Instrumentation and Sensors: Acoustics

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LA-UR-23-21806

Motivation

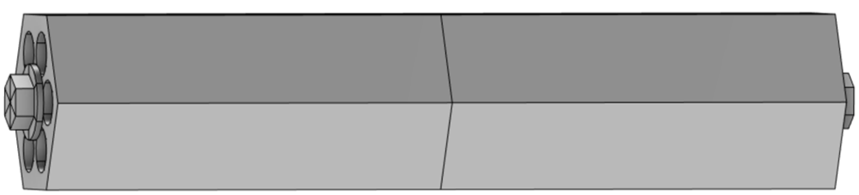
Development of **acoustic monitoring** techniques that can be coupled with **embedded sensors** for **in-situ structural monitoring** of an inaccessible microreactor core block

Diagram from LA-UR-20-20824

Goals

Demonstrate acoustic sensitivity to the **stress state** and **structural integrity** of joints between sections of a modular microreactor core-block-like object

- Use **nonlinear elasticity** to detect changes in material properties and joint integrity



- Apply **machine learning** to identify state-of-stress and the data features to prioritize in future embedded sensor deployments

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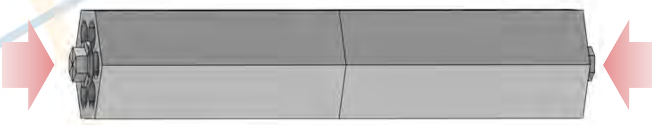
Structural monitoring using acoustics

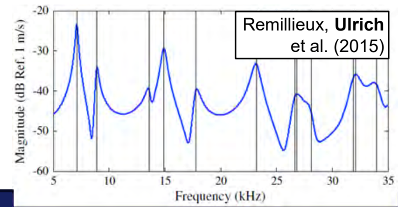
Experiment



Acoustic testing of *stressed* core-block proxy

intact (baseline), then damaged

Methods

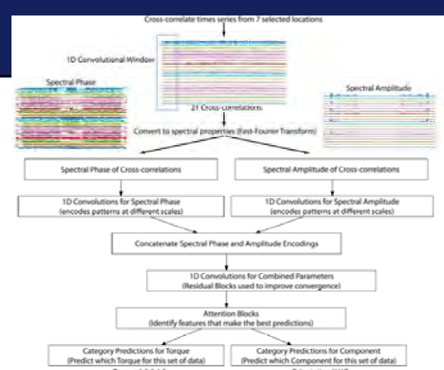


Resonant Ultrasound Spectroscopy

linear & nonlinear

Machine Learning

neural network



Outcomes

Elastic material properties

Sensitivity to varying stress states & damage

Inform future embedded sensing designs

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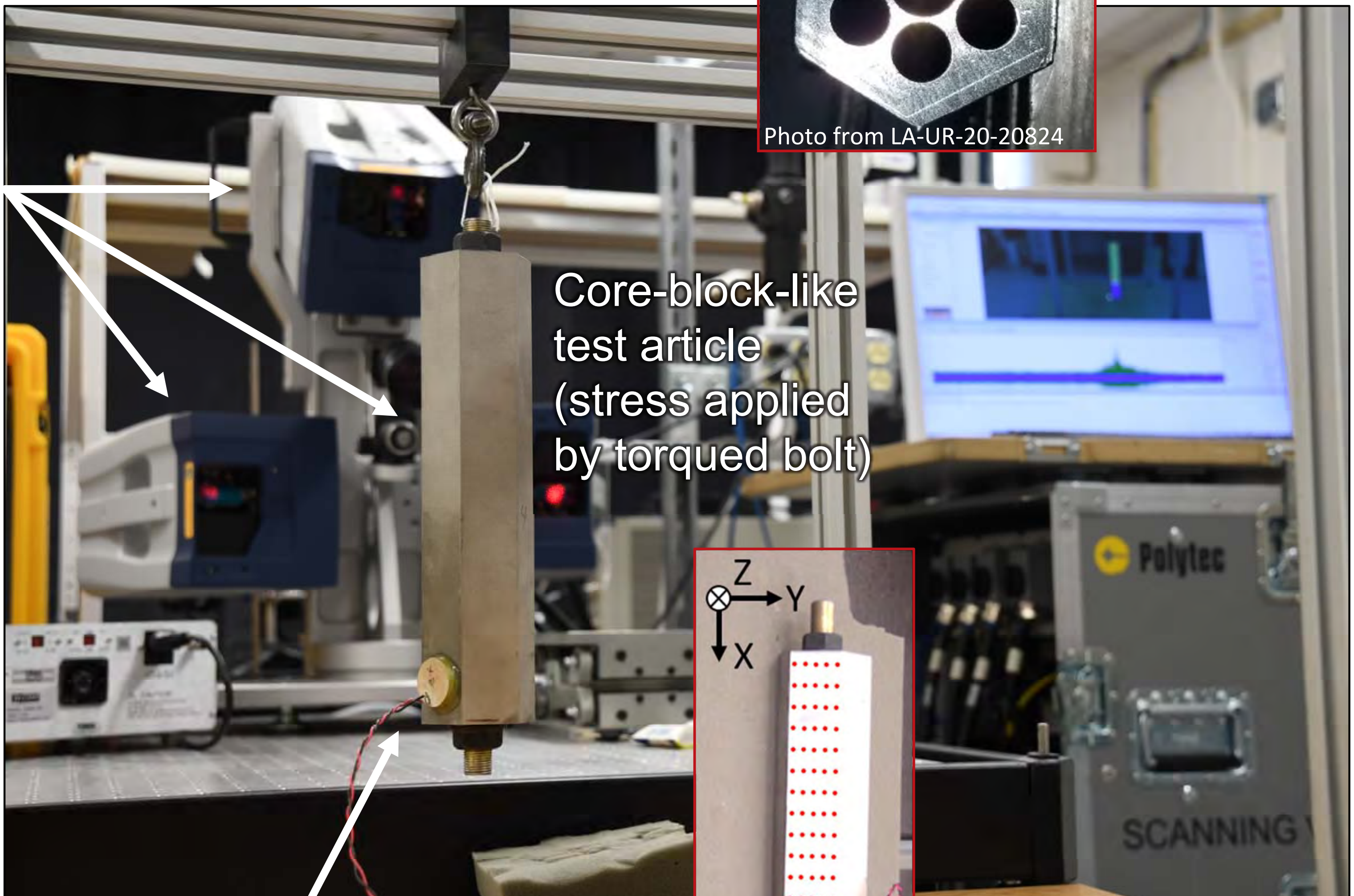
Baseline data collection

3D scanning vibrometer

amplifier

DAQ system



PZT transducer

pseudo-random input

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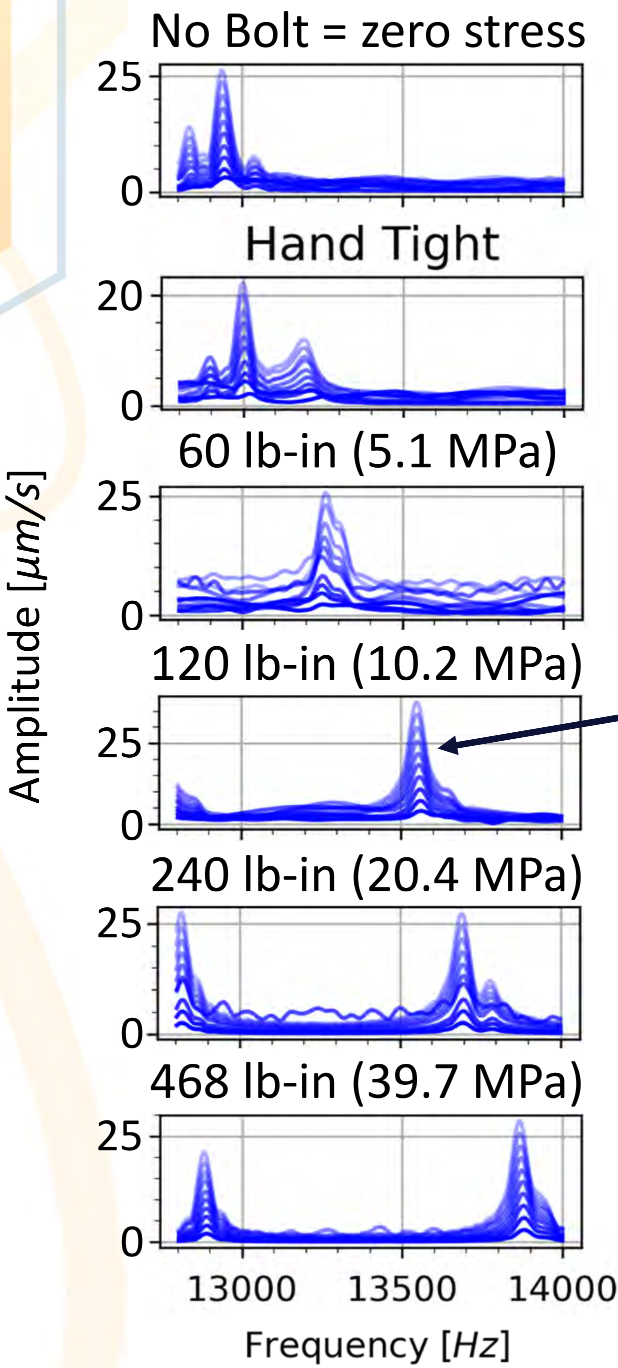
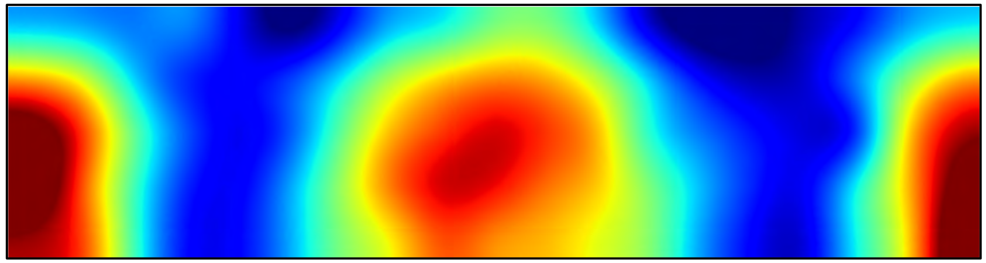
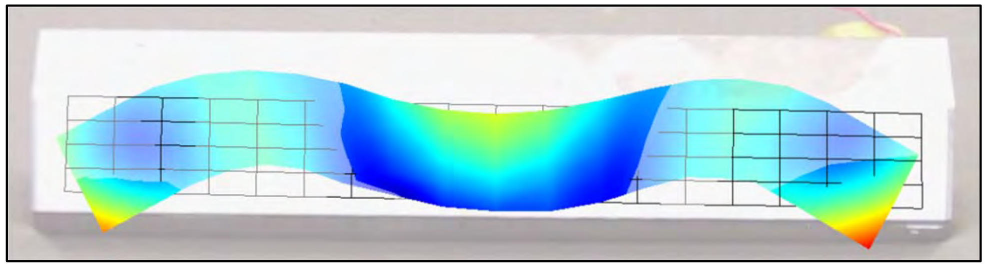
Resonant Ultrasound Spectroscopy: linear (RUS) & nonlinear (NRUS)





Out-of-plane (Z) motion



3D mode image

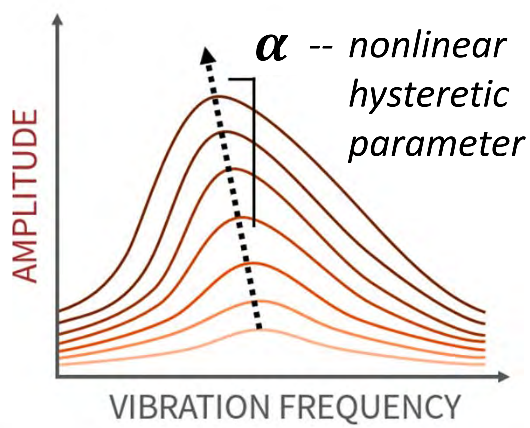
10 drive amplitudes at each applied torque level (NRUS)

Best-fitting RUS solution (5 modes):

$\rho = 8024\ \mathrm{kg/m^3}$

$E = 187.0\ \mathrm{GPa}$

$\nu = 0.303$



Payan, C., **Ulrich, T. J.**, et al. (2014). Quantitative linear and nonlinear resonance inspection techniques and analysis for material characterization: Application to concrete thermal damage. *Journal of the Acoustical Society of America.*

Remillieux, M. C., **Ulrich, T. J.**, et al. (2015). Resonant ultrasound spectroscopy for materials with high damping and samples of arbitrary geometry. *Journal of Geophysical Research: Solid Earth*.

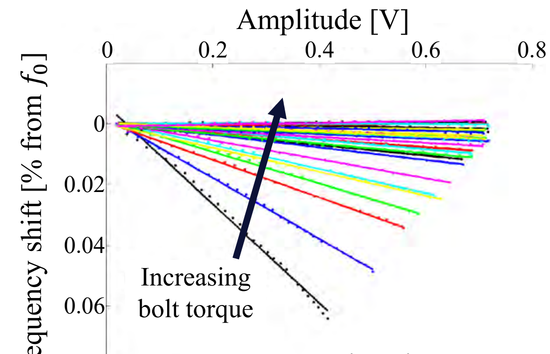
Beardslee, L. B., Remillieux, M. C., & **Ulrich, T. J.** (2021). Determining material properties of components with complex shapes using Resonant Ultrasound Spectroscopy. *Applied Acoustics.*

Geimer, P. R., Ulrich, T. J., Beardslee, L. B., et al. (2022). Finite-element-based resonant ultrasound spectroscopy for measurement of multi-material samples. *Journal of the Acoustical Society of America*.

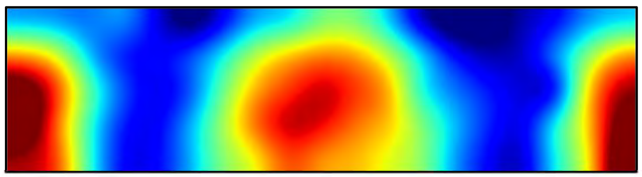
Baseline nonlinear elasticity of the sample is largely consistent regardless of stress state

Nonlinear hysteretic response (α) is highly sensitive to damage and stress

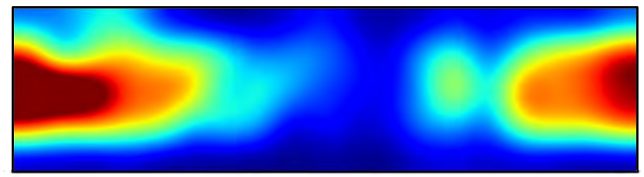
We expect α to correlate with stress after introducing a defect to the sample → nonlinearity generated at “soft” interface



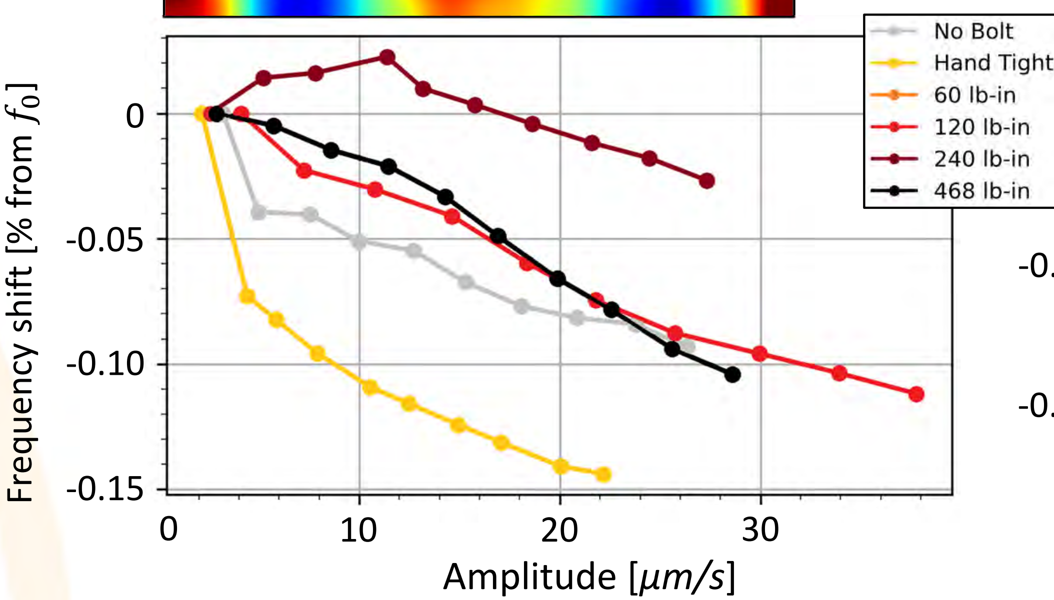
Riviere et al. (2010) *J. App. Phys.*

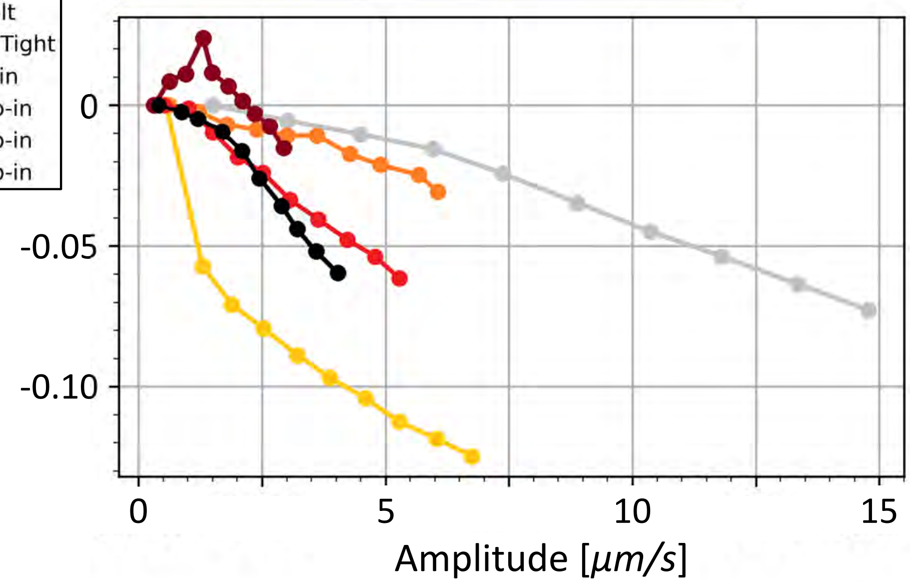


13-kHz mode



21-kHz mode





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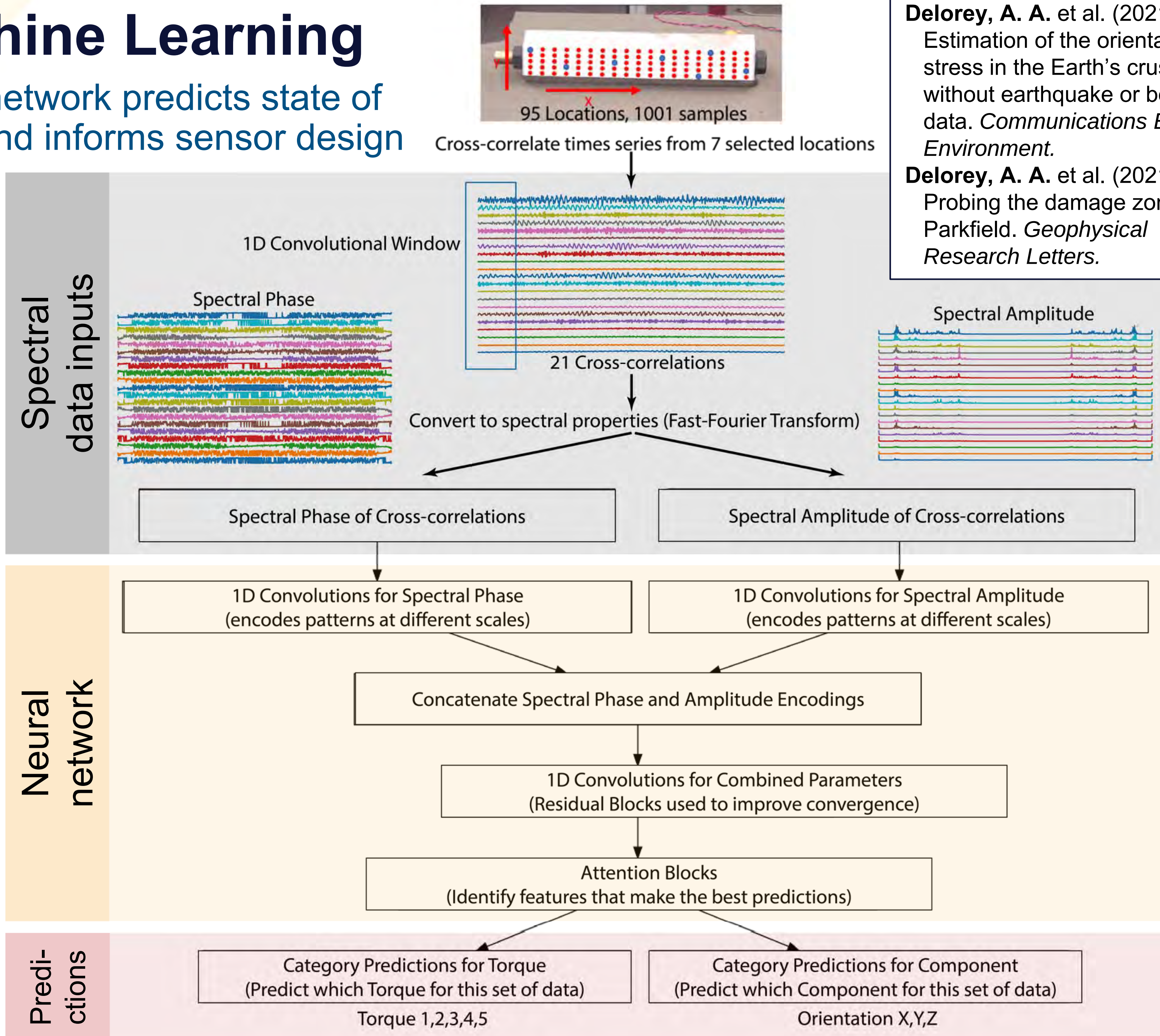
Machine Learning

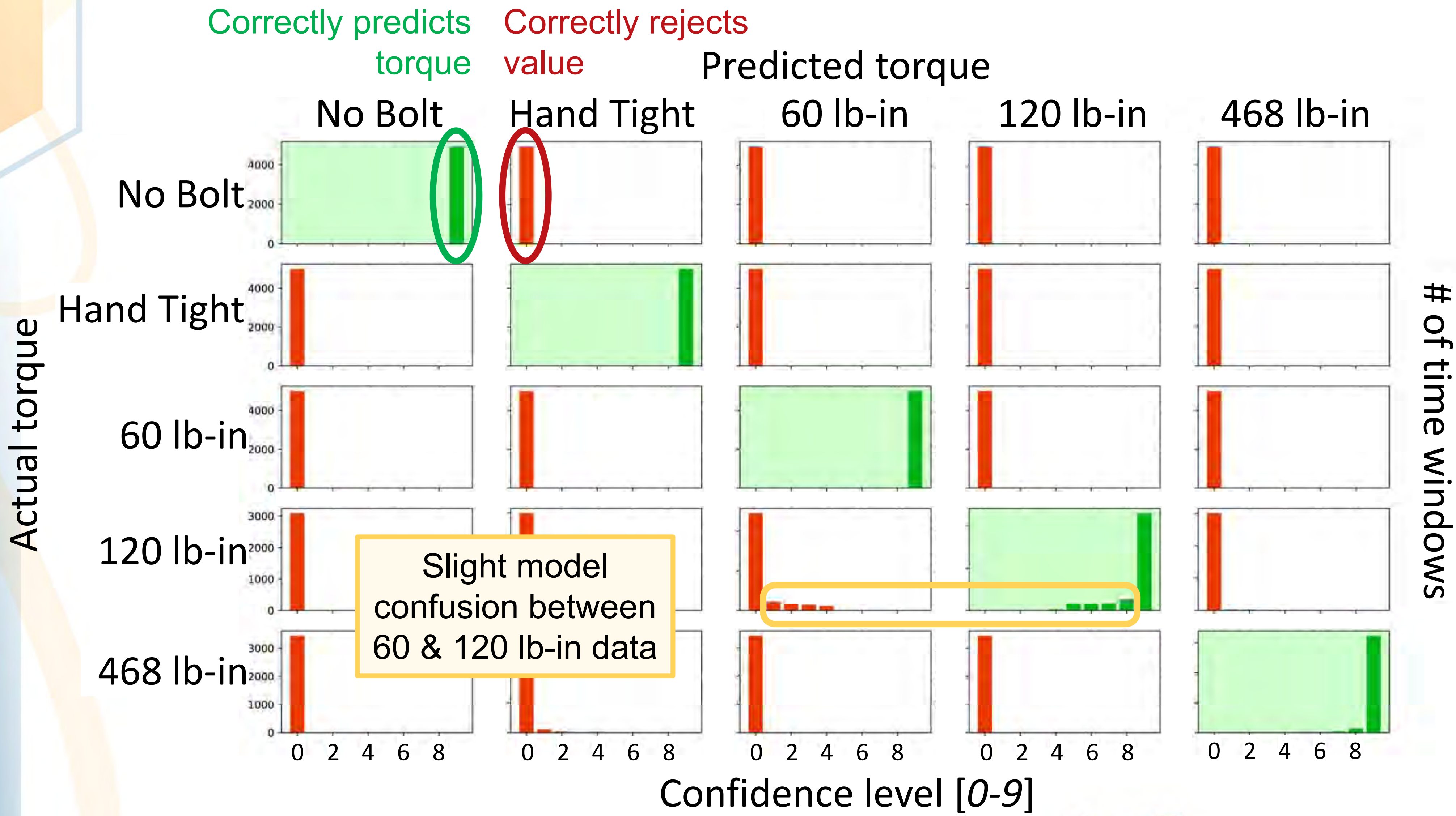
Neural network predicts state of stress and informs sensor design



Delorey, A. A. et al. (2021). Estimation of the orientation of stress in the Earth's crust without earthquake or borehole data. *Communications Earth & Environment.*

Delorey, A. A. et al. (2021). Probing the damage zone at Parkfield. *Geophysical Research Letters.*

ML model predicted stress state correctly in 94% of time windows using Y-component data



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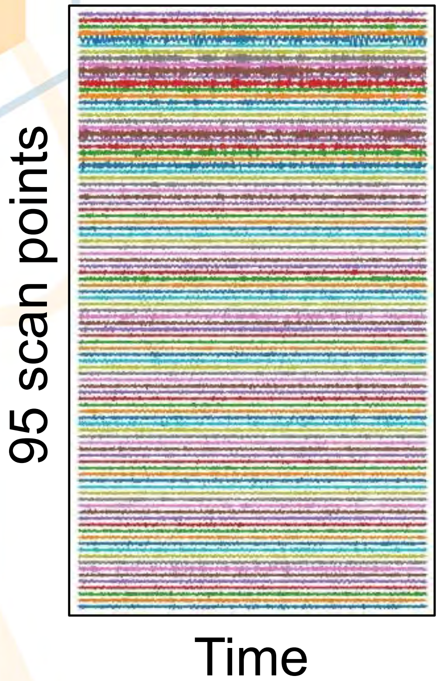
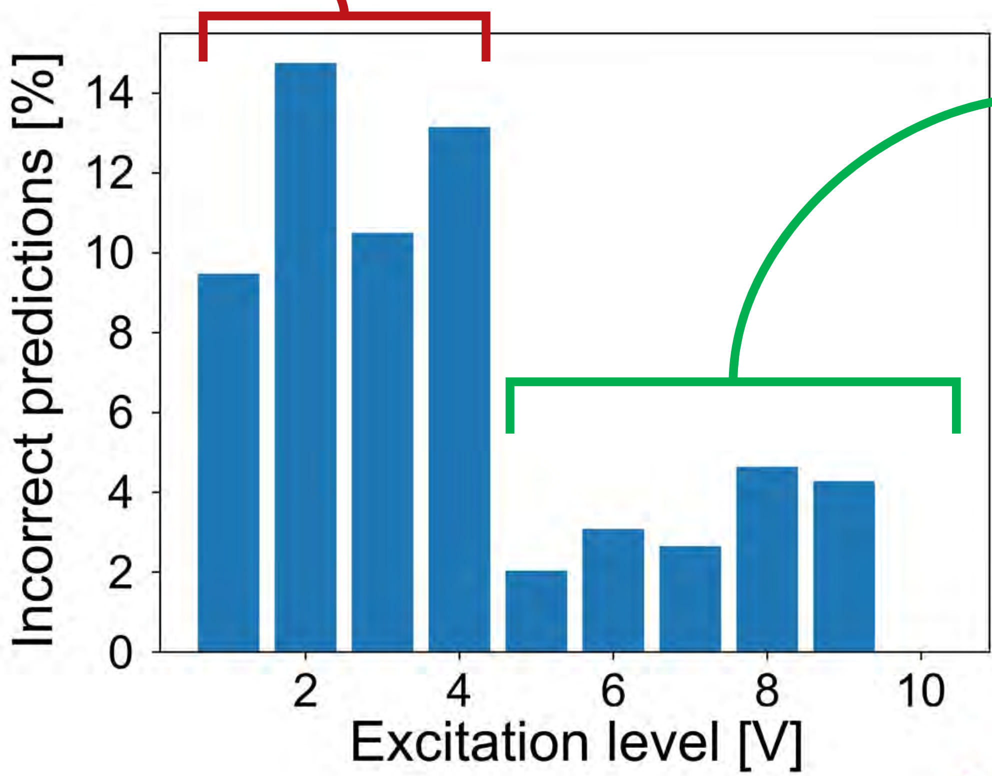
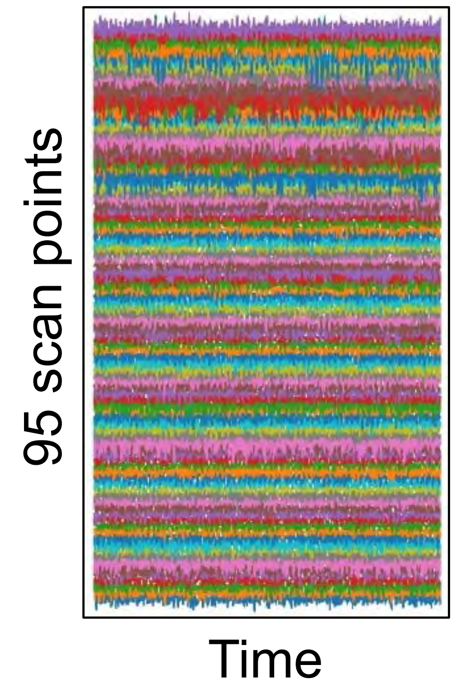
Most important data features for correct prediction are amplitude (SNR) & Y-component of motion



Amplitudes of correct predictions are ~50% higher than incorrect





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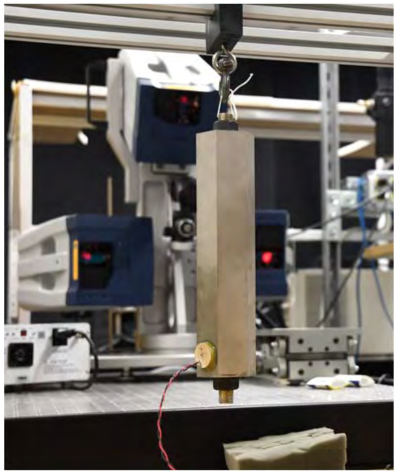
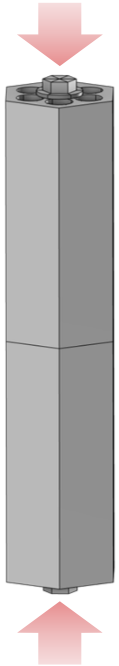
Milestone status

- **M3 report (LANL)**
  - Preliminary results and work plan to accomplish M2 objectives
  - ***Delivered on schedule*** (Feb. 10, 2023)
- **M2 report (LANL)**
  - Demonstration of acoustic sensitivity to stress changes and defects, in preparation for future embedded sensors
  - ***On track to meet due date*** (June 30, 2023)

Upcoming work

- Repeat data collection for intact sample in vertical orientation (ongoing)
  - 6 torque & 10 excitation levels
- Cut sample in half and restress, test
- Alter surface roughness of cut interface to test sensitivity to defect changes
- Integrate results with embedded sensing plan from ORNL





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