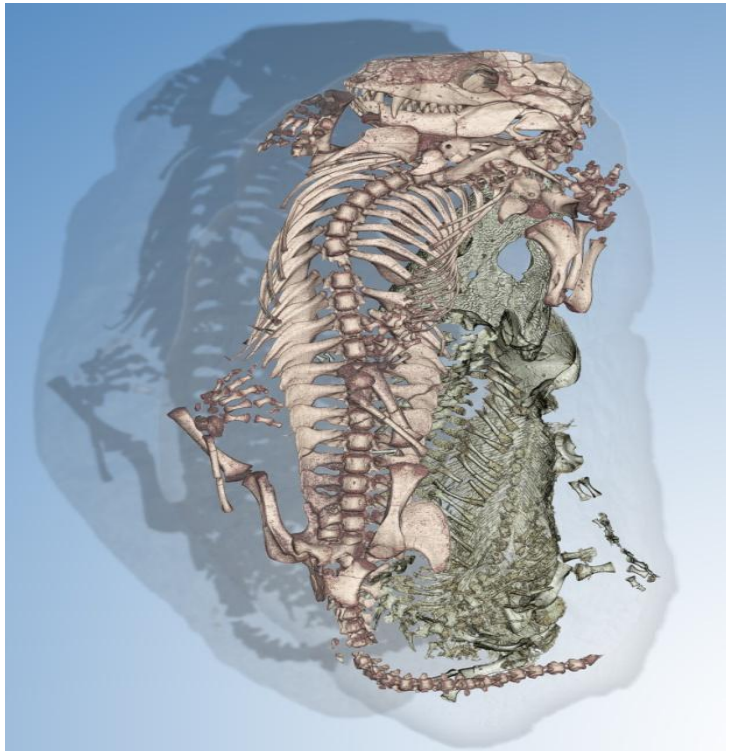
ESRF | The European Synchrotron



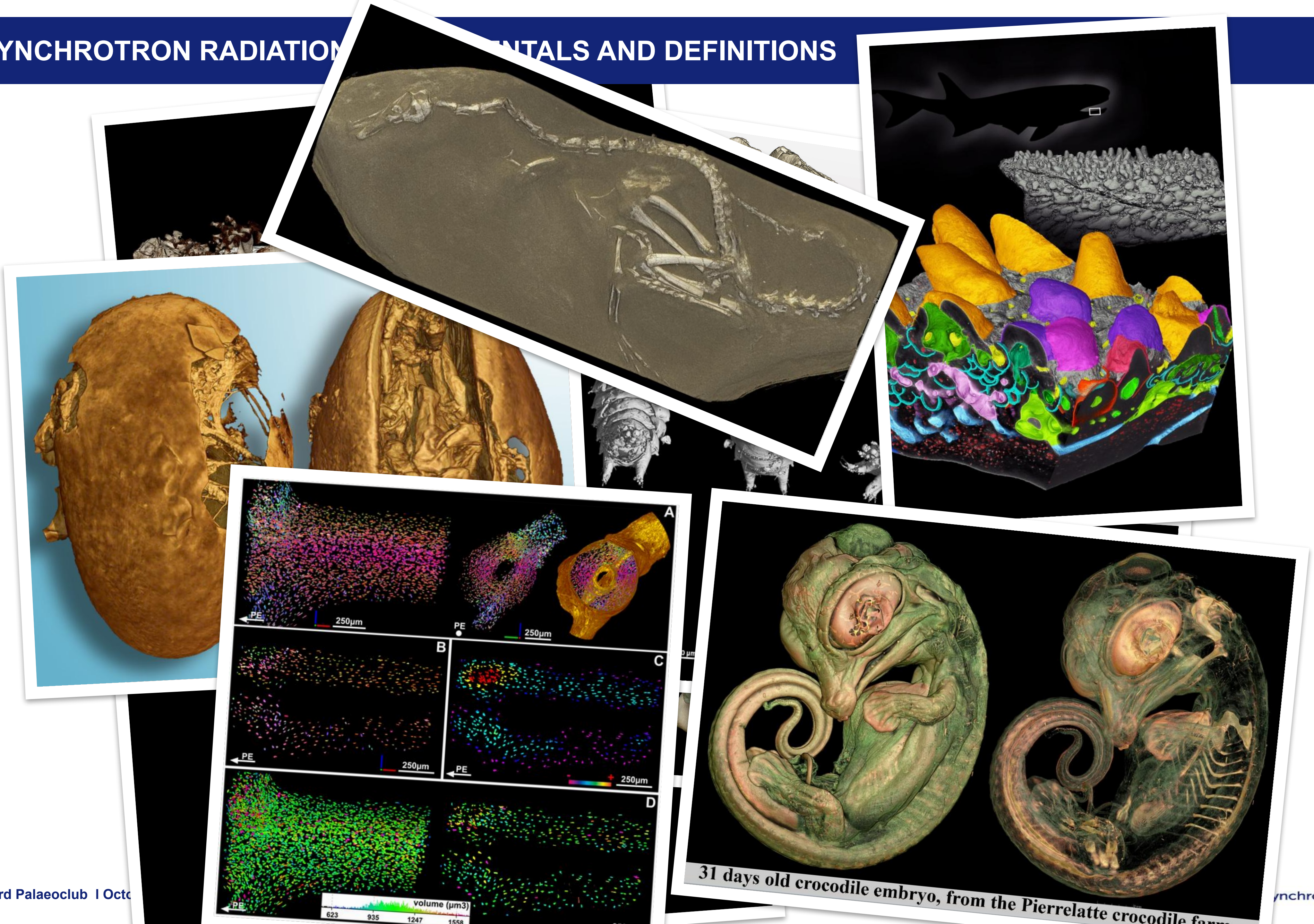
Characterisation of fossils using X-ray synchrotron µCT

-

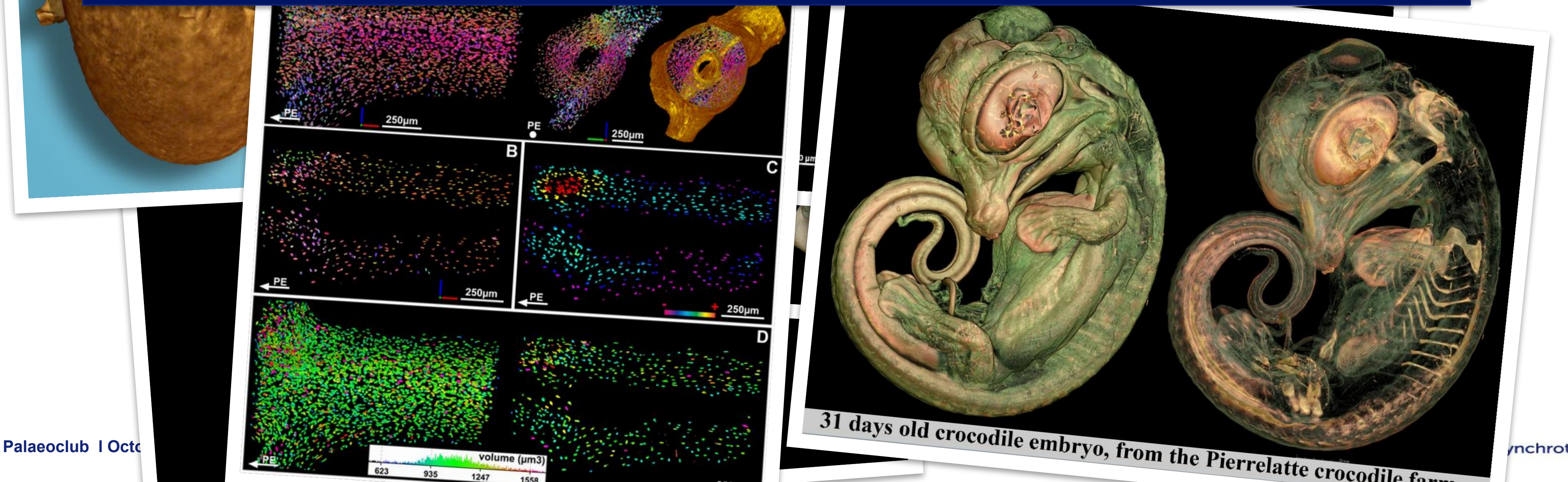
V. Fernandez

Natural History Museum UK
ESRF – Structure of Materials

SYNCHROTRON RADIATION … NTALS AND DEFINITIONS



Why and **When** is it a good idea to use a synchrotron light source?



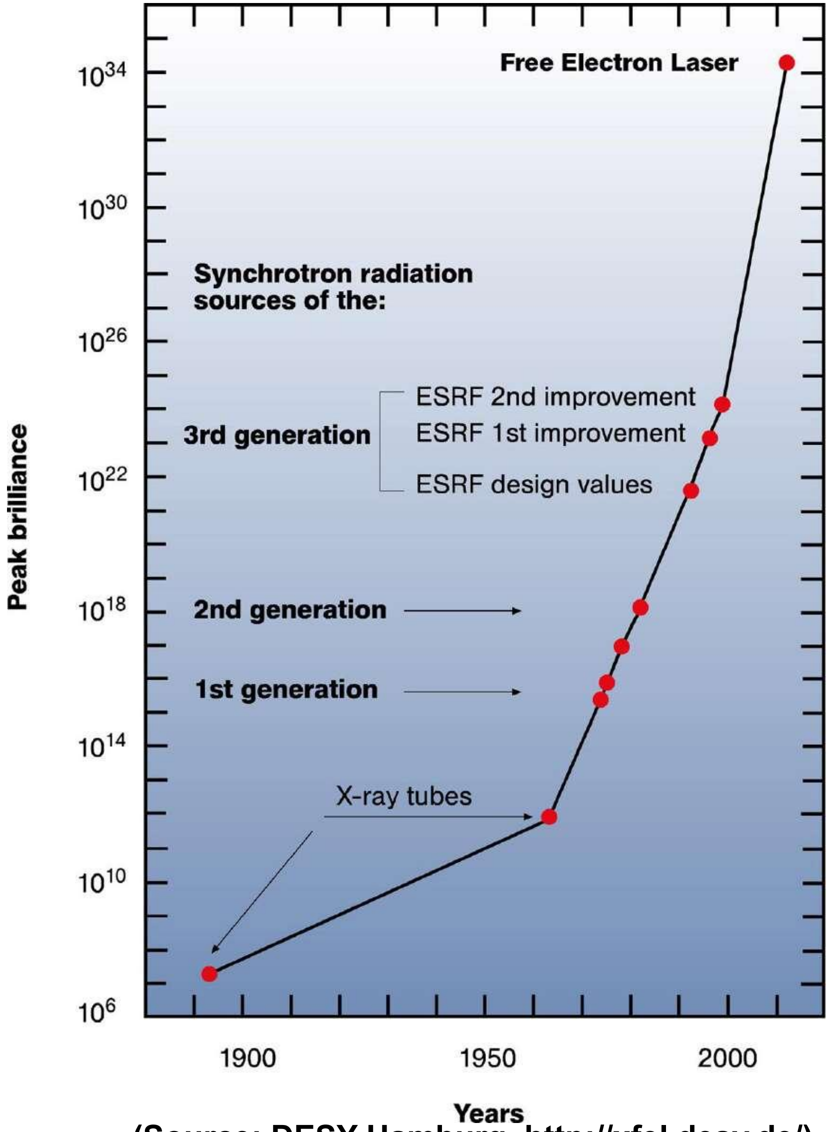
Effects on data due to main differences of beam and acquisition

- Brilliance

- Geometry

- Coherence

SYNCHROTRON VS LABORATORY SOURCES



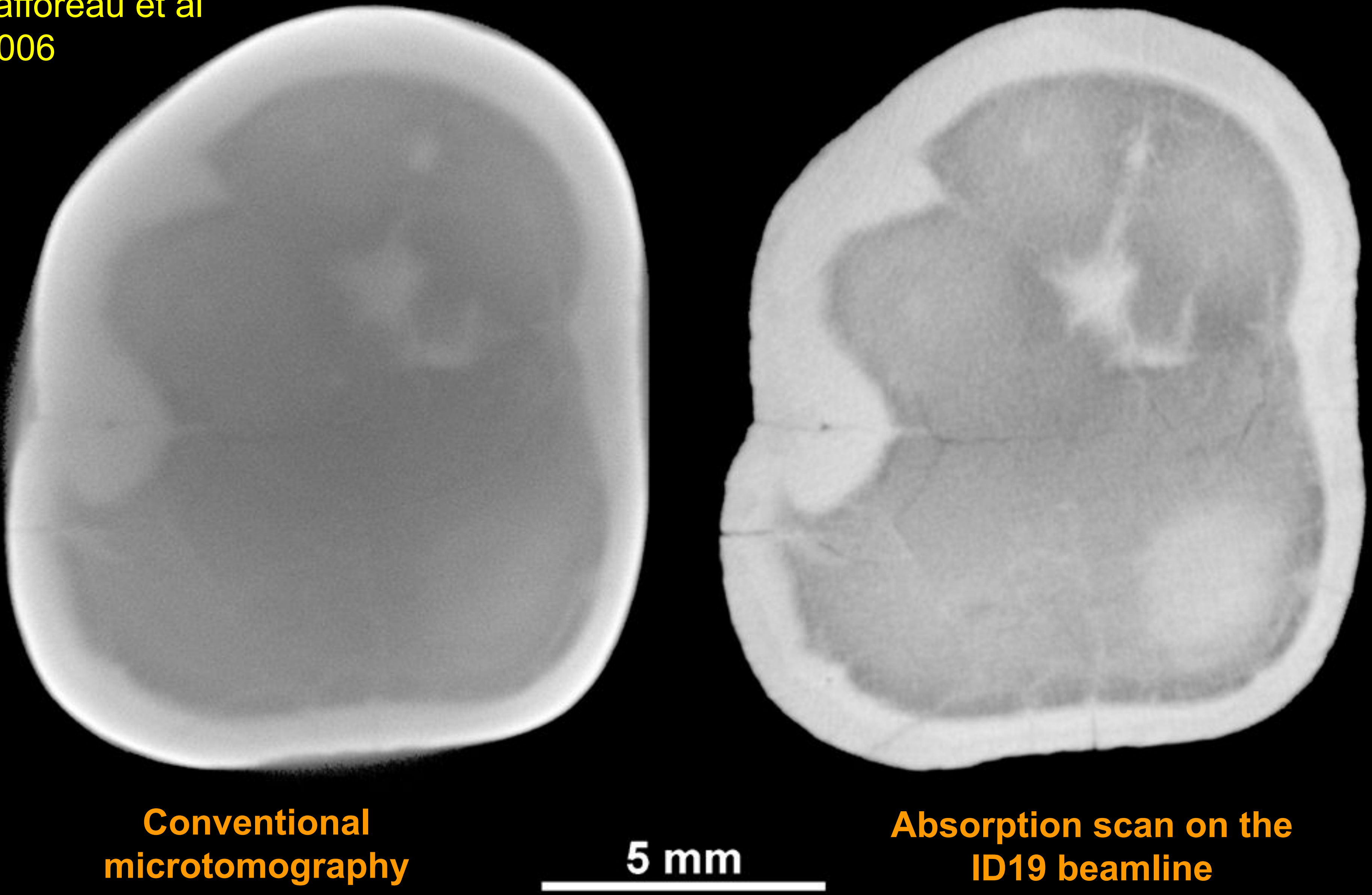
(Source: DESY Hamburg, http://xfel.desy.de/)

Synchrotrons are more brilliant than conventional sources by several order of magnitude (about 10^{14})

10 000 billions times more brilliant than X-ray produced by Lab X-ray source

First publication of a fossil imaged using synchrotron microtomography (Jaeger et al. 2003, Nature)

Tafforeau et al 2006



Conventional microtomography

Absorption scan on the ID19 beamline

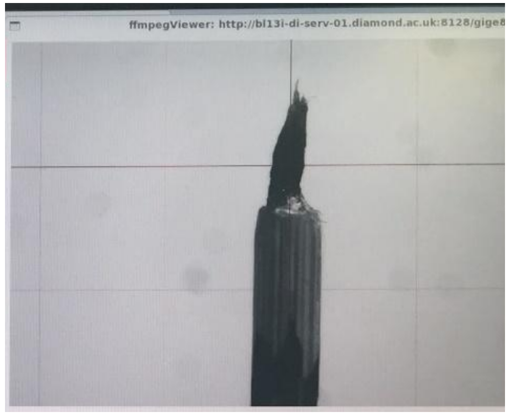
Effects on data due to main differences of beam and acquisition

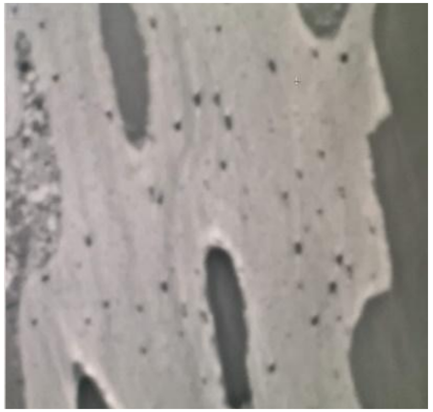
- **Brilliance:**
  - More X-ray photons => possibility to use a monochromator

- **Geometry**

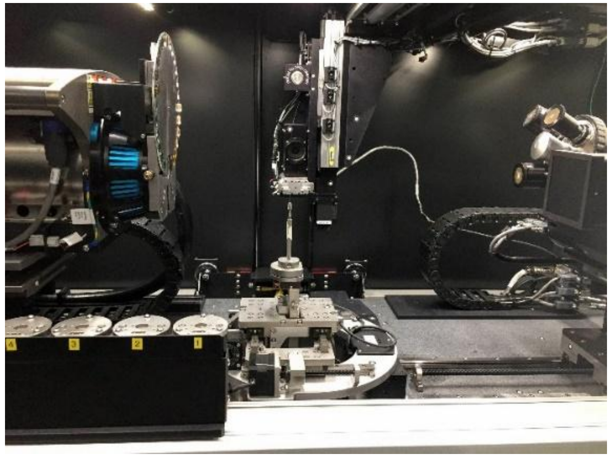
- **Coherence**

EXAMPLE OF SUB-MICRON SCAN - VIRTUAL HISTOLOGY OF FOSSILS

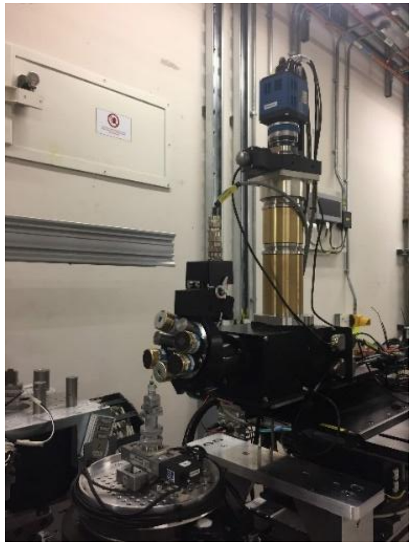




Aiming for a pixel size of 0.35 µm, energy around 20-25 keV



Lab CT @ NHM UK
Zeiss 520 Versa (10W)
~ 12-24 hours per scan



I13-2 beamline of the Diamond Light Source (UK)
~ 20 minutes per scan

Data from Davesne et al 2021

Effects on data due to main differences of beam and acquisition

- **Brilliance:**
  - More X-ray photons => possibility to use a monochromator
    => faster acquisition

- **Geometry**

- **Coherence**

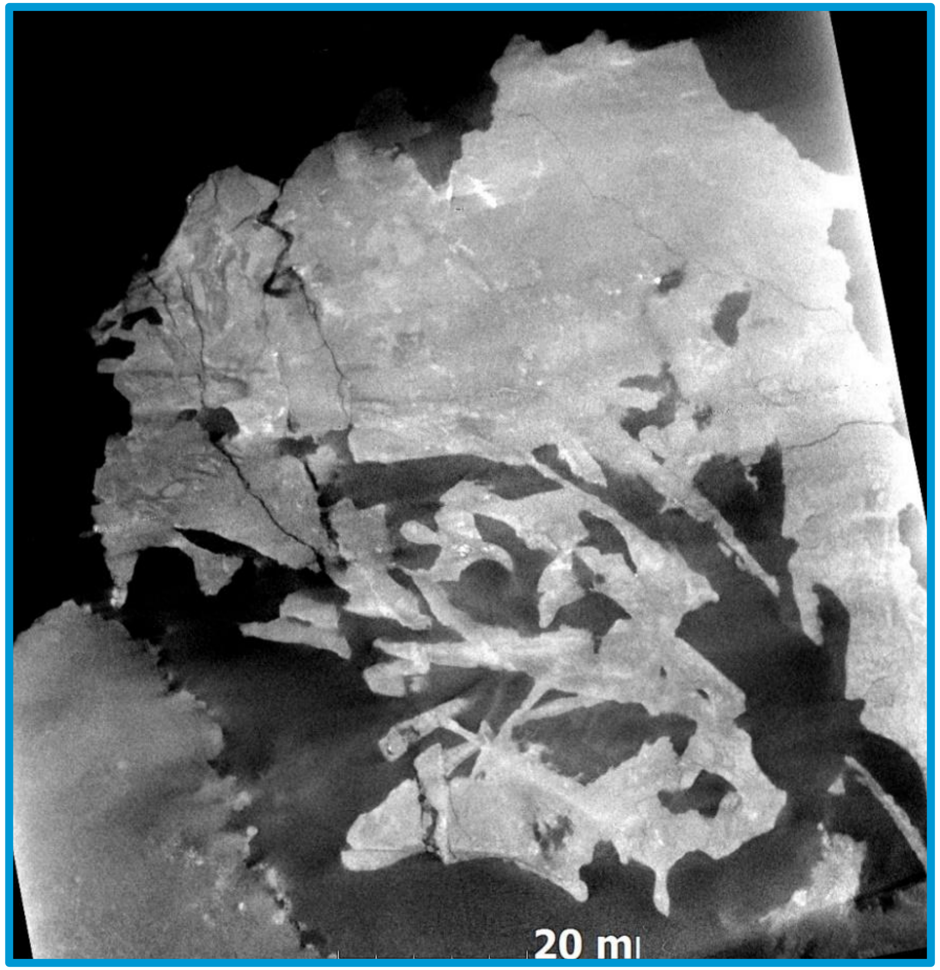
EXAMPLE OF MACRO-SCALE SCAN

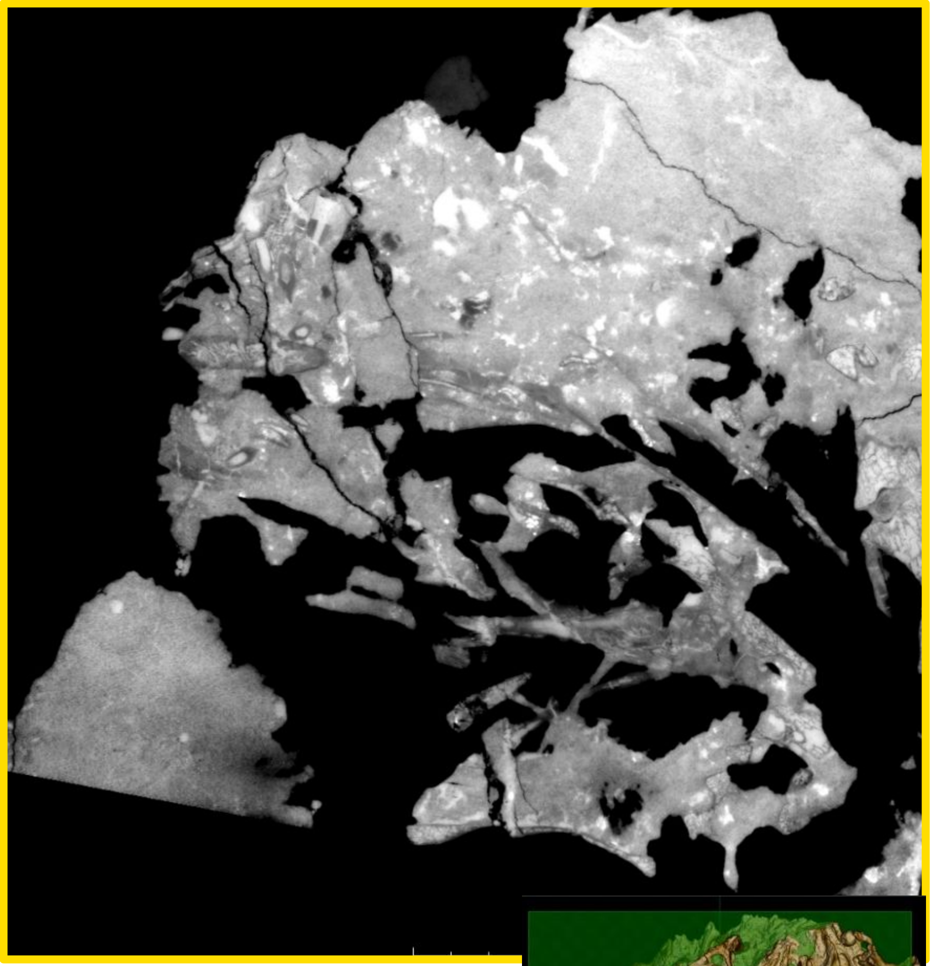
Pantydraco – Early Jurassic Dinosaur from Wales

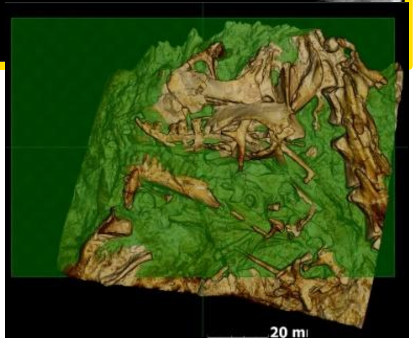
Nikon HMXST 225:
215 kV, 400 μA
3142 projection, Frame averaging 4
Exposure: **1 sec**
Filters: Cu 1 mm ; Ag 1 mm
57.64 μm pixel size
= > FOV 11.5 x 11.5 cm : **1 scan**
Scan time: 3h 30

BM05 beamline of the ESRF:
160 keV
6000 projection, Frame averaging 6
Exposure: **0.04 sec**
Filters: Mo 0.4 mm Al 25 mm W 1 mm
27.03 μm pixel size = > 4.32 x 10.4 cm
⇒ **50 scans** (with 50% overlap)
⇒ **24 minutes per scans**
⇒ **20 hours in total**

EXAMPLE OF MACRO-SCALE SCAN







Trustees of the NHMUK

EXAMPLE OF MACRO-SCALE SCAN

Trustees of the NHMUK

Effects on data due to main differences of beam and acquisition

- Brilliance:

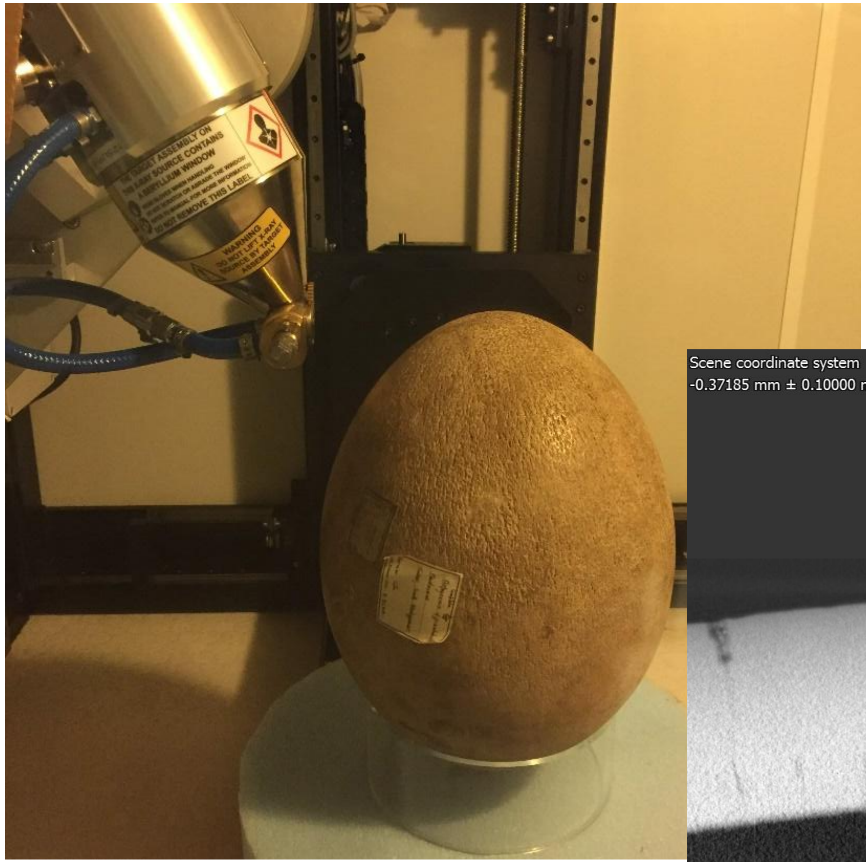
- More X-ray photons => possibility to use a monochromator
  => faster acquisition
- And/or Better signal-to-noise-ratio

- Geometry

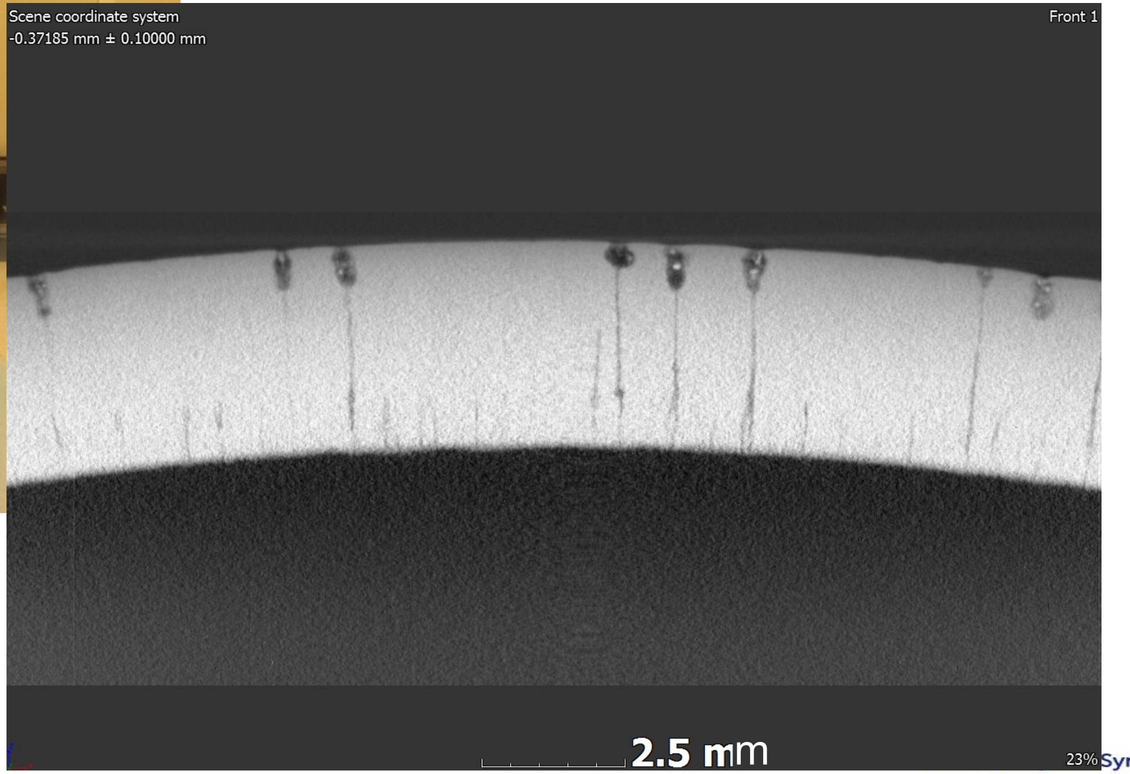
- Parallel geometry: undistorted projection (ultimately impact the resolution)
- Possibility to 'zoom in' samples more efficiently

- Coherence

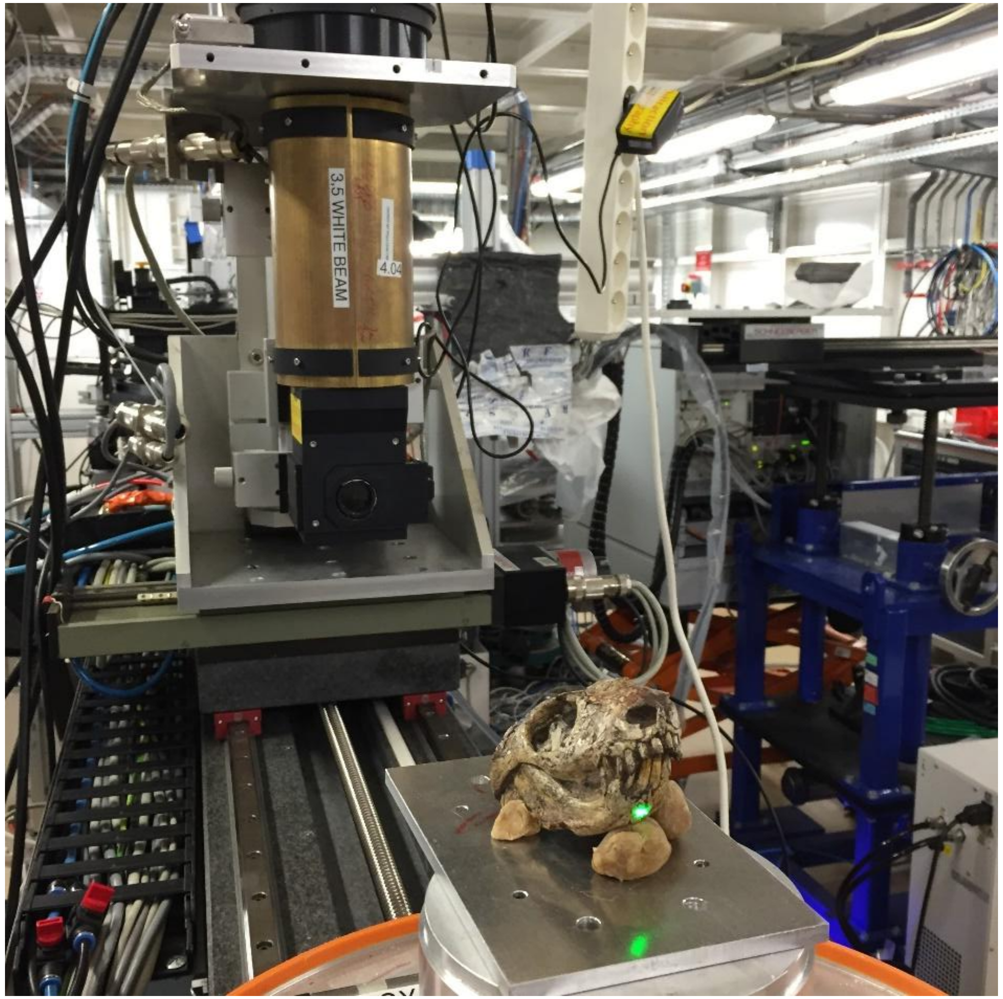
Aepyornis egg



Nikon HMXST 225:
For a XCT with a pixel size of **5 µm**, the **centre of rotation needs to be ~ 15 mm** away from the source => impossible
Limit here: 20 µm but only for the tip of the egg

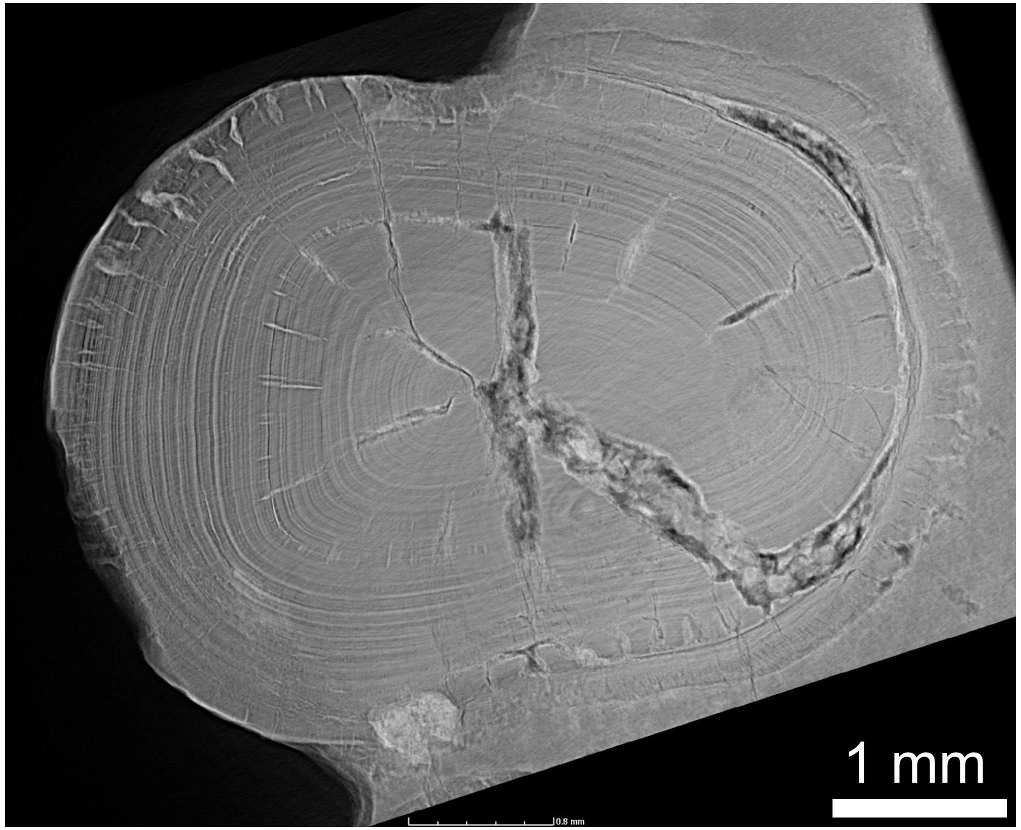


Trustees of the NHMUK



Synchrotron CT beamline:

Limit is set by maximum available energy and handling capabilities of the sample stage:



Effects on data due to main differences of beam and acquisition

- Brilliance:

- More X-ray photons => possibility to use a monochromator
  => faster acquisition
- And/or Better signal-to-noise-ratio

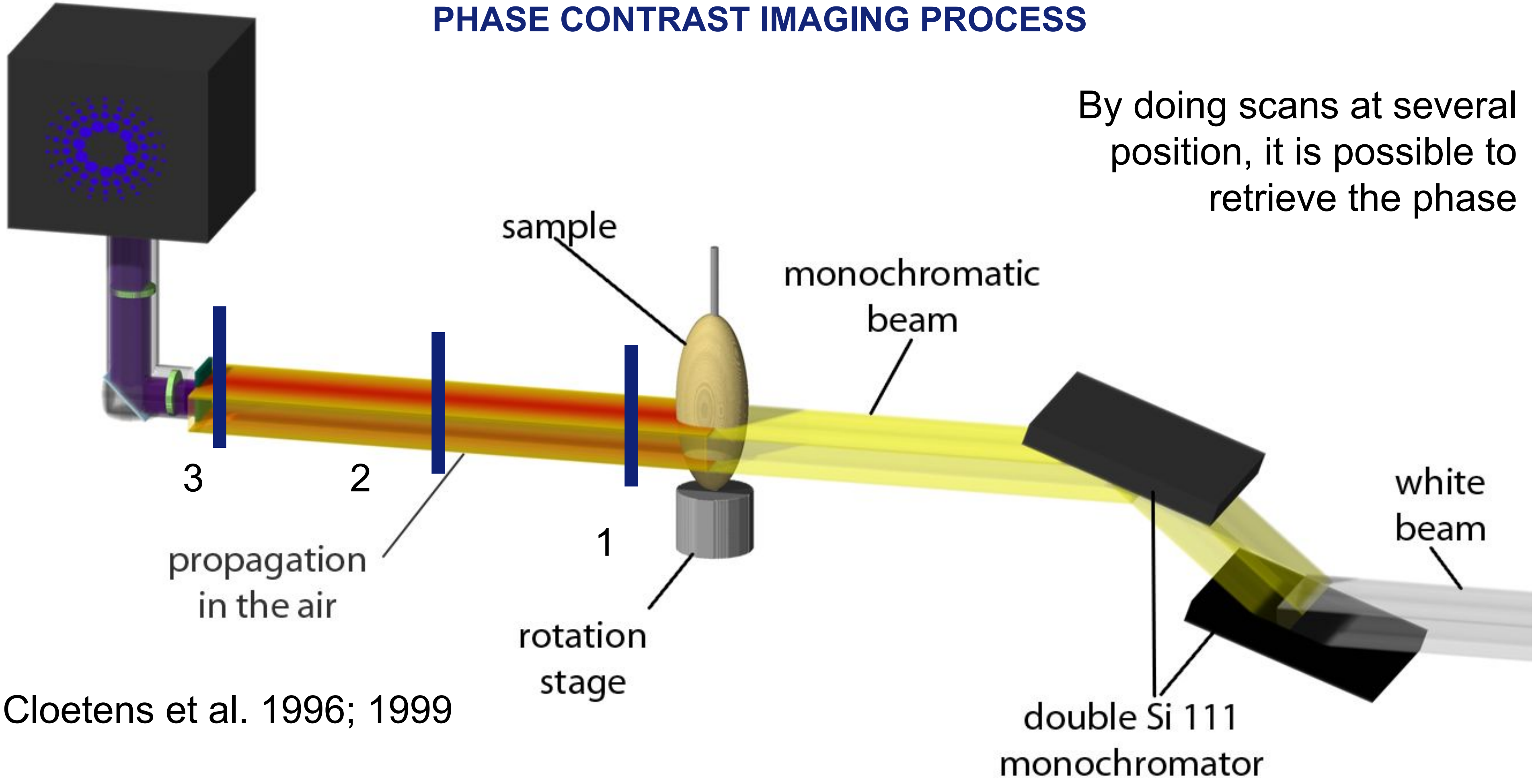
- Geometry

- Parallel geometry: undistorted projection (ultimately impact the resolution)
- Possibility to ‘zoom in’ samples more efficiently

- Coherence

PHASE CONTRAST IMAGING PROCESS

By doing scans at several position, it is possible to retrieve the phase



Cloetens et al. 1996; 1999

Cloetens, P., Barrett, R., Baruchel, J., Guigay, J.P. and Schlenker, M., 1996. Phase objects in synchrotron radiation hard x-ray imaging. *Journal of physics D: applied physics*, *29*(1), p.133.
Cloetens, P., Ludwig, W., Baruchel, J., Van Dyck, D., Van Landuyt, J., Guigay, J.P. and Schlenker, M., 1999. Holotomography: Quantitative phase tomography with micrometer resolution using hard synchrotron radiation x rays. *Applied physics letters*, *75*(19), pp.2912-2914.

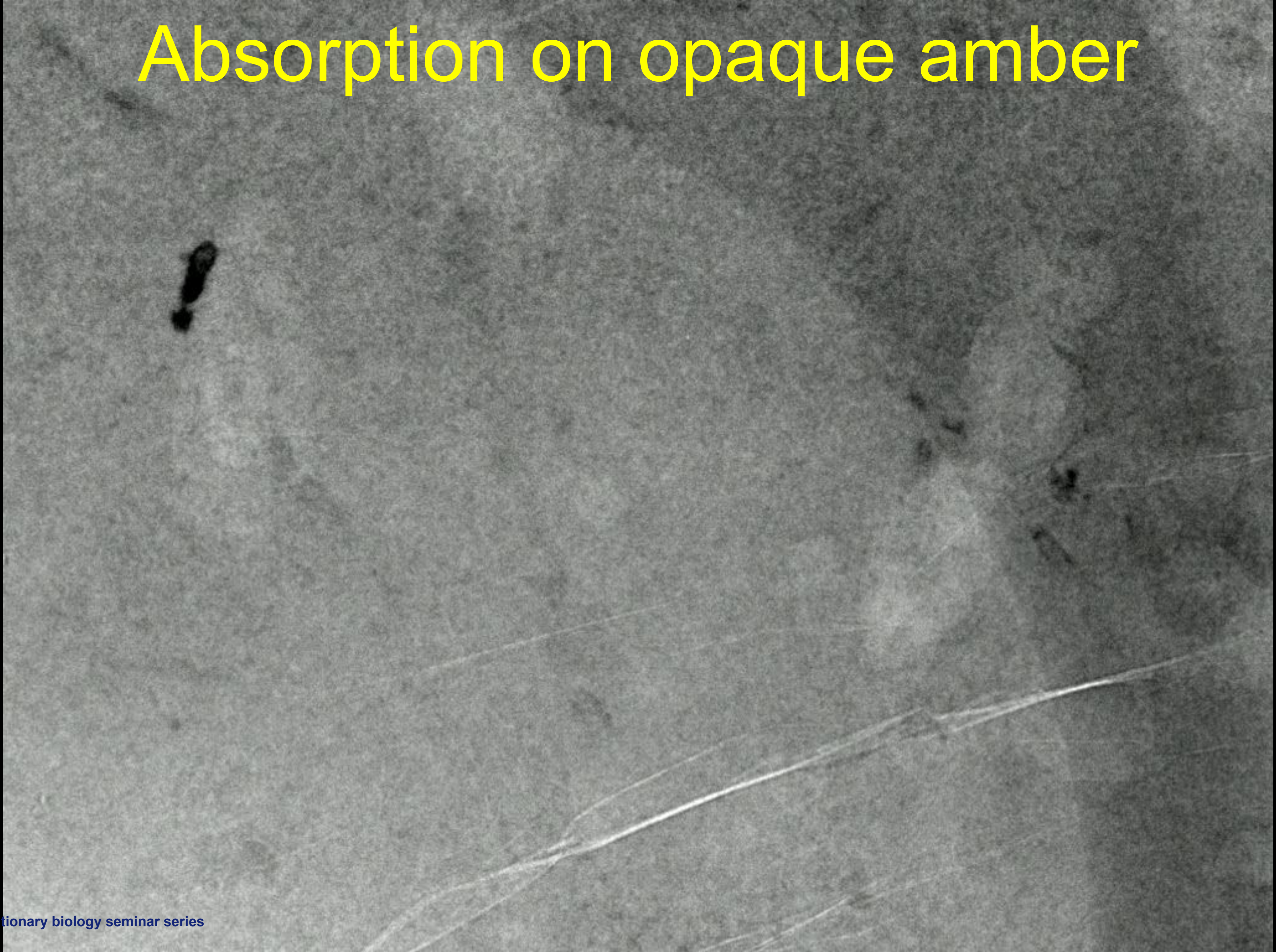
Phase contrast microtomography of arthropods embedded in amber

Specimens from Cretaceous French amber (100 Mya)

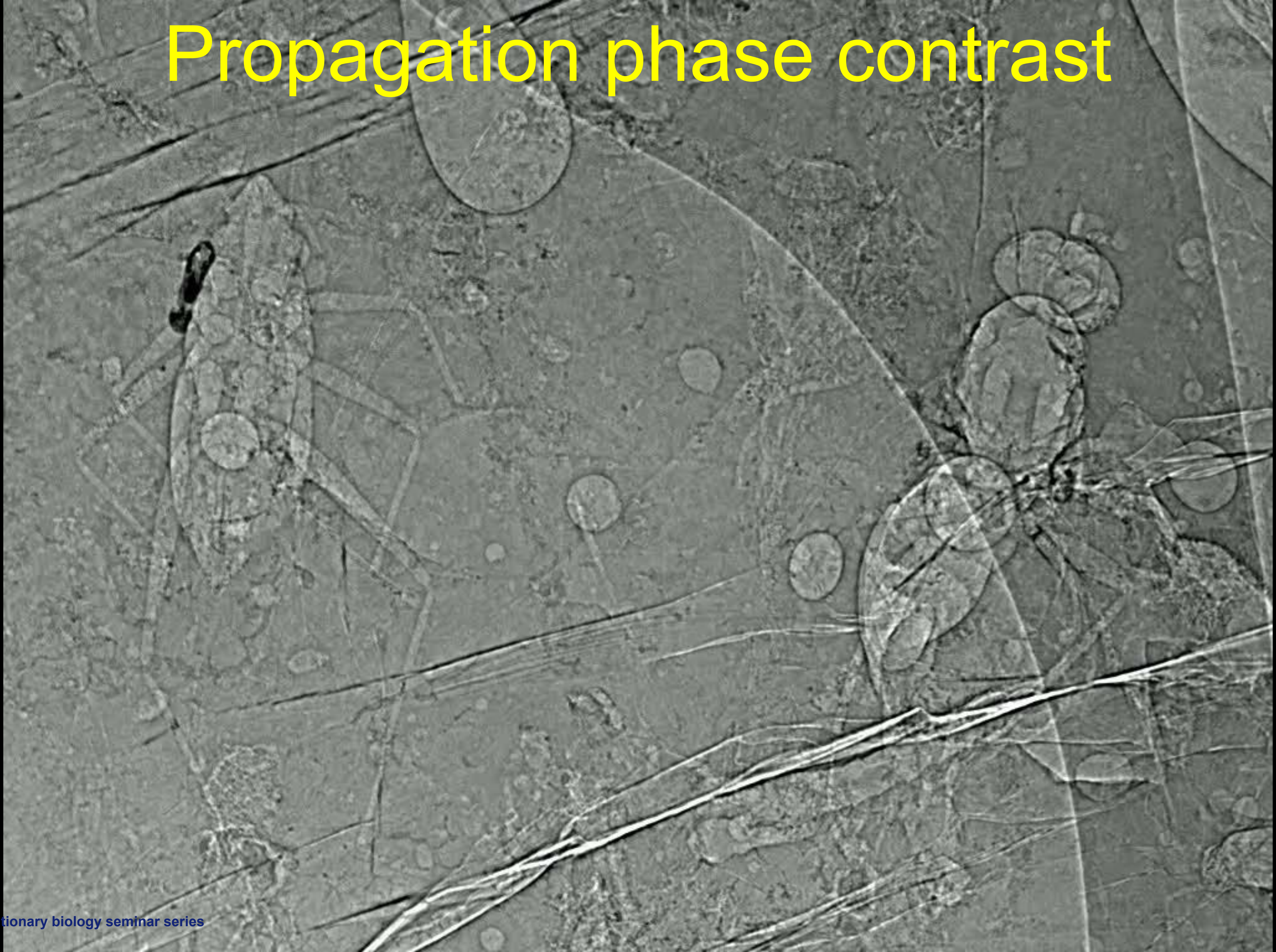
Lak et al. 2008

Lak, M., Néraudeau, D., Nel, A., Cloetens, P., Perrichot, V. and Tafforeau, P., 2008. Phase contrast X-ray synchrotron imaging: opening access to fossil inclusions in opaque amber. *Microscopy and microanalysis*, *14*(3), pp.251-259.

Absorption on opaque amber

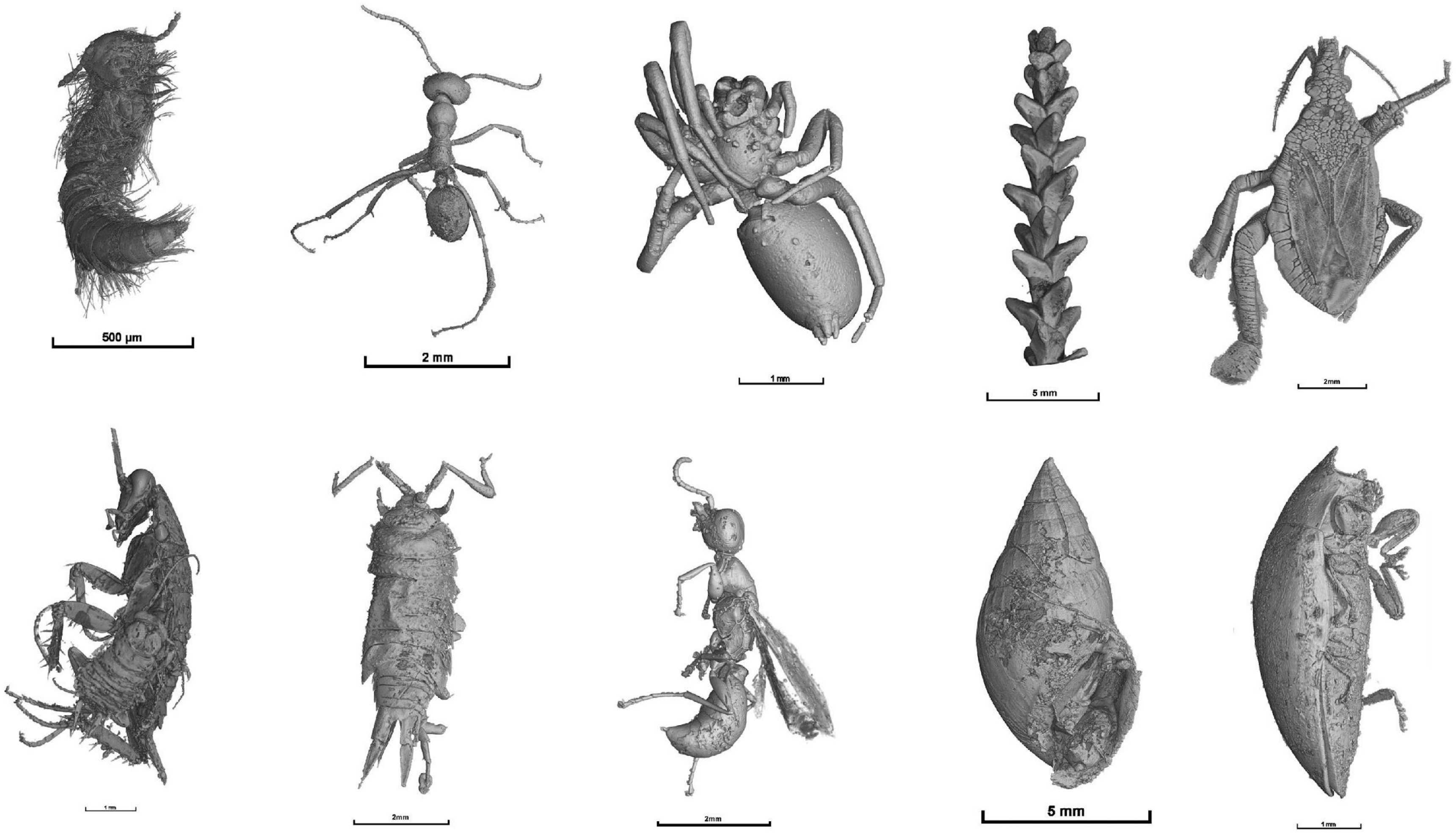


Propagation phase contrast



Damselflie
Electrohemiphlebia barucheli
Lak et al. 2009

PALAEONTOLOGY – 100 MY OLD AMBER WITH INCLUSIONS



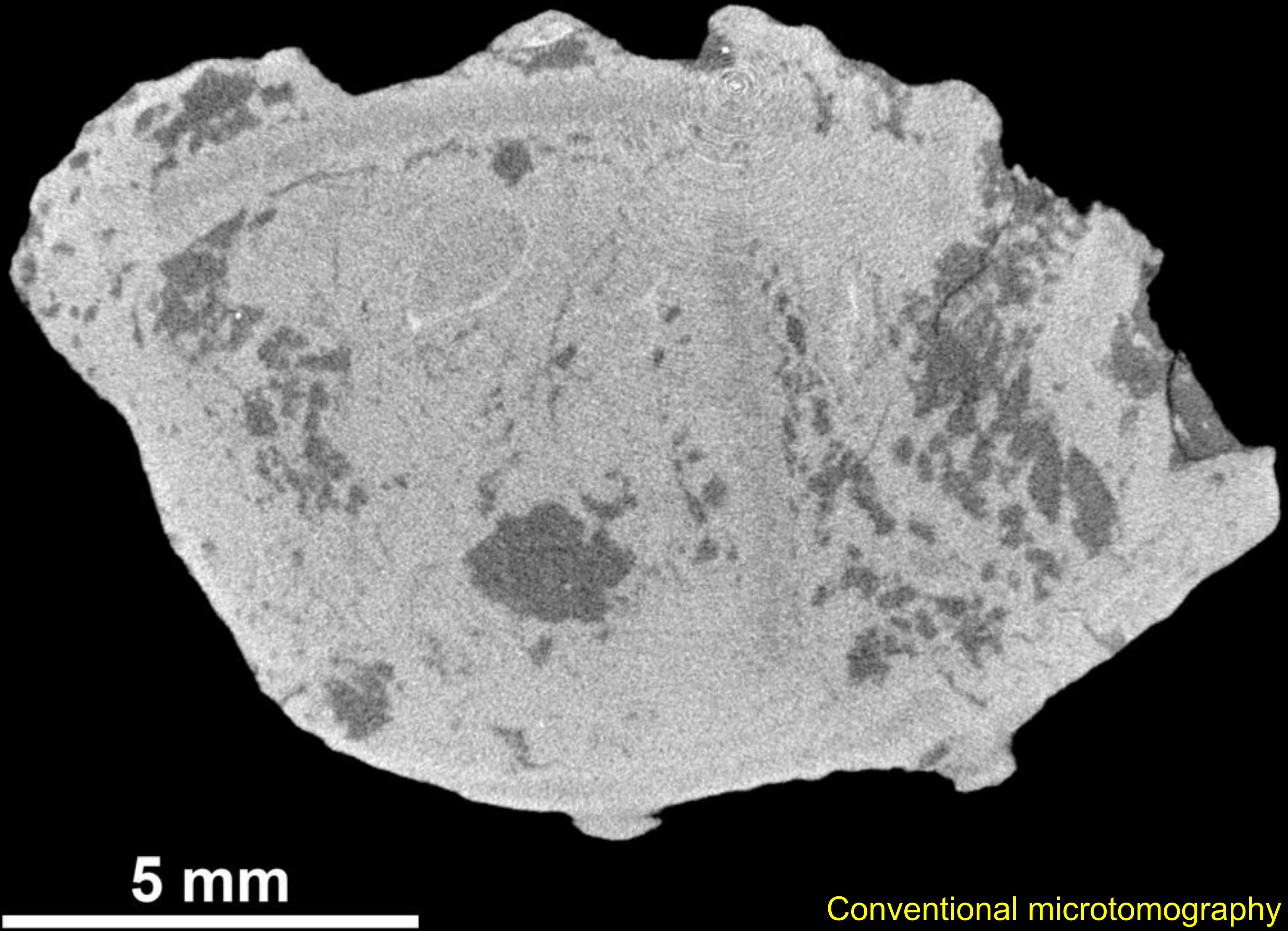
Overview of the micro-fauna

Minutes fossil eggs containing embryos from the Early Cretaceous of Thailand (140 mya)

-

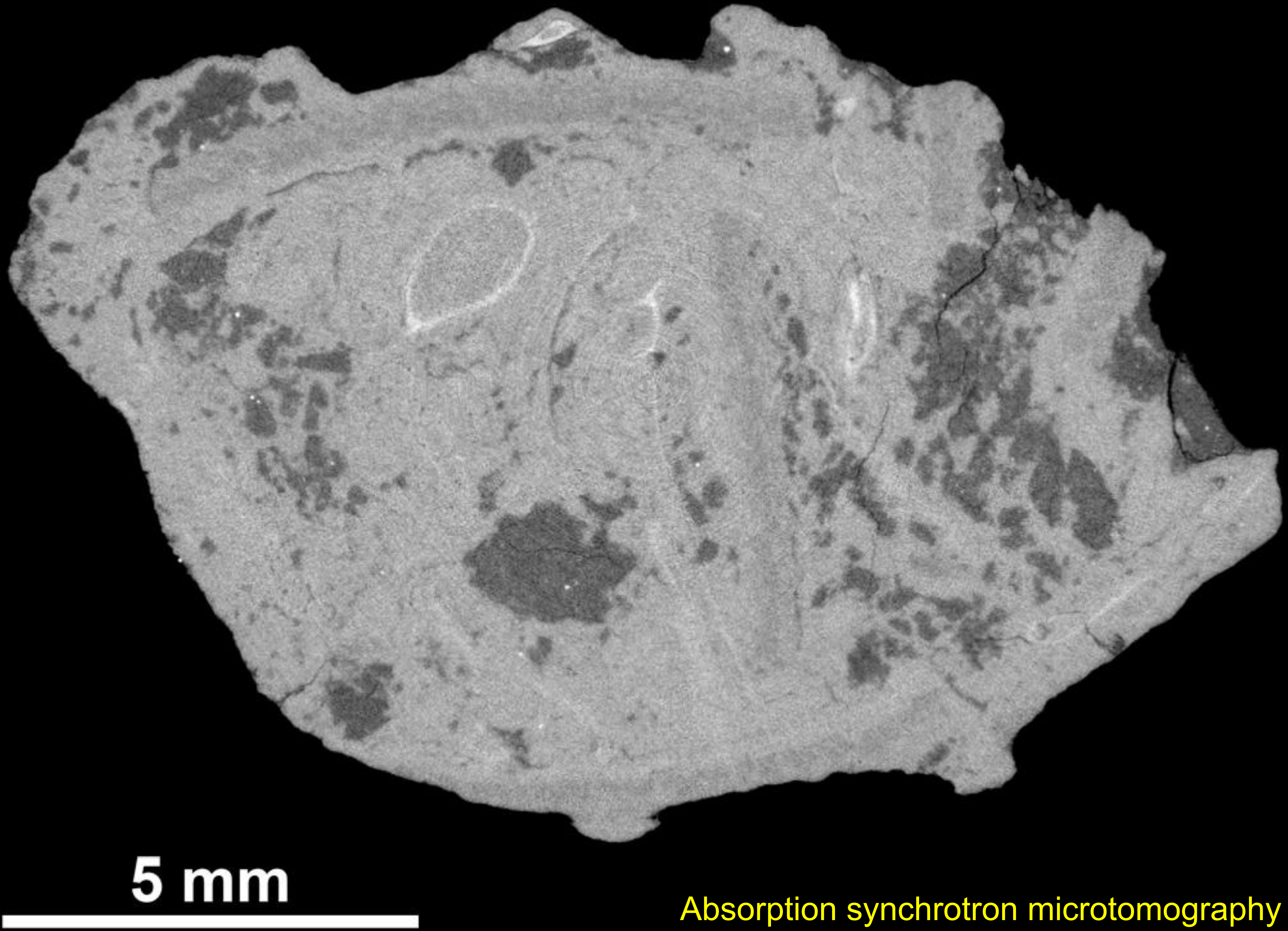
V. Fernandez, E. Buffetaut, V. Suteethorn, J.-C. Rage, P. Tafforeau & M. Kundrát

Fernandez et al 2012

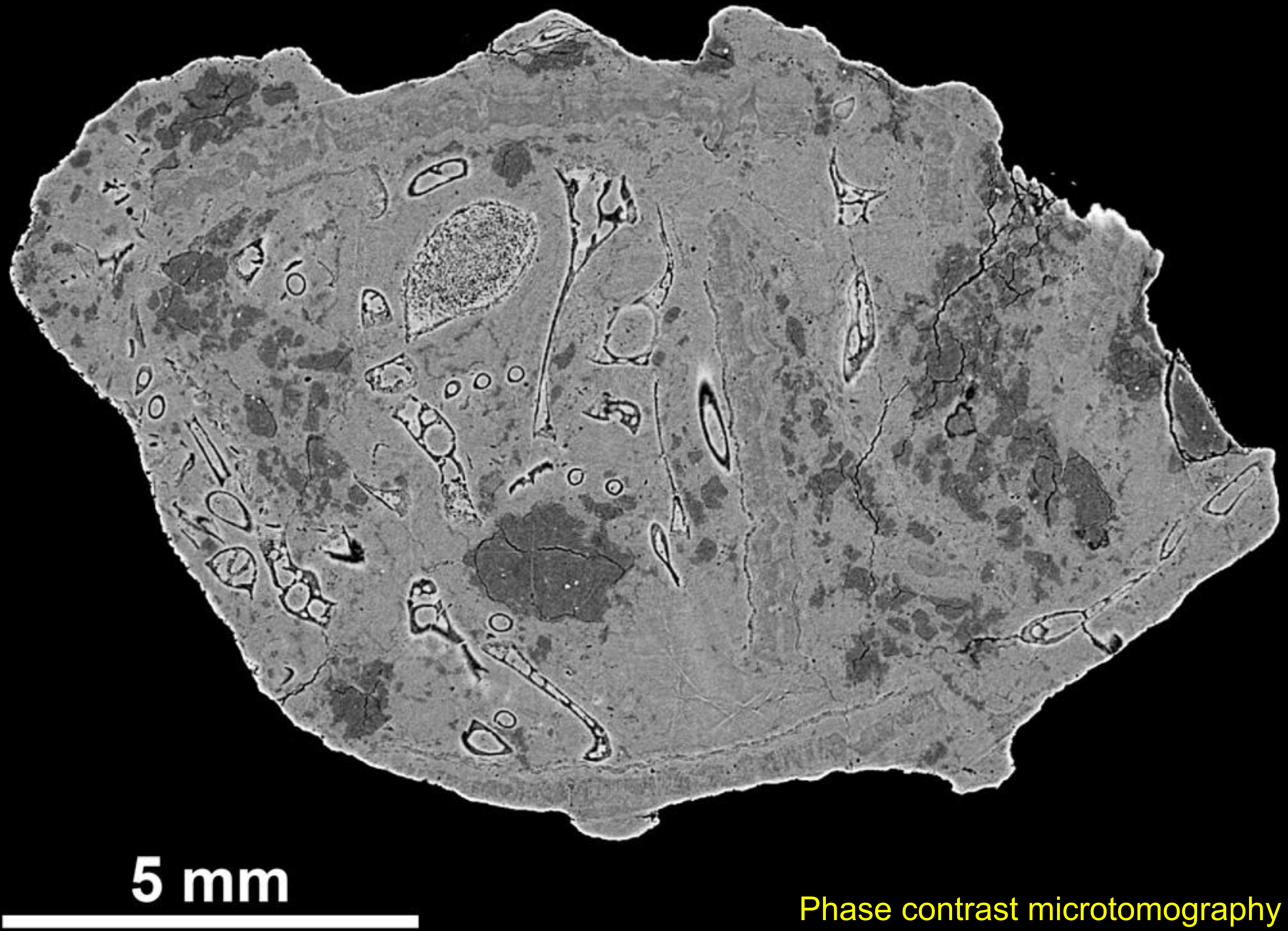


Conventional microtomography

Fernandez et al 2012



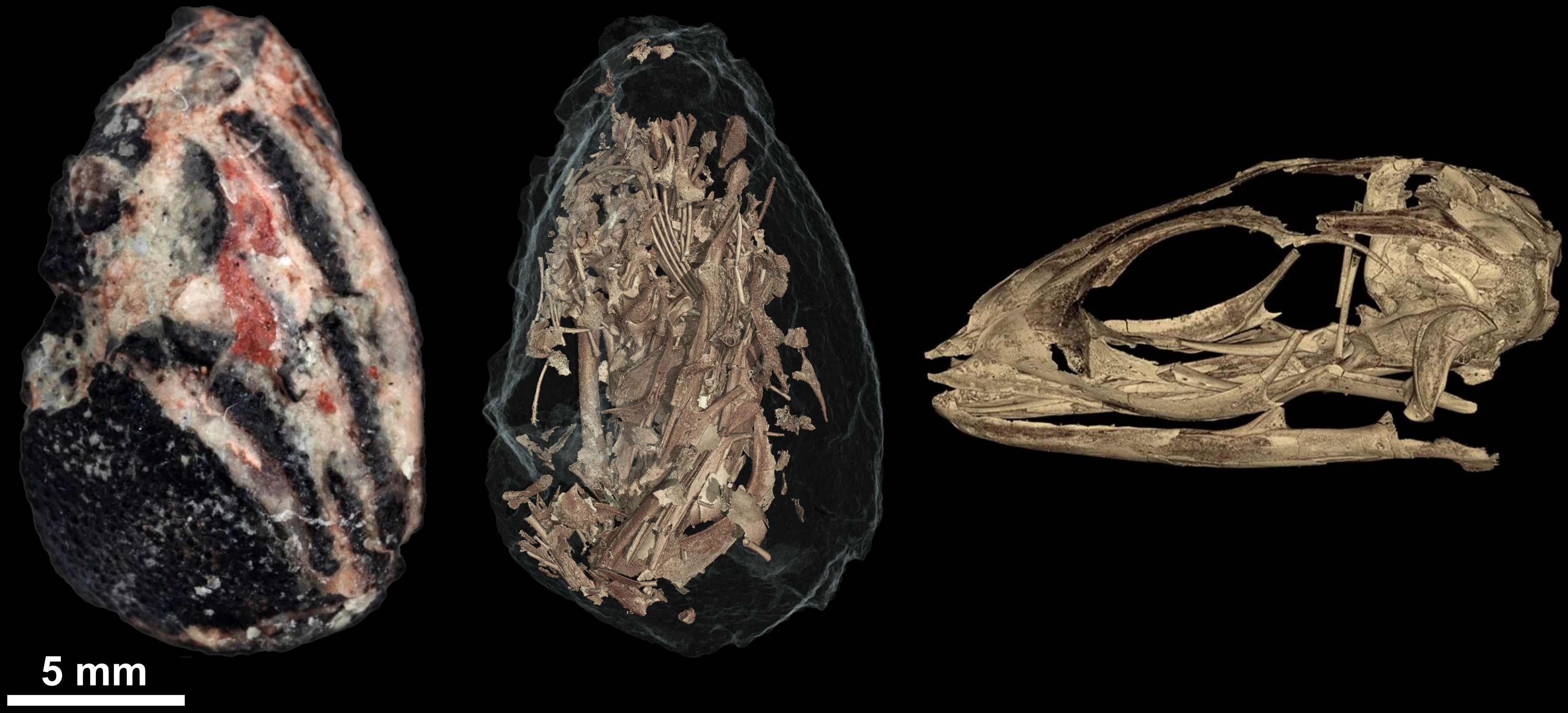
Absorption synchrotron microtomography



Phase contrast microtomography

FIRST EMBRYOS OF SQUAMATE PRESERVED IN OVO FROM THE FOSSIL RECORD

1 m sample – detector distance
5 µm voxel size
50 keV



Fernandez et al. 2015 PLOS one

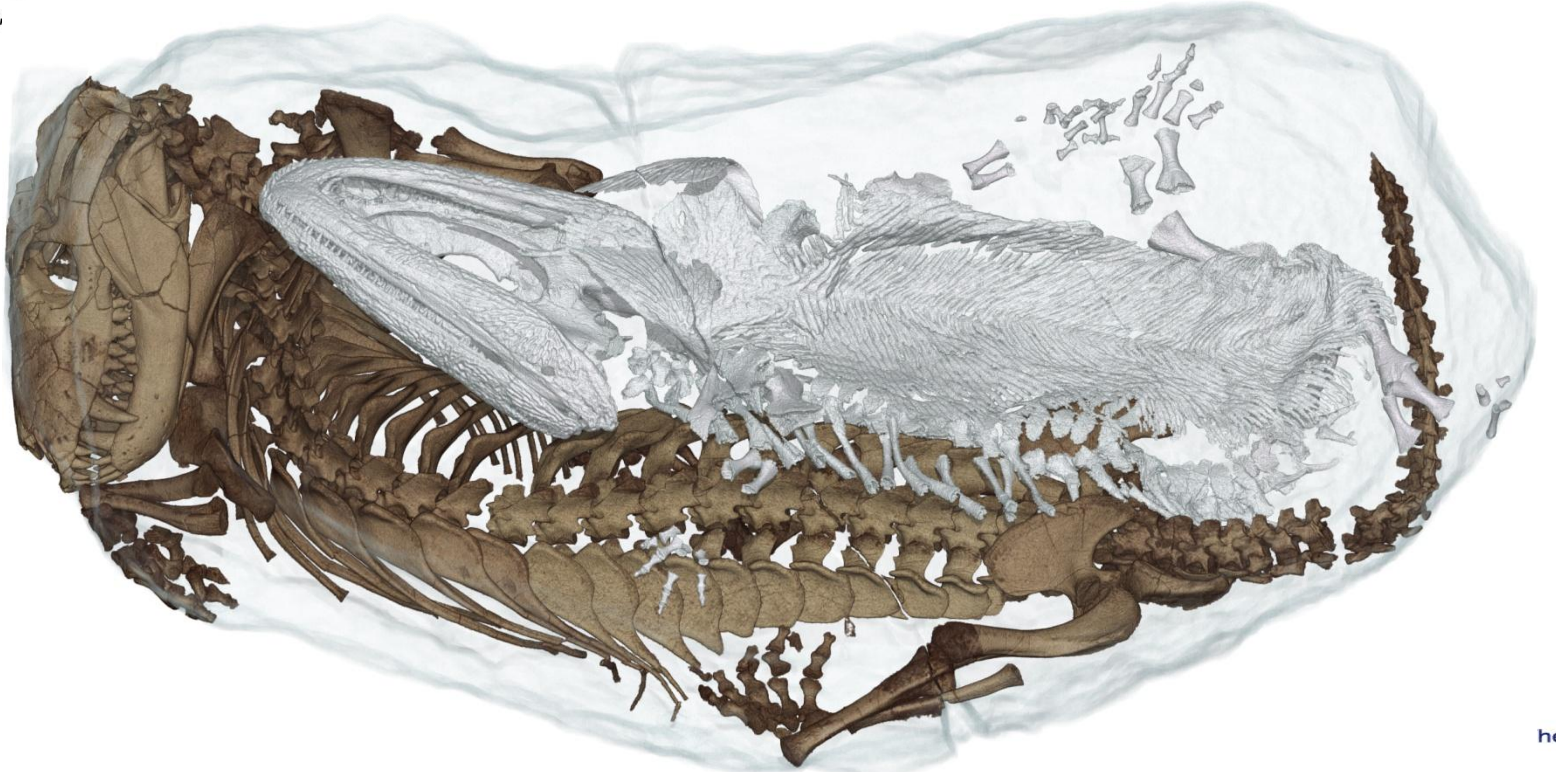
OPEN ACCESS Freely available online

PLOS | ONE

Synchrotron Reveals Early Triassic Odd Couple: Injured Amphibian and Aestivating Therapsid Share Burrow

Vincent Fernandez[1]*, Fernando Abdala[1], Kristian J. Carlson[1,2], Della Collins Cook[2], Bruce S. Rubidge[1], Adam Yates[1,3], Paul Tafforeau[4]

1 Evolutionary Studies Institute, University of the Witwatersrand, Johannesburg, Gauteng, South Africa, **2** Department of Anthropology, Indiana University, Bloomington, Indiana, United States of America, **3** Museum of Central Australia, Araluen Cultural Precinct, Alice Springs, Northern Territory, Australia, **4** European Synchrotron Radiation Facility, Grenoble,



REPORTS

Science AAAS

The Endocast of MH1, *Australopithecus sediba*

Science **333**, 1402 (2011);

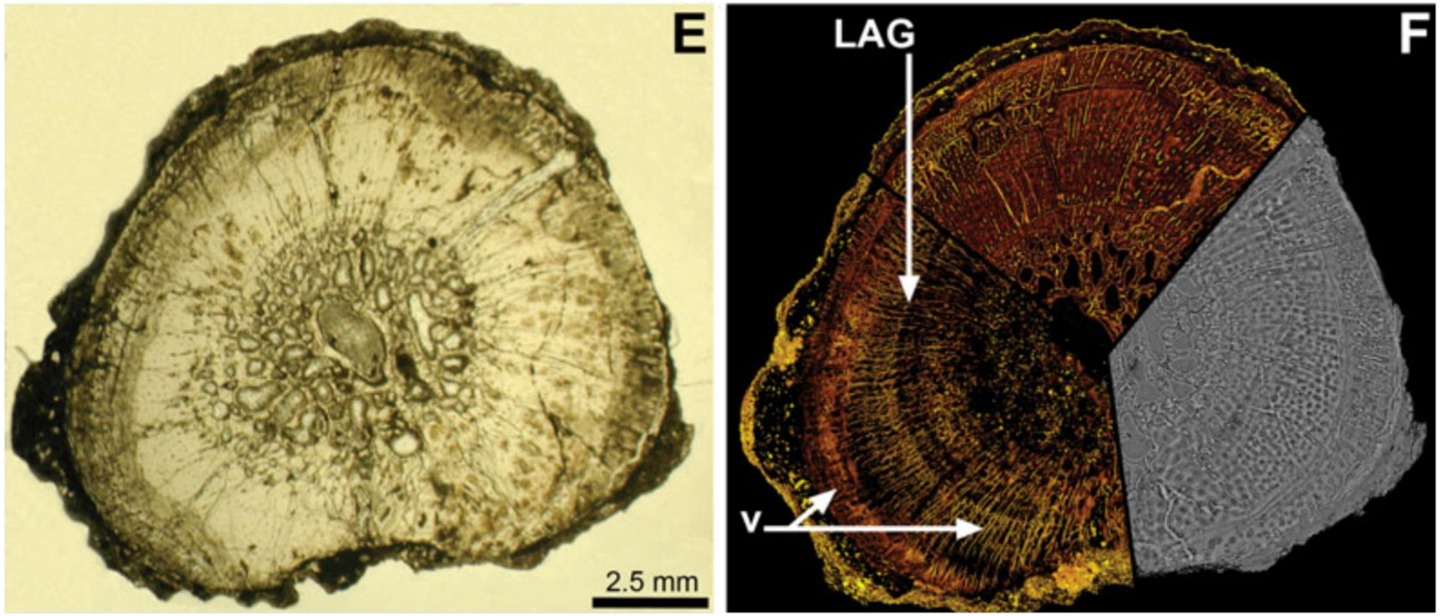
Kristian J. Carlson,[1,2]* Dietrich Stout,[3] Tea Jashashvili,[1,4,5] Darryl J. de Ruiter,[1,6] Paul Tafforeau,[7]
Keely Carlson,[6] Lee R. Berger[1,8]

Microsc. Microanal. 18, 1095–1105, 2012
doi:10.1017/S1431927612001079

Microscopy AND Microanalysis

Three-Dimensional Synchrotron Virtual Paleohistology: A New Insight into the World of Fossil Bone Microstructures

Sophie Sanchez,[1,2,*] Per E. Ahlberg,[2] Katherine M. Trinajstic,[3,4] Alessandro Mirone,[1] and Paul Tafforeau[1]

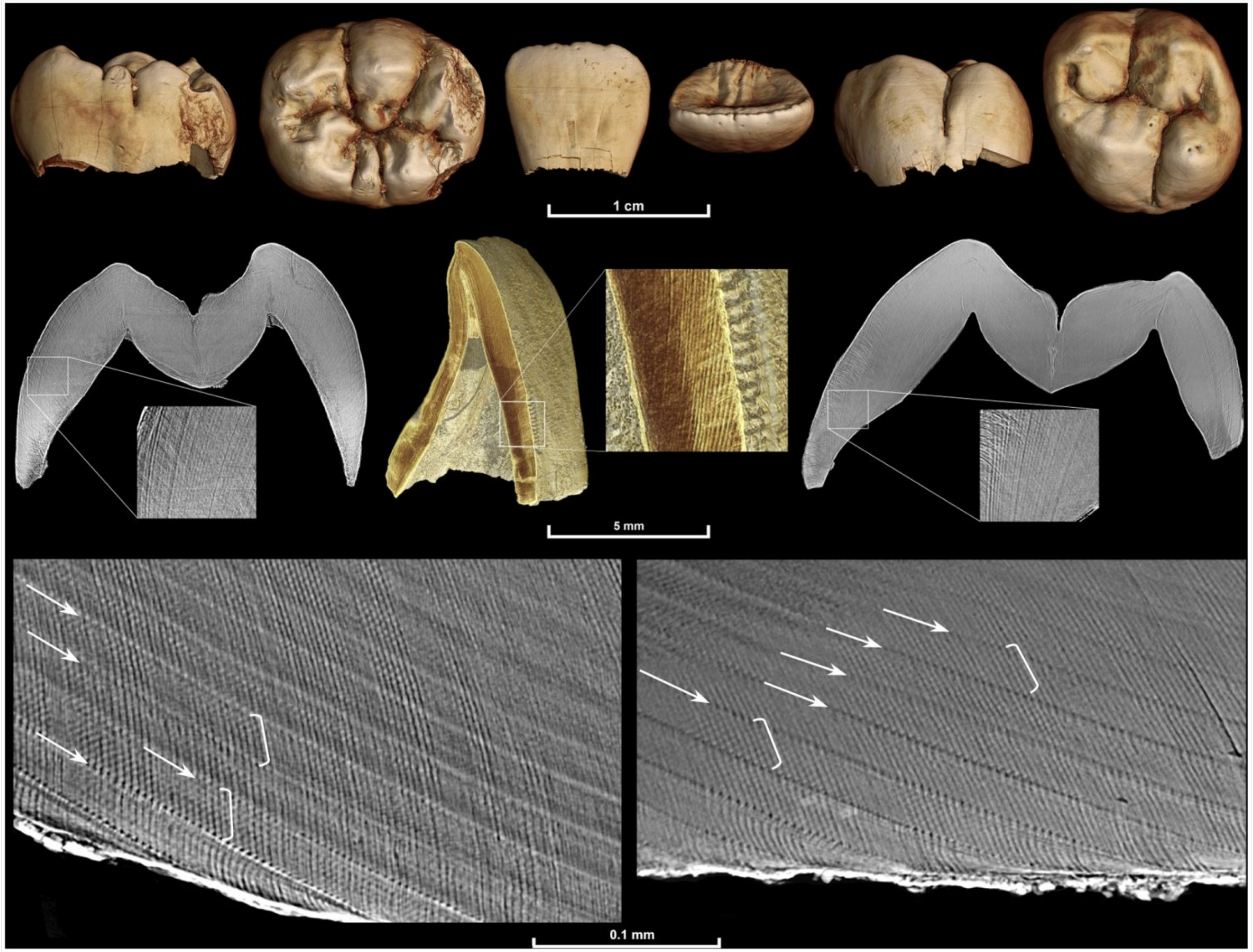


RESEARCH ARTICLE

PLOS | ONE

Dental Ontogeny in Pliocene and Early Pleistocene Hominins

T.M. Smith, P. Tafforeau, A. Le Cabec, A. Bonnin, A. Houssaye, J. Pouech, J. Moggi-Cecchi, F. Manthi, C. Ward, M. Makaremi & C.G. Menter



ACKNOWLEDGEMENTS

Many thanks to all our colleagues and collaborators who participates in these projects

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Questions?