



ICNEM 2026

International Conference on Nonlinear Elasticity in Materials

# **ABSTRACT BOOK**

CORPUS CHRISTI, TEXAS, USA

**MAY 31-JUNE 6, 2026**

## Monday, June 1, 2026

8:00 a.m. – 8:30 a.m.	<i>Shuttle to the Texas A&amp;M University-Corpus Christi University Center. 6300 Ocean Dr Unit 5783, Corpus Christi, TX 78412 Meet at the hotel entrance.</i>	<i>Omni Hotel</i>
8:30 a.m. – 9:00 a.m.	<i>Breakfast</i>	<i>Swordfish</i>
9:00 a.m. – 9:25 a.m.	<b>Welcome Remarks</b> <b>Timothy J. Ulrich</b> , Director of University Research & Relations at the Los Alamos National Laboratory (LANL) <b>David Ma</b> , Dean of the College of Engineering, Texas A&M University-Corpus Christi	<b>Bayview</b>
9:25 a.m. – 9:40 a.m.	<b>Remembrance for Robert Guyer</b> <b>Eliza McCall</b>	<b>Bayview</b>
9:40 a.m. – 10:25 a.m.	<b>Introductory course on theory and modelling in nonlinear elasticity</b> <b>Koen van den Abeele</b> , Senior Researcher, KU Leuven Kulak	<b>Bayview</b>
10:25 a.m. – 10:45 a.m.	<i>Break</i>	<i>Bayview</i>
10:45 a.m. – 11:30 a.m.	<b>Experimental Methods in Nonlinear Elasticity: An Overview</b> <b>Timothy J. Ulrich</b> , Director of University Research & Relations at the Los Alamos National Laboratory (LANL)	<b>Bayview</b>
11:30 a.m. – 11:55 a.m.	<b>Problems of long-time relaxation (slow time)</b> <b>Lev Ostrovsky</b> , Professor, University of Colorado-Boulder and University of North Carolina-Chapel Hill	<b>Bayview</b>
11:55 a.m. – 1:10 p.m.	<i>Lunch</i>	<i>Swordfish</i>
1:10 a.m. – 1:55 p.m.	<b>Observations and Applications of Nonlinear Elasticity in Earth</b> <b>Paul Johnson</b> , Senior Researcher, Los Alamos National Laboratory	<b>Bayview</b>
1:55 p.m. – 2:35 p.m.	<b>From Grain to Mesh: 2D Modeling of Nonlinear Mesoscopic Elasticity</b> <b>Ryley Hill</b> , Post-Doc, Los Alamos National Laboratory	<b>Bayview</b>
2:35 p.m. – 3:15 p.m.	<b>Parametric Study of Slow Dynamic Nonlinear Elasticity: Phenomenological models and their predictions</b> <b>Richard Weaver</b> , Professor Emeritus, University of Illinois at Urbana-Champaign	<b>Bayview</b>
3:15 p.m. – 3:30 p.m.	<i>Break</i>	<i>Bayview</i>
3:30 p.m. – 4:10 p.m.	<b>Evidence for evolution of lack-of-fusion defects induced by resonant acoustic excitation in commercially pure additively manufactured aluminum</b> <b>Ward Johnson</b> , Physicist, National Institute of Standards and Technology	<b>Bayview</b>
4:10 p.m. – 4:50 p.m.	<b>Medical Opportunities of Nonlinear Time Reversal Acoustics (NTRA)</b> <b>Alexander Sutin</b> , Adjunct Professor, Stevens Institute of Technology	<b>Bayview</b>
4:50 p.m. – 5:15 p.m.	<i>Shuttle to the Omni Hotel. 900 N Shoreline Blvd, Corpus Christi, TX 78401</i>	<i>Bayview</i>

## Introductory course on theory and modelling in nonlinear elasticity

**Koen Van Den Abeele<sup>1</sup>**

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The aim of this presentation is to give a general introduction to the field of nonlinear acoustic and elasticity, focussed on the theoretical background of mechanisms leading to nonlinear mechanics and dynamics, and the implementation of such micro- and mesoscale models in numerical simulations for a wide variety of applications involving nonlinear wave propagation.

Apart from refreshing your memory on the basics of nonlinear elasticity, the talk aims to place certain presentations of this conference within a common framework, to ensure a consistent terminology and align efforts in nonlinear acoustics in solids by providing a unified approach.

Starting from analytical models, i.e. perturbation theory, and more flexible non-analytical models, i.e. the PM approach, researchers have defined several nonlinearity parameters (typically indicated with  $b$ ,  $d$ ,  $a$ ) which can be used to quantify the degree of nonlinearity that can be observed in experimental observations. Macroscopic indicators of nonlinearity include the generation of harmonics and intermodulation frequencies, nonlinear attenuation and hysteresis, all of which can be extracted from finite amplitude wave responses by way of (Short Time) Fourier transforms, Scale subtraction, etc. Complicating factors such as the presence of external fields and non-equilibrium nonlinear effects will be shortly addressed as well.

Illustrations of these macroscopic effects will be provided based on simulations of bulk wave propagation, resonance, time reversal and sparse array network analysis.

## Experimental Methods in Nonlinear Elasticity: An Overview

**Timothy J. Ulrich<sup>1</sup>**

<sup>1</sup> Los Alamos National Laboratory and Texas A&M University

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Experimental nonlinear elasticity encompasses a broad range of phenomena and measurement approaches used to characterize material behavior beyond the linear elastic regime. Nonlinear elastic methods are capable of probing material behavior with sensitivities often far exceeding conventional linear approaches, making them particularly valuable for the investigation of microstructural evolution, defects, interfaces, and distributed damage. This presentation provides an overview of the principal experimental methods used in nonlinear elasticity, emphasizing the physical observables, measurement strategies, and practical implementation considerations associated with dynamic elastic-wave techniques. Topics include resonance-based methods such as resonant ultrasound spectroscopy (RUS) and nonlinear resonant ultrasound spectroscopy (NRUS); propagating-wave approaches including harmonic generation, wave modulation spectroscopy, and wave mixing; hybrid techniques such as dynamic acoustoelasticity testing (DAE/DAET); and focused-wave methods based on time reversal and nonlinear wave focusing. Experimental considerations associated with these methods are discussed throughout, including transducer coupling, boundary conditions, instrumentation nonlinearities, synchronization, signal processing, dynamic range, and the increasing use of noncontact approaches such as laser ultrasonics, laser Doppler vibrometry, and air-coupled excitation. The relationships between different nonlinear observables and the physical mechanisms they probe—including anharmonicity, contact acoustic nonlinearity, hysteresis, and evolving elastic state—are also examined. The goal of the presentation is to provide a broad experimental perspective and a common terminology framework for nonlinear elasticity research, supporting discussion and interpretation of the diverse experimental methods and applications presented throughout the conference.

## Problems of long-time relaxation (slow time)

**Lev Ostrovsky<sup>1</sup>**

<sup>1</sup>University of Colorado, Boulder, University of North Carolina, Chapel Hill

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Rock and non-consolidated soils exhibit three distinctive properties: anomalous elastic nonlinearity, hysteresis in stress-strain relations, and slow dynamics. These characteristics stem from grain contact detachment and attachment under stress. After impact, property restoration takes hours (laboratory) to years (earthquakes), following logarithmic time dependence with recovery time nearly independent of impact level. This behavior derives from the thermodynamic Arrhenius model with shallow second potential minima in contacts. We specifically address previously unconsidered excitation (conditioning) effects, analyzing prolonged and oscillatory excitation common in laboratory experiments. Using exponential statistics (Weibull distributions), we examine wave velocity variation dependence on initial strain under laboratory and post-earthquake conditions. The order-of-magnitude difference in recovery times between laboratory and field conditions is explained by contact volume differences. Results are compared with experimental data, demonstrating applications for non-destructive testing.

## Observations and Applications of Nonlinear Elasticity in Earth

**Paul Johnson<sup>1</sup>**

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"Nonlinear elasticity plays a crucial role in understanding the complex mechanical behavior of Earth's crust and mantle, where materials often exhibit stress-strain relationships that deviate from linear Hookean elasticity, as well as hysteresis and slow dynamics. Observations of nonlinear elastic responses are evident in a variety of geophysical phenomena, including seismic wave propagation, fault mechanics, and volcanic processes.

In seismology, nonlinear models improve the interpretation of wave velocity changes associated with earthquake nucleation, fault slip, and volcanic unrest. These models also enhance the accuracy of seismic imaging and monitoring, enabling better assessment of subsurface structures and hazard potential. In geotechnical engineering, nonlinear elasticity informs the design of stable infrastructure in regions prone to ground deformation or seismic activity. Nonlinear effects in fault zones may explain why seismic waves from one earthquake can trigger another, even at far distances from the triggering source, a phenomenon known as dynamic earthquake triggering. Furthermore, the study of nonlinear elasticity contributes to our understanding of rock damage, healing, and the evolution of mechanical properties over time. For instance, following a moderate to large earthquake nonlinear effects in the form of slow dynamics can persist for years. Understanding and characterizing nonlinear effects is essential for predicting the behavior of Earth's crust including geological reservoirs, assessing the stability of slopes and rock columns, and managing induced seismicity related to human activities such as fluid injection or extraction. In summary, the integration of nonlinear elastic theory with observational data provides a robust framework for advancing our comprehension of Earth's dynamic processes and mitigating associated risks."

## From Grain to Mesh: 2D Modeling of Nonlinear Mesoscopic Elasticity

**Ryley Hill, Robert A. Guyer, Paul A. Johnson, Zhou Lei, Christopher W. Johnson<sup>1</sup>**

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Initially documented in rock specimens at LANL in the mid-1990s, dynamic nonlinear mesoscopic elastic behavior is now understood to be a general material response, manifesting across diverse classes of materials such as polycrystalline solids, ceramic composites, metallic alloys, and granular systems. This behavior is understood to arise from “soft” regions in the microstructure such as microcracks, flat pores, and compliant bonds that strongly influence the macroscopic elastic response. We develop a numerical model, calibrated to the properties of Berea Sandstone, that captures nonlinear elastic wave behavior under both quasi-static and dynamic loading. To construct such models from real microstructures, we created a software package, Grain2mesh, which takes unprocessed mesoscopic images as input and performs automatic segmentation, preprocessing, quality control, and numerical mesh generation. In the model, stiff crystalline elastic grains are embedded in an amorphous diagenetic matrix whose stress-strain response is nonlinear and spatially heterogeneous. The soft matrix controls the rate-independent hysteresis and reproduces key features commonly observed in resonant bar and acousto-elastic experiments. For physical insight, the model enables detailed local tracking of the matrix response to identify essential force pairs that govern hysteresis and are consistent with phenomenological descriptions. These insights link nonlinear behavior to microstructural structure and retain the ability to incorporate other EOS for the diagenetic matrix. The results demonstrate that physically motivated microstructural numerical modeling can explain experimentally observed nonlinear acoustic wave phenomena.

## **Parametric Study of Slow Dynamic Nonlinear Elasticity: Phenomenological models and their predictions**

**Richard Weaver<sup>1</sup>, John Yoritomo<sup>2</sup>**

<sup>1</sup>The Grainger College of Engineering, Urbana, US

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"Several phenomenological models that aspire to quantitative description of anomalous nonlinear mesoscopic elasticity are reviewed. This class of nonlinearity, best known perhaps for slow dynamics and aging, is seen widely in imperfectly consolidated granular solids but is not well understood. Typical slow dynamic tests show that a modest conditioning oscillatory "pump" strain depresses material stiffness, which then recovers like the logarithm of time after conditioning ceases. Several phenomenological models based on physical arguments have been proposed that predict the material stiffness response to arbitrary pump strain histories during conditioning and recovery. Approximate closed form and numerical solutions to the models are presented that predict the quantitative influence of three key pump parameters: the pump's strain amplitude, the pump's strain rate, and the pump's duration. A companion presentation [1] will present laboratory measurements on Berea sandstone, concrete and a confined single aluminum bead and compare the measurements to the model predictions.

## **Evidence for evolution of lack-of-fusion defects induced by resonant acoustic excitation in commercially pure additively manufactured aluminum**

**Ward L. Johnson<sup>1</sup>, Paul R. Heyliger<sup>2</sup>, Derek Harris, Jeremy Iten<sup>3</sup>**

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<sup>2</sup> Department of Civil & Environmental Engineering, Colorado State University

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Nonlinearity and loss of resonant acoustic modes in additively manufactured (AM) commercially pure aluminum measured with nonlinear reverberation spectroscopy (NRS) have been found to be anisotropic, correlated with porosity, and dependent on accumulated duration of acoustic excitation. The physical mechanism responsible for the porosity dependence has been hypothesized as hysteretic friction between lack-of-fusion (LOF) defects under acoustic shear stress, based on correlations of anisotropy of nonlinearity and loss with geometric anisotropy of defect populations observed in Xray-CT scans and SEM images. However, no explanation has previously been offered for acoustically induced changes in nonlinearity and loss. In this report, additional NRS results are presented on the time dependence of nonlinearity and loss of resonant modes in AM aluminum with two types of symmetry: axial-shear modes with displacement gradients primarily normal to the build plane and modes with primarily radial displacements. The magnitude of the nonlinearity and loss of both types of modes decreases with accumulated excitation time. The detailed form of the dependence of nonlinearity on amplitude during resonant ringdown also changes with accumulated excitation time. At the beginning of measurements, the resonant frequencies decrease monotonically with increasing vibrational amplitude. However, after several thousand seconds of iterative alternating excitation of the two modes, the slope of the resonant frequency of the radial mode vs. signal amplitude is found to reverse in sign at the highest amplitudes. These effects are considered within the Preisach-Mayergoyz formalism for hysteretic mesoscopic elements as potentially arising from acoustically induced reductions in contact of surfaces within LOF defects.

## Medical Opportunities of Nonlinear Time Reversal Acoustics (NTRA)

**Alexander Sutin<sup>1</sup>**

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This paper discusses the specifics of nonlinear acoustic effects and time reversal acoustic (TRA) focusing in human tissues, which open new opportunities for medical diagnostics and treatment. TRA methods can provide precise energy focusing in highly heterogeneous media. Here, we consider possible medical applications where TRA focusing is combined with nonlinear acoustic effects:

1. Measurement of nonlinear acoustic properties in the focal field of a TRA system: This is the most straightforward application. We conducted tests using Nonlinear TRA for osteoporosis assessment, based on the concentration of acoustic energy from two signals with different frequencies in a small volume of bone. Tests were conducted with a human calcanei bone sample.
2. Nonlinear TRA focusing on Ultrasound Contrast Agents (UCA): This method allows for the precise treatment of target areas and enhanced drug and gene delivery. It is based on the reception of nonlinear scattering signals from UCAs, their frequency transformation, and the application of the transferred signals for TRA focusing.
3. Integration of photoacoustics with TRA: Utilizing light pulses to generate acoustic signals combined with TRA allows for high-precision focusing of intense ultrasound energy within breast cancer regions. In this dual-modality approach, the photoacoustic signal emitted by the tumor is detected by the TRA system; subsequently, the system generates a high-power, time-reversed acoustic pulse directed back to the precise coordinates of the lesion for targeted eradication.
4. New diagnostic methods based on the microwave modulation of ultrasound: In this method, modulated microwaves change tissue parameters, leading to the modulation of an ultrasound wave. This approach requires much less microwave intensity than is used in microwave thermoacoustic tomography and is expected to be applicable for breast cancer detection.

One of the objectives of this presentation is to identify and establish new collaborative partnerships with medical research organizations and clinical practitioners.

## Tuesday, June 2, 2026

8:00 a.m. – 8:30 a.m.	<i>Shuttle to the Texas A&amp;M University-Corpus Christi University Center. 6300 Ocean Dr Unit 5783, Corpus Christi, TX 78412 Meet at the hotel entrance.</i>	<i>Omni Hotel</i>
8:30 a.m. – 9:00 a.m.	<i>Breakfast</i>	<i>Swordfish</i>
9:00 a.m. – 9:10 a.m.	<b>Remarks from the Conference Committee</b>	<b>Bayview</b>
9:10 a.m. – 9:45 a.m.	<b>Influence of Interfacial Mechanics on Elastic Characterization of Encapsulated Granular Media Using Resonant Ultrasound Spectroscopy</b> Caleb Fryer, Graduate Student, Texas A&M University	<b>Bayview</b>
9:45 a.m. – 10:20 a.m.	<b>Nonlinear vibro-thermal damage imaging in thin plates by activation of defects using time-reversal elastic waves</b> Cedric Debusschere, Graduate Student, KU Leuven	<b>Bayview</b>
10:20 a.m. – 10:40 a.m.	<i>Break</i>	<i>Bayview</i>
10:40 a.m. – 11:15 a.m.	<b>Application of Continuous Full-Field Vibration Measurements in Nonlinear Resonant Ultrasound Spectroscopy for Characterization of Berea Sandstone</b> Joshua Bartlett, Graduate Student, Texas A&M University	<b>Bayview</b>
11:15 a.m. – 11:50 a.m.	<b>Contactless Ultrasonic Monitoring of Slow Dynamic Behavior</b> Sunav Raj Dahal, Graduate Student, University of Illinois Urbana-Champaign	<b>Bayview</b>
11:50 a.m. – 1:10 p.m.	<i>Lunch</i>	<i>Swordfish</i>
1:10 p.m. – 1:45 p.m.	<b>Amplitude-dependent resonance shifts in irradiated nickel</b> Grzegorz Zych, Graduate Student, AGH University of Kraków	<b>Bayview</b>
1:45 p.m. – 2:20 p.m.	<b>Considering operating deflection shapes in nonlinear resonant ultrasound spectroscopy</b> Sarah Johnson, Graduate Student, Texas A&M University	<b>Bayview</b>
2:20 p.m. – 2:55 p.m.	<b>Experimental demonstrations of the sand-plate-oscillator and 1-D wire rope vibration isolator exhibiting nonlinear and hysteresis effects</b> John Paulenich III, Graduate Student, University of Maryland	<b>Bayview</b>
2:55 p.m. – 3:15 p.m.	<i>Break</i>	<i>Bayview</i>
3:15 p.m. – 3:50 p.m.	<b>Investigation of Nonlinear Phenomena and Reproducibility of Weakly Bonded Structures</b> Luke Nester, Graduate Student, Texas A&M University	<b>Bayview</b>
3:50 p.m. – 4:25 p.m.	<b>When the field becomes the laboratory: seismic velocity changes of a shallow aquifer during controlled hydrological forcing</b> Han Bai, Graduate Student, Jilin University	<b>Bayview</b>
4:30 p.m. – 4:40 p.m.	<b>Student Awards</b>	<b>Bayview</b>
4:40 p.m. – 5:00 p.m.	<i>Shuttle to the Omni Hotel. 900 N Shoreline Blvd, Corpus Christi, TX 78401</i>	<i>Bayview</i>

# Influence of Interfacial Mechanics on Elastic Characterization of Encapsulated Granular Media Using Resonant Ultrasound Spectroscopy

**Caleb Fryer, Joshua Bartlett, Pablo Tarazaga<sup>1</sup>, Timothy J. Ulrich<sup>2</sup>, Richard Livings, Paul Geimer<sup>3</sup>**

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Nondestructive evaluation (NDE) methods for compressed granular compounds remain limited, despite their importance in applications such as agricultural feed, pharmaceutical tablets, and high energy (HE) pellets. Resonant ultrasound spectroscopy (RUS) has shown strong potential for characterizing the elastic properties of isolated granular solids, including pentaerythritol tetranitrate (PETN), but its extension to practical systems is complicated by nonlinearities introduced through multi-material coupling and interfacial contact conditions. This work investigates the feasibility of characterizing a PETN surrogate contained within an aluminum enclosure, referred to as a pellet-canister assembly (PCA), with the objective of understanding how dynamic coupling between the granular core and metallic boundary influences the inferred elastic tensor. To address these challenges, a finite element model is developed to simulate the coupled system, enabling systematic analysis of interface behavior, boundary conditions, and modal interactions. Simulated resonance spectra are then compared with experimental measurements to quantify deviations from traditional single-material RUS assumptions, with particular emphasis on identifying mode shapes and frequency shifts that are most sensitive to interfacial effects. The results highlight the limitations of conventional inversion approaches when applied to heterogeneous, confined systems and provide insight into how interfacial mechanics bias elastic property estimation. This study establishes a framework for extending RUS-based NDE methodologies to realistic multi-material configurations and supports the development of more robust characterization techniques for granular and HE materials in operational manufacturing environments.

Keywords: nondestructive evaluation, high energy, resonant ultrasound spectroscopy, pentaerythritol tetranitrate, multi-material coupling, elastic tensor

[LA-UR-26-24433]

Student Presentation Survey:



## **Nonlinear vibro-thermal damage imaging in thin plates by activation of defects using time-reversal elastic waves**

**Cedric Debusschere, Koen Van Den Abeele<sup>1</sup>, Mathias Kersemans, Yusheng Ma<sup>2</sup>**

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The ability to detect defects in materials is of great importance in industry. The presence of defects alters material properties, often compromising the structural performance of critical components. Ultrasonic detection techniques mainly rely on the fact that defects alter incoming sound waves, either through scattering and attenuation (linear) or through the activation of dynamical phenomena such as clapping and friction, giving rise to non-linear effects in the wave propagation. In the current work, we exploit the fact that defects act as localized non-linear sources within a material and couple this behavior to the transfer of acoustic energy into thermal energy in order to locate their position by means of full-field thermography.

The basic idea is to apply the principle of time-reversal to focus vibrational energy at a specific region in the material. In combination with filtering techniques (most notably the scaling subtraction method), it is possible to direct this energy directly on a defect without prior knowledge about its location. As a result, the defect will get strongly activated and converts part of the acoustic energy into heat (due to clapping and friction), acting as a localized thermal source. The heat signature produced by thermal diffusion from this internal heat source can then be recorded at the surface with an IR-camera, revealing the location of the defect. Each step in this procedure will be illustrated by 2D and 3D simulations for thin plates and guided waves.

Student Presentation Survey:



## **Application of Discrete Full-Field Vibration Measurements in Nonlinear Resonant Ultrasound Spectroscopy for Characterization of Berea Sandstone**

**Joshua Bartlett, Sarah Johnson, Pablo Tarazaga<sup>1</sup>, Timothy J. Ulrich<sup>2</sup>, Richard Livings<sup>3</sup>**

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Nonlinear characterization of geological materials is essential for environmental management, engineering safety, and energy exploration, where reliable prediction of dynamic material response is critical. The nonlinear elastic behavior of rocks provides insight into microstructural features such as crack networks, grain contacts, and damage evolution, supporting improved state assessment and more physically grounded constitutive modeling. Nonlinear resonant ultrasound spectroscopy (NRUS) is widely used to probe these effects; however, conventional implementations rely on global resonance frequency shifts and single-point measurements, not incorporating the spatial component of the strain. This assumption limits the ability to resolve heterogeneous nonlinear behavior arising from localized strain and mode-dependent responses. To address this limitation, a framework is introduced that integrates operational deflection shape (ODS) analysis with NRUS using scanning laser Doppler vibrometry (SLDV) for full-field vibration measurement. A cylindrical Berea sandstone sample is tested across a broad frequency range under progressively increasing high-amplitude harmonic excitation to drive nonlinear response, while SLDV is used to reconstruct ODS patterns and capture amplitude-dependent modal evolution. This full-field approach separates global resonance shifts from localized modal distortions, revealing spatially heterogeneous nonlinear effects not captured by pointwise NRUS measurements. The evolution of ODS with increasing drive levels is quantified, with emphasis on strain-induced mode distortion and redistribution of energy across the specimen. These observations distinguish uniform elastic stiffness fluctuations from localized microstructural contributions associated with crack networks and grain-scale interactions. By comparing global resonance metrics with spatially resolved modal indicators, the study highlights the limitations of spatially uniform strain assumptions in nonlinear characterization and demonstrates that ODS reconstruction enhances sensitivity to heterogeneous nonlinear dynamics in Berea sandstone, providing a more complete analysis for interpreting amplitude-dependent resonant behavior in geomaterials.

Keywords: nonlinear resonant ultrasound spectroscopy, operational deflection shape, scanning laser Doppler vibrometry, Berea sandstone

[LA-UR-26-24336]

[Student Presentation Survey:](#)



## Contactless Ultrasonic Monitoring of Slow Dynamic Behavior

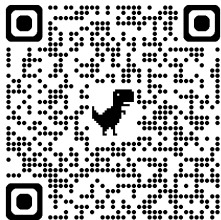
**Sunav Raj Dahal, John S. Popovics<sup>1</sup>**

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Non-classical, nonlinear dynamic behavior in solids containing microcracks manifests in two regimes: fast dynamics, the instantaneous strain-dependent modulus reduction, and slow dynamics, a logarithmic-in-time recovery of elastic modulus following a high-strain perturbation. While fast dynamics measurements require relatively complex experimental setups, slow dynamics evolves over longer time scales and can be easier to capture and measure. This work presents a preliminary feasibility study of a fully air-coupled ultrasonic method for measuring slow dynamic responses, enabling contactless and non-destructive characterization of damage. Ultrasonic surface waves are propagated in cracked and pristine glass prisms and cracked and crack-free regions of a concrete beam, recorded before and after mechanical conditioning was applied. Subtle changes in wave propagation velocity are assessed using stretching cross-correlation. In pristine glass, negligible slow dynamics recovery was observed ( $\sim 0.05\% \Delta V/V$ ) compared with that of cracked glass ( $\sim 0.3\% \Delta V/V$ ). Comparative measurements with contact-sensors showed considerable difference in recovery behavior, with the contact measurements showing larger recovery ( $\sim 0.8\% \Delta V/V$ ). In the concrete beam, crack-free regions showed negligible slow dynamics recovery ( $\sim 0.05\% \Delta V/V$ ), while cracked regions showed significant recovery ( $\sim 0.4\% \Delta V/V$ ). Agreement between contact and air-coupled measurements was good in concrete. The results show that slow dynamic behavior can be detected and quantified in a fully contactless manner using ultrasonic surface waves and further reveal interesting aspects of slow dynamics behavior in cracked solids.

[Student Presentation Survey:](#)



## Amplitude-dependent resonance shifts in irradiated nickel

**Grzegorz Zych, Łukasz Pieczonka<sup>1</sup>**

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Nonlinear resonance methods provide enhanced sensitivity to microstructural changes that may remain weakly expressed in conventional linear elastic measurements. In this work, nonlinear resonance ultrasound spectroscopy (NRUS) was used to assess the influence of irradiation on the amplitude-dependent resonance response of nickel. Resonance sweeps were performed over frequency ranges containing selected resonant modes at progressively increasing excitation levels, and the resulting resonance frequency shifts were quantified from fitted response curves. Experimental stability was verified through temperature monitoring and repeatability tests to separate material nonlinear response from thermal and instrumental contributions. Measurements revealed an amplitude-dependent resonance frequency shift, with increased shift magnitude observed in irradiated specimens. The observed separation between material states indicates that irradiation produces a measurable modification of the nonlinear resonance response. These results demonstrate that NRUS can resolve subtle irradiation-related changes in nickel and support its use as a nondestructive technique for nonlinear elastic characterization and damage assessment.

Student Presentation Survey:



## Considering operating deflection shapes in nonlinear resonant ultrasound spectroscopy

**Sarah Johnson, Pablo Tarazaga<sup>1</sup>, Timothy J. Ulrich<sup>2</sup>**

<sup>1</sup>J. Mike Walker '66 Department of Mechanical Engineering, Texas A&M University, College Station

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Geological materials have challenging dynamic response due to their complex micro and meso scale behavior. The nonlinear behavior is present at strain levels that are much smaller than in classically nonlinear systems. Changes in dynamic behavior have previously been quantified using nonlinear resonant ultrasound spectroscopy (NRUS) to obtain a bulk nonlinear parameter,  $\alpha$ , describing how the resonance frequencies shift with increasing excitation amplitudes. NRUS tests are usually performed by studying fundamental longitudinal mode at a single point. However, localized nonlinear effects can be observed when many points on the surface of the test specimen are measured. Using a 3D scanning laser doppler vibrometer, operating deflection shapes (ODS) are captured and different types of ODS are easily identified. The ODS are used to gain more information about the system dynamics and nonlinear behavior. Here, three studies on a Berea sandstone rod are presented that show examples of additional information provided by considering ODS in analysis. First, the different mode types are measured and show different nonlinear parameters depending on ODS type. This study shows that flexural resonance  $\alpha$  are unique from longitudinal and torsional resonance  $\alpha$ 's. Secondly, in a longitudinal NRUS study, ODS are measured and show differences that can be quantified as another metric for the nonlinearity in the system. Results indicate that the changes in ODS are due to localized increases in strain and attenuation at ODS nodes. Lastly, using the spatial component of strain that is captured by measuring many points on the test specimen, we determine that the changes in strain due to the ODS are large enough to measure  $\alpha$  with a single amplitude excitation. These results will enable single amplitude NRUS as a testing technique. These studies show the utility in considering ODS in NRUS testing.

[LA-UR-26-23744]

[Student Presentation Survey:](#)



## Experimental demonstrations of the sand-plate-oscillator and 1-D wire rope vibration isolator exhibiting nonlinear and hysteresis effects

**John Paulenich III<sup>1</sup>, Murray S. Korman<sup>2</sup>**

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Experiments using a soil-plate-oscillator (SPO) involve a vertical cylindrical column of granular medium (masonry sand or 6 mm diam glass beads) that is supported by an air-backed thin circular elastic acrylic plate (11.4 cm diam and 3.2 mm thick) that is rigidly clamped to the bottom of a thick-walled aluminum tube. The soil column is driven from below using an electrodynamic system. Here, an AC coil placed on axis and below the plate, drives a 1 cm diam 1.5 cm long rare earth magnet that is fastened to the underside center of the plate. The coil is electrically driven by a swept sinusoidal (constant current source) slowly varying chirp. An optical sensor located below the plate measures the displacement vibration. In nonlinear tuning curve experiments the resonant frequency decreases significantly with incrementally increased amplitude sweeps – representing a softening in the nonlinear system. For fixed amplitude experiments, the resonant frequency vs. the granular medium mass loading (over the plate) reaches a minimum and then increases with increased loading. This is due to the granular medium's flexural stiffness – which overcomes the mass loading effects. For water loading, the frequency always decreases since there is no bending stiffness. A theoretical bilinear force vs. displacement model (Iwan) describes the arched tuning curves for both sand and 6 mm diam glass bead loading. A small wire rope (vibration) isolator WRI experiment exhibits hysteresis effects that are comparable to SPO results. Here, an S-load cell wheatstone bridge strain gauge measures the force, while an optical sensor measures the displacement. Demonstrations of these oscillators will be presented.

[Student Presentation Survey:](#)



## Investigation of Nonlinear Phenomena and Reproducibility of Weakly Bonded Structures

**Luke Nester, Pablo Tarazaga<sup>1</sup>, Timothy J. Ulrich<sup>2</sup>**

<sup>1</sup>J. Mike Walker '66 Department of Mechanical Engineering, Texas A&M University, College Station

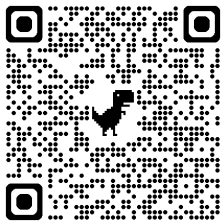
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Bonded specimens are widely used across engineering applications and often exhibit more complex behavior than monolithic materials. Interfaces between contacting surfaces, adhesive layers, and other bonds can introduce nonlinearity into the dynamic response, complicating efforts to model structural behavior. Due to their widespread use, there is significant value in characterizing bonded interfaces using nondestructive testing methods. This study investigates the nonlinear phenomena that arise from bonded interfaces. A pair of gauge blocks are weakly bonded through inherent surface interactions and act as specimen with a well-defined interface. Gauge blocks provide a controlled and repeatable test specimen, making them uniquely suitable for studying isolated interface behavior. A parametric study explores multiple bonding cases by varying the conditions under which the blocks are bonded, allowing for a systematic assessment of how interface conditions influence the dynamic response. Because single amplitude vibration testing cannot capture nonlinear behavior exercised through changes in excitation amplitude, Nonlinear Resonant Ultrasound Spectroscopy (NRUS) is employed for multi-amplitude dynamic testing. To quantify the effective mechanical properties of the bond, uniaxial tensile testing is conducted as a baseline for comparison. The results of this study aim to improve the understanding and testing of nonlinear behavior at bonded interfaces and support the development of more accurate and representative models.

[LA-UR-26-24180]

[Student Presentation Survey:](#)



## When the field becomes the laboratory: seismic velocity changes of a shallow aquifer during controlled hydrological forcing

Han Bai<sup>1</sup>, Richard Kramer<sup>2</sup>, Xuan Feng<sup>3</sup>, Clément Estève<sup>4</sup>, Yang Lu<sup>5</sup>, Götz Bokelmann<sup>6</sup>

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High-resolution monitoring of shallow aquifers in both time and space is becoming increasingly important as pressures from groundwater exploitation and the impacts of climate change intensify. Here, we use approximately 4 months of dense seismic-noise observations acquired during a pumping test in Nickelsdorf, Austria, to investigate the spatiotemporal response of relative seismic velocity changes ( $dv/v$ ) in a shallow aquifer under controlled pumping–recovery conditions, where  $dv/v$  serves as a field-scale indicator sensitive to stress-dependent nonlinear elasticity in the shallow subsurface. Unlike traditional  $dv/v$  monitoring based on coda-wave interferometry, this study reconstructs noise cross-correlation functions from long-term, stable train-generated noise and estimates  $dv/v$  within a ballistic-wave time window. The results show that  $dv/v$  stably tracks groundwater-level variations at high temporal resolution and varies approximately linearly with mean groundwater level during pumping–recovery cycles. One-dimensional along-array inversion further shows that pumping-related  $dv/v$  anomalies are temporally synchronized with the pumping process and are concentrated mainly between the two wells, weakening outward. Sliding-window tests further demonstrate that, in a strongly directional and highly repeatable noise environment, ballistic-wave  $dv/v$  provides a more stable characterization of local shallow hydrological perturbations than later time windows located away from the main ballistic-wave energy, highlighting its potential for monitoring subsurface perturbations in strongly directional noise fields.

Student Presentation Survey:



### Wednesday, June 3, 2026

8:00 a.m. – 8:30 a.m.	<i>Shuttle to the Texas A&amp;M University-Corpus Christi University Center. 6300 Ocean Dr Unit 5783, Corpus Christi, TX 78412 Meet at the hotel entrance.</i>	Omni Hotel
8:30 a.m. – 9:00 a.m.	<i>Breakfast</i>	Swordfish
9:00 a.m. – 9:40 a.m.	<b>Introduction to the non-classical nonlinear acoustics</b> <b>How do the impact magnitude and duration affect the recovery process in rock?</b> <b>Lev Ostrovsky</b> , Professor, University of Colorado-Boulder and University of North Carolina-Chapel Hill	Bayview
9:40 a.m. – 10:20 a.m.	<b>Investigation of white-noise-based nonlinear resonant ultrasound spectroscopy for non-destructive evaluation</b> <b>Paul Geimer</b> , Scientist, Los Alamos National Laboratory	Bayview
10:20 a.m. – 10:40 a.m.	<i>Break</i>	Bayview
10:40 a.m. – 11:20 a.m.	<b>Fast Nonlinear Resonant Ultrasound Spectroscopy (NRUS) based on fixed-phase Resonance Tracking</b> <b>Marco Scalerandi</b> , Professor, Polytechnic University of Turin	Bayview
11:20 a.m. – 12:00 p.m.	<b>Parametric Study of Slow Dynamic Nonlinear Elasticity: Experiments and comparison with models</b> <b>John Yoritomo</b> , Research Physicist, U.S. Naval Research Laboratory	Bayview
12:00 p.m. – 1:15 p.m.	<i>Lunch</i>	Swordfish
1:15 p.m. – 1:45 p.m.	<i>Shuttle to the Omni Hotel. 900 N Shoreline Blvd, Corpus Christi, TX 78401</i>	Bayview
1:45 p.m. – 2:00 p.m.	<i>Break</i>	Hotel
2:00 p.m. – 2:30 p.m.	<i>Shuttle to the Texas State Aquarium 2710 N Shoreline Blvd, Corpus Christi, TX 78402</i>	El Camino
2:30 p.m. – 5:00 p.m.	<b>Texas State Aquarium Visit</b>	Aquarium
5:00 p.m. – 7:00 p.m.	<i>Dinner at the Texas State Aquarium</i>	Citgo Skyline Room
7:00 p.m. – 7:30 p.m.	<i>Shuttle to the Omni Hotel. 900 N Shoreline Blvd, Corpus Christi, TX 78401</i>	Aquarium

**1. Introduction to the non-classical nonlinear acoustics**  
**2. How do the impact magnitude and duration affect the recovery process in rock?**

**Lev Ostrovsky<sup>1</sup>**

<sup>1</sup>University of Colorado, Boulder, University of North Carolina, Chapel Hill

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This presentation addresses several issues that remain unresolved after the development of the thermodynamic model for the long-time recovery in structured materials, which has been successfully applied to describe the long-time relaxation of acoustic waves in rock. Rock and non-consolidated soils exhibit three distinctive properties: anomalously strong elastic nonlinearity, hysteresis in stress-strain relations, and long-time relaxation (slow dynamics). These characteristics stem from detachment and attachment of grain contacts under stress. In hysteretic materials, nonlinear waves behave fundamentally differently—in resonators, the nonlinear frequency shift is proportional to strain amplitude  $A$ , and the third harmonic to  $A^2$ , which is impossible for any analytical stress-strain relationship. After impact, property restoration can take hours in laboratory experiments and years following earthquakes, typically following logarithmic time dependence. Crucially, recovery time is almost independent of impact level in each experiment. This behavior derives from the thermodynamic Arrhenius model with a shallow second potential minimum in grain contacts. These issues refer to the impact (excitation) effects, which remained practically unconsidered before. Here, we briefly analyze the prolonged excitation, including the oscillating one, and its effect on the subsequent relaxation. Then, using the exponential statistics, we consider the dependence of the wave velocity variation on the initial strain, in the laboratory and after an earthquake. The results are compared with the available experimental data.

## Investigation of White-Noise-Based Nonlinear Resonant Ultrasound Spectroscopy for Non-Destructive Evaluation

**Paul Geimer<sup>1</sup>, Timothy J. Ulrich<sup>2</sup>**

<sup>1</sup>Los Alamos National Laboratory, Los Alamos, NM, US

<sup>2</sup>Los Alamos National Laboratory and Texas A&M University

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Nonlinear resonant ultrasound spectroscopy (NRUS) offers a non-destructive evaluation approach that measures strain-dependent hysteretic behavior, providing enhanced damage sensitivity compared to traditional linear resonance methods. Previous research has demonstrated that NRUS responses vary depending on both the spatial distribution of material defects and the chosen excitation approach. Traditional NRUS protocols rely on frequency-swept sinusoidal signals, which has predominantly confined the technique to controlled laboratory settings. In this work, we investigate NRUS characterization using white-noise excitation signals, selected for their resemblance to the stochastic, wideband forces encountered in field monitoring conditions. Test specimens representing diverse nonlinear behaviors (acrylic, sandstone, fractured steel) were excited using bonded piezoelectric transducers at progressively higher amplitudes, with laser doppler vibrometry capturing the nonlinear response. When benchmarked against traditional NRUS measurements, our approach yields consistent patterns in the nonlinear parameter, demonstrating analogous magnitude relationships between specimens and stable elastic behavior for equivalent vibrational modes. Quantifying strain during white-noise excitation presents challenges due to concurrent activation of multiple resonances, though recent experimental work has started to separate these overlapping contributions. These results suggest white-noise-driven NRUS may be suitable for field-based applications while providing additional insight into nonlinear elastic mechanisms.

[LA-UR-26-23729]

## **Fast Nonlinear Resonant Ultrasound Spectroscopy (NRUS) based on fixed-phase Resonance Tracking**

**Marco Scalerandi<sup>1</sup>, Jan Kober, Radovan Zeman<sup>2</sup>**

<sup>1</sup> DISAT, Politecnico di Torino, Turin, Italy

<sup>2</sup> Institute of Thermomechanics, Czech Academy of Sciences, Prague, Czech Republic

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Conventional Nonlinear Resonant Ultrasound Spectroscopy (NRUS) relies on repeated frequency sweeps at increasing drive amplitudes to extract amplitude-dependent resonance frequency and damping. However, as a consequence of slow dynamics, the material parameters do not remain constant during the acquisition time and thus their measurement is inherently sensitive to the measurement protocol. Furthermore, sweeping through frequencies, even with the same strain amplitude, means different materials are tested because the different strain profiles produce different distributions of modulus and damping variations along the tested sample. In other words, in repeated ultrasonic experiments, samples in different (and not stable) elastic states are probed, thus making the observations a mixture of several (poorly controlled) contributions. Experimental advantages are expected when the temporal resolution is increased by reduction of the acquisition time and when the material is tested using the same mode throughout the full experiment.

To this purpose, we introduce here a resonance tracking methodology for nonlinear ultrasonic experiments that enables continuous identification of the resonance frequency without the need for full frequency sweeps. The method is founded on phase-based resonance detection combined with a discrete-time update scheme and a simple predictive model. This approach allows measurements to be performed significantly faster while maintaining the system in resonance throughout the experiment (keeping constant phase). The proposed approach is validated and some applications are discussed, in particular for what concerns NRUS, conditioning and relaxation monitoring.

## **Parametric Study of Slow Dynamic Nonlinear Elasticity: Experiments and comparison with models**

**John Yoritomo<sup>1</sup>, Richard Weaver<sup>2</sup>**

<sup>1</sup> Physical Acoustics Branch, United States Naval Research Laboratory, 4555 Overlook Ave SW, WA, DC 20375, US

<sup>2</sup> The Grainger College of Engineering, Urbana, US

Contact: [john.y.yoritomo.civ@us.navy.mil](mailto:john.y.yoritomo.civ@us.navy.mil)

The predictions of several phenomenological models that aspire to quantitative description of anomalous nonlinear mesoscopic elasticity, in particular slow dynamics, are compared with laboratory measurements. A companion presentation [1] reviewed these models and presented approximate closed form and numerical solutions to them. Predictions for the quantitative influence of three key pump parameters—the pump's strain amplitude, the pump's strain rate, and the pump's duration—were highlighted in the companion piece and will be recapitulated in this presentation. Here we present laboratory measurements on Berea sandstone, concrete and a confined single aluminum bead and find that slow dynamic responses are linear in pump strain and independent of pump frequency. Measurements also show that, after pump-off, stiffness recovers over times far longer than the pump duration. One of the considered models, based on a picture of fast brittle damage and slow healing, successfully matches all these behaviors.

[1] Parametric Study of Slow Dynamic Nonlinear Elasticity: Phenomenological models and their predictions

## Thursday, June 4, 2026

8:00 a.m. – 8:30 a.m.	<i>Shuttle to the Texas A&amp;M University-Corpus Christi University Center. 6300 Ocean Dr Unit 5783, Corpus Christi, TX 78412 Meet at the hotel entrance.</i>	Omni Hotel
8:30 a.m. – 9:00 a.m.	<i>Breakfast</i>	Swordfish
9:00 a.m. – 9:40 a.m.	<b>Acoustic excitation to infer flexural characteristics of paired thin films</b> <b>Nakul Deshpande</b> , Post-Doc, Los Alamos National Laboratory	<b>Bayview</b>
9:40 a.m. – 10:20 a.m.	<b>Nonlinear and Time Reversal acoustics in nonlethal weapons</b> <b>Alexander Sutin</b> , Adjunct Research Professor, Stevens Institute of Technology	<b>Bayview</b>
10:20 a.m. – 10:35 a.m.	<i>Break</i>	Bayview
10:35 a.m. – 11:15 a.m.	<b>Dynamics of structures under complex frequency excitations</b> <b>Raj Kumar Pal</b> , Assistant Professor, Texas A&M University	<b>Bayview</b>
11:15 a.m. – 11:55 a.m.	<b>Toward a Microstructure-Dependent Interpretation of Nonlinear Resonant Ultrasound Spectroscopy</b> <b>Jean-Briac le Graverend</b> , Associate Professor, Texas A&M University	<b>Bayview</b>
11:55 a.m. – 1:05 p.m.	<i>Lunch</i>	Swordfish
1:05 p.m. – 1:45 p.m.	<b>Nonlinear Compressibility Measurement of Cells and Particles in Acoustophoretic, Microfluidic Channels</b> <b>Yong-Joe Kim</b> , Associate Professor, Texas A&M University	<b>Bayview</b>
1:45 p.m. – 2:25 p.m.	<b>Adapting Nonlinear Elastic Measurements to Earth Studies</b> <b>Andrew Delorey</b> , Research Geophysicist, Los Alamos National Laboratory	<b>Bayview</b>
2:25 p.m. – 2:40 p.m.	<i>Break</i>	Bayview
2:40 p.m. – 3:20 p.m.	<b>Cavitation of nonlinear solids</b> <b>Justin Wilkerson</b> , Associate Professor, Texas A&M University	<b>Bayview</b>
3:20 p.m. – 3:40 p.m.	<b>Laboratory For Advanced Energy, Biological Fluids, &amp; Imaging (LAEBI)</b> <b>Dr. Jian Sheng</b> , Professor of Engineering, Texas A&M University-Corpus Christi	<b>Bayview</b>
3:40 p.m. – 3:45 p.m.	<i>Walk to the Laboratory for Advanced Energy, Biological Fluids, &amp; Imaging (LAEBI)</i>	
3:45 p.m. – 4:40 p.m.	<b>Laboratory for Advanced Energy, Biological Fluids, &amp; Imaging (LAEBI) Tour</b> <b>Jian Sheng</b> , Professor of Engineering, Texas A&M University-Corpus Christi	<b>LAEBI</b>
4:40 p.m. – 5:00 p.m.	<i>Shuttle to the Omni Hotel. 900 N Shoreline Blvd, Corpus Christi, TX 78401</i>	Bayview

## **Acoustic excitation to infer flexural characteristics of paired thin films**

**Nakul Deshpande<sup>1</sup>, K.X. Eng<sup>2</sup>, K.C. Bennett, D.T. Beckman, A. Graff, E.C. Bryant<sup>3</sup>**

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<sup>2</sup>Princeton University, Princeton, NJ 08544

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Vibrometry-based inverse methods for mechanical characterization of multi-body systems are not readily transferable to thin polymer films because film response is sensitive to spatial variability in thickness, density, viscoelasticity, imposed in-plane stress, and anisotropy. We combine experiments and numerical modeling to estimate an effective (isotropized) flexural rigidity for paired thin films by inverting resonant-frequency data over a range of applied tensile loads. The influence of tensile loading on out-of-plane vibration is described using a hybrid variational formulation for transverse displacement, coupled to classical plate-buckling concepts. The resulting forward model is solved in the frequency domain using finite-element analysis and is validated by comparison with laser Doppler vibrometry measurements. Using a small calibration subset of the measured resonances, the approach predicts the remaining resonant frequencies across the tested load range, enabling inference of effective flexural properties from the observed device response.

## Nonlinear and Time Reversal acoustics in nonlethal weapons

**Alexander Sutin<sup>1</sup>**

<sup>1</sup>Stevens Institute of Technology, 1 Castle Point Terrace, Hoboken, NJ 07030

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Nonlethal weapons are designed to achieve military or law enforcement objectives by incapacitating personnel or materiel while minimizing fatalities and permanent injury. Unlike traditional kinetic or chemical agents, directed energy solutions—specifically acoustic systems—offer a scalable response ranging from verbal warnings to physiological disruption.

The most recognized commercial acoustic system is the LRAD (Long Range Acoustic Device). International developments include the Russian Shepot (Whisper) and Inferno systems, alongside recent advancements in Chinese handheld sonic weaponry. These systems leverage the self-demodulation of ultrasound in air (the "parametric array" effect) to generate highly directional sound beams. However, the efficiency of parametric arrays remains a significant technical limitation due to the primary wave nonlinear saturation.

Speculative applications of these technologies have been cited regarding Havana Syndrome (Anomalous Health Incidents) and the reported use of "discombobulator" technology during the 2026 capture of the Venezuelan president. Another considered explanation for these phenomena is other nonlinear effect - the microwave auditory effect or Frey effect. This involves sound generated directly inside the head when a subject is exposed to modulated microwave radiation.

Acoustic nonlethal action is significantly more effective in water than in air, allowing for intensive wave application in diver deterrence. While conventional interdiction relies on ecologically disruptive air guns, Time Reversal Acoustics (TRA) offers a precision alternative. TRA enables acoustic localization and targeted sound focusing on a hostile diver with minimal impact on the marine environment. In this configuration, the acoustic noise radiated by the diver allows them to act as an active, self-disclosing acoustic beacon, enabling the system to focus energy back onto the source with surgical accuracy.

## Dynamics of structures under complex frequency excitations

**Raj Kumar Pal, Wenbo Li, Pablo Tarazaga, Skriptyan Syurhi<sup>1</sup>**

<sup>1</sup>J. Mike Walker '66 Department of Mechanical Engineering, Texas A&M University, College Station

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We investigate the dynamics of mechanical resonators driven by excitations that include an oscillating or harmonic component with an amplitude that decays exponentially over time. We refer to these as complex-frequency excitations, and we show that the resulting response is quasi-steady; i.e., after an appropriate transform, the response of the new variable corresponds to the steady-state behavior under a harmonic excitation. A procedure is presented to determine the amplitude-frequency response and effective quality factor based on this steady-state behavior. Optimal excitations are identified for both single- and multi-degree-of-freedom systems that result in the amplitude-frequency response approaching that of an undamped system. The feasibility of the proposed method is verified through numerical simulations. Experiments with cantilever beams made of acrylic show a 249-fold increase in the effective quality factor. Next, we investigate the accuracy of natural frequency estimation in mechanical systems under noise using such excitations. We employ tools from information theory, namely Fisher information, to systematically quantify the sensitivity of complex-frequency excitation to noise. The theoretical predictions are verified through Monte-Carlo numerical simulations. Our results indicate that optimal parameter selection can significantly enhance Fisher information, leading to improved estimation accuracy under complex-frequency excitations compared to conventional harmonic excitations. Experimental results demonstrate the advantages of complex-frequency excitation in terms of accuracy and robustness for natural-frequency estimation. These findings establish a foundation for the development of high-performance sensors and novel nondestructive evaluation methods.

## Toward a Microstructure-Dependent Interpretation of Nonlinear Resonant Ultrasound Spectroscopy

**Jean-Briac le Graverend<sup>1</sup>**

<sup>1</sup>Department of Aerospace Engineering, Texas A&M University, College Station

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Nonlinear Resonant Ultrasound Spectroscopy (NRUS) is among the most sensitive probes of sub-critical material state currently available, yet its physical interpretation remains fundamentally limited: the nonlinear parameters it produces are scalar quantities extracted at the specimen scale that are sensitive to microstructure but do not resolve it. The obstacle is structural. Classical approaches connect microstructure to nonlinear elastic response at the RVE scale — but the resonant frequency is not a local quantity. It is determined by the global stiffness distribution integrated over the entire measurement volume, and any model that does not treat it as such will misattribute the sources of nonlinearity.

The FE<sup>2</sup> framework is the natural resolution. At the macroscale, the full specimen is solved as a structural dynamic problem. At each macroscopic Gauss point, the constitutive response is computed from a crystal plasticity boundary value problem on a microstructurally informed RVE, with homogenized stress and consistent tangent stiffness passed upward at every increment. Sub-yield inelastic mechanisms at the grain scale propagate directly into the macroscopic resonant response, and conditioning and recovery behavior emerge as natural consequences of the crystal plasticity kinetics rather than separately postulated phenomena. The result is a forward map from microstructural state to NRUS observables that is physics-grounded and microstructure-dependent by construction — and that admits, for the first time, a well-posed inversion from measured NRUS signatures to quantitative microstructural state.

## **Nonlinear Compressibility Measurement of Cells and Particles in Acoustophoretic, Microfluidic Channels**

**Yong Joe Kim<sup>1</sup>, Han Wang<sup>2</sup>, Zhongzheng Liu<sup>3</sup>, Arum Han<sup>4</sup>**

<sup>1</sup>J. Mike Walker '66 Department of Mechanical Engineering, Texas A&M University, College Station

<sup>2</sup>Department of Earth System Science, Tsinghua University, Beijing, China

<sup>3</sup>TDK InvenSense, San Jose, California

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Compressibility of particles and cells is an interesting physical property that can be utilized in label-free separation; in particular, compressibility-dependent cell separation modalities have gained significant interest since red blood cells (RBCs) and cancer cells are observed to have different compressibility compared to benign cells. Specifically, it has been known that a cancer cell with the higher metastatic potential has the higher compressibility. However, systems capable of continuous and simultaneous label-free separation of particles and cells based on their sizes and compressibility at high throughput have been rarely investigated. Acoustophoresis-based microfluidic separation utilizes intrinsic differences in vibro-acoustic properties of target samples under nonlinear acoustic excitations, and can be achieved using simple microfluidic systems without need for cumbersome sample preparation steps. Thus, this approach has gained significant interest as the most viable label-free separation method in terms of its strong force generation, high throughput, high specificity, and low capital and operation cost. However, the design of state-of-the-art acoustophoretic microfluidic systems has been mainly derived from a simplistic analytical acoustic model in a "static" fluid medium with uniform temperature distribution. Therefore, it is difficult to consider the real-world effects of "moving" fluid media, viscous boundary layers, and locally elevated temperature that significantly influence the motion of particles and cells. In this presentation, a numerical modeling method is introduced to address these deficiencies, significantly improving the predictability and specificity of the acoustophoretic separation. As an application of the numerical method, a camera with a microscope was used to record the trajectories of cancer cell motions under nonlinear acoustic excitation in a microfluidic channel. Then, the experimental trajectories were curve fitted to the predicted ones to identify the compressibility of the cells. The cells with the highest metastatic potential showed the highest compressibility, which is consistent with previously reported clinical observations.

## Adapting Nonlinear Elastic Measurements to Earth Studies

**Andrew Delorey, Christopher Johnson<sup>1</sup>**

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In Earth Science, virtually all experiments studying nonlinear behavior of rocks have been performed at the laboratory scale. Except for a few specialized cases, field scale studies have been largely out of reach due to an inability to replicate or adapt experimental protocols performed in the laboratory. Field scale problems that we would like to address include quantifying evolving material properties in tectonically active regions, and quantifying fracture density and permeability in reservoir applications. As in laboratory studies, we would like to be able to capture elastic response to an applied strain. We can measure small changes in elasticity in the Earth using ambient noise and differential empirical Green functions, but only by averaging over long periods of time (months to years). This is sufficient for measuring slowly changing properties, but not for measuring changes that occur over hours to days. The primary challenge is that changes in the ambient wavefield are typically bigger than changes in the elasticity of the rocks making it difficult to measure the latter. Most natural strain perturbations occur over hours to days, so long term averages cannot capture nonlinear behavior at these time scales. Signal processing in ambient noise studies have not significantly improved since its widespread usage began over 20 years ago. The fundamental problem is that when we cross-correlate two sensor time series, we make ambiguous the effect of artifacts in the raw wave field on the apparent elasticity of the medium. We are working on a machine-learning based method to augment cross-correlations with information about the raw wavefield to remove this ambiguity and separate the effects of the wave field and the elasticity of the medium. This involves simulating a realistic representation of the Earth's ambient wave field including source spectra, source locations, and scattering properties.

## Cavitation of nonlinear solids

**Justin Wilkerson, Alexandria Rogers, Jacob Rogers<sup>1</sup>**

<sup>1</sup>J. Mike Walker '66 Department of Mechanical Engineering, Texas A&M University, College Station

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In many applications (e.g. contact sports, vehicular accidents, blunt force trauma, traumatic brain injury, drug delivery, surgeries), biological tissues and other soft matter are subject to complex, multi-axial stress states that can induce a variety of material deformation and failure modes. Cavitation is a particular soft matter failure mode that is insufficiently understood and poorly characterized. To the best of the authors' knowledge, cavitation has only been investigated in initially stress-free samples. The lack of data for soft matter behavior under multi-axial stress states prevents the development and validation of generalized cavitation theories. This study introduces a superimposed shear cavitation (SSC) apparatus that enables an examination of the role torsional shear stress plays in cavity nucleation, expansion, and collapse in soft matter. Our proposed SSC test expands on the well-established needle-induced cavitation (NIC) experiment by housing the gel in a Taylor–Couette cell instead of a conventional beaker. This modification enables the application of azimuthal shear stresses to the gel sample prior to the insertion and pressurization of the syringe needle. To demonstrate its capability, our SSC apparatus was used to measure the critical pressure of tri-block copolymer (PMMA-PnBA-PMMA) gel samples pre-loaded with various degrees of torsion. In a limited set of experiments, cavitation pressure was found to generally increase with increasing amount of applied pre-shear stress, in qualitative agreement with a generalized cavitation theory first introduced by Lopez-Pamies and co-workers, thereby providing some degree of evidence that the SSC apparatus is functioning as intended. Motion tracker particles embedded in the top surface of the gel provide additional evidence that the SSC apparatus generates the intended azimuthal pre-deformation field.

## **Overview of Laboratory For Advanced Energy, Biological Fluids, & Imaging (LAEBI)**

### **Jian Sheng<sup>1</sup>**

<sup>1</sup> Professor of Engineering, Texas A&M University-Corpus Christi

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This presentation will provide an overview of research activities within the Laboratory for Advanced Engineering and Biological Interfaces (LAEBI), with an emphasis on the role of nonlinear mechanical behavior in functional materials, biological systems, and complex interfaces. Current research spans adaptive and sensor-enabled materials, soft polymer-metal composites, photocatalytic nanoparticles, bio-inspired surfaces, and the characterization of live biomaterials under dynamic loading conditions. Applications include microscale sensing and actuation, interfacial transport phenomena, microbial interactions, turbulence-interface coupling, and sustainable energy systems