Development of a Wide-Range X-ray Emission Spectroscopy Measurement System with Transition Edge Sensors and Microwave Multiplexed Readout

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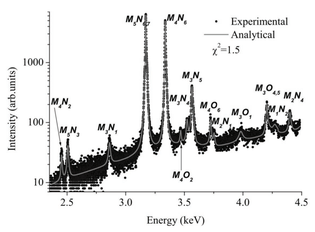
Motivation

Goal: Measure high-resolution X-ray emission spectra (XES) of model compounds to calibrate atomic models and build library of chemical spectral information.

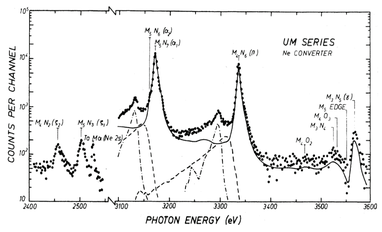
LANL Hyperspectral X-ray Emission (HXI) Project application: Uranium compounds

Existing U M emission spectra typically only address metallic U. We need comprehensive measurements of U M spectra of different chemical compounds to demonstrate chemical differences and to build accurate theoretical models. (See Croce et. al HXI poster LA-UR-19-26600)

Example published metallic U M spectra showing minor peaks (satellites) and spectral structure:

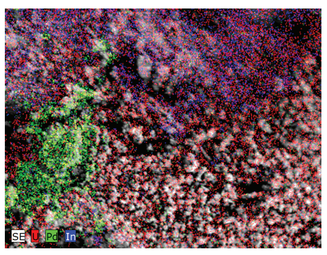


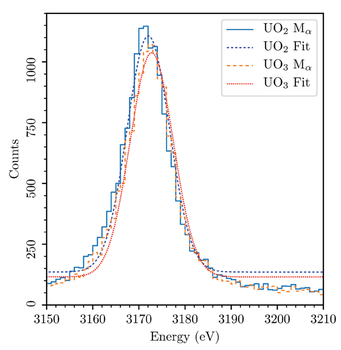
S.P. Limandri et al., Phys. Rev. A - At. Mol. Opt. Phys. 78 (2008)

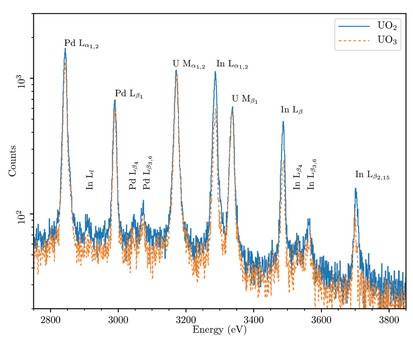


O. Keski-Rahkonen, M.O. Krause, Phys. Rev. A. 15 (1977) 959.

HXI Project application: U M spectroscopy with in-situ calibration in SEM. *Upper Left*: SEM image of UO_2 mixed with Pd and In. *Lower Right*: U M region acquired with STAR Cryoelectronics MICA-1600. *Lower Left*: U M_α showing shift of ~700 meV. Precise in-situ calibration is needed to constrain the U M peak position within 100 meV. High-resolution X-ray emission spectroscopy will validate theoretical models and provide a database of chemical shifts and positions/intensities of minor peaks (satellites).

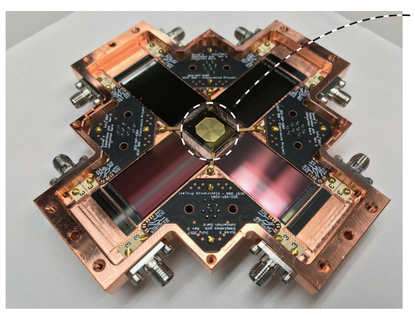




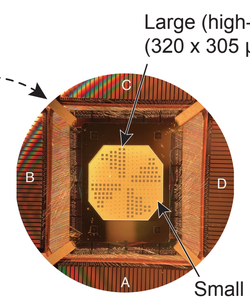


NIST TES Detector Arrays

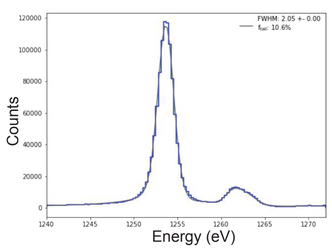
New 128-pixel TES detector arrays from NIST incorporate two pixel sizes for low- and high-energy-range performance, with RF-SQUID microwave multiplexed readout from the University of Colorado.



"Swiss Cross" detector package: 128 pixels bonded at once (choose large or small). Integrated RF-SQUIDS and resonators allow readout of all 128 pixels on single feedline @ ~5 GHz.



82 good channels, ΔE = 2.05 eV at 1.25 keV (Mg Ka)

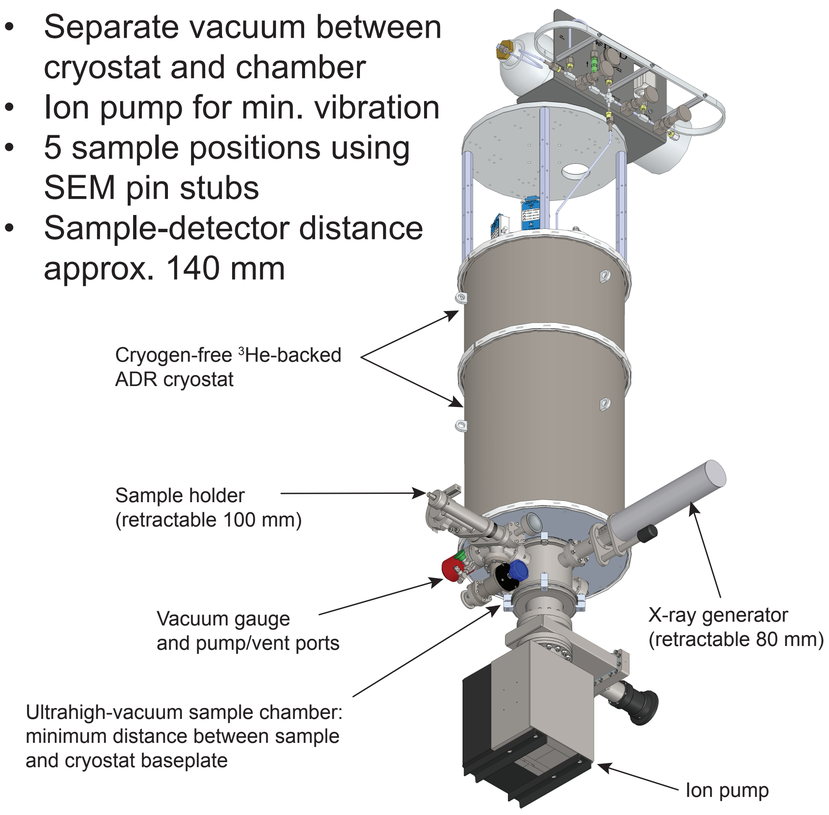


Tested small (low-energy) pixel performance:
2.05 eV FWHM @ Mg K_α

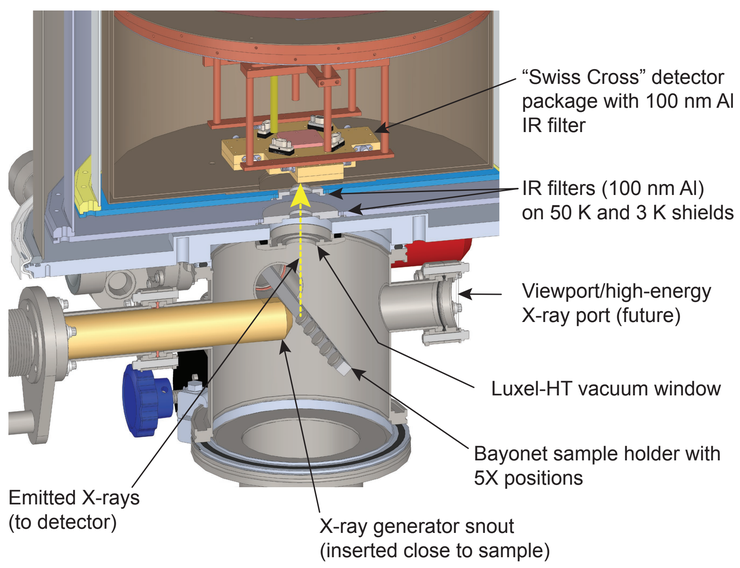
XES System: Design

Adapt existing ADR cryostat instrumented for microwave TES readout with hybrid X-ray TES array and X-ray analysis chamber of bulk samples. X-ray excitation gives low-background (Bremsstrahlung-free) emission spectrum.

- Separate vacuum between cryostat and chamber
- Ion pump for min. vibration
- 5 sample positions using SEM pin stubs
- Sample-detector distance approx. 140 mm

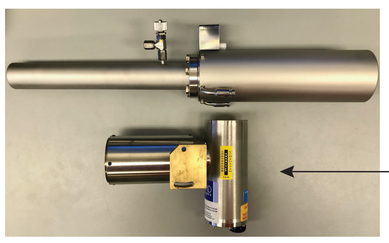


Cutaway view of sample chamber and cryostat



Choice of X-ray generators:

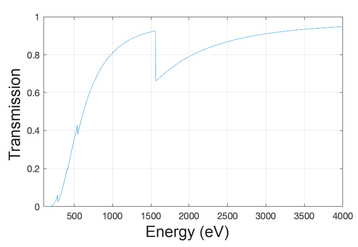
- Prevac RS40B1 for low energy (U M/N emission, low-Z elements); Al/Mg or Cu/Ti anode
- Oxford XTF5011A for high energy (U L emission), Rh anode with focusing optic

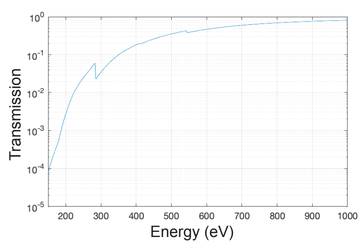


Prevac: < 15 keV with Al/Mg or Cu/Ti anodes

Oxford: <40 keV with Rh anode, focusing optics

X-ray transmission of vacuum window + IR filters: suitable for light element analysis (K emission from C, N, O, F) simultaneous with heavy elements



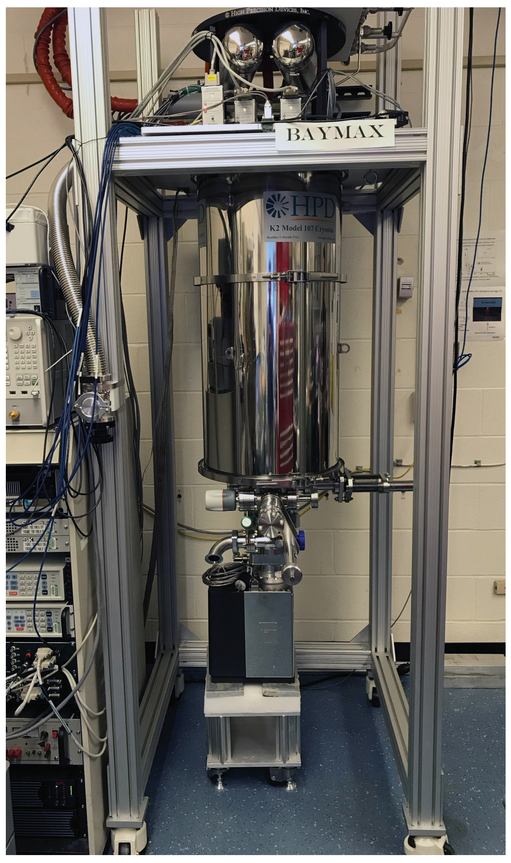


System Commissioning

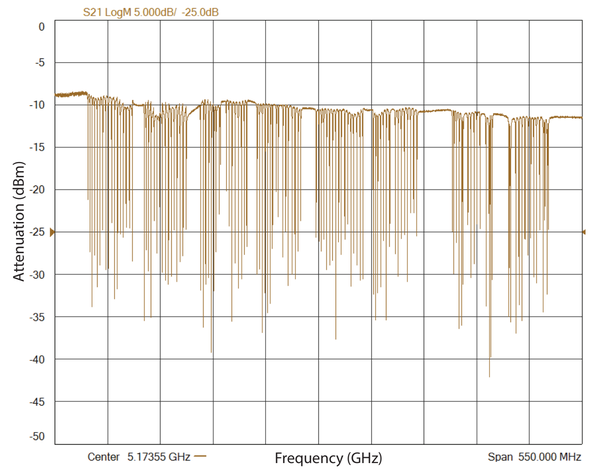
Current status:

- Detector package installed in cryostat, microwave readout tested
- X-ray analysis chamber assembled and awaiting X-ray generator installation

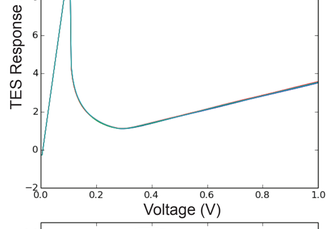
X-ray sample chamber installed on cryostat

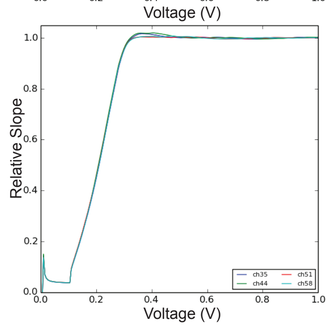


Resonators

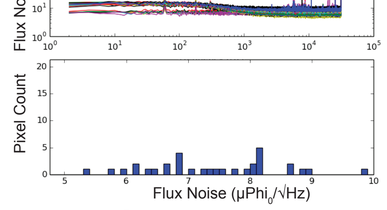


Typical I-V curves

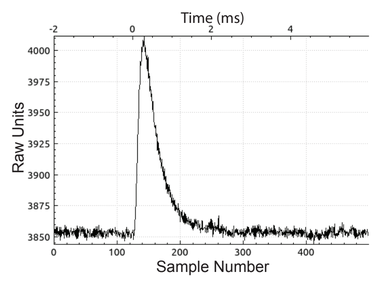




Readout noise



Pulse from sealed source



Summary: X-ray spectroscopy system based on TES detectors will allow high resolution over a large energy range (200 eV - 15 keV). This will enable simultaneous high-precision measurement of X-rays from heavy and light elements in a variety of compounds to validate models and build a spectral database for chemical state analysis.