

From unconventional superconductivity, through relaxor ferroelectrics to multiferroicity: Deploying Uniaxial Strain, multi-modality, and dynamic X-ray scattering.

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In this talk I will layout a brief picture of my research at beamline 6-ID-B at the Advanced Photon Source (APS) by presenting some recent results and describing a vision of what I plan for in the post source upgrade (APS-U) after 2022.

Beamline 6-ID-B primarily serves the condensed matter community providing resonant x-ray and magnetic scattering for single crystal systems, with a particular interest in epitaxial thin films (1). In order to drive our leading edge scientific importance we continuously develop metrological capabilities which are then made available to our user community. Here, I will introduce recent tools that are helping our users drive their scientific endeavors forward including, low temperature uniaxial strain in a multimodal setup, and dynamic *in-situ* measurement configuration. Presenting recent results on single crystal unconventional superconducting pnictide systems BaFe_2As_2 and EuFe_2As_2 parent compounds we demonstrated uniaxial strain capability (2-4). In addition I will present results of ongoing studies of relaxor ferroelectrics (PMN-PT) using the *in-situ* AC-XRD giving us the ability to study the microscopic behavior of piezoelectric devices *in-operando*.

Finally, I will present results from the intriguing rare earth-titanate, EuTiO_3 . This material is an excellent platform to explore the interplay between spin, charge, symmetry, structure, and polarity within a single system (5-7) and to expand the sample environment control capabilities that now serve a broader range of scientific interests. EuTiO_3 has allowed us to study the phenomenon of magnetoelectric (ME) coupling, an interaction between magnetic and electric polarization. We try to untangle this ME behavior in this single phase system and in the process demonstrate a 'giant' ME cross-field control capability in the rare earth perovskite (5). In bulk form it is both antiferromagnetic and paraelectric. Both anti- and ferro-magnetic interactions are present between different nearest europium neighbors allowing for the notion of a magnetic quantum critical point through a combination of doping or strain (8). Fortuitously, like SrTiO_3 , this system is also considered potentially quantum paraelectric or 'incipient' ferroelectric, this conjures the notion of bi-criticality or possibly the emergence of a multiferroic quantum critical point (8).

1. <https://www.aps.anl.gov/Sector-6/6-ID-B-C/Publications>
2. P. Malinowski *et al.*, "Suppression of superconductivity by anisotropic strain near a nematic quantum critical point", *Nat. Phys.* **16**, 1189 (2020).
3. J.J. Sanchez *et al.*, "The spontaneous elastoresistivity coefficient within the nematic ordered phase of iron pnictides", arXiv:2006.09444 [cond-mat.str-el]
4. Strain-tunable metamagnetic transition in EuFe_2As_2 probed by x-ray magnetic circular dichroism, Joshua J Sanchez *et al.*, arXiv:2012.00623 [cond-mat.supr-con]
5. P. J. Ryan *et al.*, "Reversible Control of Magnetic Interactions by Electric Field in a Single Phase Material.", *Nat. Commun.* **4**, 1334 (2013).
6. J.-W. Kim *et al.*, "Emergent Superstructural Dynamic Order due to Competing Antiferroelectric and Antiferrodistortive Instabilities in Bulk EuTiO_3 " *Phys. Rev. Lett.* **110**, 027201 (2013).
7. Multiferroic behavior in EuTiO_3 films constrained by symmetry, P.J. Ryan *et al.*, *Phys. Rev. B* **101**, 180409 (2020).
8. Multiferroic quantum criticality, A. Narayan, Andrés Cano, A.V. Balatsky, N.A. Spaldin, *Nat. Mat.* **18**, 223 (2019).