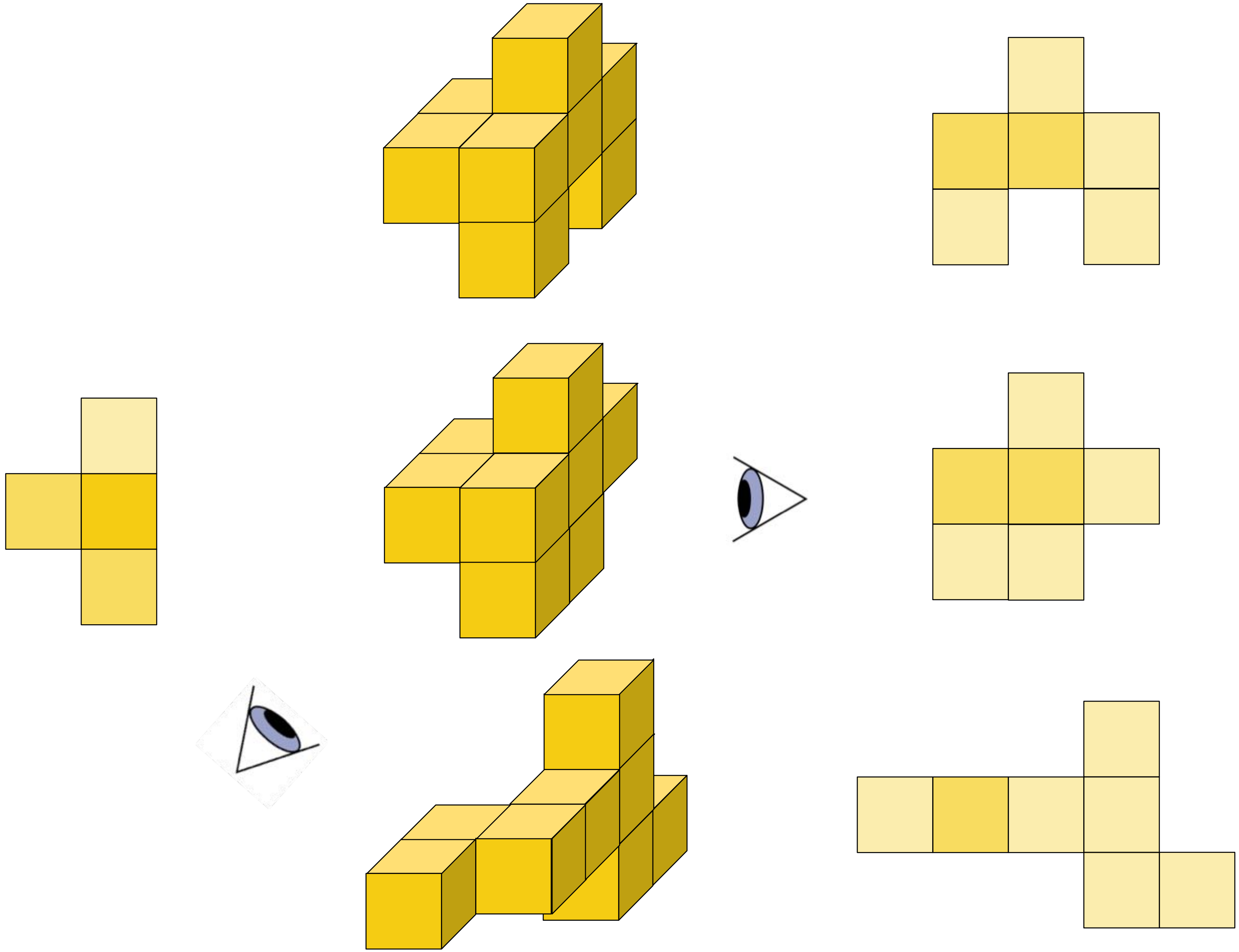
Rasmus Ischebeck

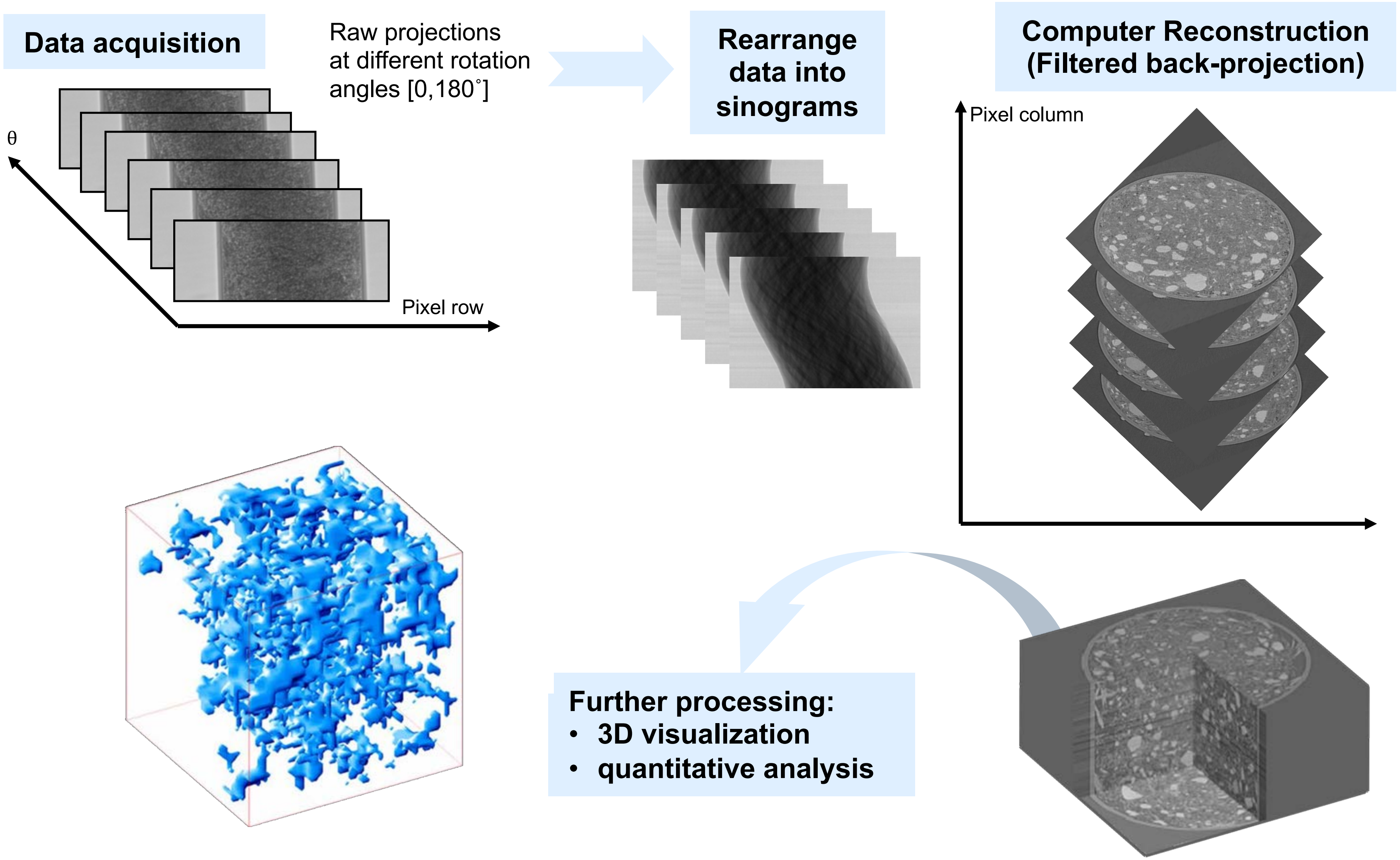
Uses of Synchrotron Radiation

Joint Universities Accelerator School

Micro-Tomography

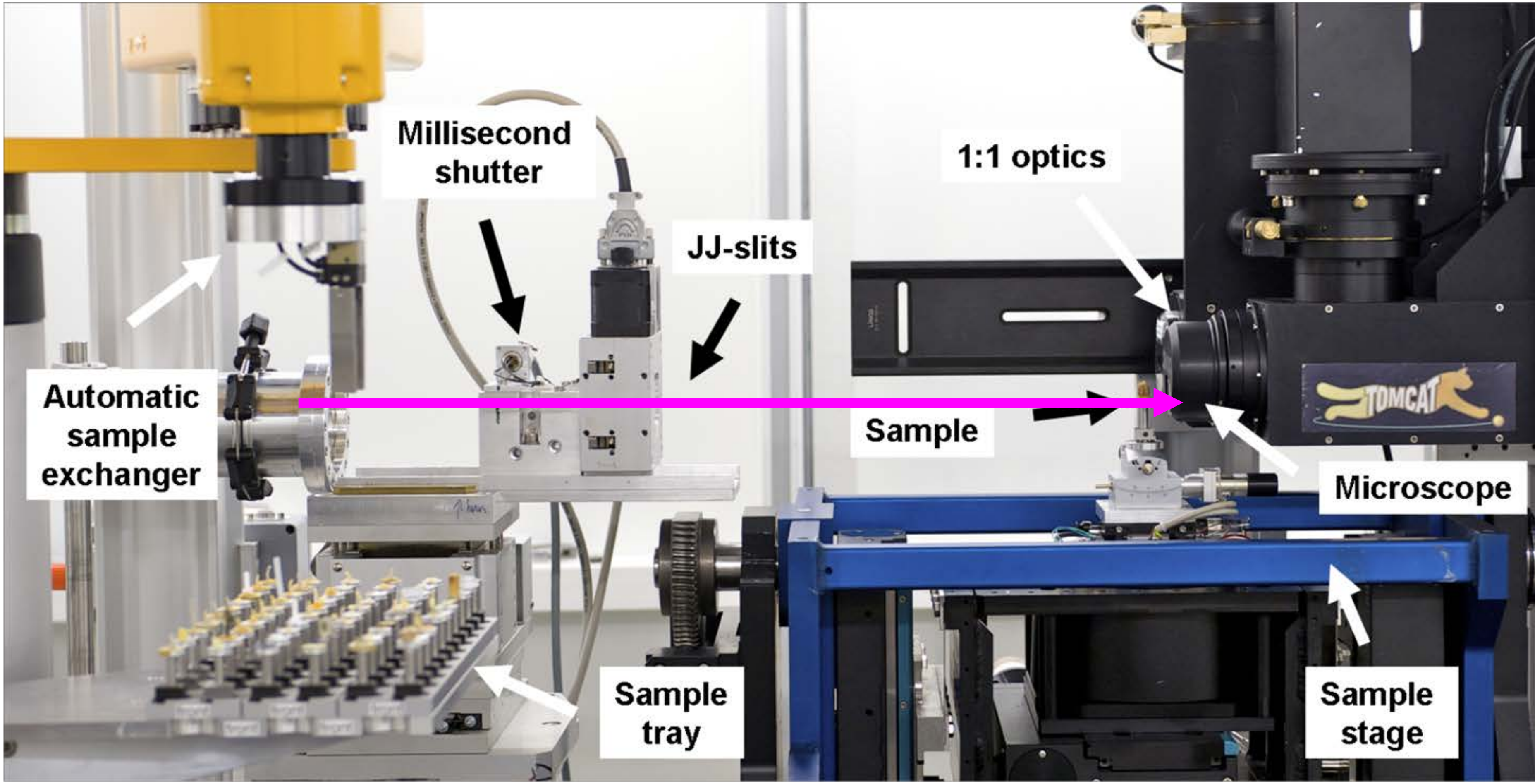


Microtomography principle



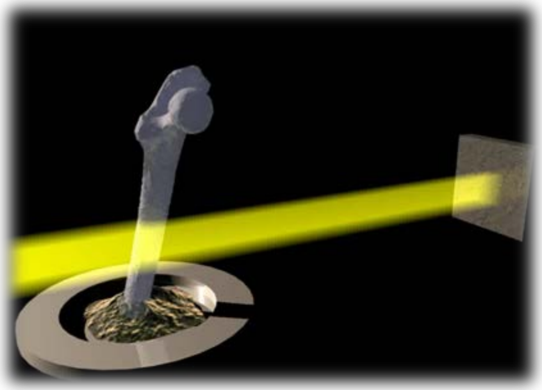
State-of-the-art SRXTM (1-50 um)

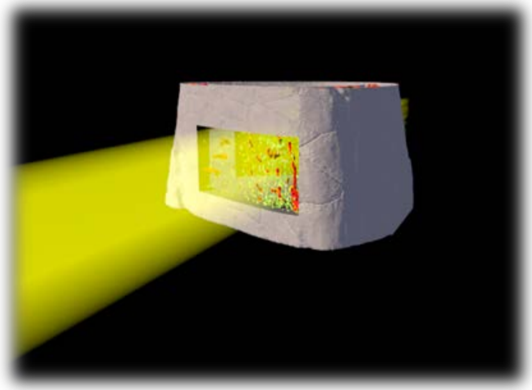
State-of-the-art SRXTM (1-50 um)

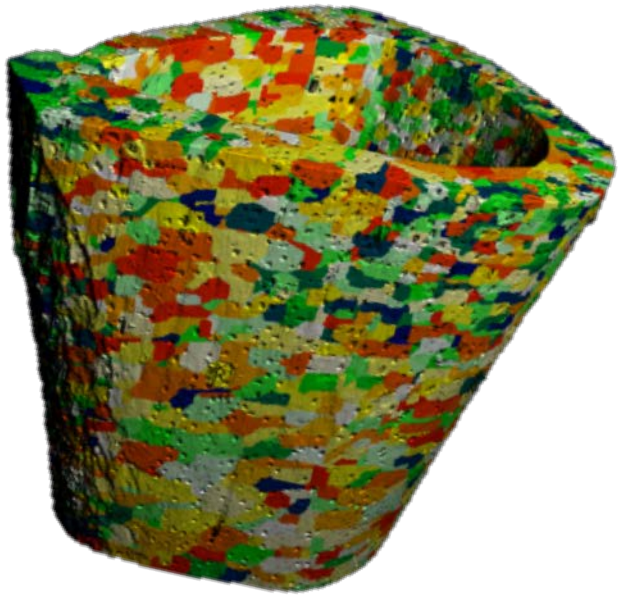


1 micron resolution routinely achieved at 10% MTF

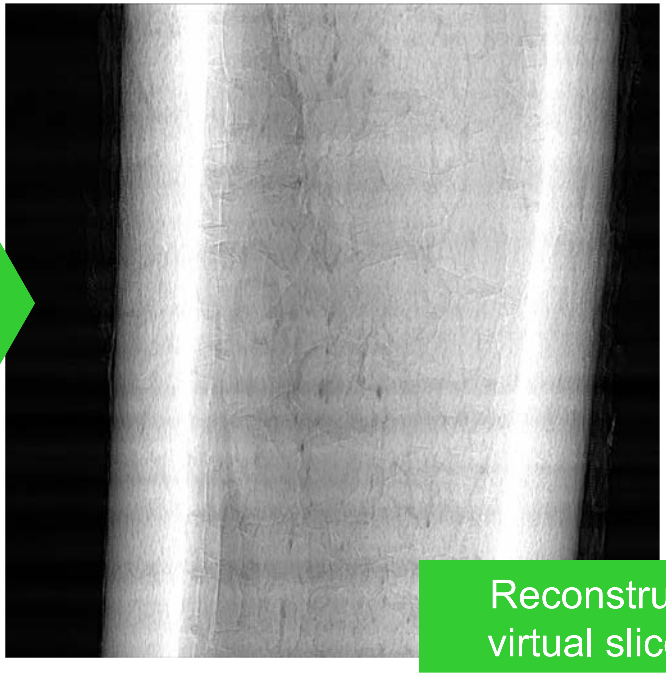
Gathering complex information



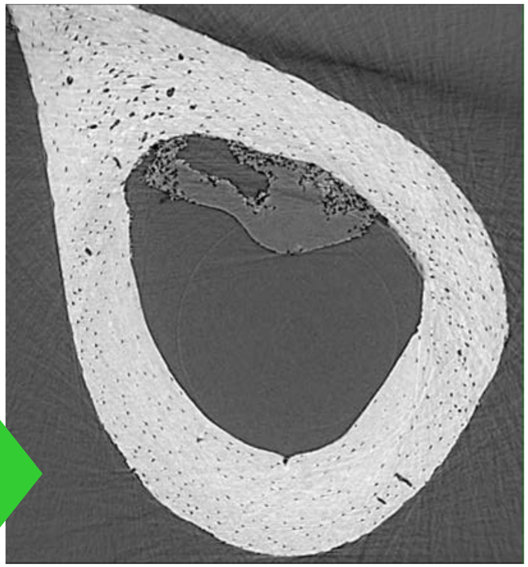




Measure
X-ray projections



Reconstruct
virtual slices



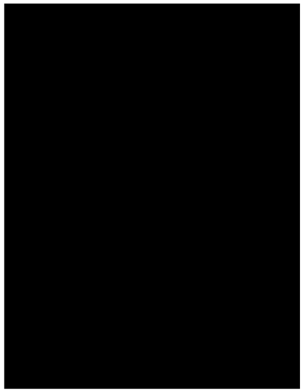
TOMCAT

The X-ray tomographic microscopy beamline at the Swiss Light Source

- Tomographic microscopy: non-destructive, high-throughput, high-resolution, 3D imaging technique
  - Wide spatial resolution: nano-micro-meso scales (0.1-10 μm)
  - High density resolution enhanced by phase contrast
    - Very small source
    - Strong collimated beam
    - Large distance between source and experiment

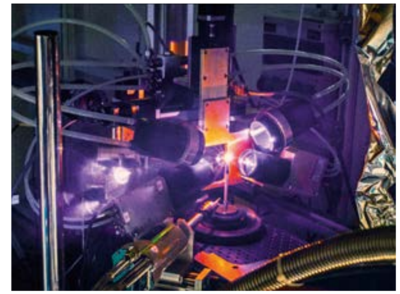
    } Interference phenomena with X-rays
  - Broad range of sample sizes (10 μm – 20 mm)
  - High temporal resolution: 3D data acquisition in less than 1 s

Capabilities at TOMCAT

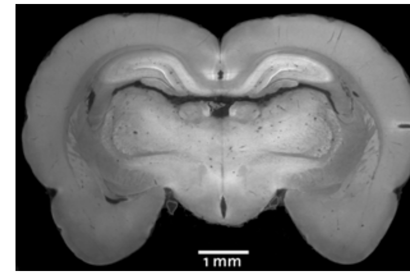


Spatial Resolution
10 microns – 0.1 microns

Automation
Large scale studies



In-situ capabilities
Furnace/Cryo/Traction



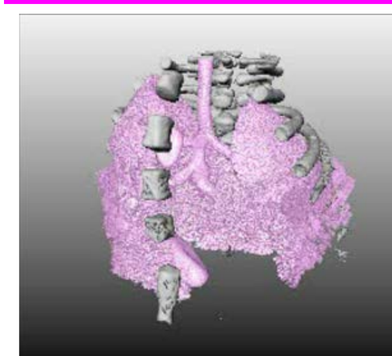
Density Resolution
Phase contrast imaging

TOMCAT

Ultra-fast tomography

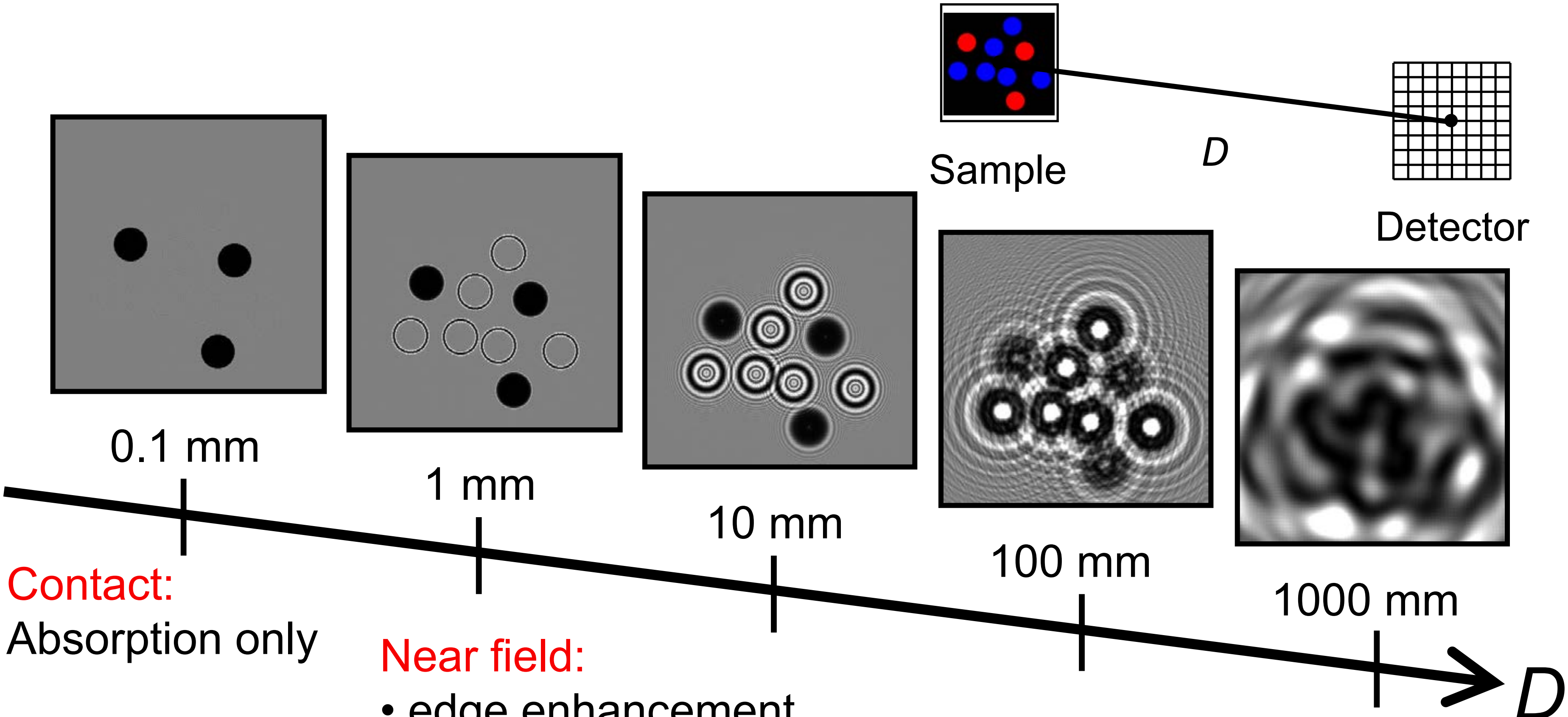
High-speed micro radiology

In-vivo 3D microscopy



Phase contrast

Propagation-based image formation



Contact:
Absorption only

Near field:
- edge enhancement
- phase objects detectable

SINGLE STEP PC-IMAGING (e.g. Paganin)
HOLOTOMOGRAPHY

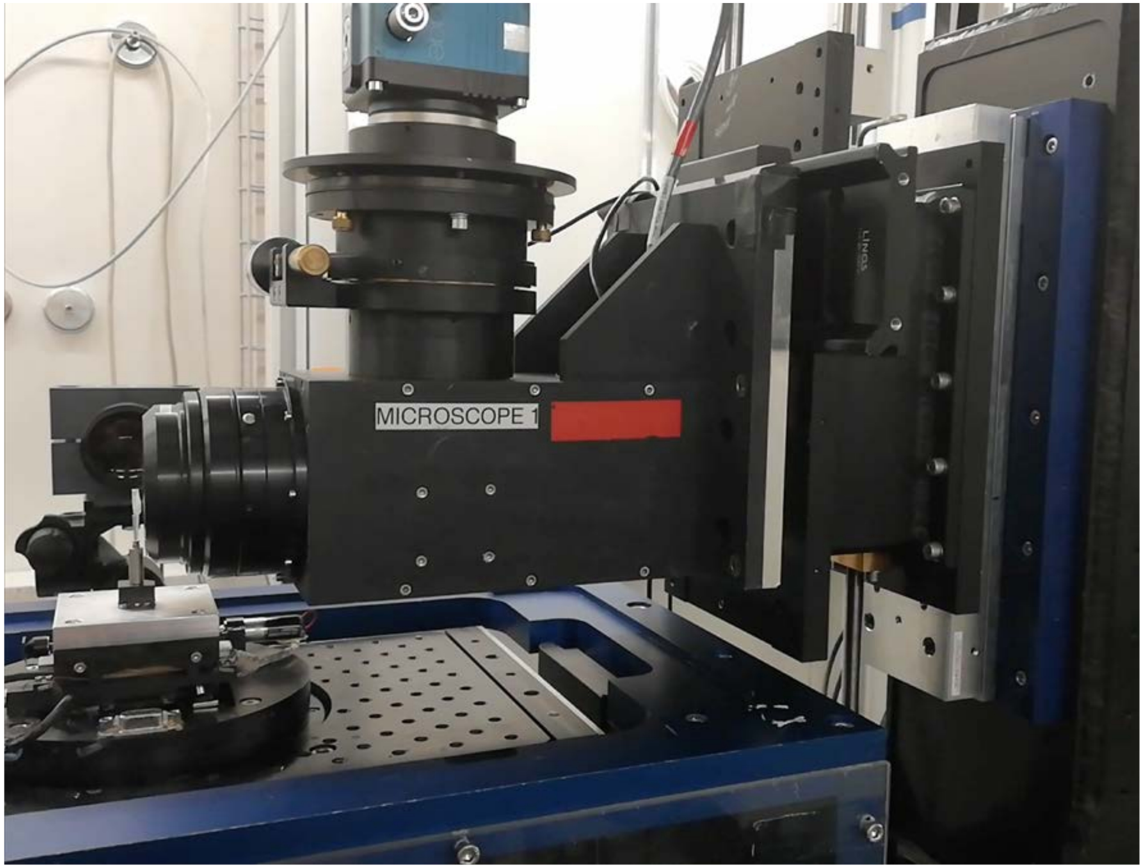
Far field:
- Coherent Diffraction Img.

Ptychography…

Cartoon courtesy: T. Weitkamp, SOLEIL

The effect of propagation distance

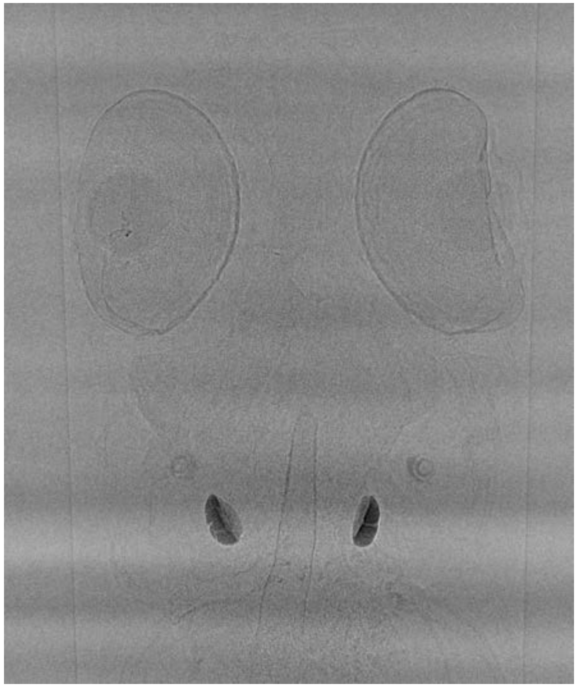
- Continuous data acquisition during camera motion
- Flat field corrected, shaking reduced



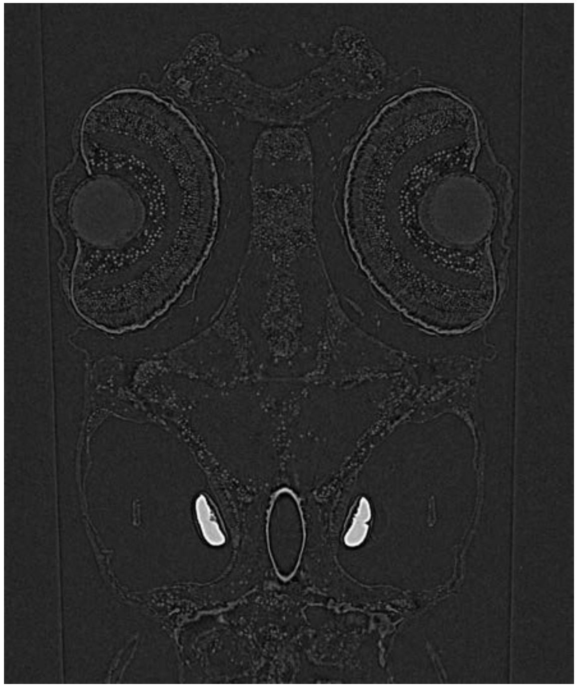
Sample courtesy of E. Cörek, J. Huwyler, University of Basel

Phase vs. absorption reconstruction

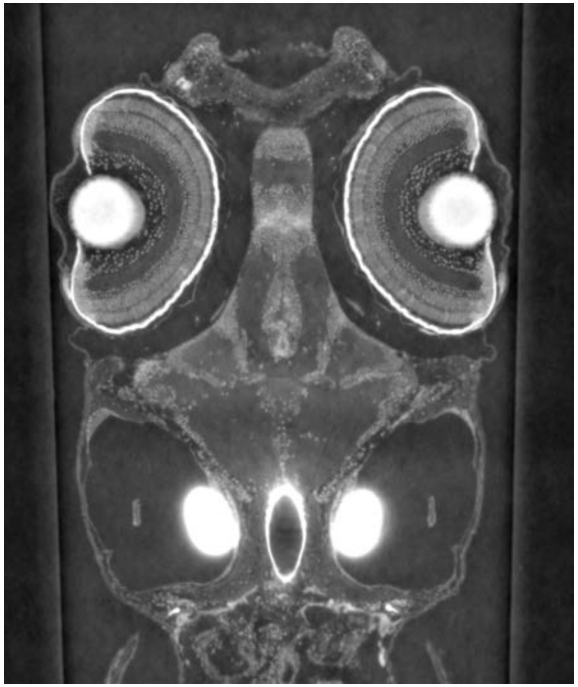
Radiographic projection



Absorption reconstruction coronal slice

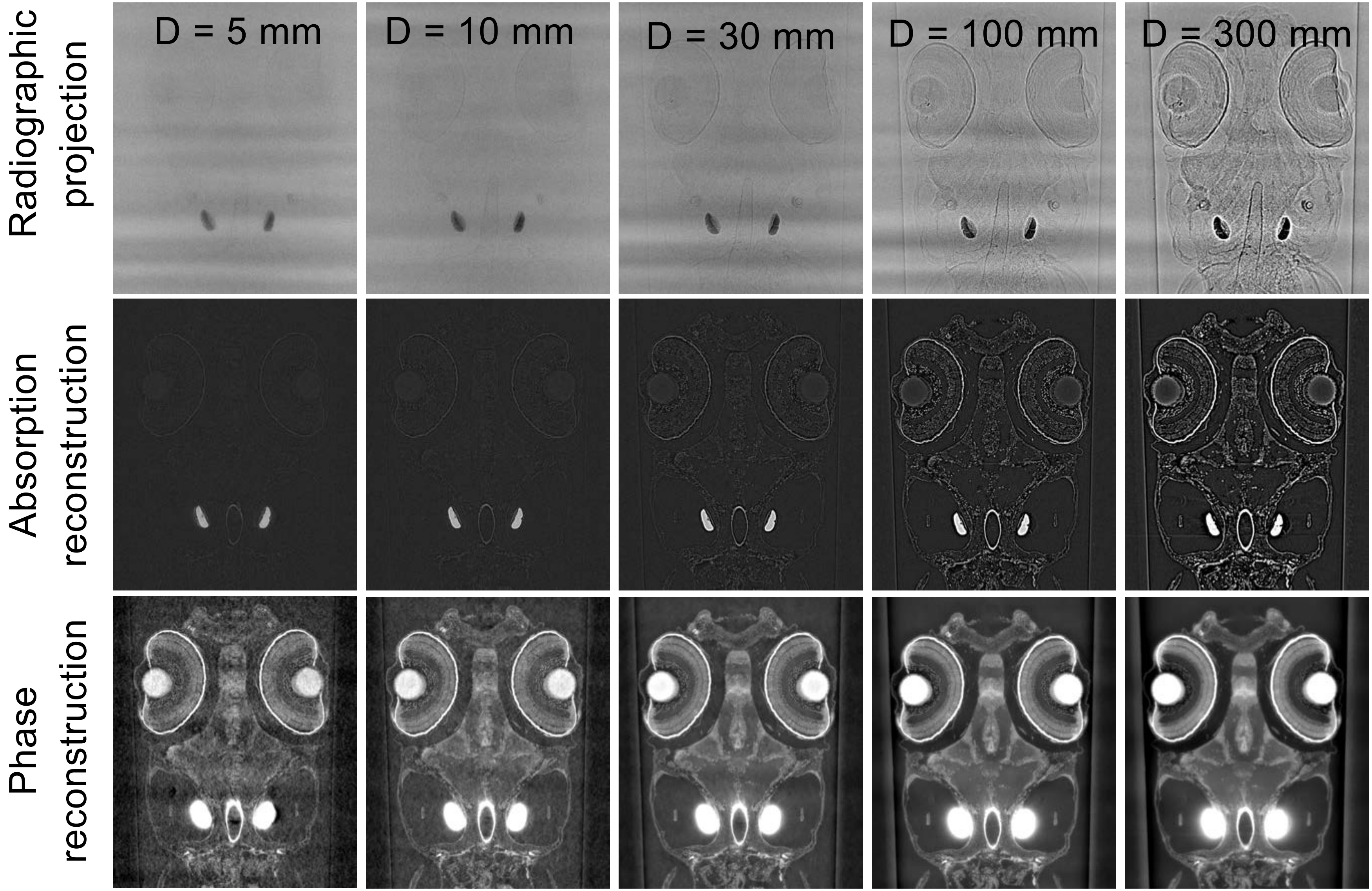


Phase reconstruction coronal slice

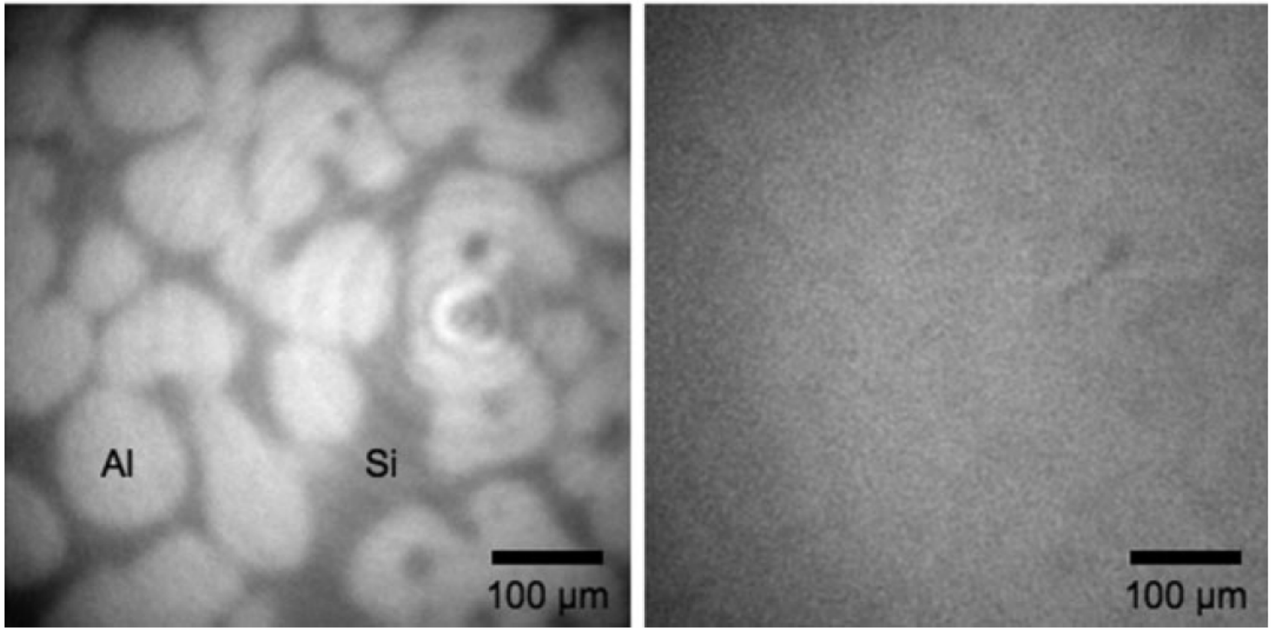


Propagation distance = 30 mm
Pixel size = 0.65 um
Energy = 21 keV

Phase vs. absorption reconstruction



Why phase contrast imaging?



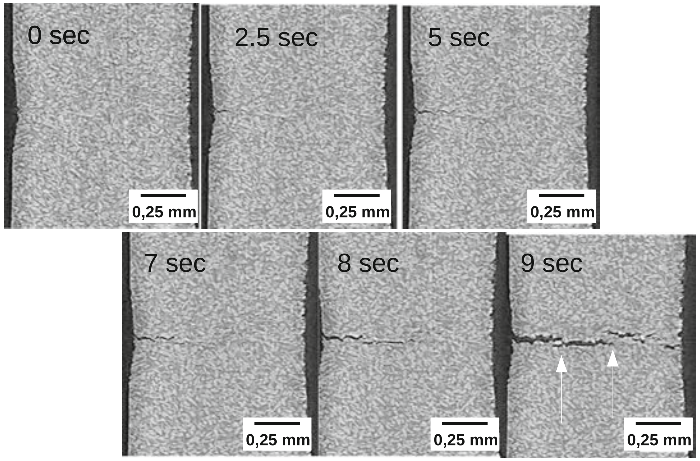
Differential phase contrast X-ray imaging

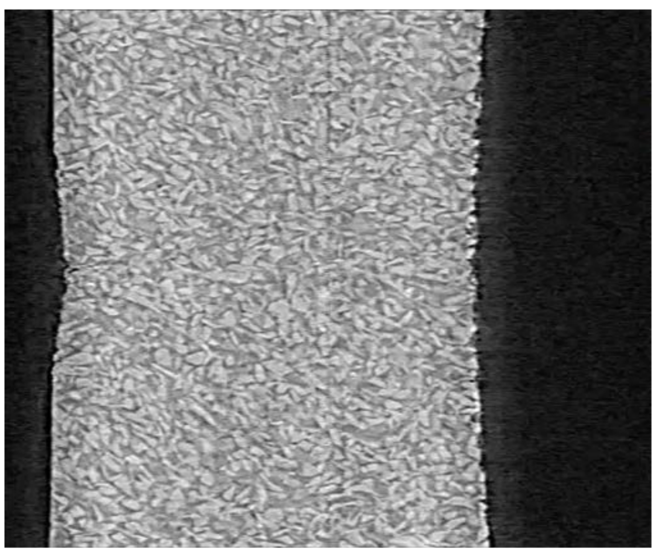
Traditional absorption-based X-ray imaging

McDonald et. al., Adv. Eng. Mater. (2010)

Dynamic experiments

In-situ 20 Hz tomographic imaging





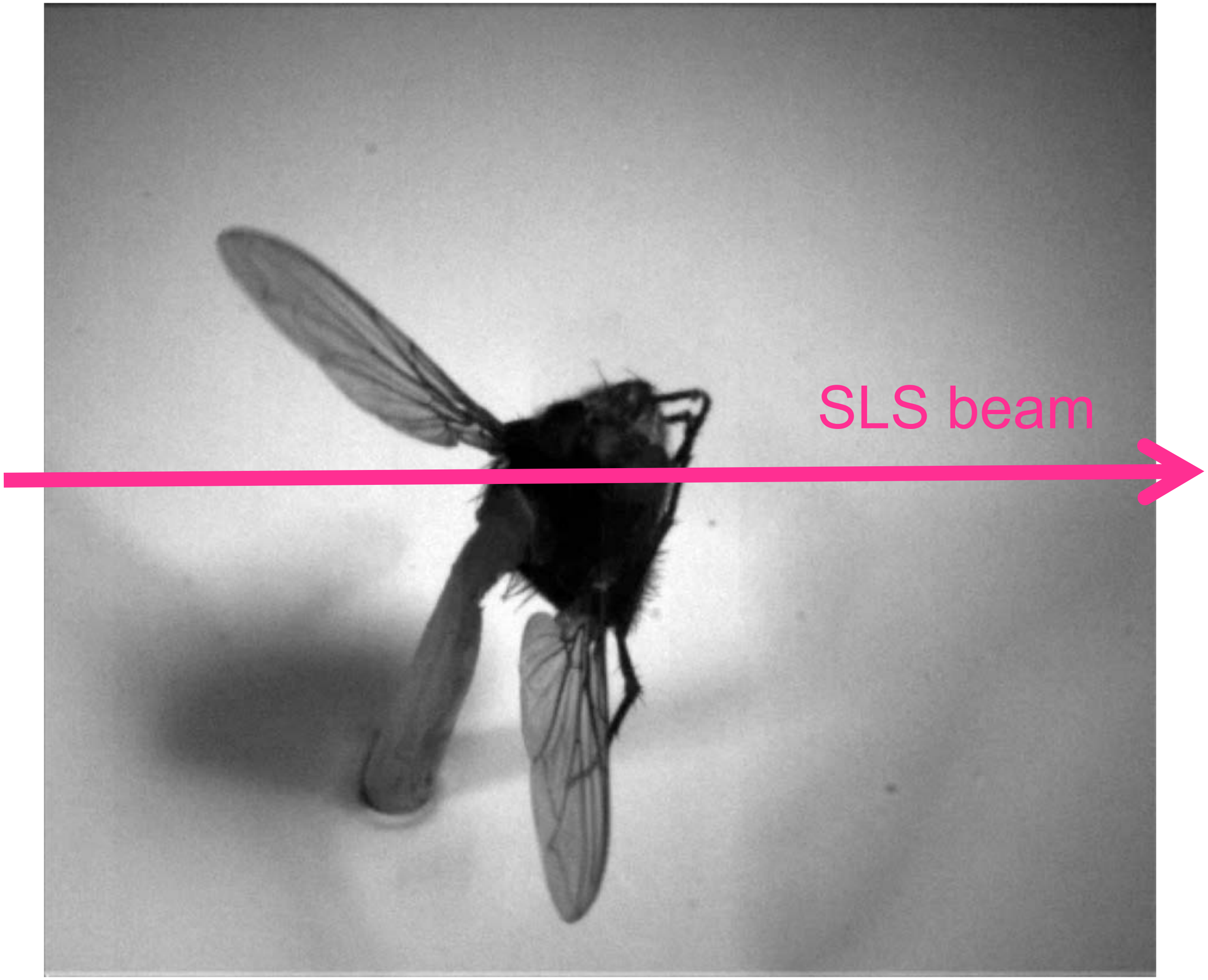
- Crack propagation dynamics under tensile load
- 20 (!) 3D volumes per second

Movie playing in real time (9 seconds, 180 frames)

Maire et. al., Int J Fract (2016)

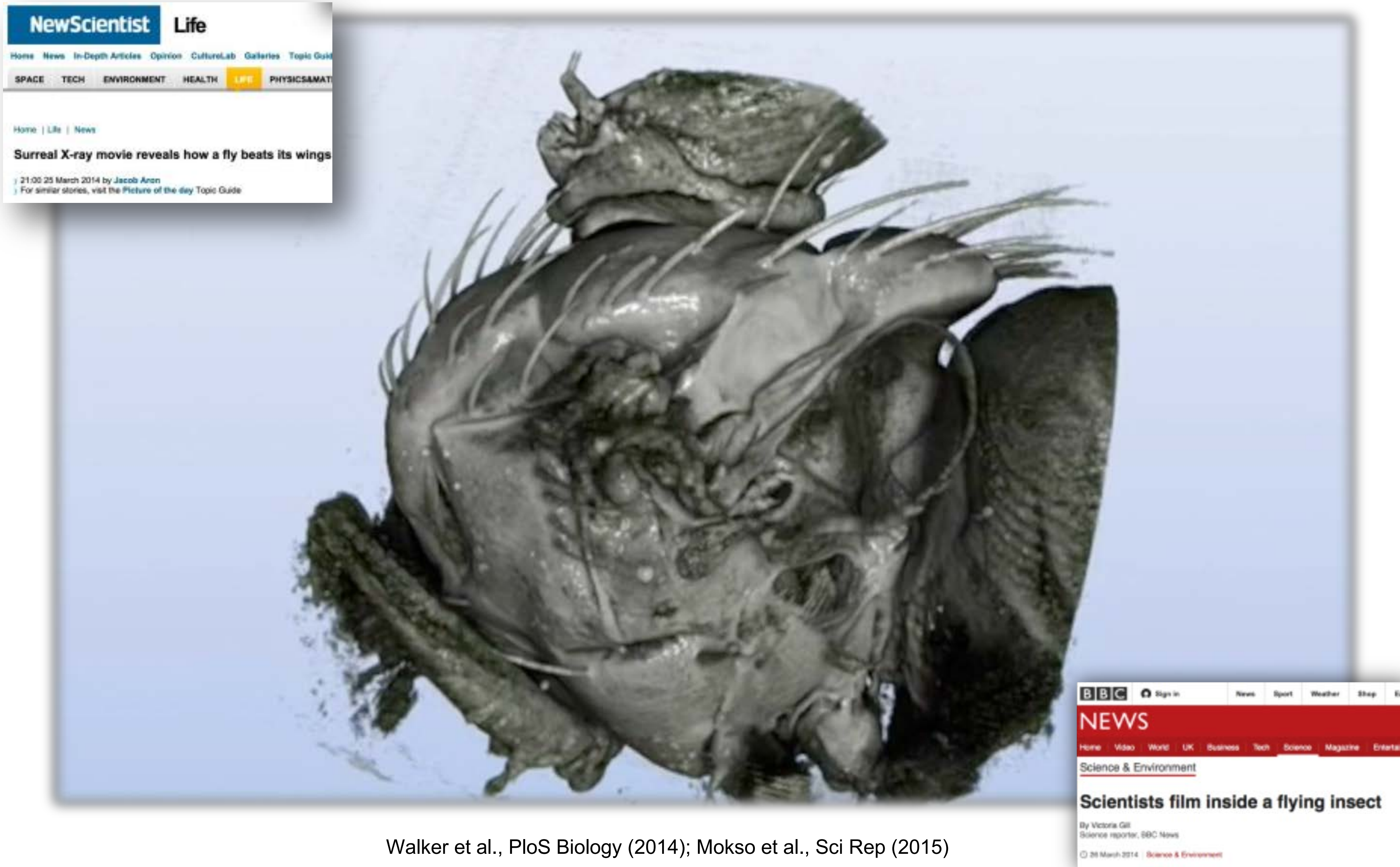
How does a fly really fly?

Wings beat at 150 Hz !!



2500 X-ray images per second…

Muscles and tracheal network *during* flight



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Surreal X-ray movie reveals how a fly beats its wings

21:00 25 March 2014 by Jacob Aron

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Science & Environment

Scientists film inside a flying insect

By Victoria Gill
Science reporter, BBC News

26 March 2014 Science & Environment

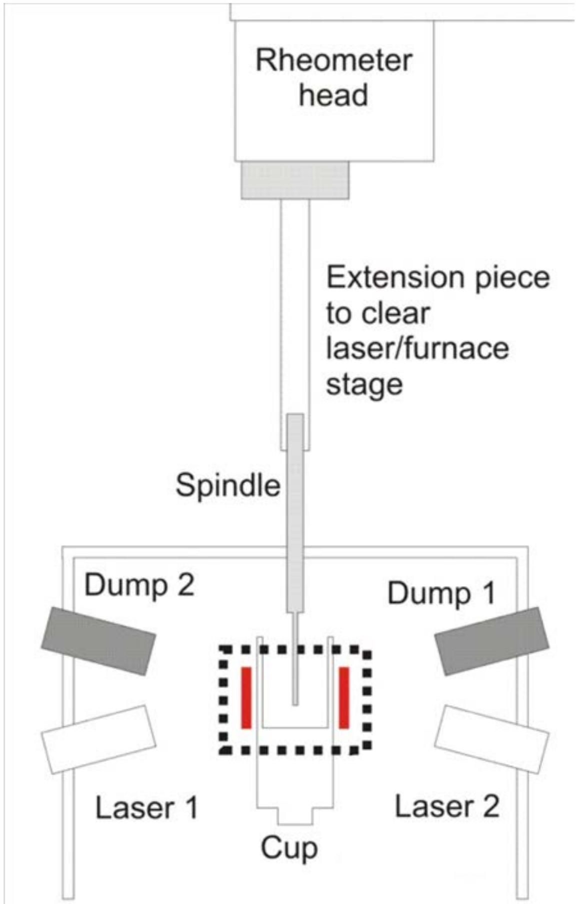
Walker et al., PloS Biology (2014); Mokso et al., Sci Rep (2015)

Imaging magmas on the move

- Collaboration with Durham University:
  Kate Dobson

Investigate the rheology and mobility of three-phase magmas

- Crystal-bearing magma formed by sintering of glas beads and quartz crystals
- In situ rheometer setup
- In situ IR laser heating to 1300 ° C
- Induce shear forces by a small differential rotation between crucible and rheometer spindle

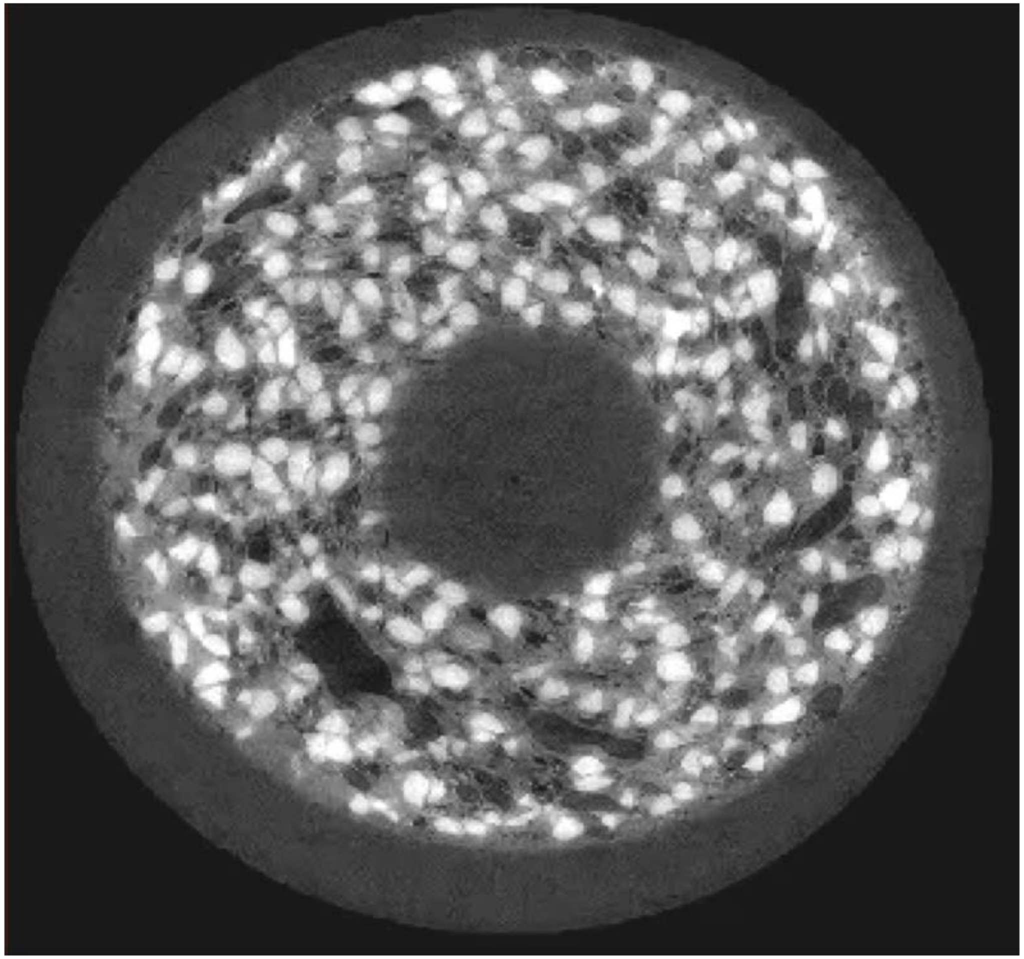


NERC grant NE/M018687/1 Dobson (2016), Durham University

Imaging magmas on the move

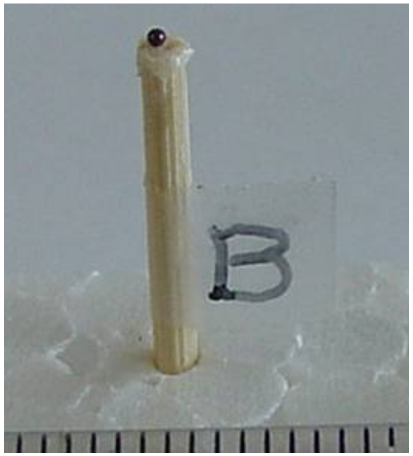
Scan parameters:

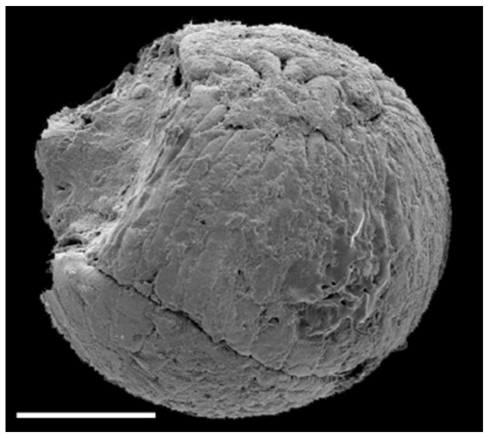
- Pixel size: 2.7 µm
- Polychromatic beam
  mean energy ~ 30 keV
- 1ms exposure time
  1000 projections
  → 1 second scan time
- Acquire one scan every 8 s



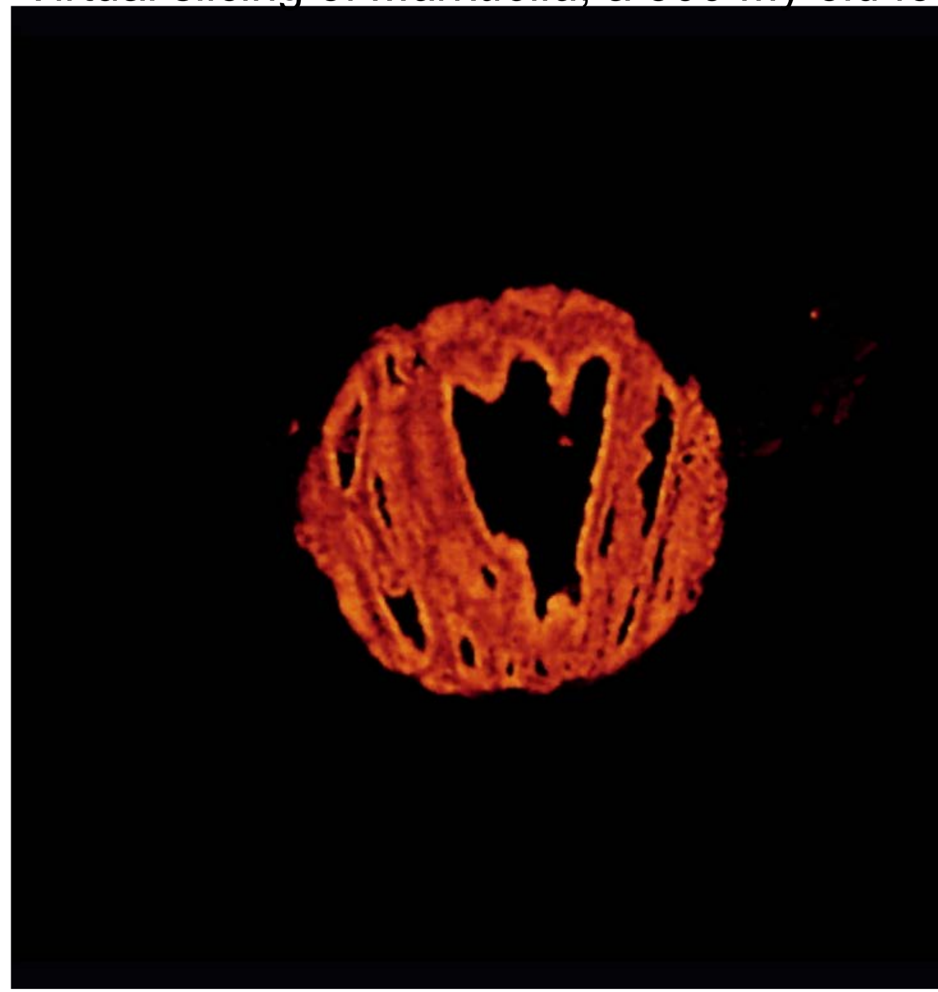
Paleontology

Trivial specimen preparation – Preserved sample



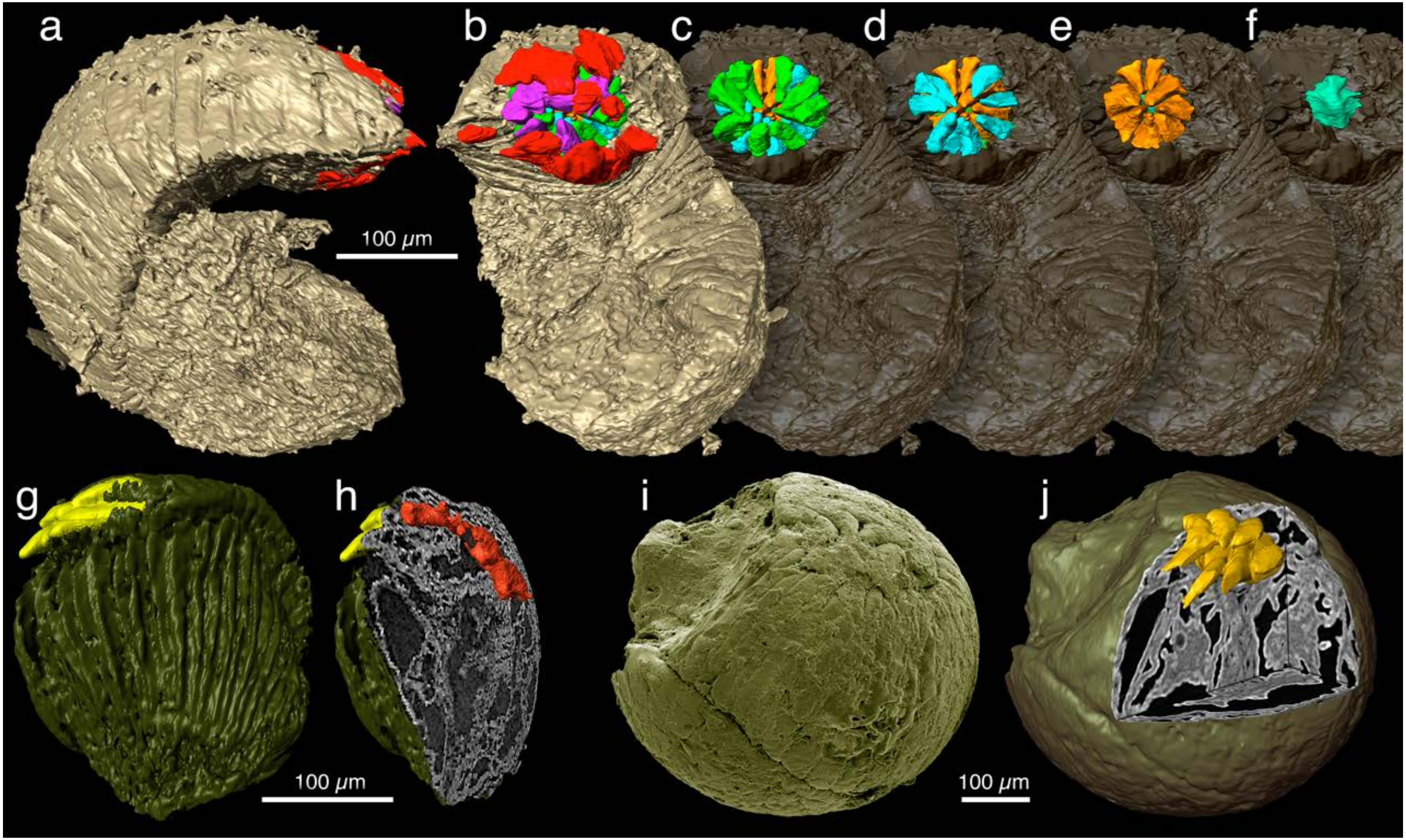


Virtual slicing of *Markuelia*, a 500 My old foss



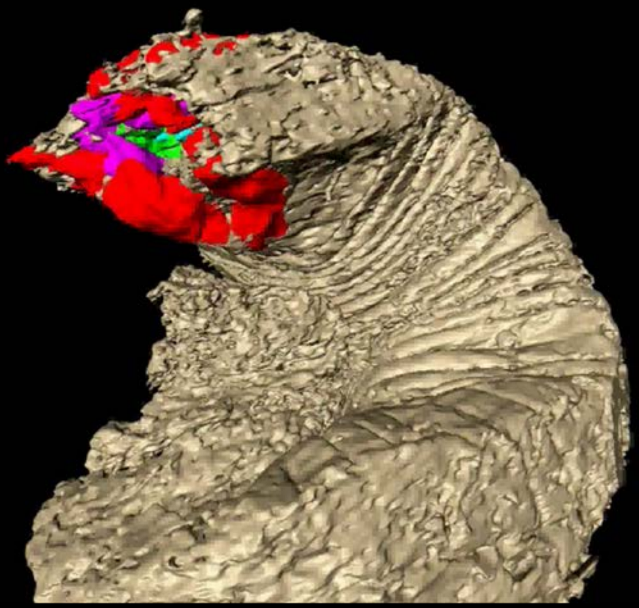
Donoghue et al (2006) Nature 442:680-3

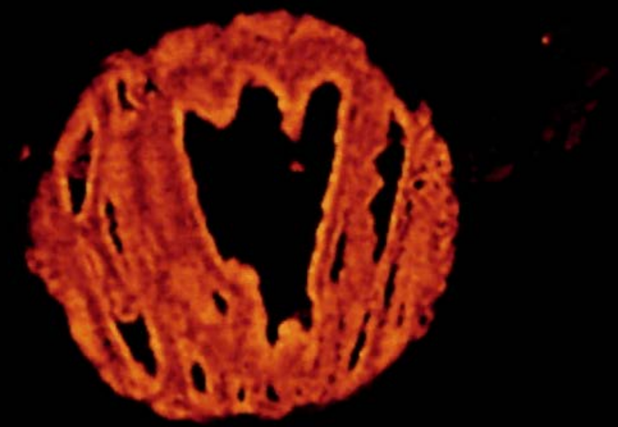
Complex image analysis and data interpretation



Donoghue et al (2006) Nature 442:680-3

Markuelia, the first "predator" on earth





Donoghue et al (2006) Nature 442:680-3

Biomedical

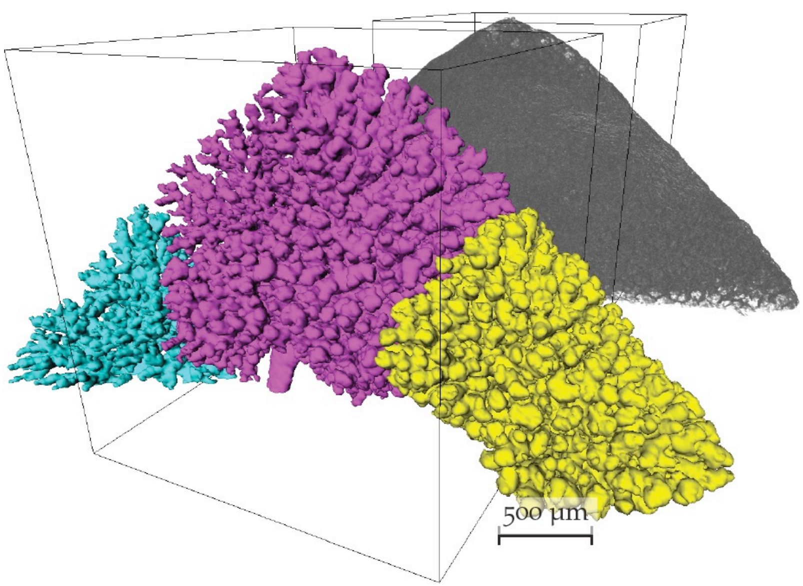
Modeling the rat pulmonary acinus – The data

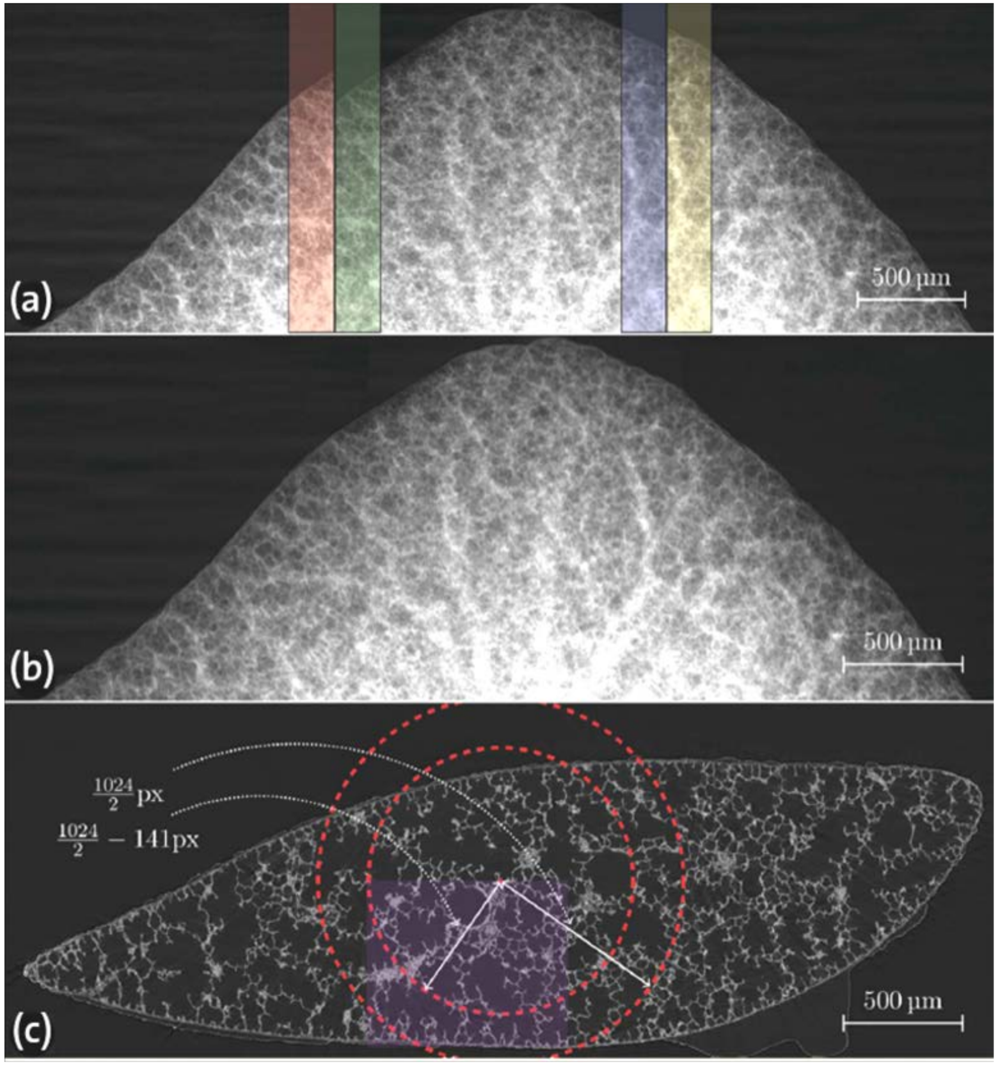
Raw data

- 2.5% glutaraldhehyde filling by 20 cm constant H_2O pressure
- Postfixation with 1% OsO_4 and paraffin embedding
- 12.398 keV, 1.48 microns pix. siz.

Scanning protocol

- Wide-field scanning with approx. 3000 pixel within 4.5 mm





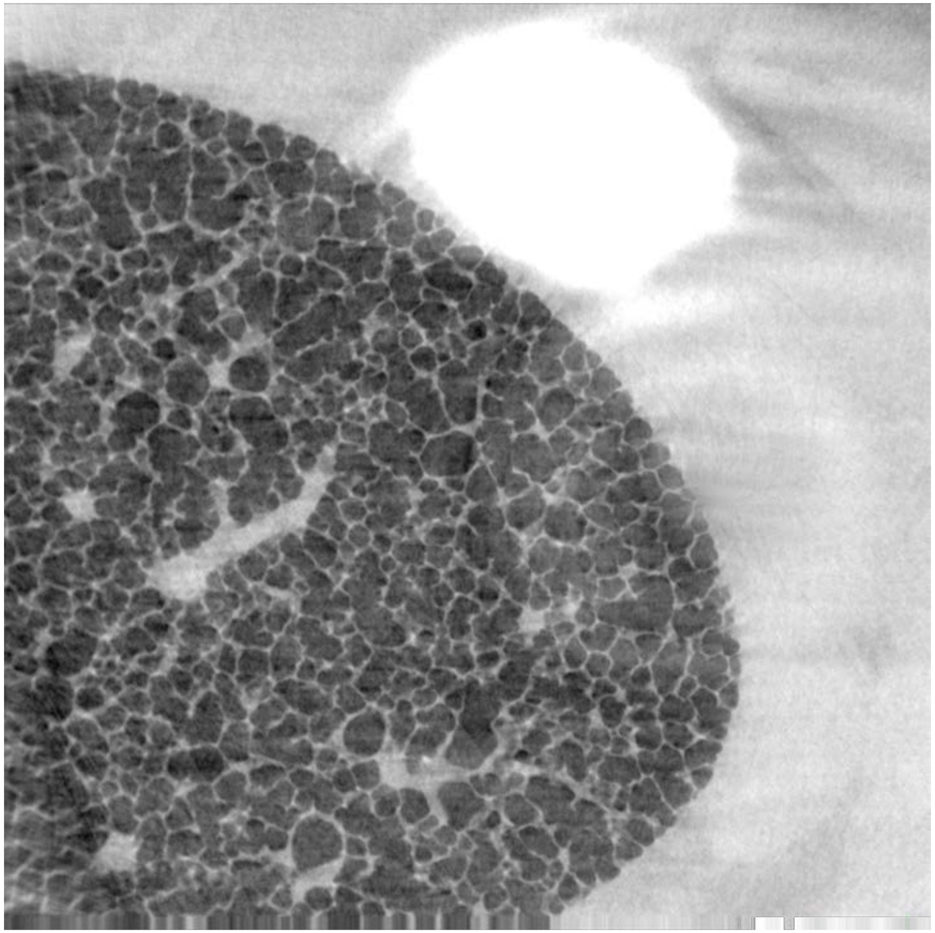
From Haberthür et al., Journal of Synchrotron Radiation, 17(5), (2010)

In-vivo lung imaging at the micron scale

- Consequences of mechanical ventilation
- Dynamics of alveolar recruitment

Experimental parameters

- 14 days old rat
- t_{exp} = 1 ms, t_{scan} = 600 ms
- 5x pressures: 15, 20, 25, 30, 35 cmH_2O

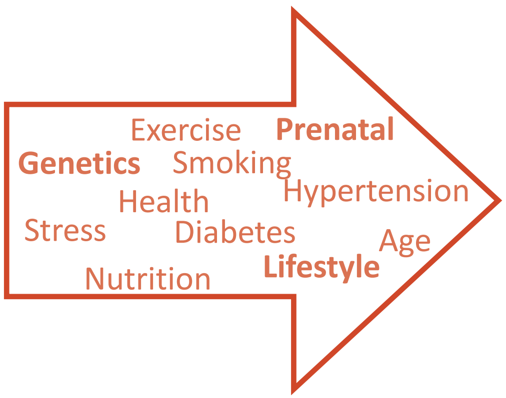


Courtesy: G. Lovric

Cardiac research questions

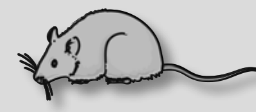
Cardiovascular diseases (CVD) are the 1st cause of mortality in the world

⇒ Impact on the heart structure from whole heart down to microstructure: cardiac remodelling



Heart Imaging Project

CVD animal models



SHR, LAD, etc.

Universitat Pompeu Fabra Barcelona

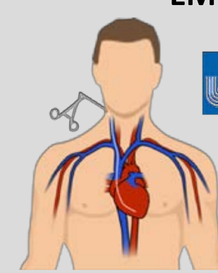
CLÍNIC BARCELONA Hospital Universitari

Fetuses with CHD

Universitat Pompeu Fabra Barcelona

UCL

EMBs

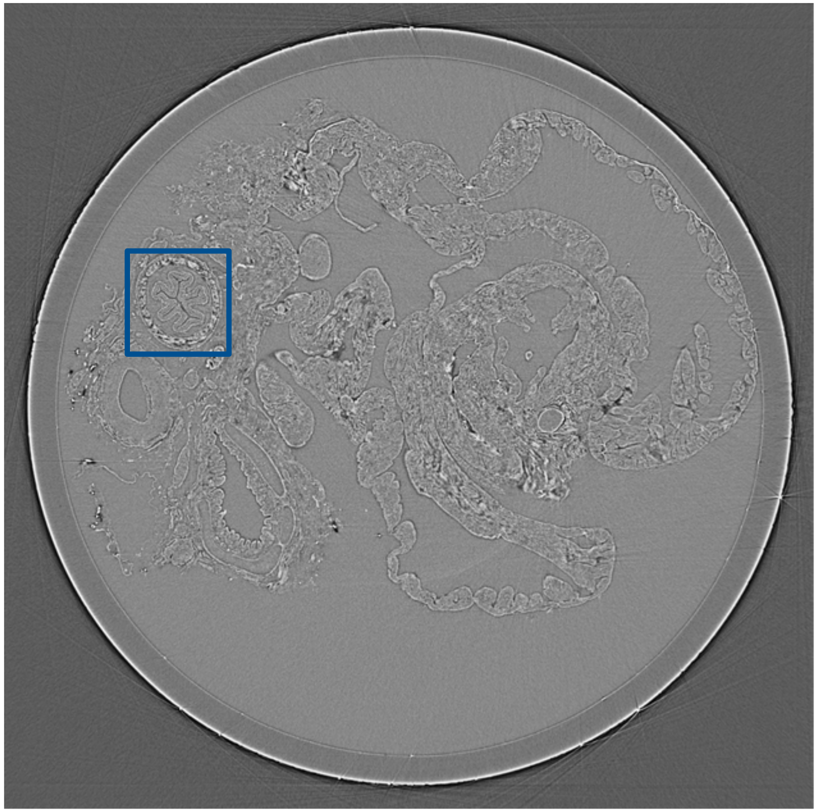


UniversityHospital Zurich

KBCH

- Educational: understanding cardiac microstructure and the influencing factors of the remodelling
- Improve computational modelling approaches: analyse for instance the flow or function, use the structure as input
- Crucial for more personalized medicine treatments

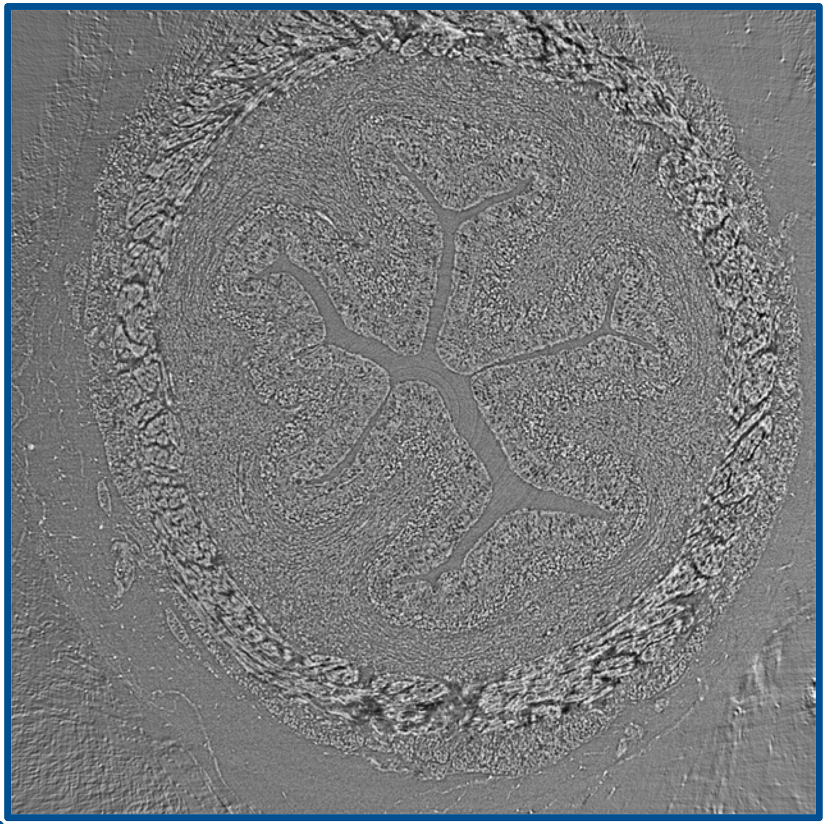
Multiscale Imaging Acquisition Protocol



ES2

5.8 um pixel size
XXs, ZZs and Ys sample position
Xc and Yc camera position

Multiscale_Coords.ijm



ES1

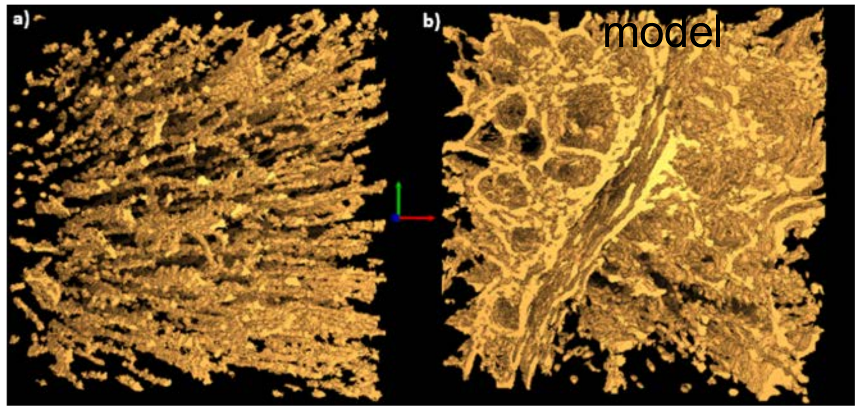
0.65 um pixel size
XXs', ZZs' and Ys' sample position
Xc' and Yc' camera position

Histological validation of Rat Models

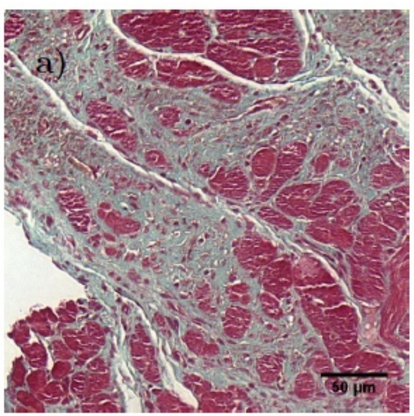
Septum LV

Control

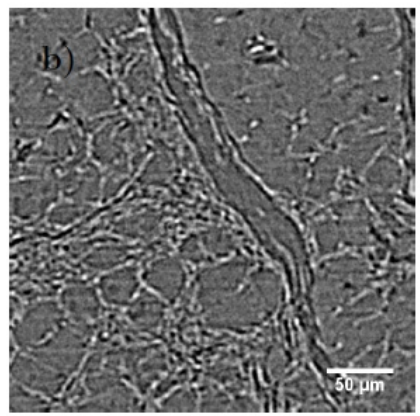
Fibrotic model



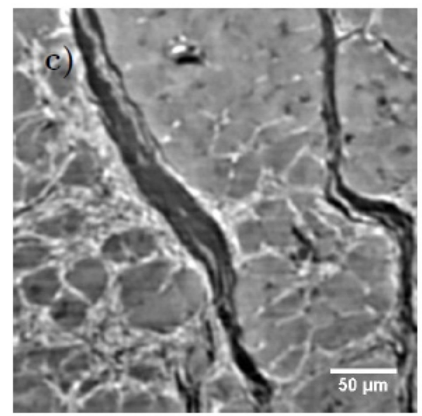
Fibrotic model



Masson Trichrome Histology



Non phase retrieved



Phase retrieved

Dejea, H. *Master Thesis* (2017)

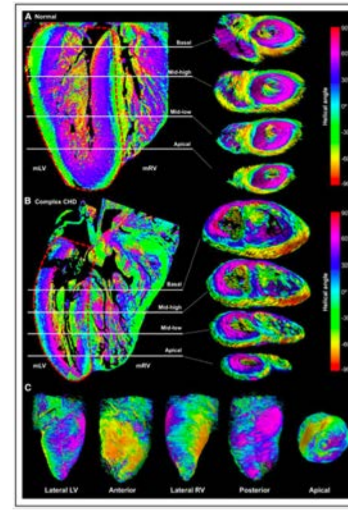
Human Foetal hearts with CHD

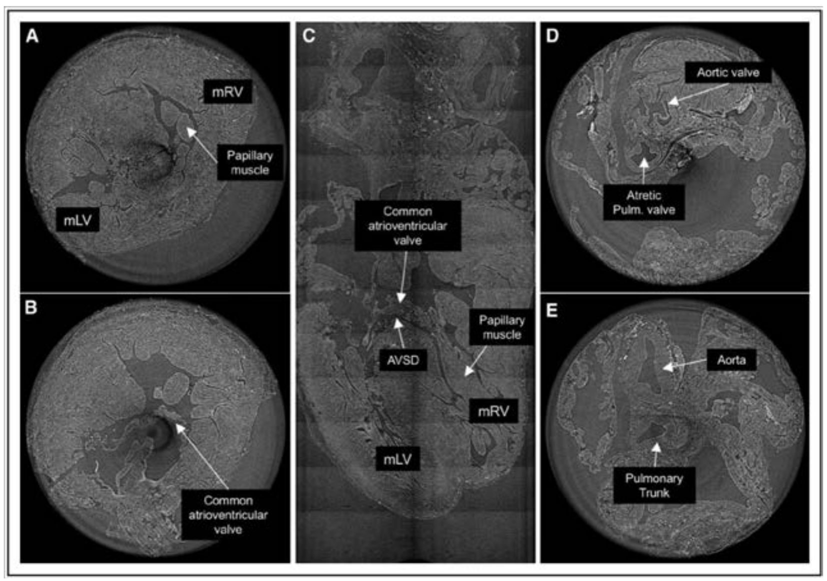
Circulation: Cardiovascular Imaging

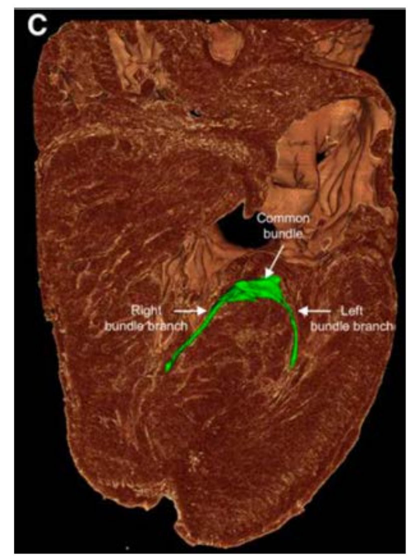
ORIGINAL ARTICLE

Complex Congenital Heart Disease Associated With Disordered Myocardial Architecture in a Midtrimester Human Fetus

Patricia Garcia-Canadilla, PhD
Hector Dejea, MSc
Anne Bonnin, PhD
Vedrana Balicevic, MSc
Sven Loncaric, PhD
Chong Zhang, PhD
Constantine Butakoff, PhD
Jazmin Aguado-Sierra, PhD
Mariano Vázquez, PhD
Laurence H. Jackson, PhD
Daniel J. Stuckey, PhD
Cristoph Rau, PhD
Marco Stampanoni, PhD
Bart Bijnens, PhD*
Andrew C. Cook, PhD*







P. Garcia-Canadilla *et al*, Circulation: Cardiovascular Imaging. 2018;11:e007753

Questions?

Nick Veasey