PHYSICS MATTERS:
Science to facilitate Human Heritage

Margaux Schmeltz – Paul Scherrer Institute (PSI)

Postdoctoral fellow at the TOMCAT beamline, X-ray tomography group

margaux.schmeltz@psi.ch

Laboratory for Optics and Biosciences (LOB)

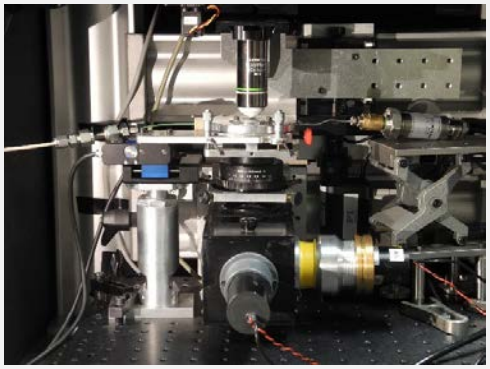
LOB: Interface Optics & Biology

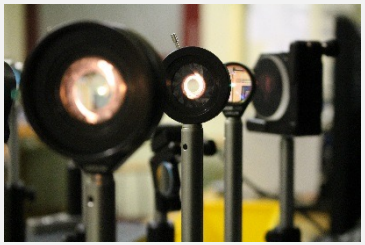
Microbial adaptation • Biomolecule dynamics • **Advanced microscopies** • Nanoimaging

Team *Second Harmonic Generation Microscopy*

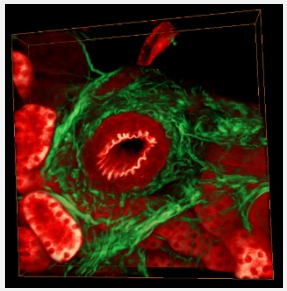
- **Marie-Claire Schanne-Klein** (Directrice de Recherche, CNRS)
- **Gaël Latour** (Maître de Conférence, Université Paris-Sud)

Instrumentation



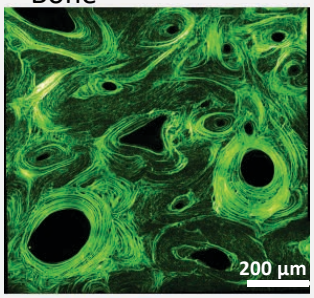


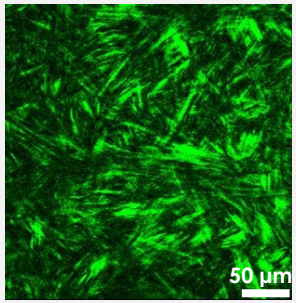
Biological tissues imaging



Kidney artery

Bone

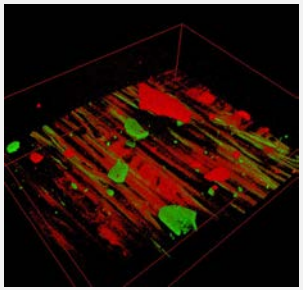




Cornea

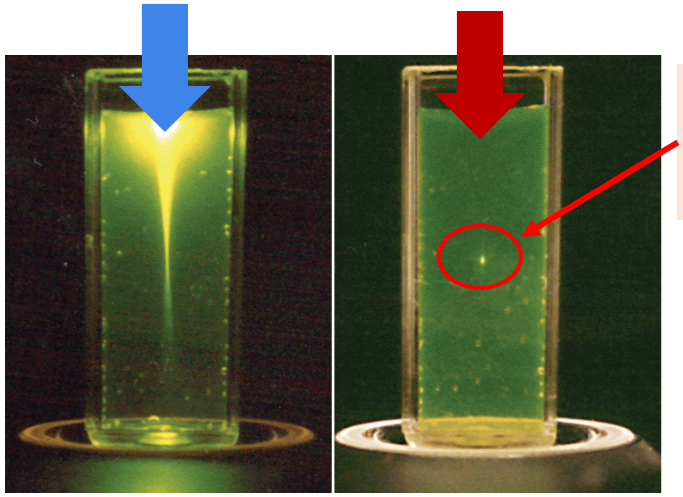
Cultural Heritage studies

Latour et al. Opt. Exp. (2012)



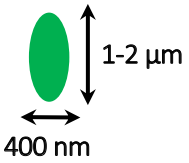
Varnished wood

Multiphoton microscopy



Zipfel & Webb (Cornell Univ.)

Intrinsic optical sectioning = 3D resolution

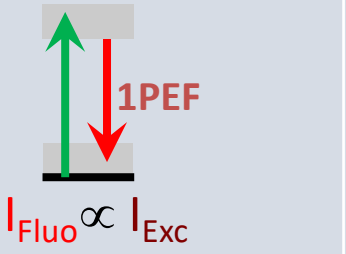


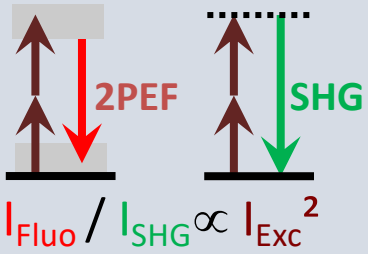
☺ **Less phototoxicity / photobleaching**

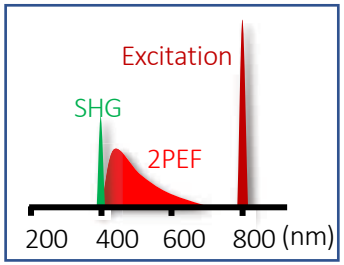
☺ **High penetration depth**

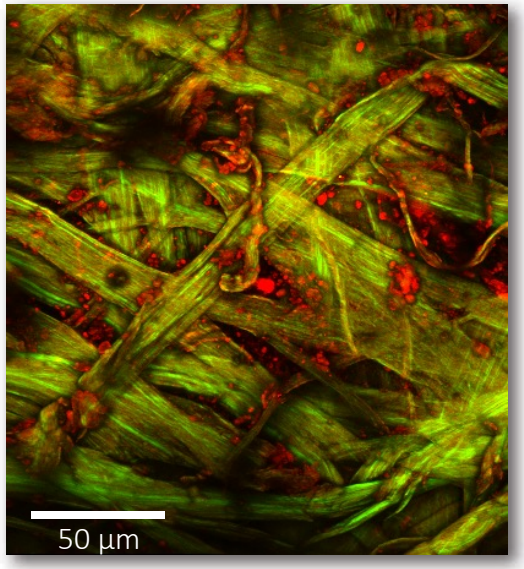
☺ **Different modes of contrast**

☺ **Specificity without staining**









Contemporary parchment

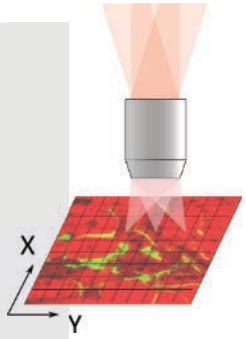
➢ **2PEF** (fluo) = 2-Photon Excited Fluorescence
=> keratine, fat residues, lignin, …

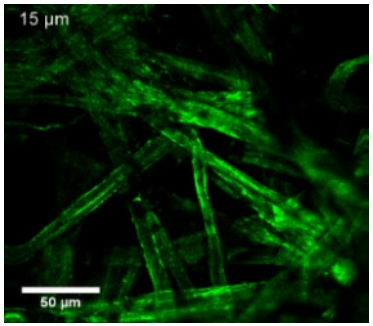
➢ **SHG** = Second Harmonic Generation
=> fibrillar collagen, myosin, cellulose, …

3D acquisitions

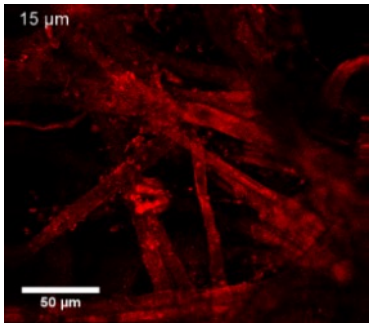
Acquisition time ~1 s / image (500 x 500 pixels)

images 2D

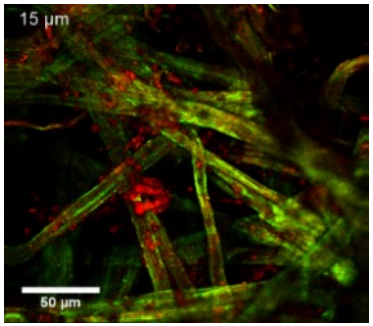




SHG : collagen

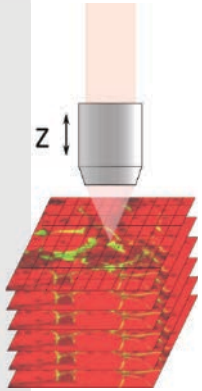


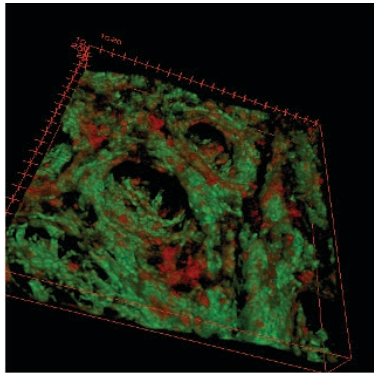
fluorescence : collagen
+ fat, elastin

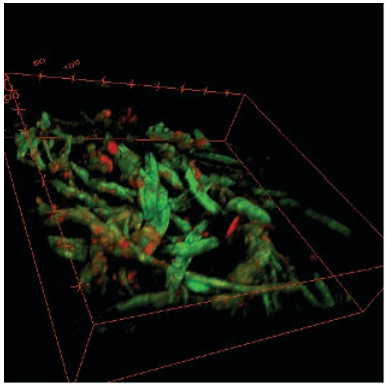


SHG + **2PEF**

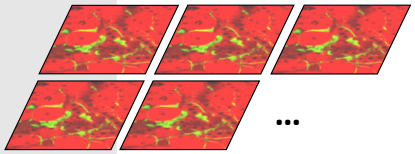
reconstruction 3D

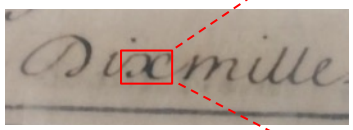


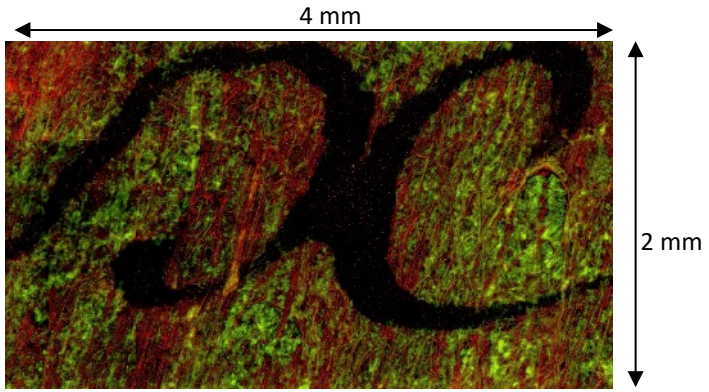




mosaïc
➔ **Increase field of view**





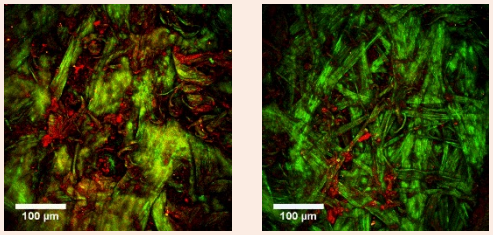


Multiphoton microscopy in cultural heritage

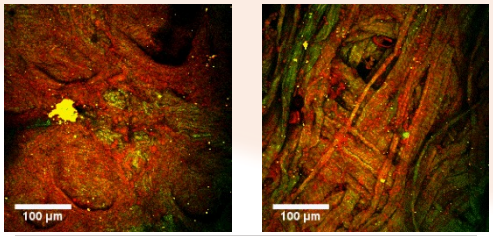
Applications

➔ collagen-based materials

parchment

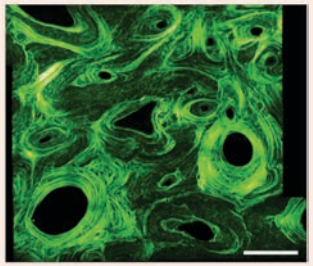


leather



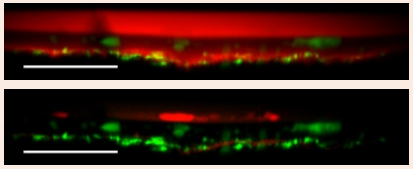
Adapted from Robinet et al, ICOM-CC 2017

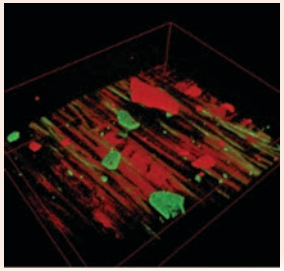
bone



Genthial et al., Sci. Reports, 2017

➔ varnishes and pigments

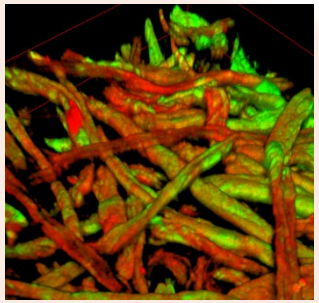




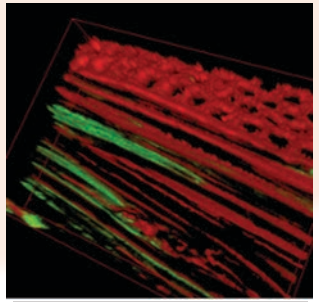
Latour et al, Opt. Express, 2012

➔ cellulose

Whatman paper



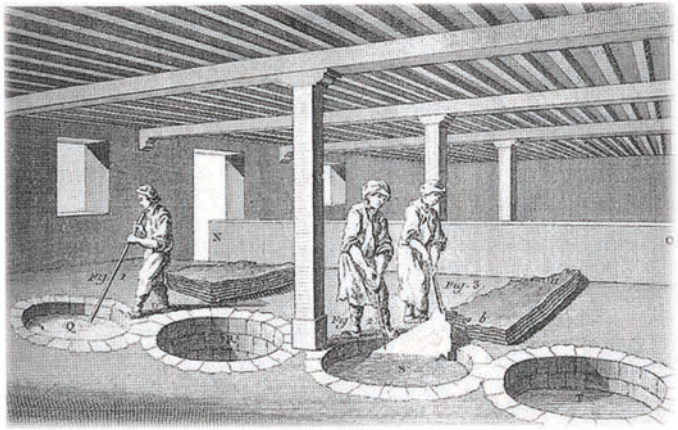
wood



Courtesy of G. Latour
Reynaud et al, PNAS, 2020

Parchment

Leather



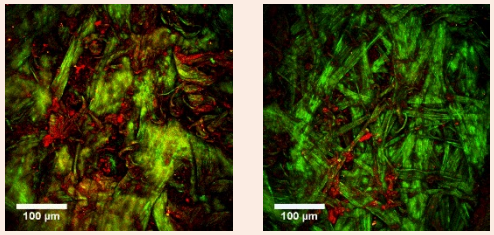
Natural history specimens

Multiphoton microscopy in cultural heritage

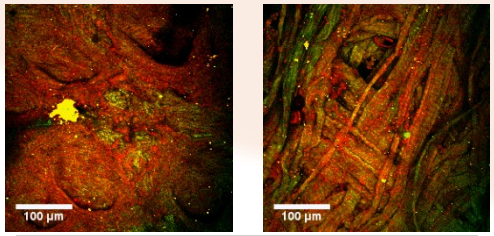
Applications

➔ collagen-based materials

parchment

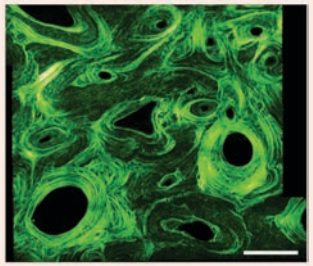


leather



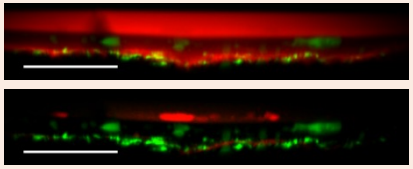
Adapted from Robinet et al, ICOM-CC 2017

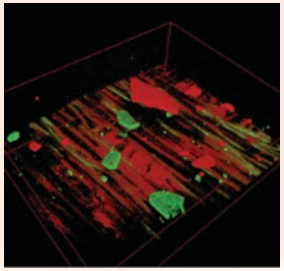
bone



Genthial et al., Sci. Reports, 2017

➔ varnishes and pigments

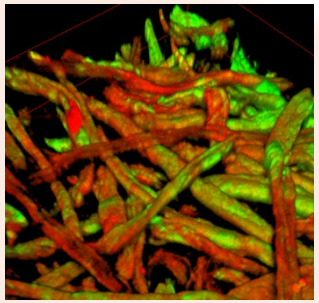




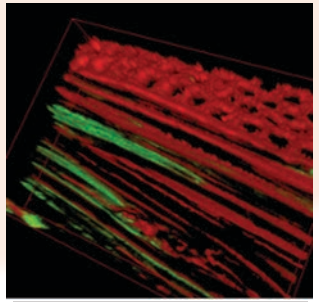
Latour et al, Opt. Express, 2012

➔ cellulose

Whatman paper

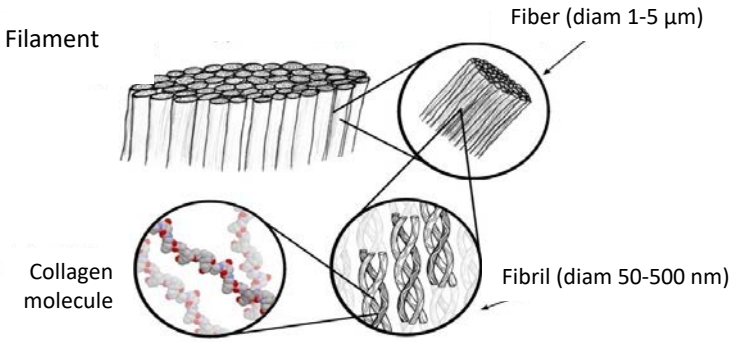


wood



Courtesy of G. Latour
Reynaud et al, PNAS, 2020

Animal skin dried with salt

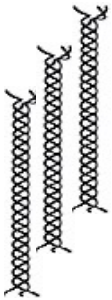


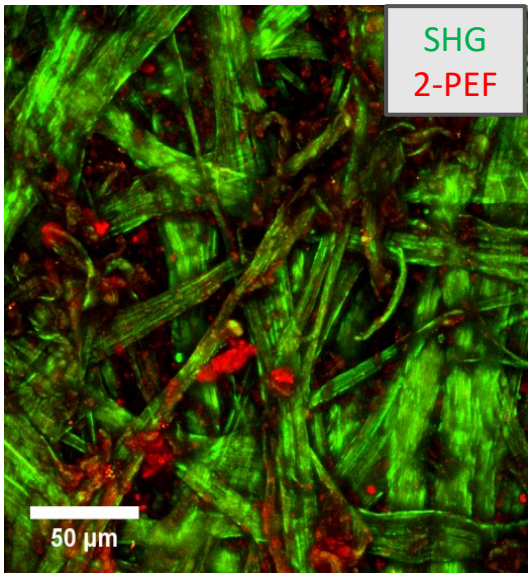
Mainly fibrillar collagen – type I

SHG signals ⇔ hierarchical organization and alignement of collagen fibrils

Multiphoton microscopy on parchments

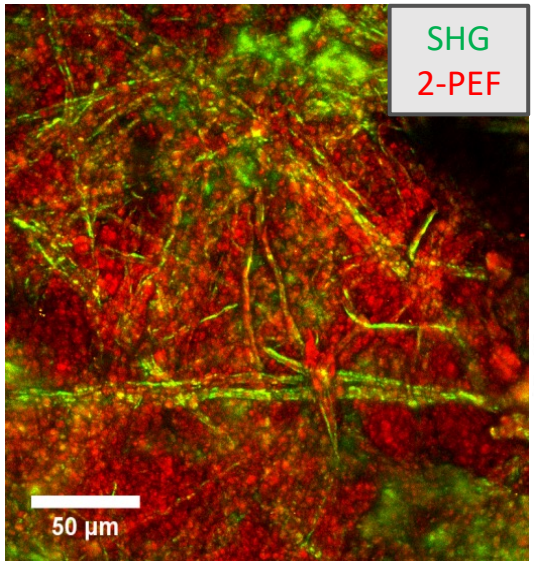
Latour *et al.*, **Sci. Rep.**, 2016



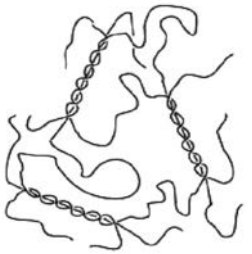


Fibrillar collagen ➔ SHG

denaturation



Gelatin ➔ no SHG but 2PEF



Need to access intermediate states

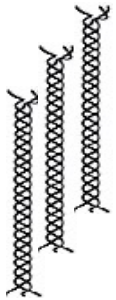
Degradation quantification

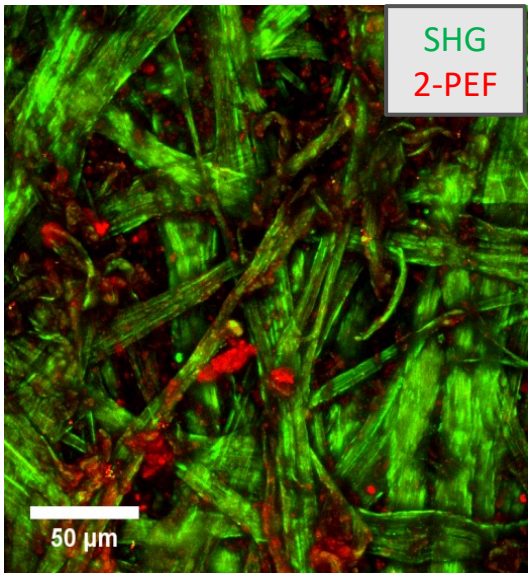
Differential Scanning Calorimetry (DSC)

Destructive ! It needs a sampling (~ 1 mg)...

Multiphoton microscopy on parchments

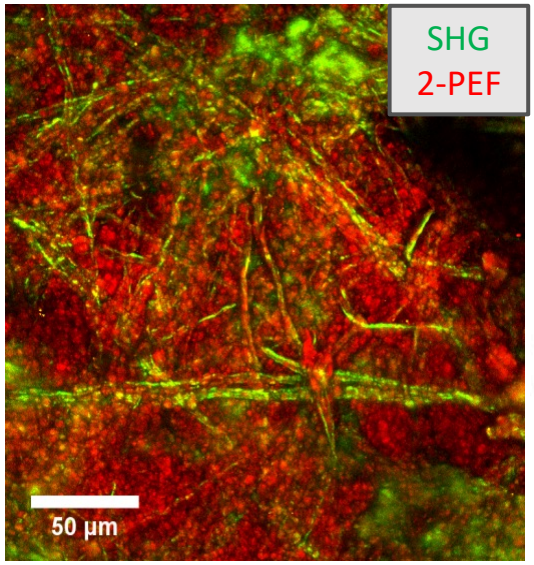
Latour *et al.*, Sci. Rep., 2016



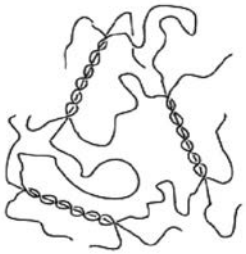


Fibrillar collagen ➔ SHG

denaturation

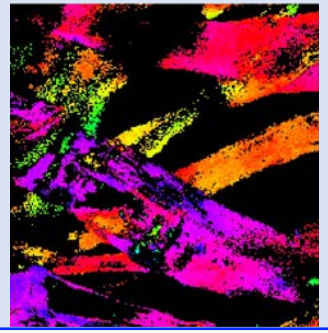


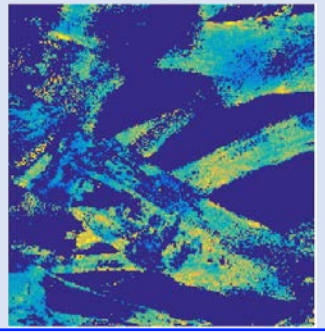
Gelatin ➔ no SHG but 2PEF



Need to access intermediate states
Degradation quantification

Quantitative information with polarization-resolved SHG (P-SHG)

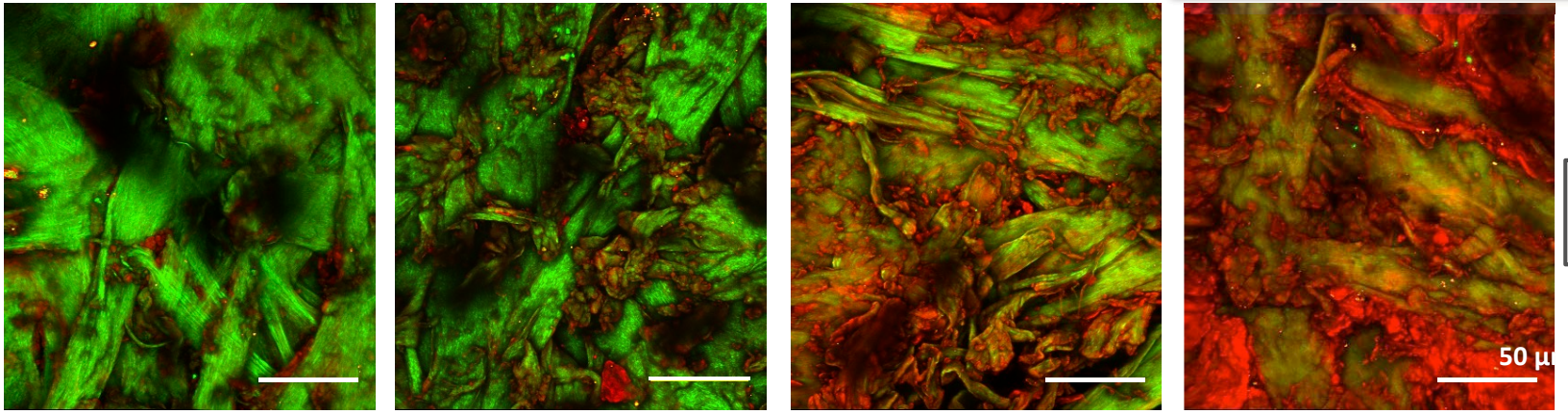




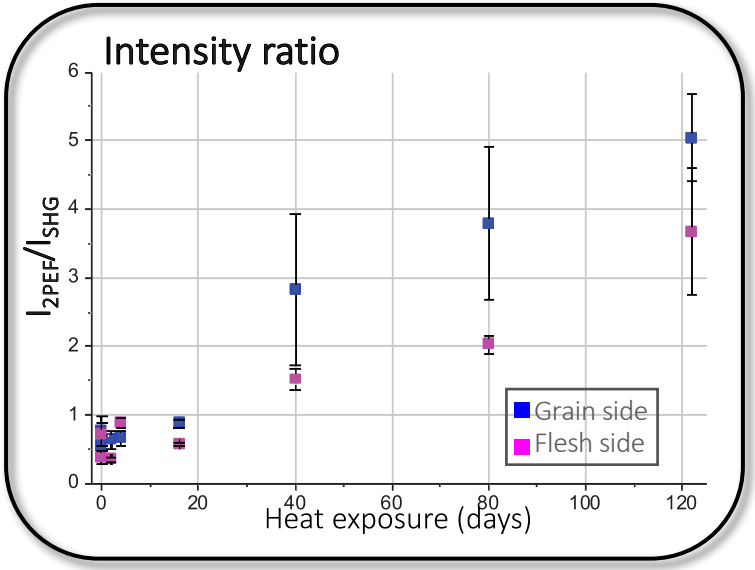
Study on model parchments

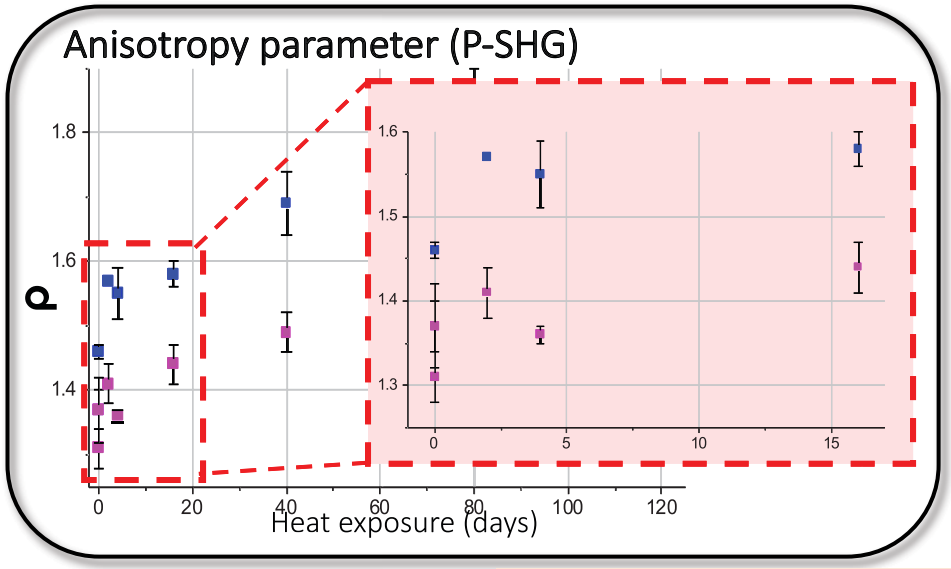
Artificially degraded parchments (european IDAP project)

Schmeltz *et al., Science Advances*, 2021



reference | 16 days | 40 days | 122 days



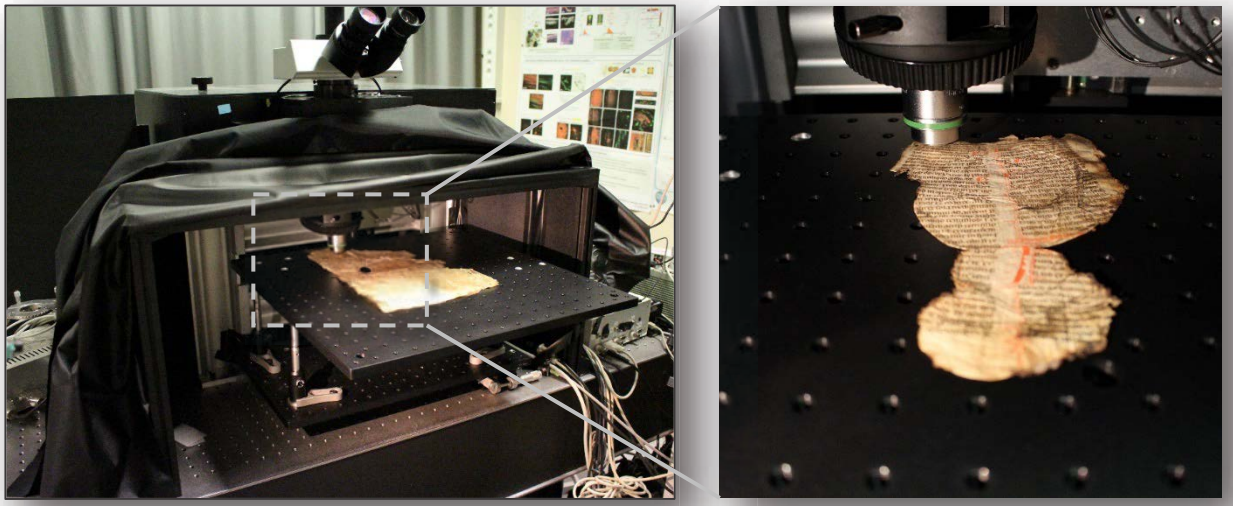


- Linear increase of $I_{2\text{-}PEF}/I_{SHG}$
- Increase of the ρ within the first stages of degradation

Anisotropy parameter <=> local degradation of collagen

Study on ancient parchments

Manuscripts from Chartres, France



Mappa Mundi, Albi, France

Mappa Mundi, 8th century, Albi, France

- Air objective
- Field of view: 1070 x 1070 µm²
- Working distance: 15 mm

Slides: courtesy of G. Latour and L. Robinet

Case study

Retrieving knowledge from the Chartres fire-damaged medieval manuscripts

Funding: Fondation des Sciences du Patrimoine
Médiathèque de Chartres: Catherine Merlin, Michèle Neveu
IRHT: Claudia Rabel, Dominique Poirel, Joanna Fonska, Gilles Kagan, François Bougard
LOB: Marie-Claire Schanne Klein, Gaël Latour, Margaux Schmeltz
Bibliothèque Ecole Polytechnique: Delphine Gallot, Marie-Claire Thooris
DYPAC: Pierre Chastang, Isabelle Brettauer
CRC: Laurianne Robinet, Fabien Pottier, Anne Michelin, Sylvie Heu-Thao

May 26th, 1944, bombing of the city of Chartres

Slides: courtesy of G. Latour and L. Robinet

The restoration of the Chartres' manuscripts


A LA BIBLIOTHÈQUE NATIONALE...

L'INSTITUT DE BEAUTÉ DES


VIEUX MANUSCRITS

Regards, February 1946

Restoration by the french National library in 1945


A LA BIBLIOTHÈQUE NATIONALE

On ressuscite les manuscrits brûlés ou noyés pendant la guerre

Ce Soir, October 1945

Washing in water-formalin baths


Les manuscrits brûlés et rongés de vers sont mis à tremper dans une solution antiseptique et tannante

Drying between blotter under press


Sortis du bain, les feuillets traités sont mis immédiatement sous presse entre des buvards.

(Photos Willy Ronis.)

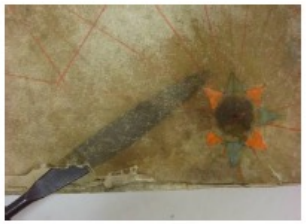
Slides: courtesy of L. Robinet

Effect of the fire on the parchments

Slides: courtesy of L. Robinet

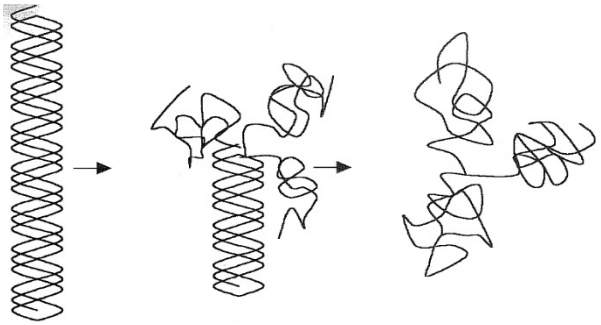
Exposure to heat (fire)

- Parchment shrinkage
- Flexibility loss: parchment becomes brittle
- Yellowing/darkening



Exposure to water

- Additional shrinkage / gelatinisation
- Increased transparency or darkening



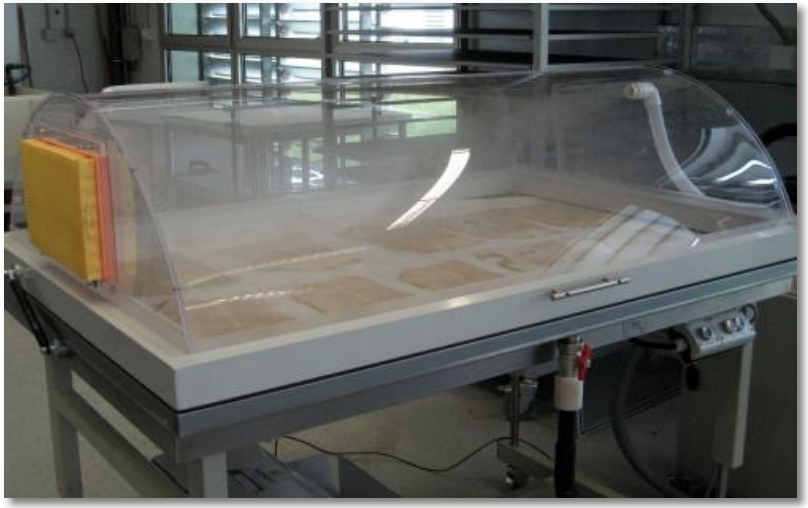
Well-preserved parchment

Gelatinised parchment

Relaxation of the parchments

By the French national library in 2009

Parchment humidification



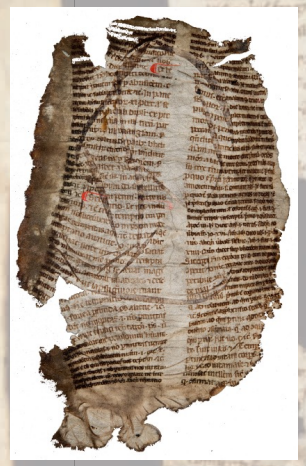
Parchment drying under tension

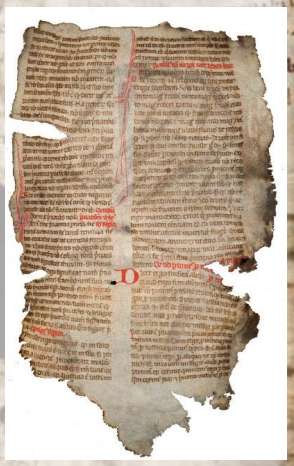
Slides: courtesy of L. Robinet

Aims of the project

Assessment of the parchment degradation

No treatment *Treated in 2009*



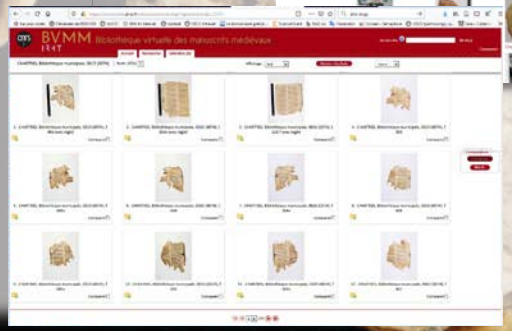


Why ?

- Select the best conservation treatment
  → **Impact of humidification done in 2009 ?**
- Define suitable conservation conditions

Improvement of document legibility and digitization

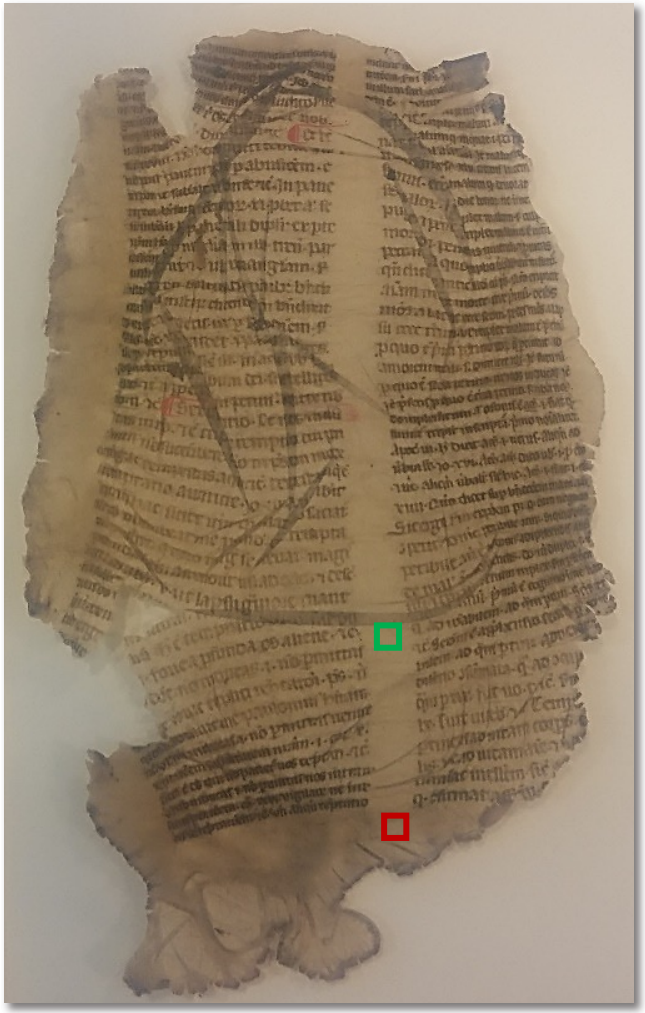
- Offer a technical solution to improve the degraded documents legibility
- Large-scale application (thousands of pages): Time and cost-effective
- Identification of the text and online presentation with scientitific description



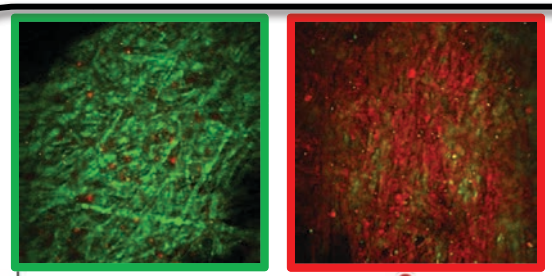
Slides: courtesy of G. Latour and L. Robinet

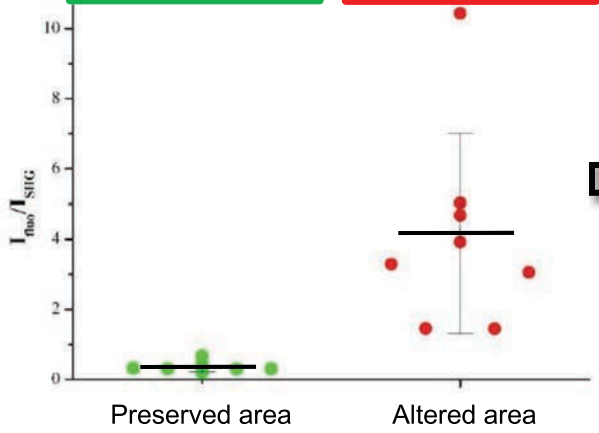
Quantification of degradation with MPM

Batch 205 – Folio 88 - recto

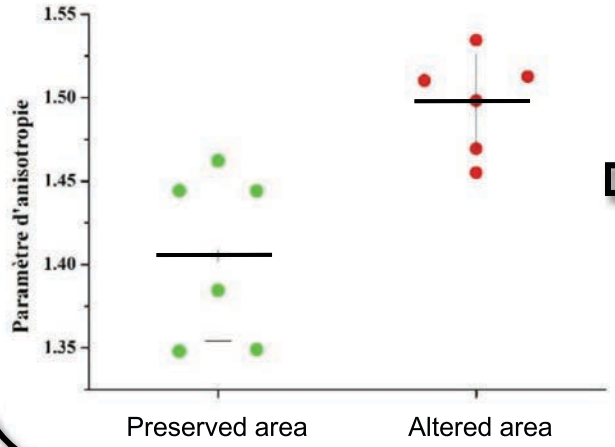


Schmeltz *et al.*, *Science Advances*, 2021





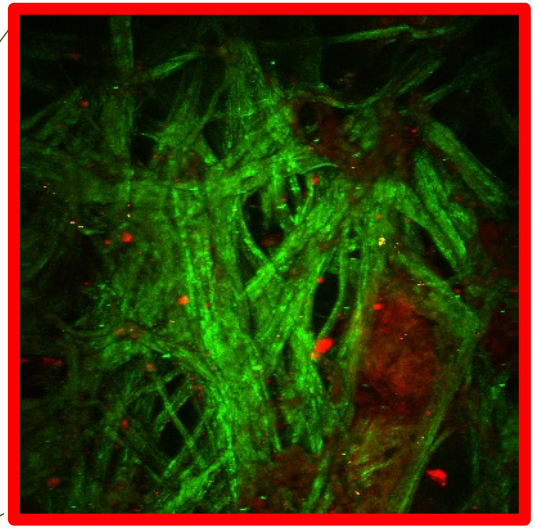
$I_{2\text{-PEF}}/I_{SHG}$ increases in the parchment edges



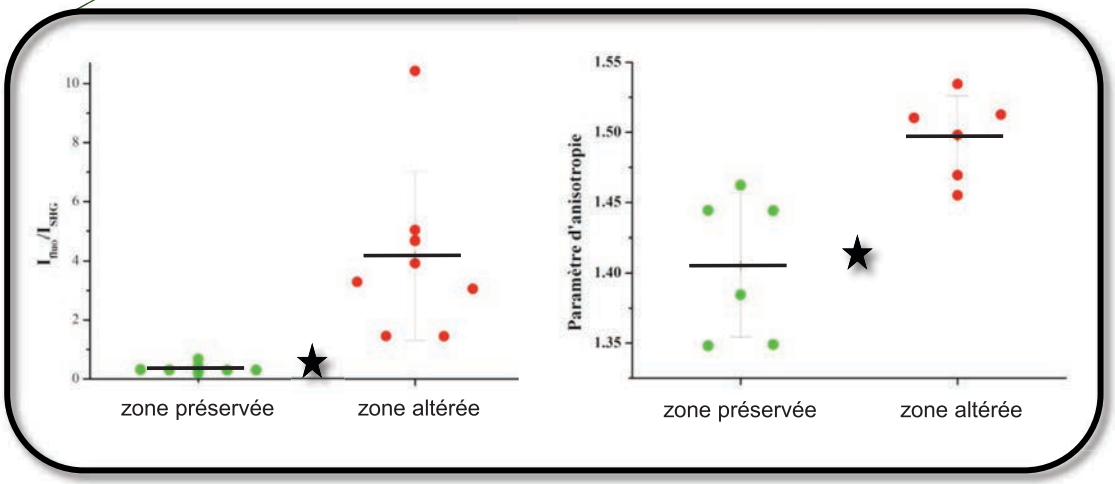
Disorder (ρ) increases in degraded areas

Validation of the humidification process

Batch 205 – folio 301 recto



Schmeltz *et al.*, *Science Advances*, 2021



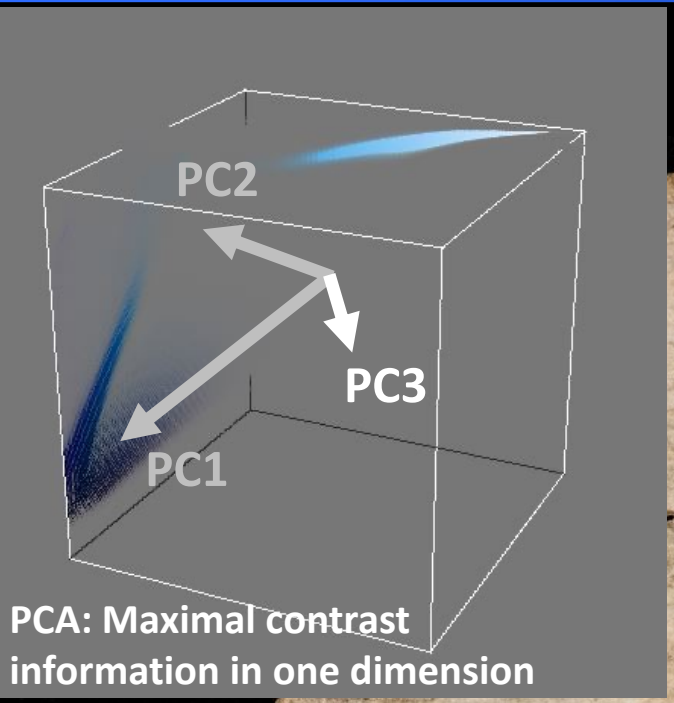
➔ No degradation induced by humidification treatment

Improving legibility: UV photography

Pottier *et al., Journal of Cultural Heritage*, 2019

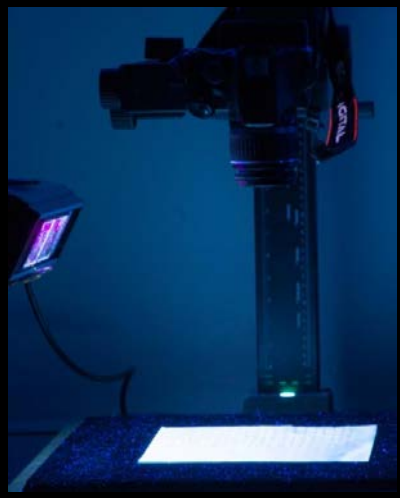
Improving legibility: UV photography

Pottier *et al.*, *Journal of Cultural Heritage*, 2019



PCA: Maximal contrast information in one dimension

Large-scale applications → digitization



Gilles Kagan
IRHT, Medieval manuscripts digitization

UV fluorescence and standard photographs
of 2 manuscripts = 64 leaves x2 (both sides)
→ a few hours

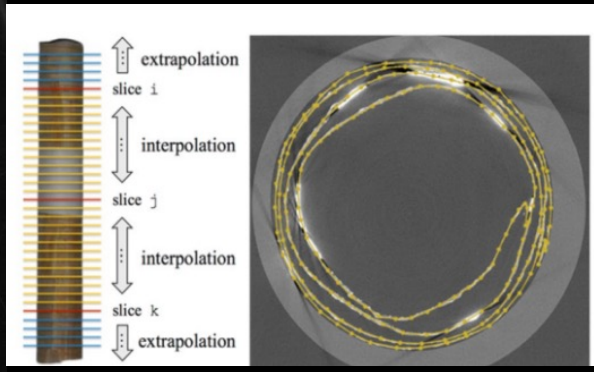
https://www.manuscrits-de-chartres.fr/en

MUSÉUM NATIONAL D'HISTOIRE NATURELLE

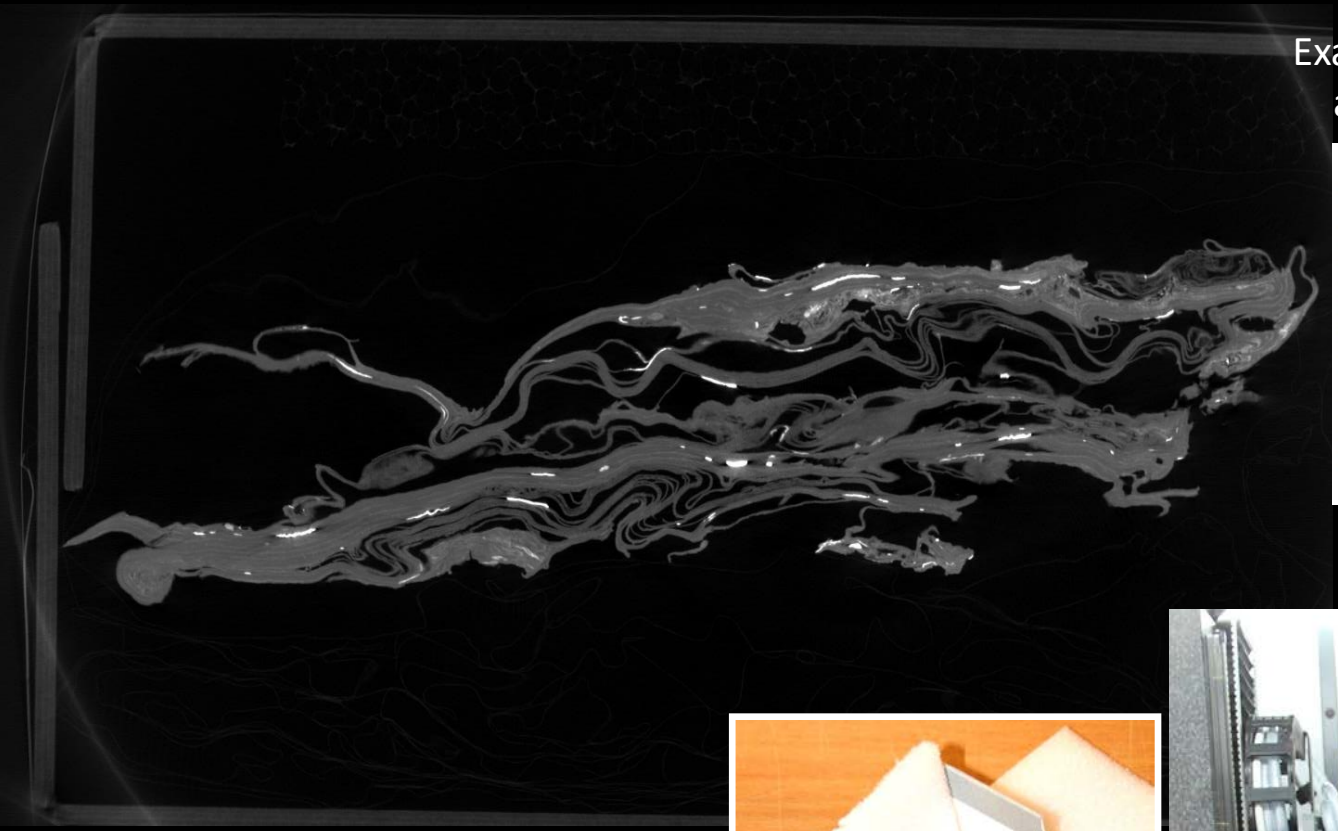
ACCÈS SCIENTIFIQUE À LA TOMOGRAPHIE À RAYONS X

ASTRX

Example of what can be achieved after strong data processing:



Baum et al., 2017, Appl. Phys. A.



MUSÉUM NATIONAL D'HISTOIRE NATURELLE

ACCÈS SCIENTIFIQUE À LA TOMOGRAPHIE À RAYONS X ASTRX

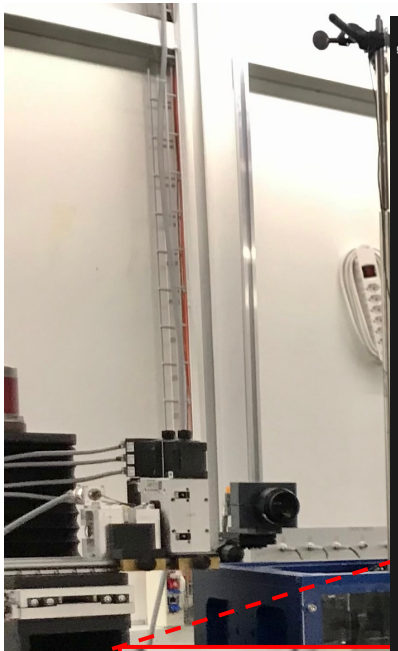
PAUL SCHERRER INSTITUT

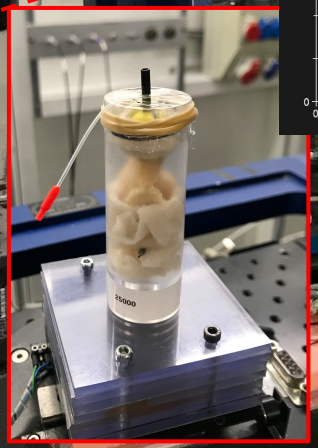
PSI

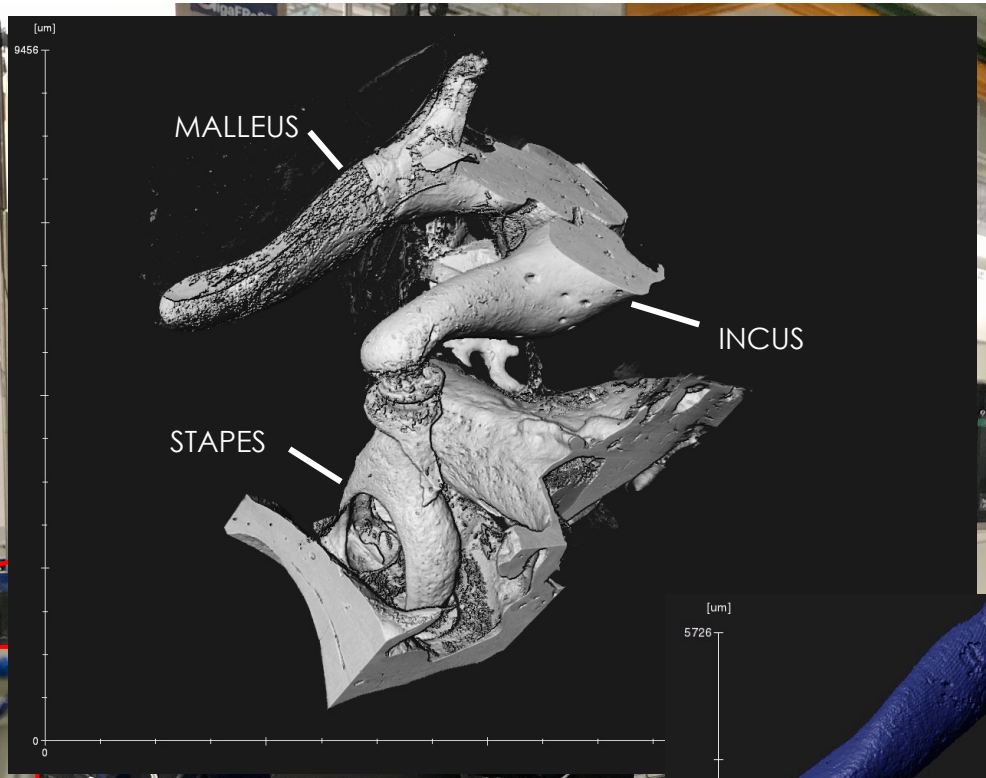
Paleonthology and cultural heritage studies at TOMCAT

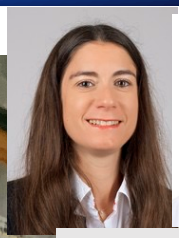
TOMCAT

My Postdoc: dynamic tomography of the middle ear

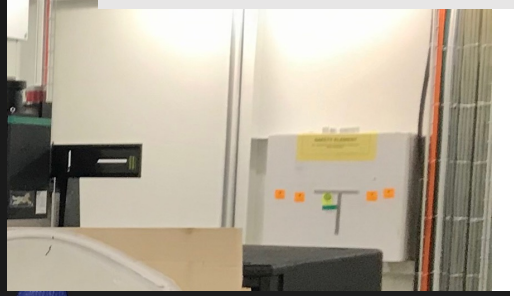


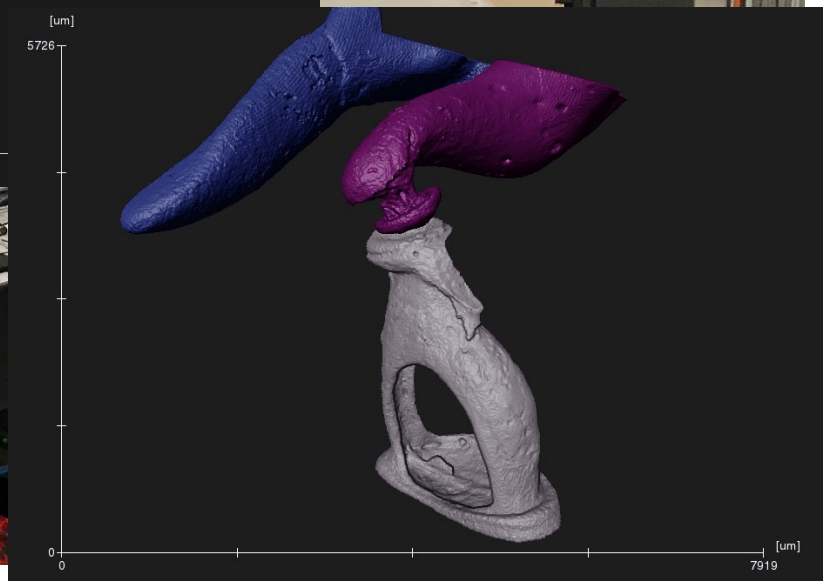






Dr. Anne Bonnin
PD Dr. med. Lukas Anschuetz
Aleksandra Ivanovic



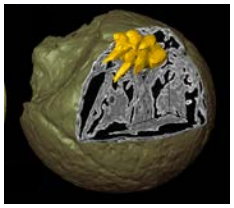


Microtomography of ancient material

PAUL SCHERRER INSTITUT

Dr. Federica Marone
Prof. Marco Stampanoni

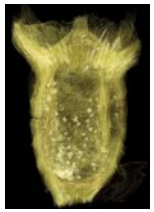
500 My | 350 My | 100 My | Iron age | 1898 | now



Doshuanto Embryos

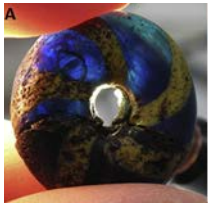
First "predator" on earth

Galeaspids



Charcoalified Seeds

Investigate the manufacturing process to date and locate the production



Glass beads

Cuno Amiet

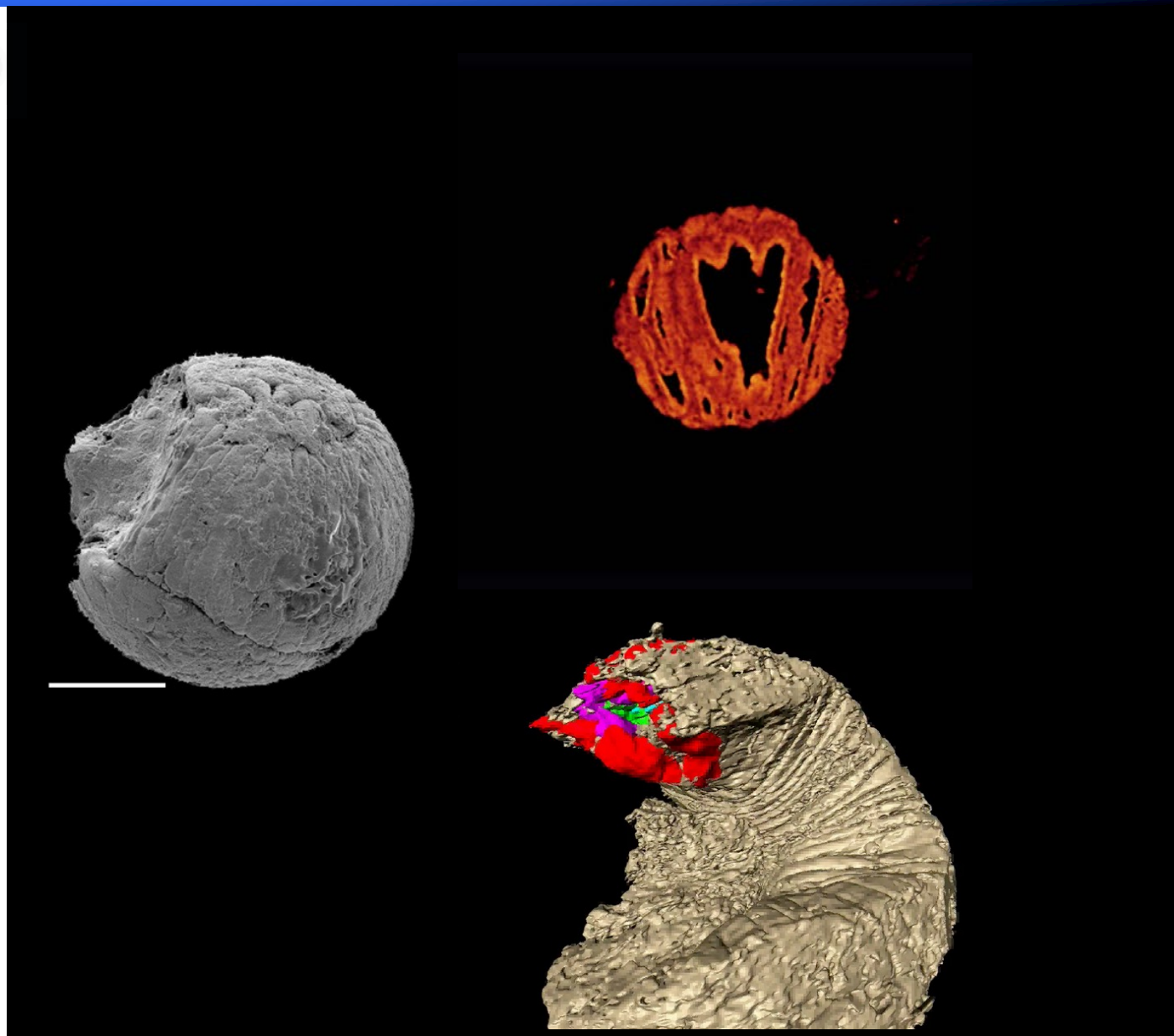
Porosity study for conservation treatments efficiency

Human teeth

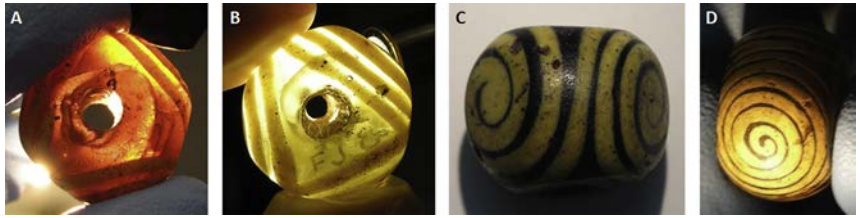
Markuelia, the first "predator" on earth

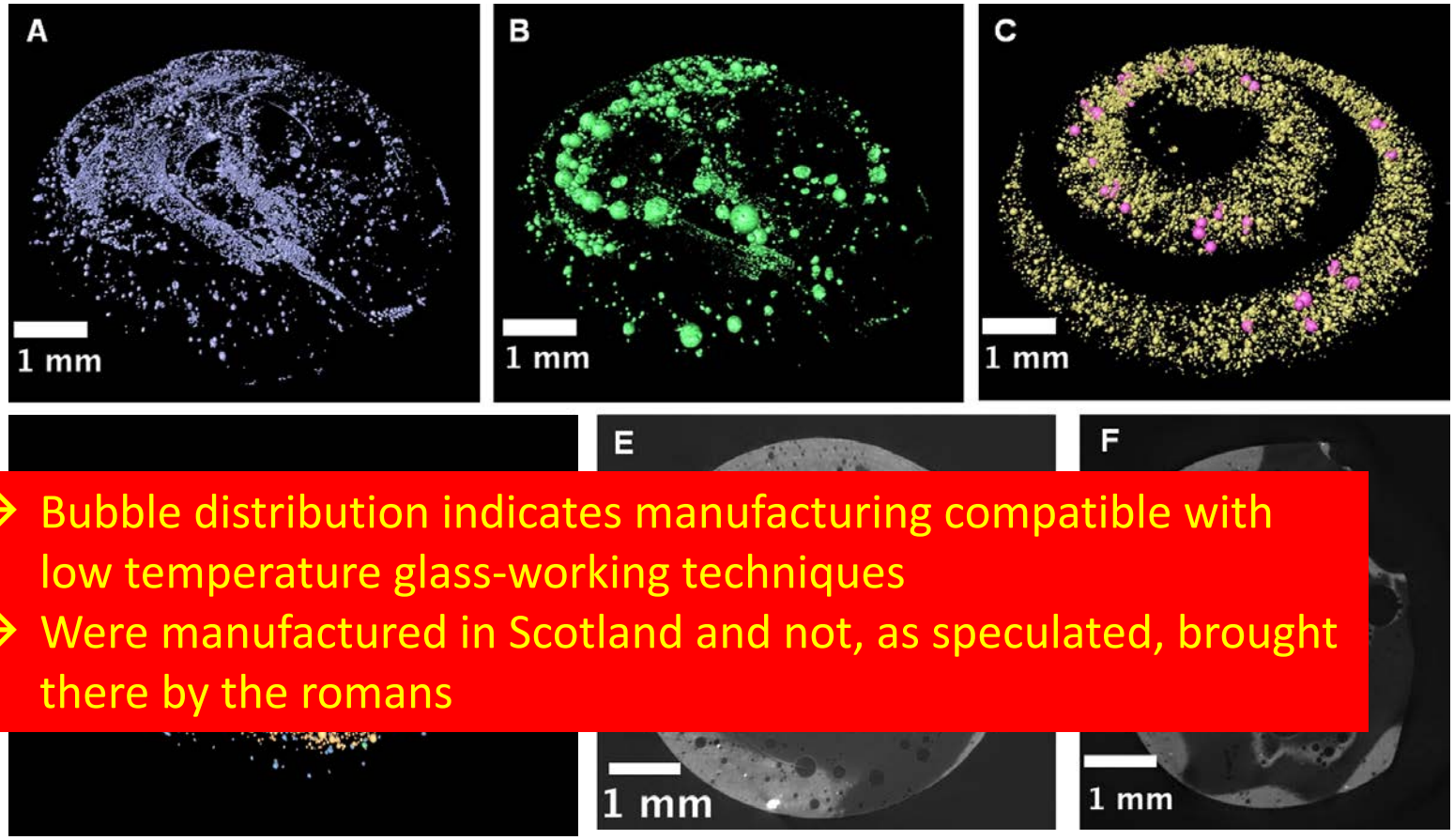
Donoghue et al (2006) Nature 442:680-3

Simple specimen preparation!



Unwinding the spiral: discovering the manufacturing method of Iron Age Scottish glass beads





→ Bubble distribution indicates manufacturing compatible with low temperature glass-working techniques

→ Were manufactured in Scotland and not, as speculated, brought there by the romans

Fig. 5. Bubble distribution in Class 13, spiral decorated beads. **A, B, C, D** and **E**. Museum record: ABDUA:15543; **F**. Museum record: ABDUA:15514. **A**. Seeds and small bubbles ($Ø < 100$ μm) in the translucent glass of the top section. **B**. Bigger bubbles ($Ø > 100$ μm) in the translucent glass. Note the cluster of large air traps ($Ø < 500$ μm) on the left hand side, developed in the glass of the body at the border with the decoration. **C**. Small (yellow) and big (pink) bubbles in the leaded glass. **D**. Reconstruction of all the bubbles of all sizes in top section. **E** and **F**. Internal cross-section of the two beads under investigation, showing an inter-layer of seeds between cores of contaminated waste glass and coating layers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

Bertini et al., Journal of Archeological Science 43 (2014)

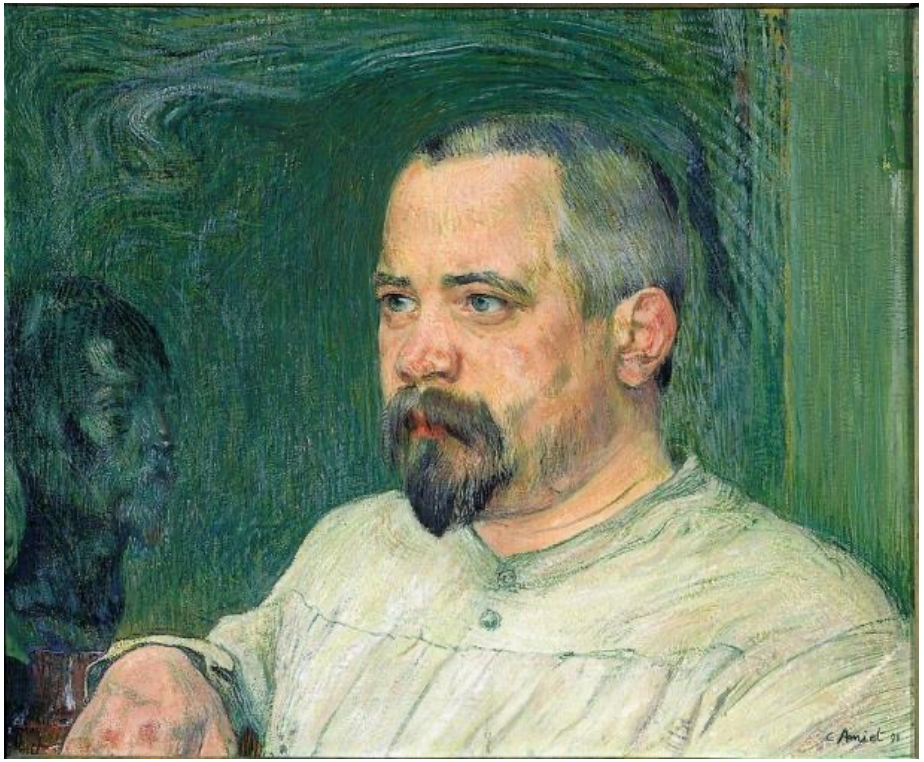
The secrets of jawless fishes from China (350 My)

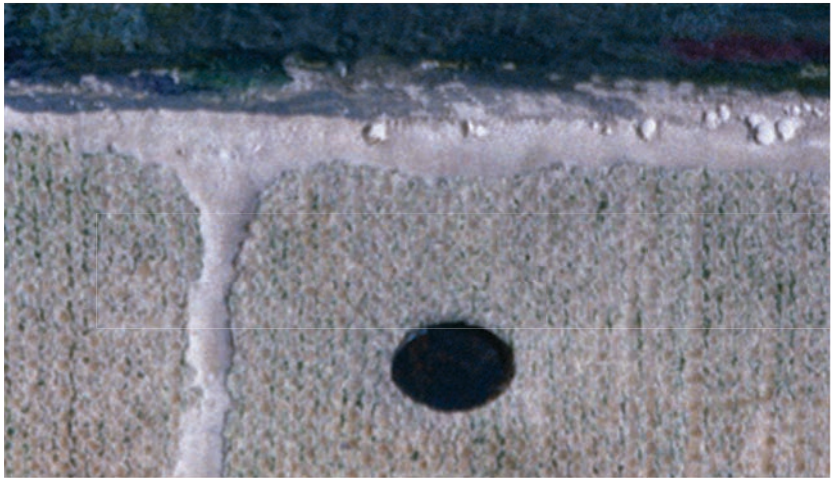
Gai et al (2011) Nature 476:324-7

Natural endocast

Porosity quantification and percolation issues

Cuno Amiet (1868-1961)
Portrait of Max Leu, 1898, Kunstmuseum Solothurn





Porosity is relevant for diffusion mechanisms and crucial for conservation issues!

C. Gervais et al., Applied Physics A, 111 (1), 2013

Porosity quantification and percolation issues

Cuno Amiet (1868-1961)
Portrait of Max Leu, 1898, Kunstmuseum Solothurn

→ Top layer: very fine well-connected porosity
Middle layer: less connectivity but large spherical pores.
Lower layer: connected small pores and a few large spherical pores

→ Ground layer has the capability of absorbing medium from paint layers applied onto it or conservation treatments although limited capability of fast transport.

C. Gervais et al., Applied Physics A, 111 (1), 2013