☒ **Talk** ☒ **Poster**

Trace-Level Nanoscale Chemical Mapping in Complex Environmental Matrices

Ajith Pattammattel[1], Robert Root[2], Dmitri Gavrilov[1], Ryan Tappero[1],Yong S Chu[1], Jon Chorover[2], Hanfei Yan[1]

1. National Synchrotron Light Source II, Brookhaven National Laboratory, Upton, NY, USA

2. Department of Environmental Science, University of Arizona, Tucson, AZ 85721, USA

Author Email: pattammattel@bnl.gov

Quantifying chemical speciation at trace-level concentrations within heterogeneous environmental samples remains a formidable challenge. Recent advances in hard X-ray nanoprobes at next-generation synchrotron light sources offer transformative, multimodal imaging capabilities, combining absorption, phase contrast, elemental mapping, and chemical sensitivity with spatial resolution down to ~10 nm, micron-scale penetration depth, and detection limits of only hundreds to tens of thousands of atoms [1]. In this presentation , I will highlight the latest developments in nanoscale X-ray Absorption Near-Edge Structure (nano-XANES) and XRF imaging at the Hard X-ray Nanoprobe (HXN) beamline of NSLS-II, with particular focus on trace-level chemical speciation and ultra-high spatial resolution. Following our sub-50 nm nano-XANES imaging achieved via Fresnel zone plates [2], we have deployed multilayer Laue lenses (MLLs) to attain sub-20 nm chemical mapping at incident energies of 12–18 keV. This breakthrough enables chemically specific imaging of as few as ~20,000 atoms, an unprecedented capability for environmental matrices. I will present a detailed case study on arsenopyrite particles (< 500 nm) derived from mine tailings. By integrating sub-20 nm nano-XANES with high-resolution X-ray fluorescence mapping, we elucidate nanoscale oxidation pathways and arsenic bioaccessibility in in vitro exposure models, revealing key insights into pollutant transformation and mobilization. In addition, I will introduce XMIDAS, our open-source data-analysis suite designed for robust, community-driven processing of nano-XANES datasets [3]. Together, these technical advancements and scientific applications demonstrate the power of high-resolution, trace-level chemical imaging for environmental and geochemical research. I will conclude with an outlook on future instrumentation enhancements and interdisciplinary collaborations aimed at broadening nanoscale chemical speciation in complex environmental systems.

References

[1] M. G. Masteghin, T. Gervais, S. K. Clowes, D. C. Cox, V. Zelyk, A. Pattammattel, Y. S. Chu, N. Kolev, T. J. Stock, N. J. Curson, others, Benchmarking of X-Ray Fluorescence Microscopy with Ion Beam Implanted Samples Showing Detection Sensitivity of Hundreds of Atoms. *Small Methods*, 2301610 (2024).

[2] A. Pattammattel, R. Tappero, M. Ge, Y. S. Chu, X. Huang, Y. Gao, H. Yan, High-sensitivity nanoscale chemical imaging with hard x-ray nano-XANES. *Sci. Adv.* **6**, eabb3615 (2020).

[3] A. Pattammattel, R. Tappero, D. Gavrilov, H. Zhang, P. Aronstein, H. J. Forman, P. A. O'Day, H. Yan, Y. S. Chu, Multimodal X-ray nano-spectromicroscopy analysis of chemically heterogeneous systems. *Metallomics* **14**, mfac078 (2022).