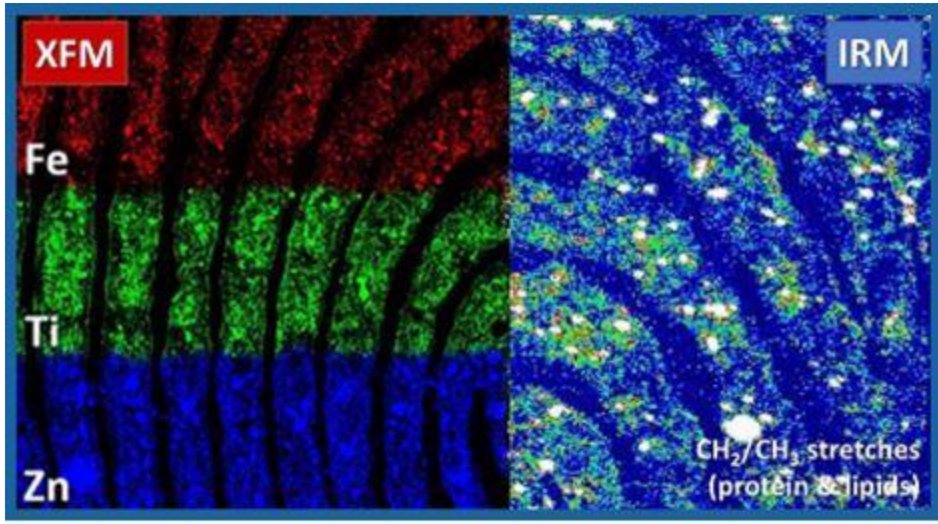
XFM capabilities

mail-in & remote access
data analysis GeoPIXE on ASCI

David Paterson



Virtual XFM & IRM Microscopy Workshop at the Australian Synchrotron

20th & 21st May 2021

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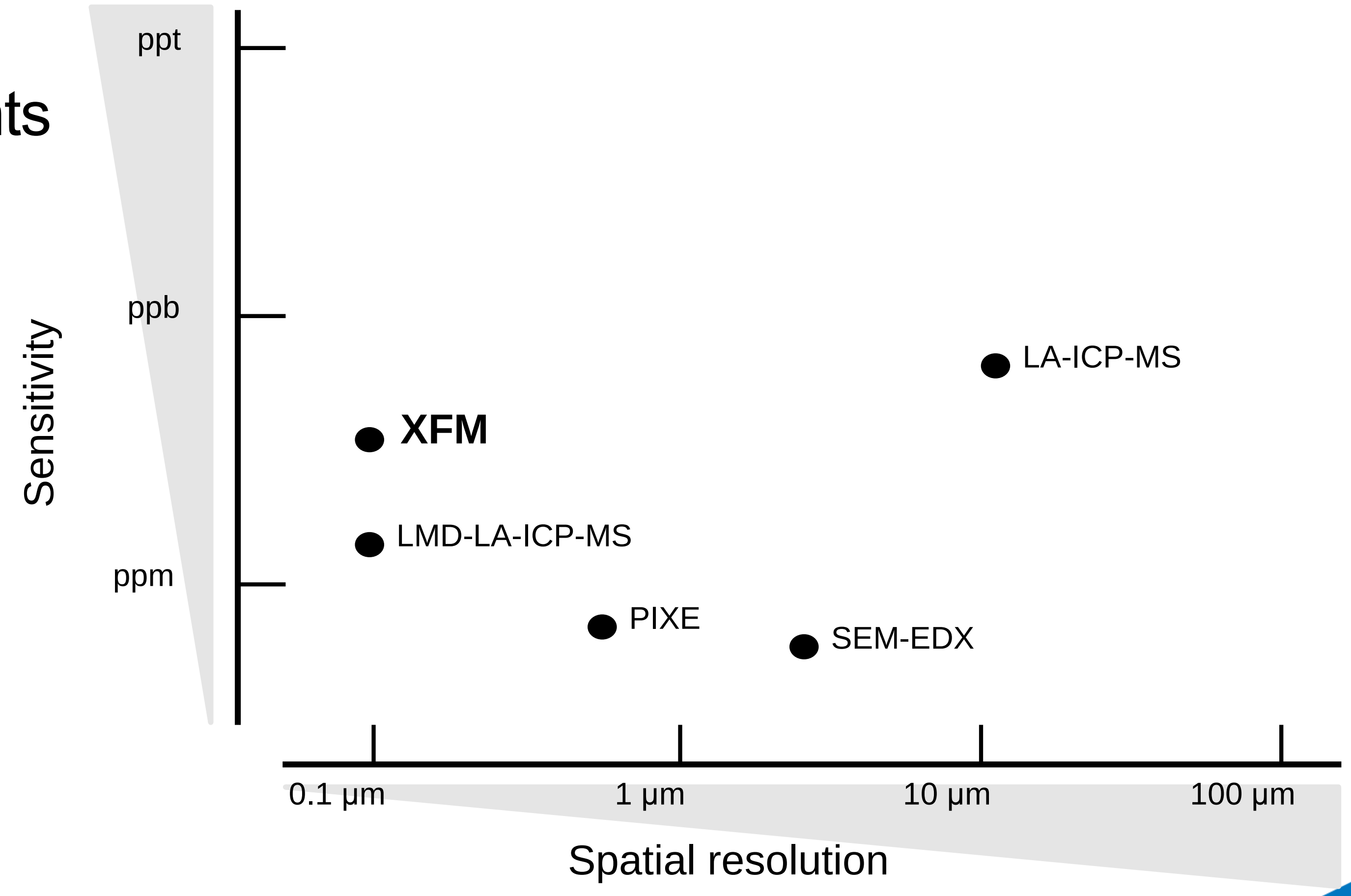
mercury: arsenic :iron
Hg: As: Fe

Outline

XFM capabilities	• X-ray Fluorescence Microscopy • Milliprobe and High-energy capabilities (Daryl) • Ptychography (Cameron)
Beyond 2D **Time resolved**	• XRF Tomography • Chemical Speciation Imaging XANES imaging • Real time imaging, time resolved studies
Remote access **Data analysis**	• Mail-in capabilities • GeoPIXE data analysis in ASCI environment
Future	• DMM => higher flux at higher energies • Higher spatial resolution => 600 nm • Nanoprobe beamline (Cameron)

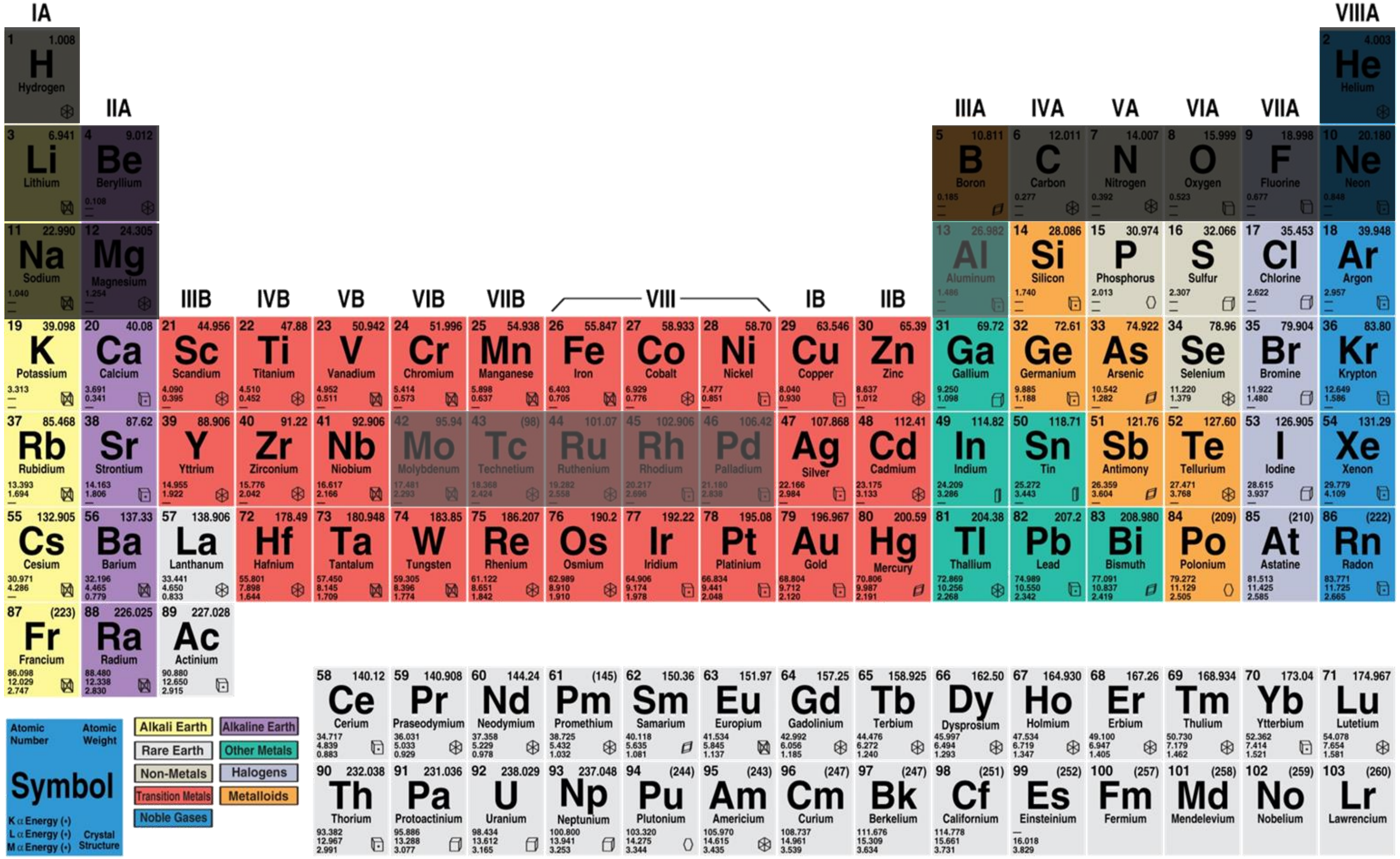
X-ray Fluorescence Microscopy (XFM)

- Simultaneous access to 10+ elements
- No contrast agents required
- Quantitative
- High signal-to-noise ratio
  - ppb sensitivity, improving with Z
- Little sample damage
- Extended penetration depth
  - Study “intact” specimens
- Sensitive to chemical bonding
  - XANES mapping



X-ray Fluorescence Microscopy

www.ansto.gov.au/user-access/instruments/australian-synchrotron-beamlines



https://asuserwiki.atlassian.net/wiki/spaces/UO/pages/22609927/XFM+Beamline

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X-ray Fluorescence Microscopy

Energy range: 4 to 25+ keV

- Hard x-ray microprobe $\Delta E/E$ ~10-4
- X-ray fluorescence mapping (μ-XRF)
- X-ray fluorescence μ-XANES => XANES imaging
- X-ray fluorescence tomography
- Scanning X-ray Diffraction Microscopy, Ptychography

Australasia's only hard X-ray microprobe, but Nanoprobe coming very soon!

XFM team

David Paterson

- Environmental and geological science

Daryl Howard

- Cultural heritage, forensic and mm-scale investigations

3rd Scientist recruiting now!

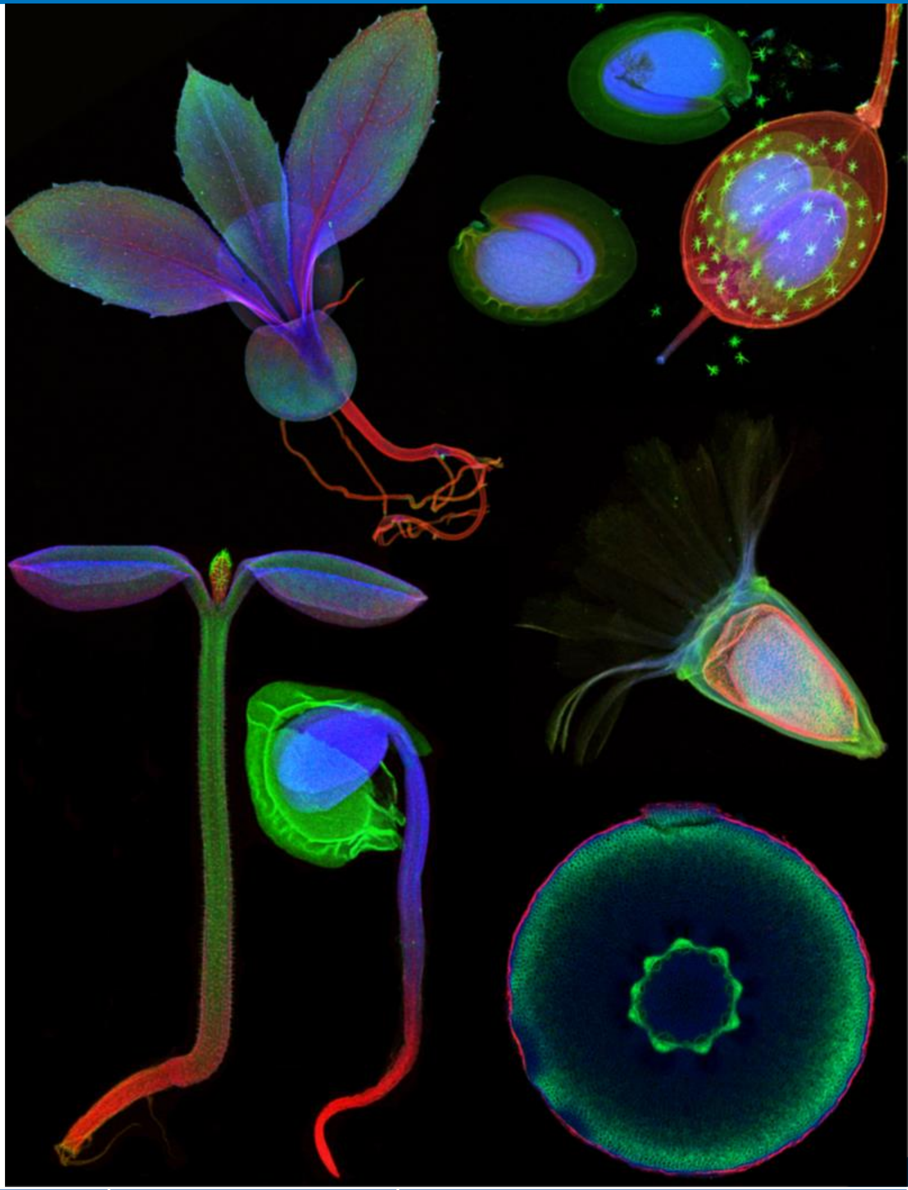
Past XFM scientists

Cameron Kewish Nanoprobe scientist

- SXDM, Ptychography analysis pipeline + EIGER detector experiments

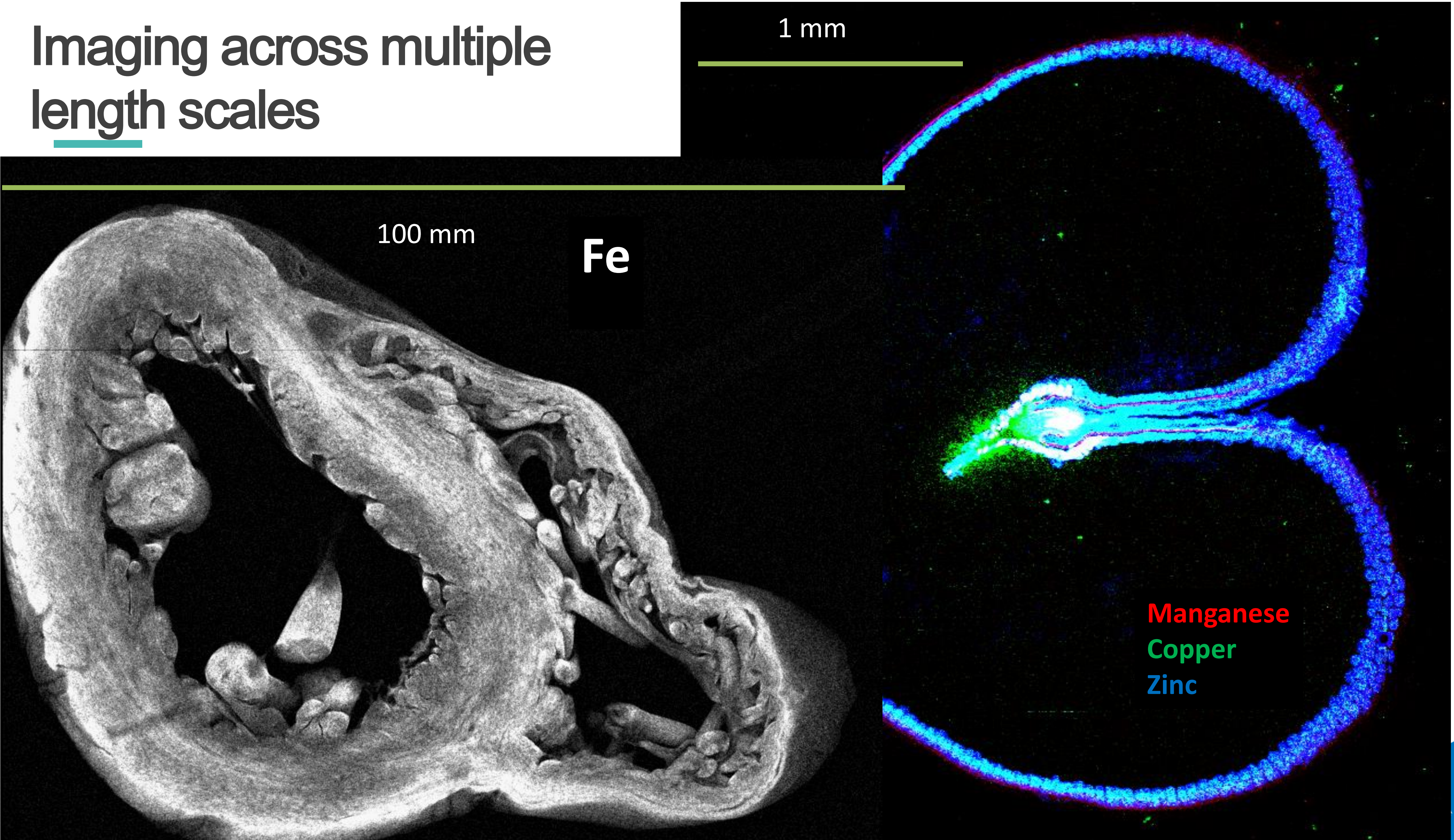
Martin de Jonge Nanoprobe lead scientist

- biological, biomedical and life science, tomography



Probe	Resolution	Field of View H X V
KB Microprobe	**1 μm**	**140 X 100 mm**
Milliprobe	50 μm	600 X 1200 mm

Imaging across multiple length scales



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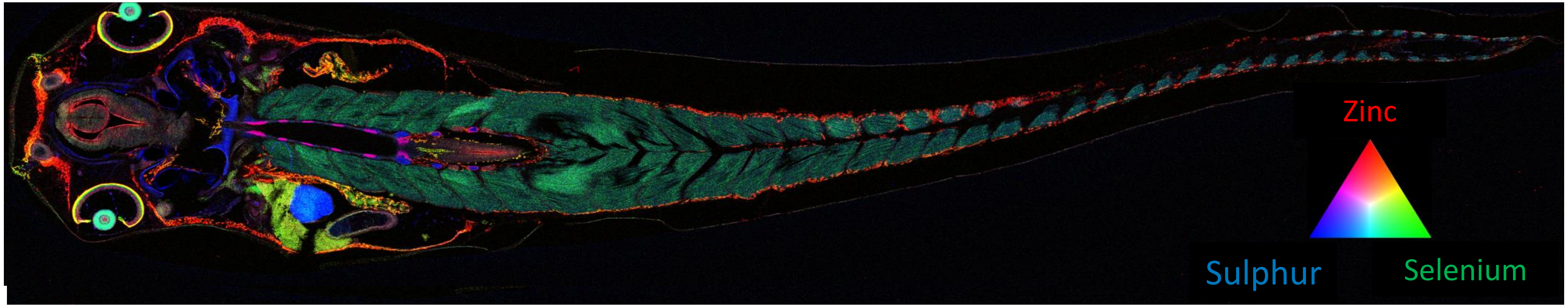
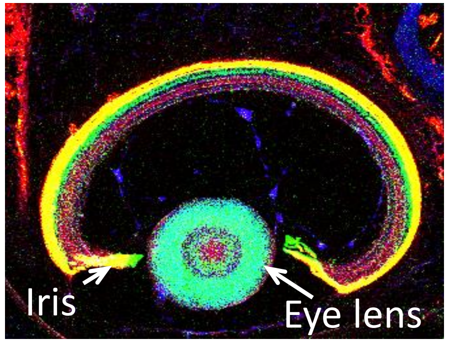
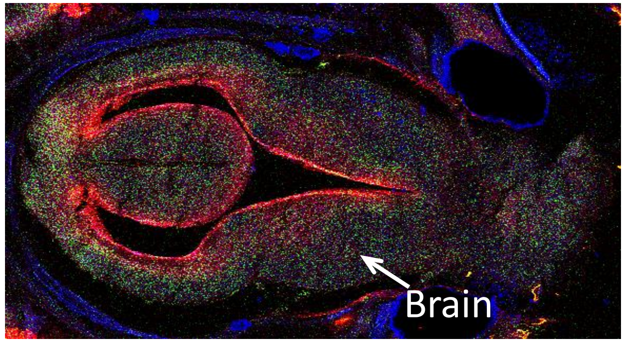
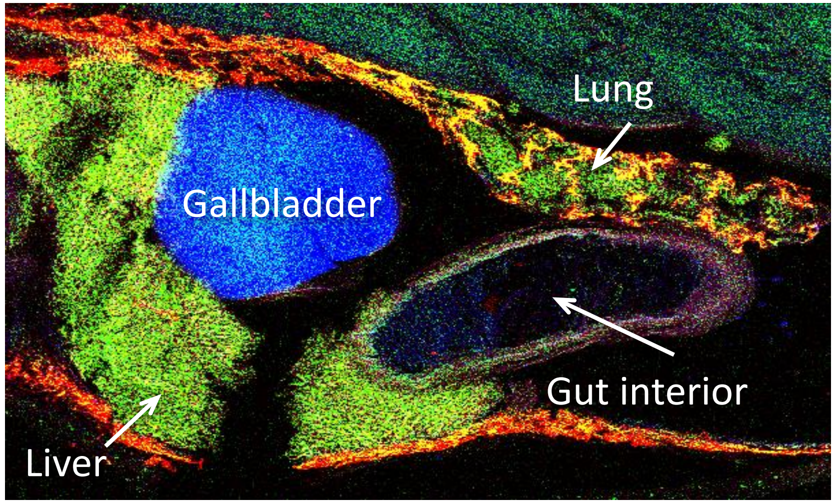
Bioaccumulation on the micron scale

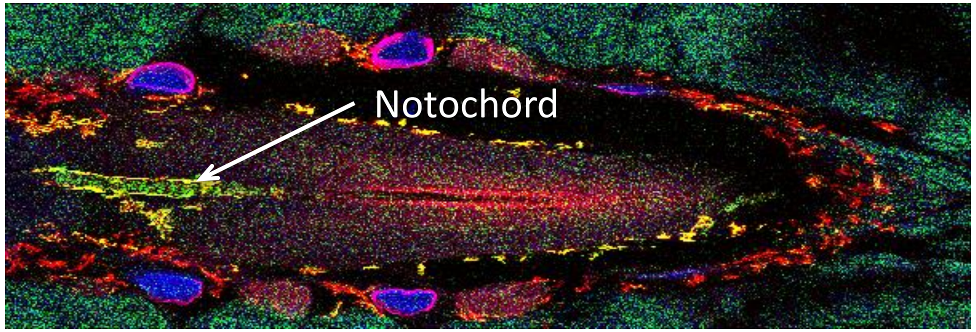
Tadpole exposed to SeIV (30 µg/L) for 7 days





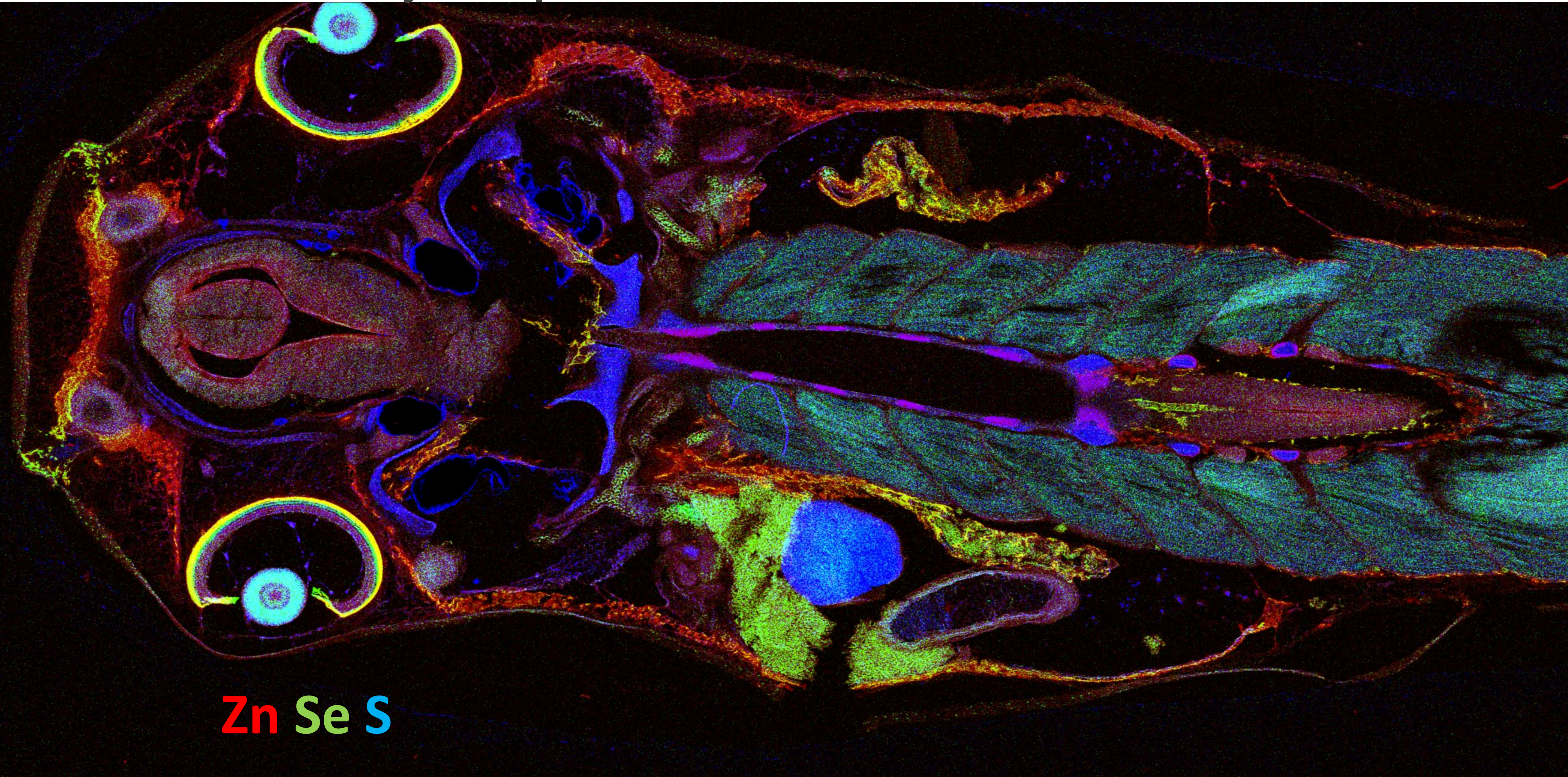






Chantal Lanctôt (Griffith University), Tom Cresswell (Environmental Research ANSTO) *et al.*

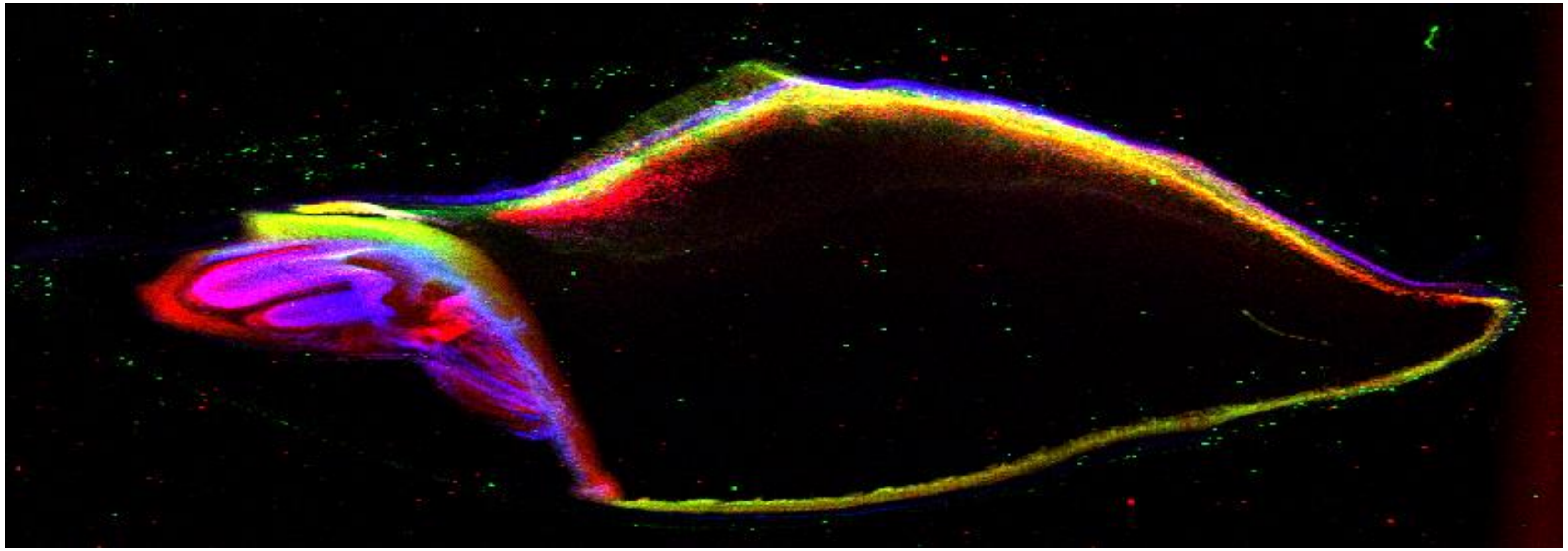
Selenium toxicity in aquatic environments



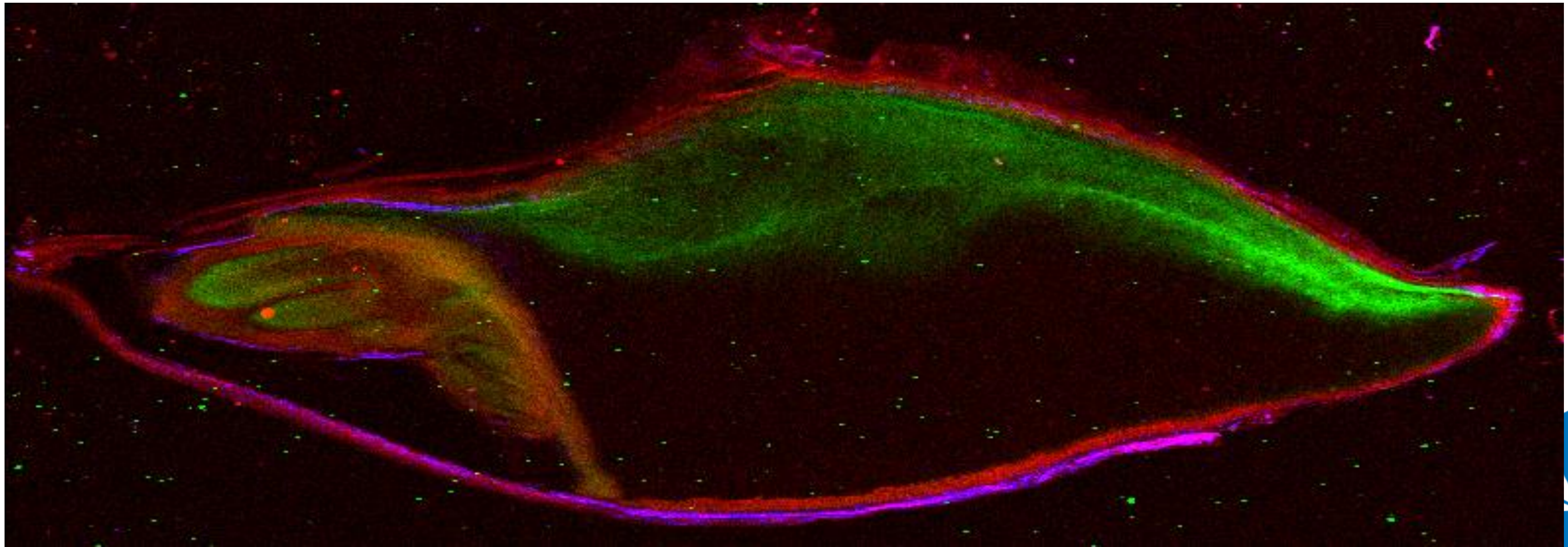
Megapixels/hour: bio-fortification of cereal grains

10 keV
incident

Potassium
Copper
Calcium



Lombi *et al.*
J. Exp. Botany
62, 273 (2011).



Zinc
Iron
Manganese

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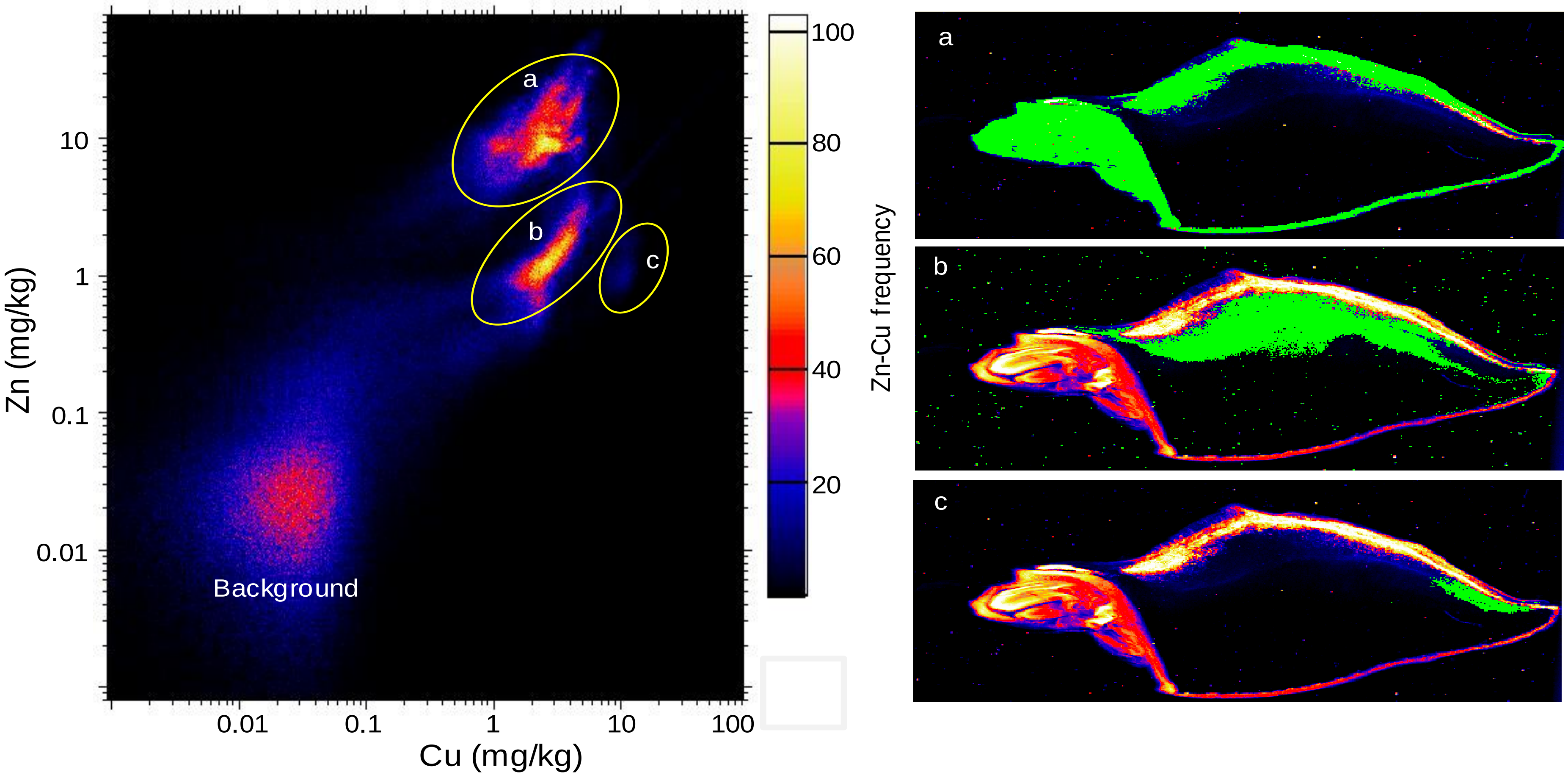
High definition analysis of elemental correlations



Enzo Lombi, *et al*. Journal of Experimental Botany **62**, 273 (2011).
“Megapixel imaging of micronutrients in mature barley grains.”

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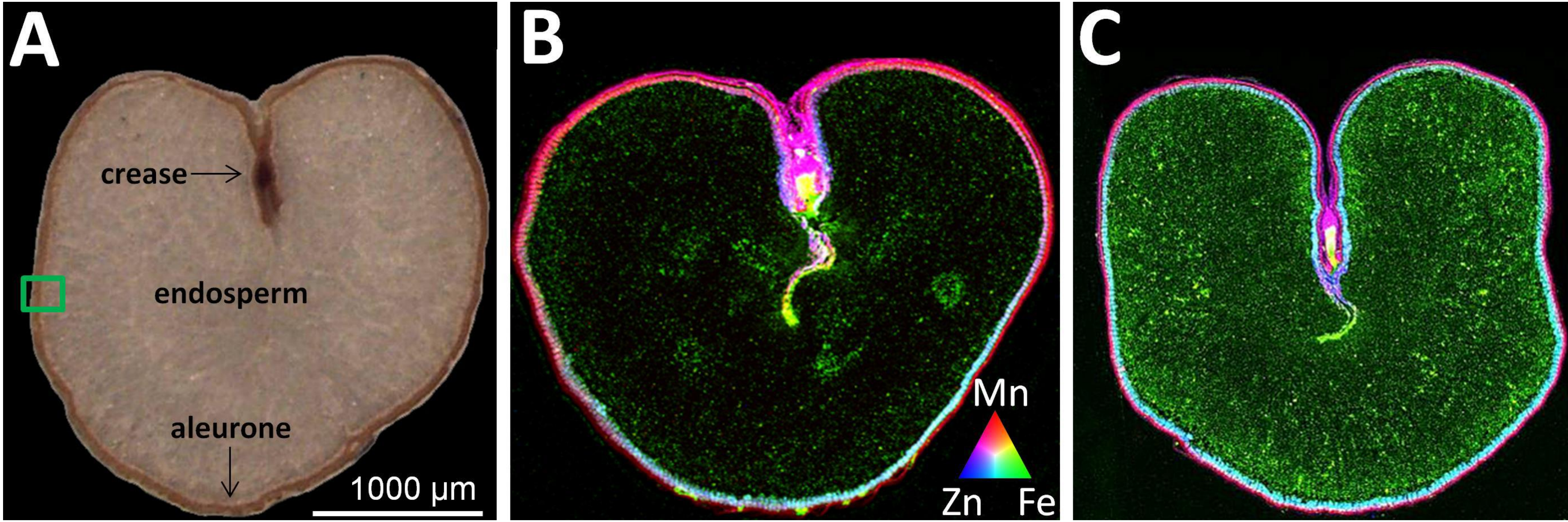
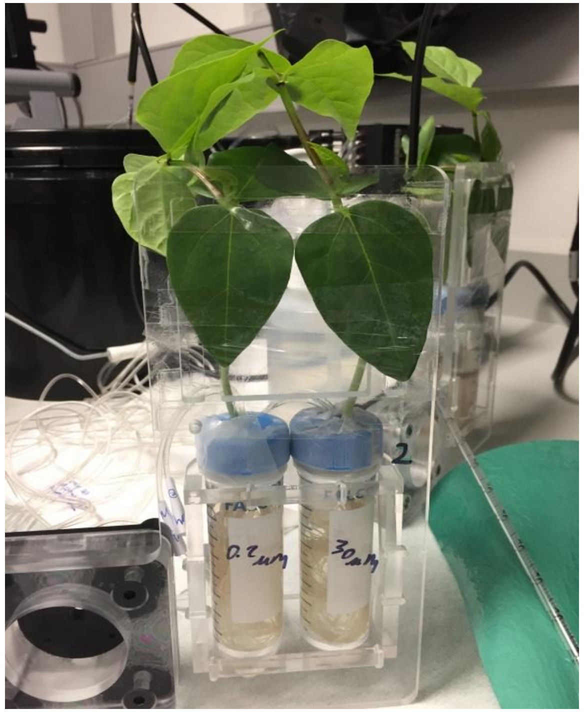
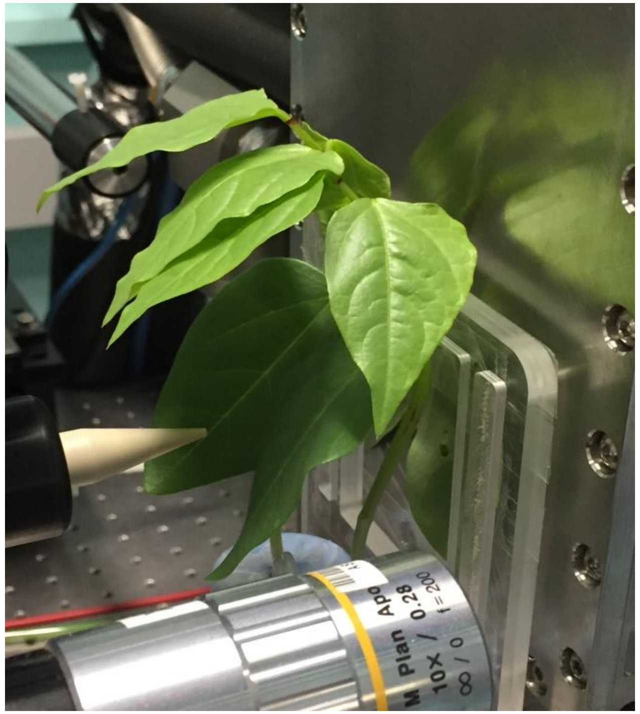
Nutrition: iron biofortification in rice and wheat



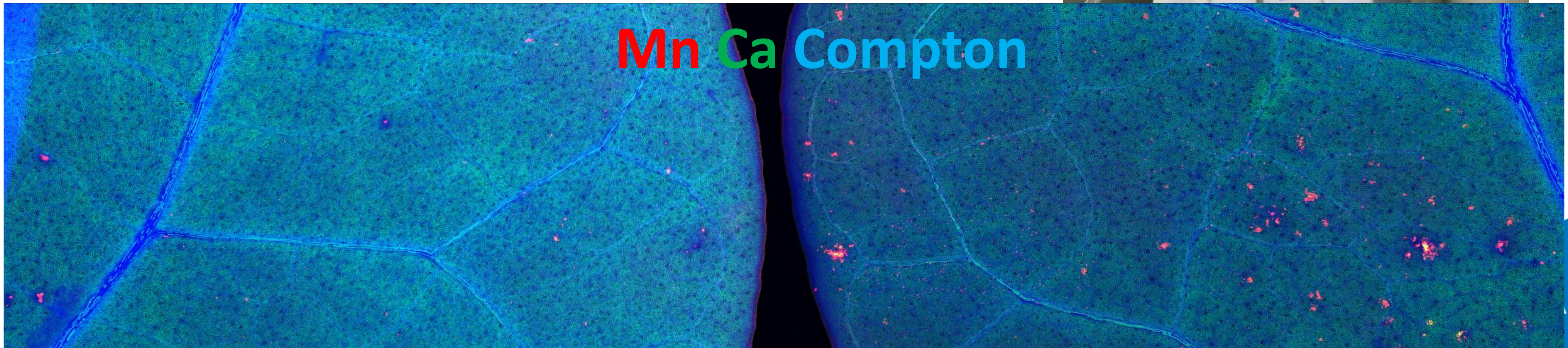
Trijatmiko *et al.*, ***Biofortified indica rice attains iron and zinc nutrition dietary targets in the field***, Scientific Reports **6** 19792 (2016).

In situ and time-based studies

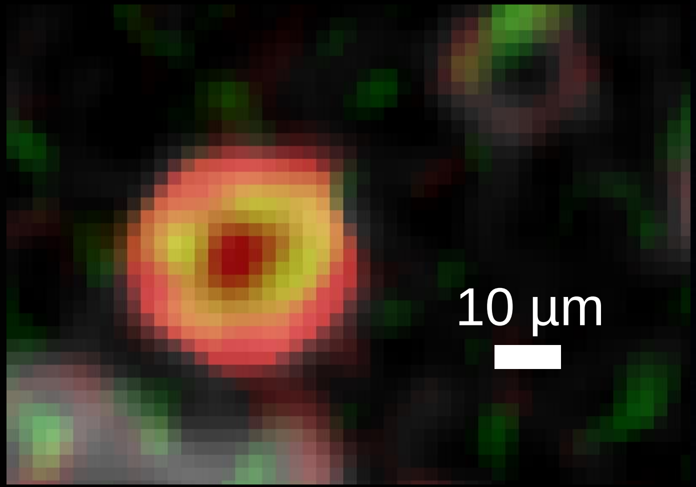


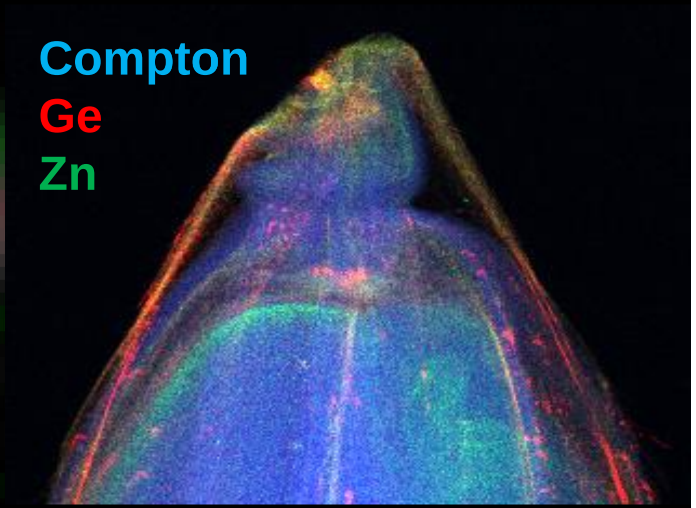


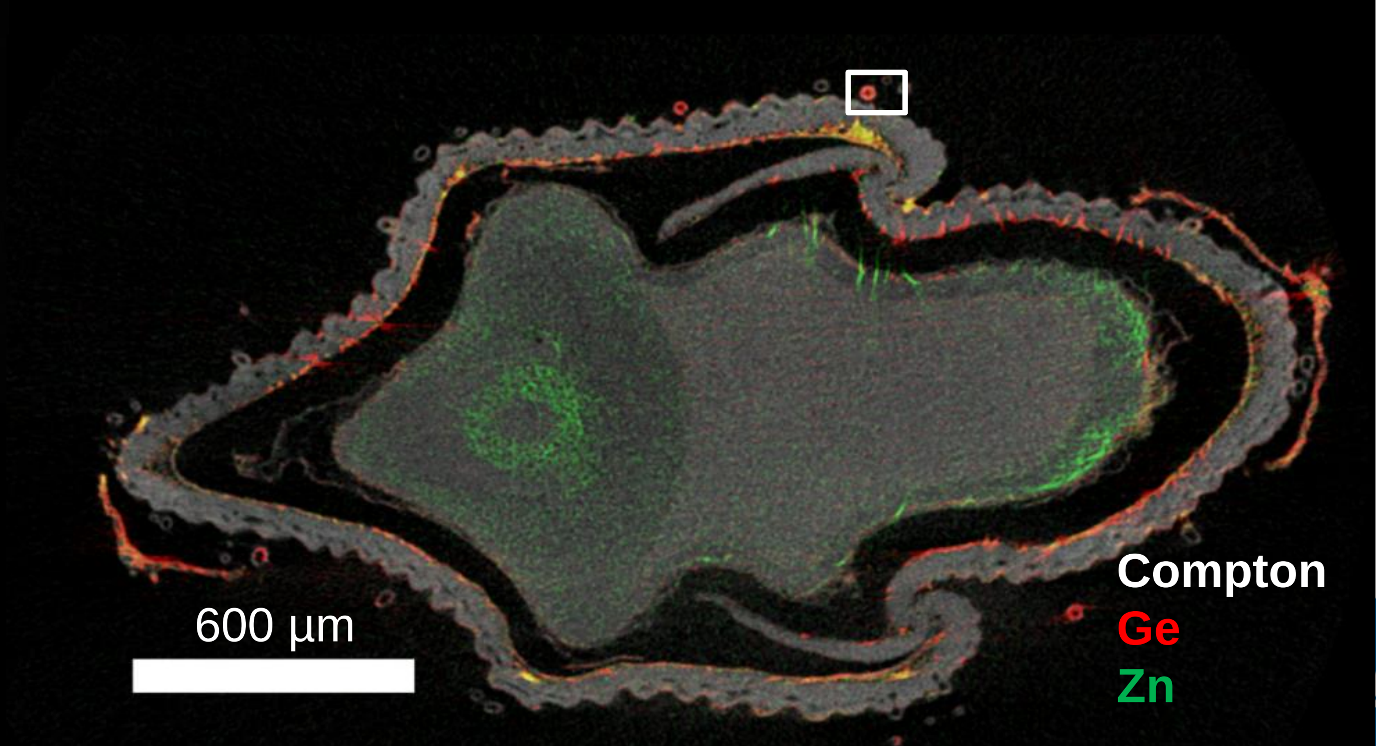
Blamey *et al*. Environmental & Experimental Botany **156**, 151 (2018)



High-definition fast fluorescence tomography

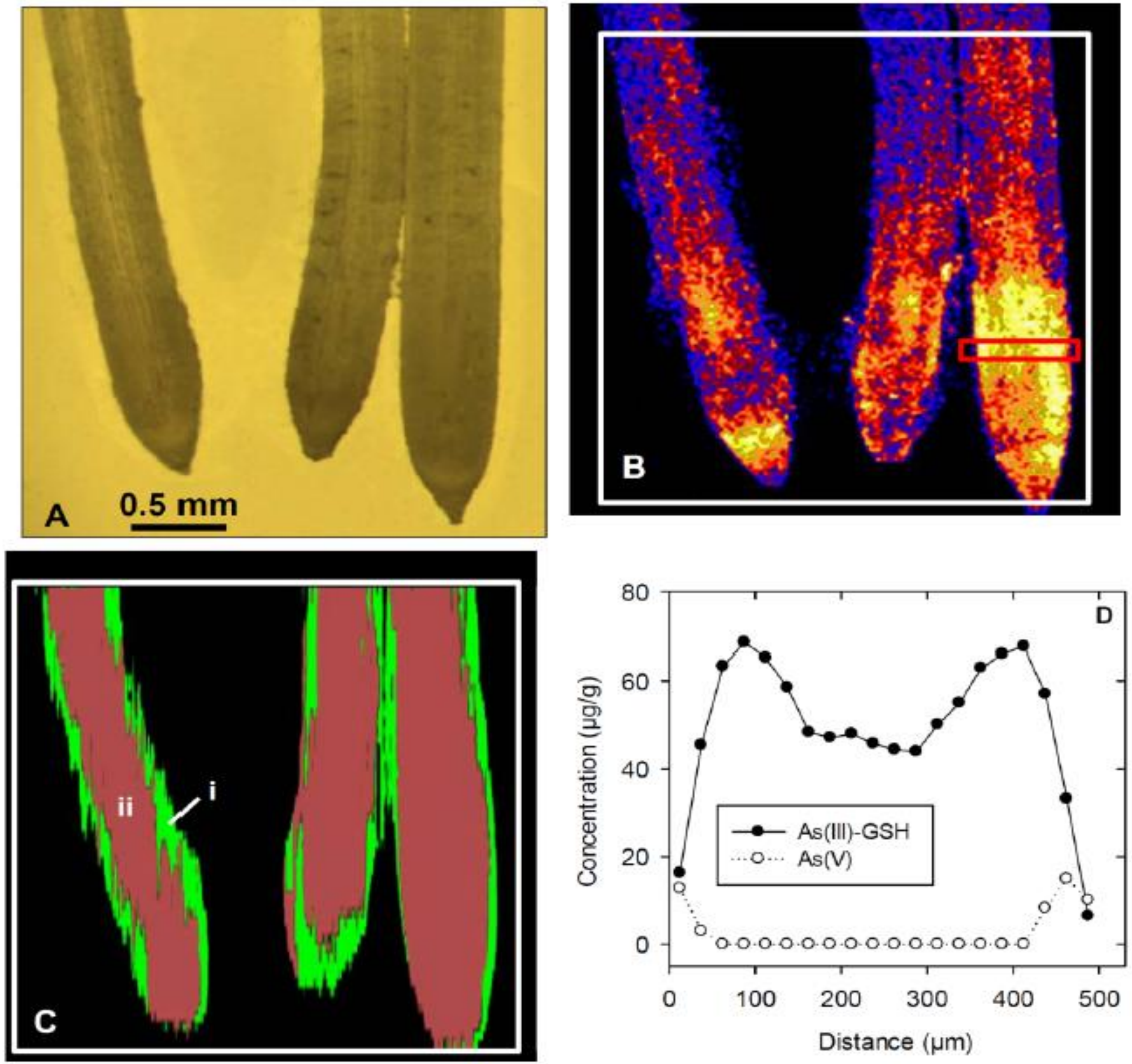






Δ = 2 µm, τ = 2 ms
2291 pixels, 2001 projections (4.6 Mpix).
3 hrs measurement time
Rice grain with husk,

Detailed XANES analysis in hydrated roots



Wheat roots exposed 2 µM As(V) ca. 24 hr

A. Light micrograph taken after completion of the XANES imaging
B. Elemental map showing total As distribution after the XANES imaging.
C. Spatial distribution of pixel-populations identified by comparing energy intensities.
D. Concentrations of uncomplexed As(V) and As(III)-thiol complexes in the transect = red rectangle in B.

Kopittke *et al.* **New Phytologist 201**, 1251-1262 (2014).

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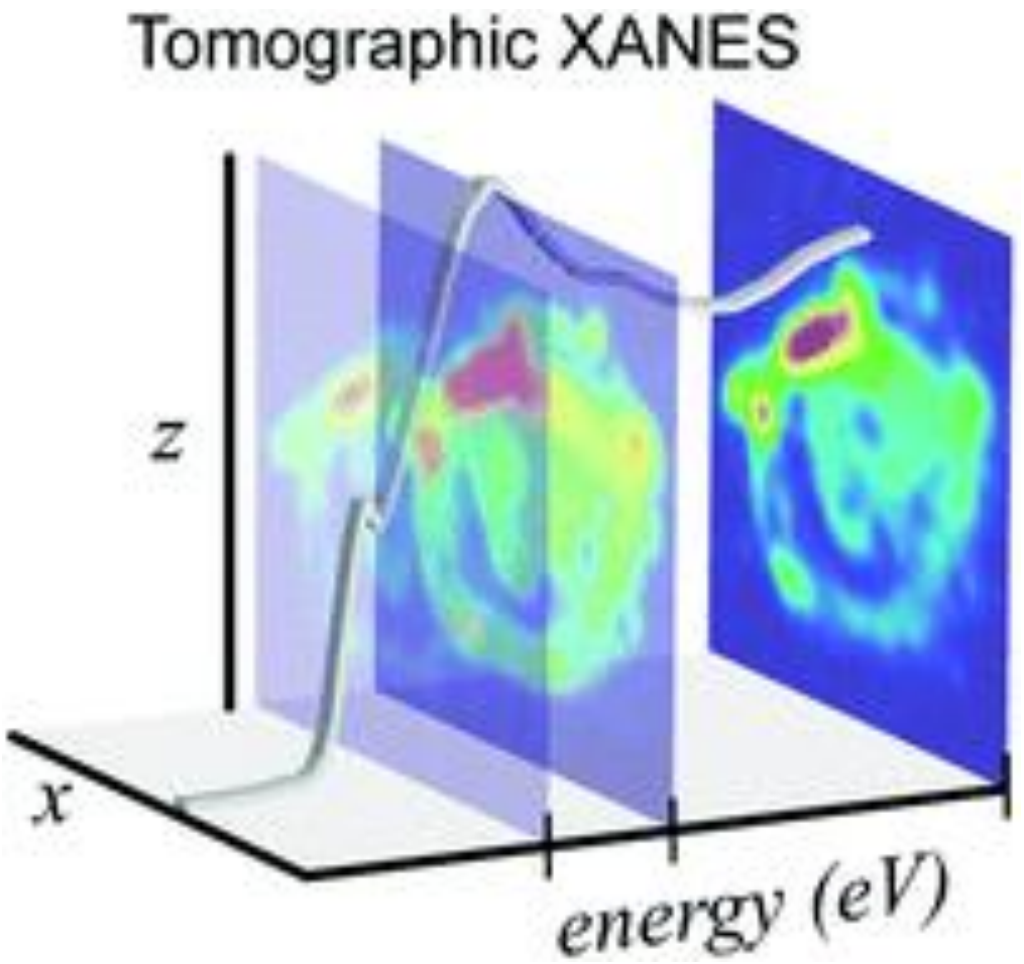
Tomographic XANES

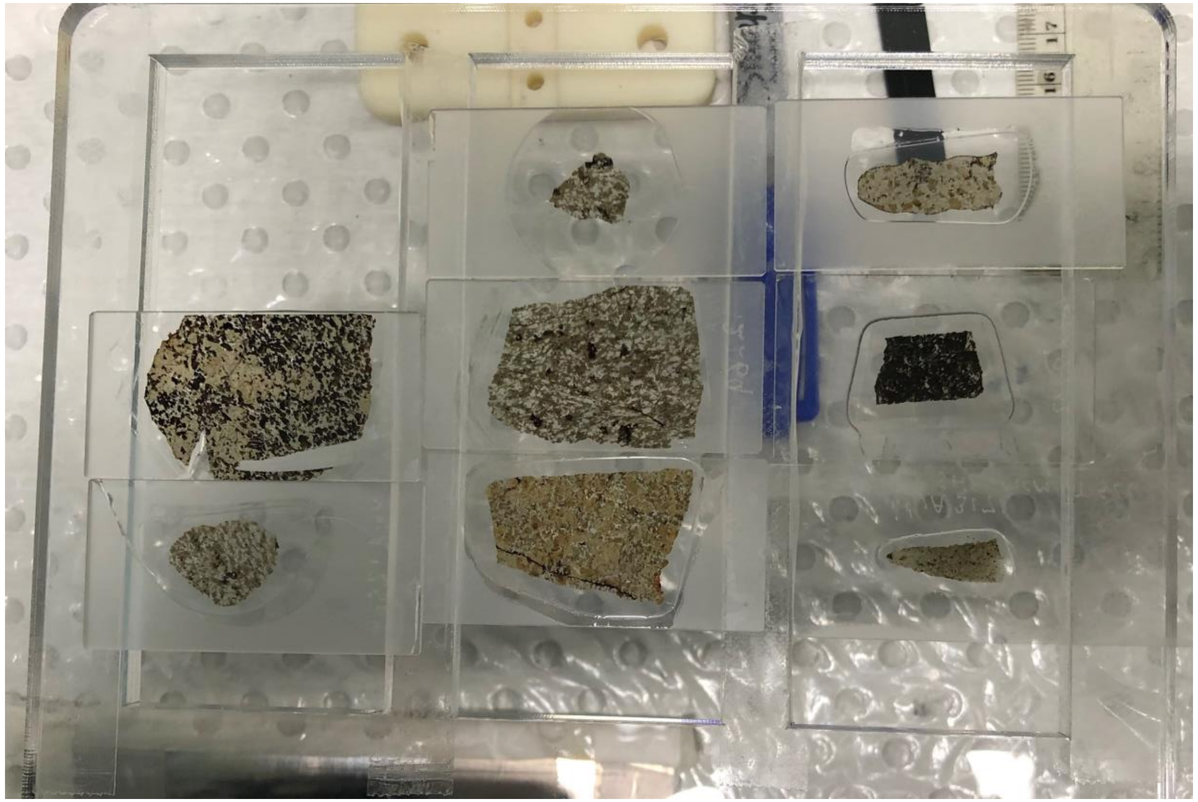
- Fluorescence X-ray absorption near-edge structure tomography
- Study the spatial arrangement of biological coordination chemistry within intact organisms
- Demonstrated by mapping the distribution of cuprous and cupric complexes within *Drosophila melanogaster*.



S. A. James, et al.
Visualising Coordination Chemistry:
Fluorescence X-ray Absorption Near Edge Structure Tomography,
Chem. Comm. **52,** 11834–11837 (2016).

Mail-in and remote access and guidance

- XFM conducted 90% of experiments fully remotely during COVID restrictions
- Ideal Mail-in samples:
  - robust
  - transportable
  - do not require complicated on-site preparation and mounting
  - E.g. petrographic sections
- ASCI is powerful environment for data analysis and real time experiment guidance
  - Overview scan of entire platen
  - Selecting ROIs for detailed analysis



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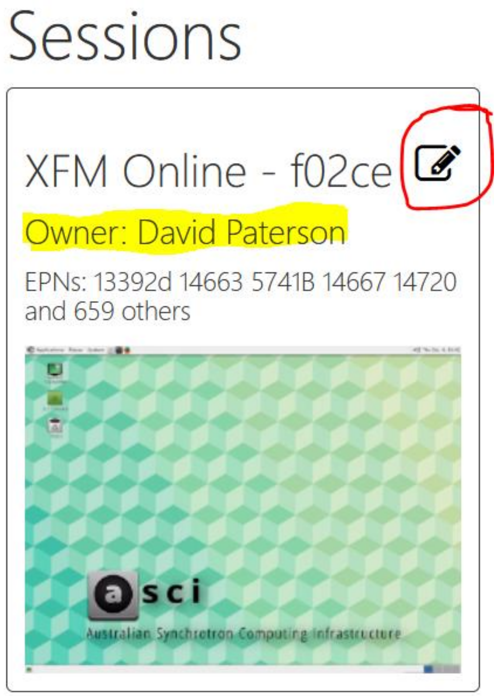
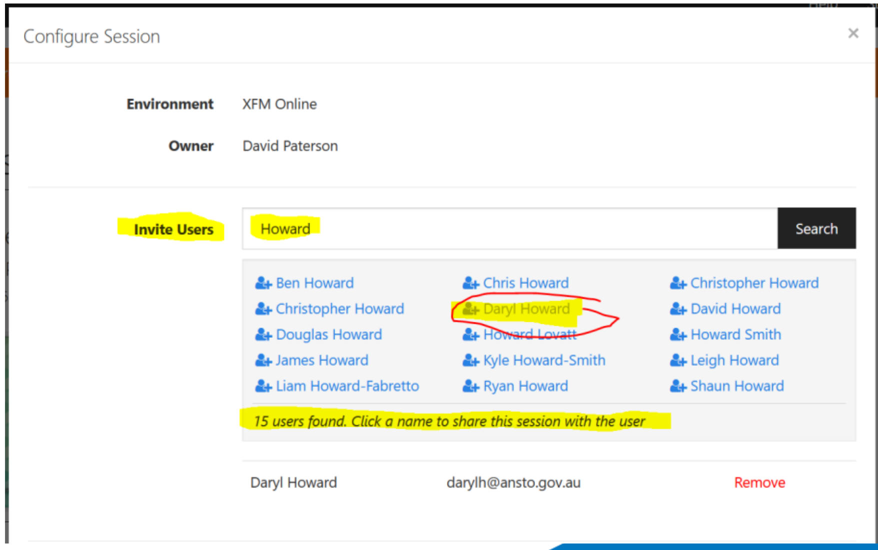
Data analysis: GeoPIXE within ASCI sessions

- Ideal environment to
  - Share data
  - Remote and on-site
  - Train new collaborators
  - Collaborate on
- data analysis & synthesis
  - During (XFM on-line) and
  - After (XFM Offline) your experiment





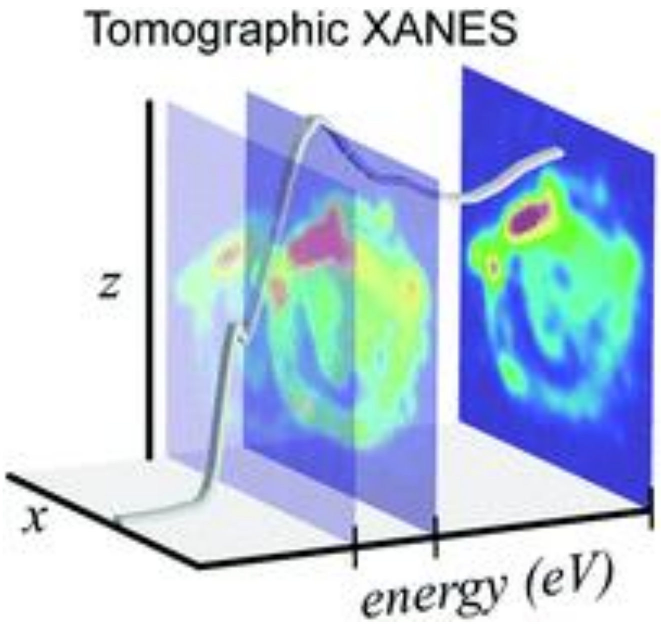
Summary and outlook

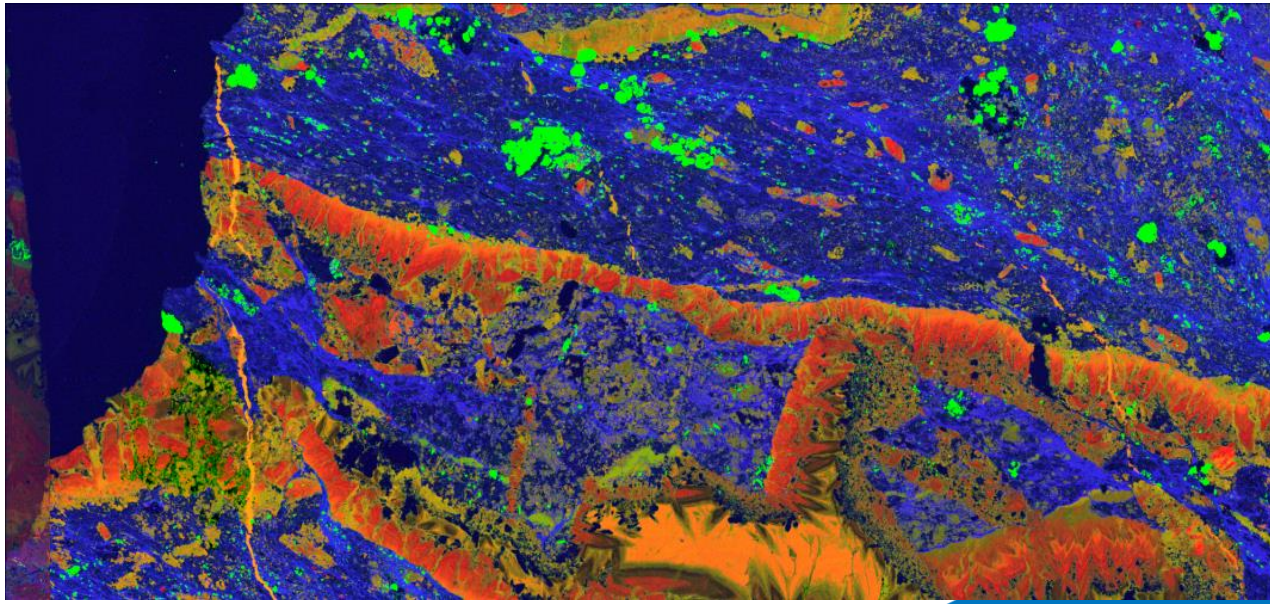
XFM

- ➢ Fast efficient mapping
- ➢ Fluorescence tomography
- ➢ Chemical XANES imaging
- ❑ Correlated ptychography
- ❑ 4D studies
  - › Time resolved
  - › XANES 3D tomography

Future

- ○ Higher energy (20 - 30 keV)
- ○ Higher flux (DMM)
- ○ Remote Access enhancements





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Thank you

Any Questions?

Acknowledgements

XFM Daryl Howard, Martin de Jonge, Juliane Reinhardt, Cameron Kewish, Michael Jones, Simon James, ...

ANSTO Nader Afshar, Andy Starritt, Adam Walsh, Noel Basten, Nicole Cain, ...

CSIRO Chris Ryan, Robin Kirkham, Murray Jensen, D…

Collaborators / material contributed

University of South Australia: Enzo Lombi, Erica Donner, …
University of Melbourne: Alex Johnson, …
University of Queensland: Peter Kopittke, Peng Wang, …
The Florey Institute: Gaiwan McColl, …
Queensland University of Technology: Michael Jones, ..

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