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Title: Applied Acoustics from sensing to particle manipulation

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Intended for: Collaboration exploration with TAMU

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Applied Acoustics from sensing to particle manipulation

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Texas A&M University
College Station, TX
21 Apr 2022

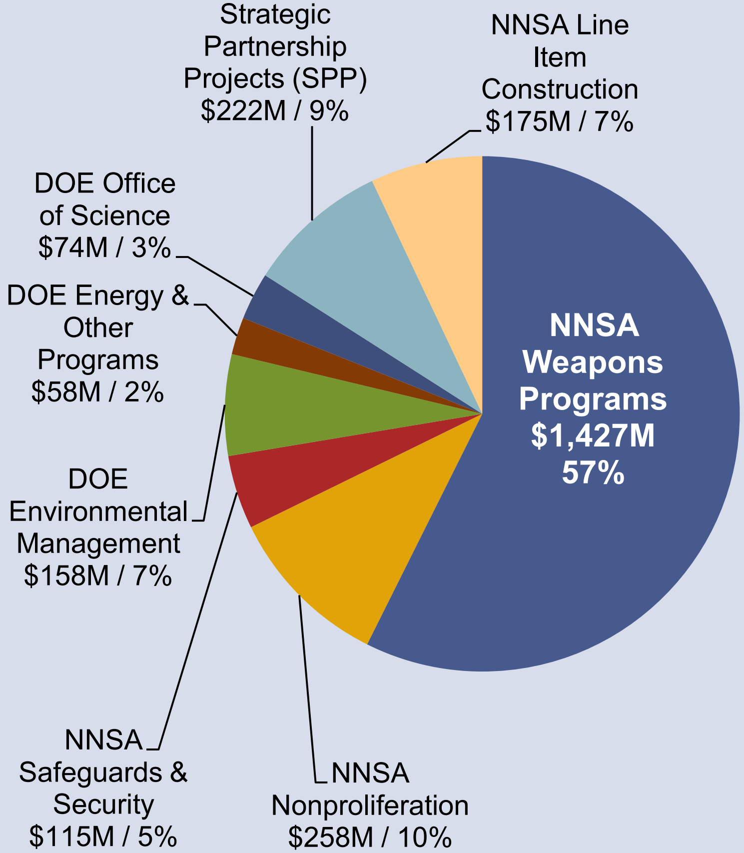
LA-UR-22-XXXXX

Los Alamos National Laboratory

- 36 square miles
- 47 technical areas
- 1,280 buildings / 9M sq ft
  - 11 nuclear facilities
  - 40% are more than 40 years old
- 268 miles of roads (100 paved)

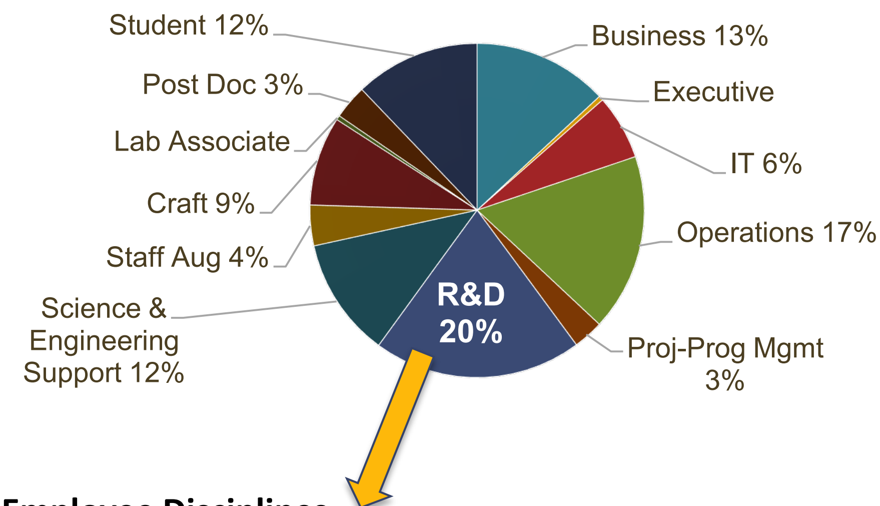
As a National Security Laboratory, applying multidisciplinary capability is inherent in our broad funding and workforce base

FY17 Estimated Budget Authority: $2.49B

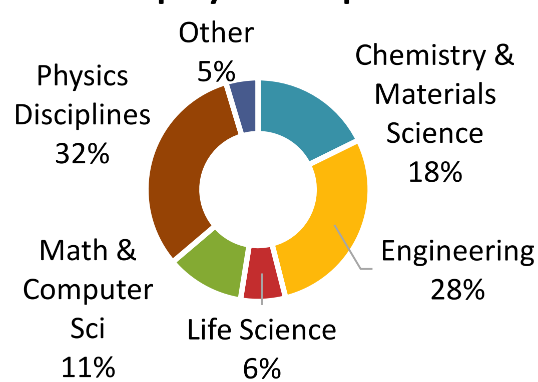


Approx. 11,000 National Security specialists collaborate in a wide variety of technical disciplines

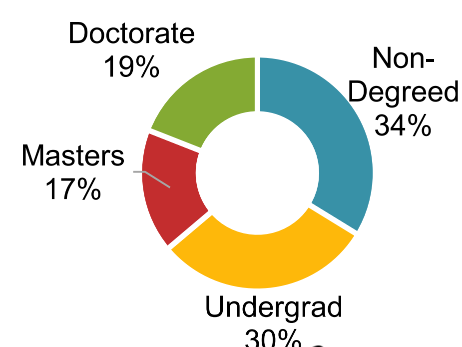
Employee Categories



R&D Employee Disciplines



Degreed Workforce



Applied Acoustics Team

http://www.lanl.gov/orgs/mpa/mpa11/AcousticsAndSensorsTeam

Cristian Pantea

Team Leader

Vamshi Chillara

Research Scientist
Electric Imp Spectr
Chevron)
Well Integrity Monitoring
CO_2 sequestration (DOE)
μarchitected Waveguides (LDRD-ECR)

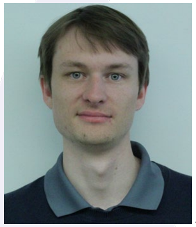
John Greenhall

Research Scientist
Machine Learning
3DHEAT
Defects Thermoel Wafers
NDE weapons components
Electronics design

Craig Chavez

Research Technologist
Mechanical and Electronics Design, and System Configuration

Eric Davis



Postdoc
Well Integrity Monitoring
CO_2 sequestration (DOE)
D_2O content in heavy water
3DHEAT
Acoustic Monitoring of Pu
NDE of weapons components

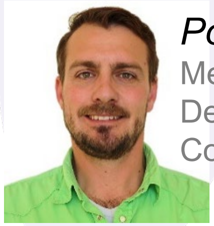
Milo Prisbrey

Postdoc
Machine Learning
Acoustic manipulation
Waveform inversion
**Joint w/ CCS-7*

Dipen Sinha

Visiting Scientist
Defects Thermoel Wafers
Welding inspection
NDE of weapons components
Electronics design

Pavel Vakhlamov



Post-Master
Mechanical and Electronics Design, and System Configuration

Alan Graham

Research Associate
Defects detection in wafers
Welding inspection
NDE of weapons components

Sincheng Huang

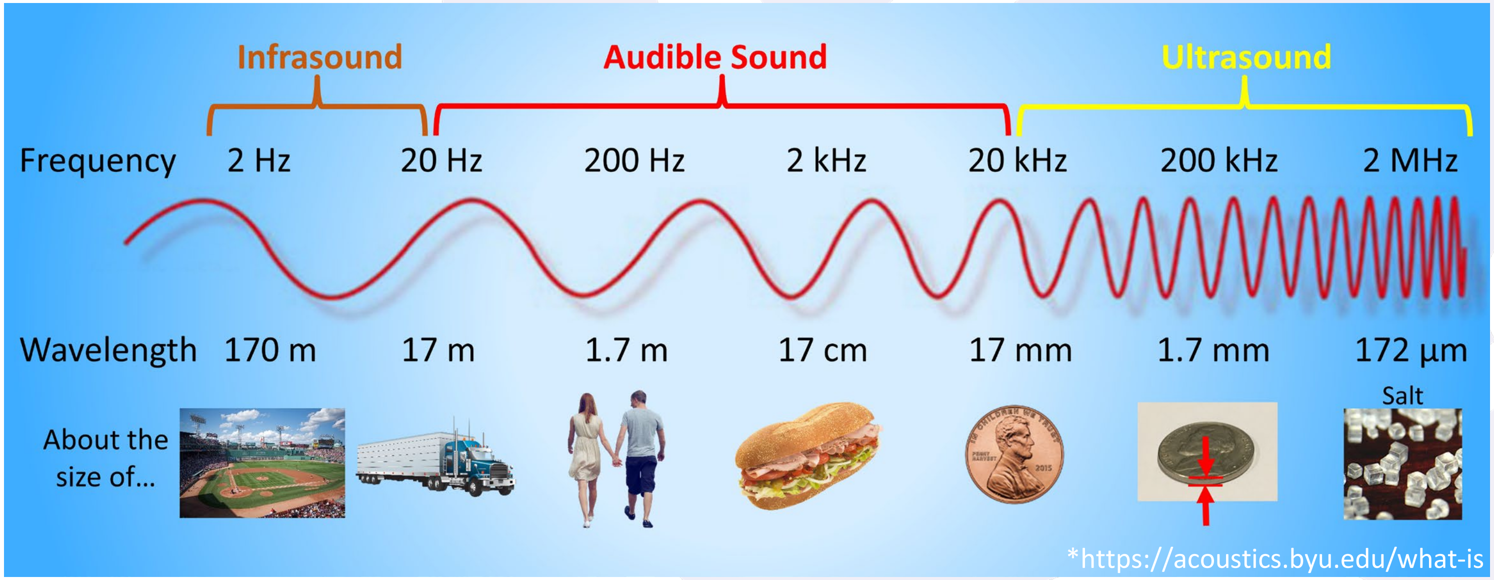
Grad Student
Instrumentation development
LabView programming
D_2O content in heavy water

- DOE NNSA Laboratory Residency Graduate Fellowship LRGF
  - **Jazmin Ley** U Nebraska-Lincoln
- DOE NNSA **MSIPP** (Minority Serving Institutions Partnership Program)
  - 4 students FIU, NMSU, UTEP
- 3 High-school students

Acoustics

Acoustics = the branch of physics concerned with the properties of sound (Wikipedia)

Acoustics = the science that deals with the production, control, transmission, reception, and effects of sound (Merriam-Webster)



Acoustics

Audio range: ***20 Hz – 20 kHz***

Musical notes:
e.g. guitar

Note	E	A	D	G	B	E
Frequency (Hz)	82	110	147	196	247	330

Voice - speech: 85 - 155 Hz (male) 165 - 255 Hz (female) 250 - 300 Hz (child)

Piano: 27 Hz – 4.2 KHz

Voice – singers: 65 Hz (deep bass voice) 1.3 kHz (soprano)
* female high-pitched scream: 3 kHz

Whistling: 2-4 kHz

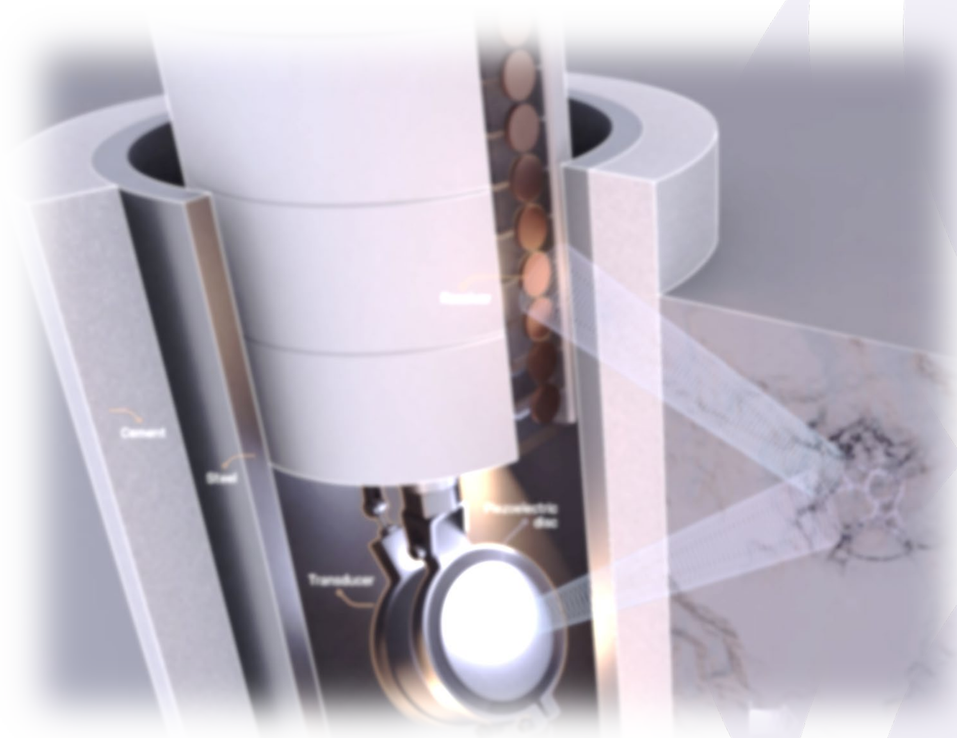
A good sound system: 35 Hz – 22 kHz

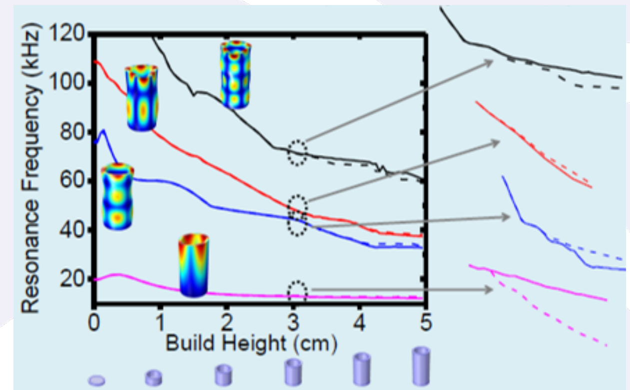
My hearing range: ***30 Hz – 15 kHz***

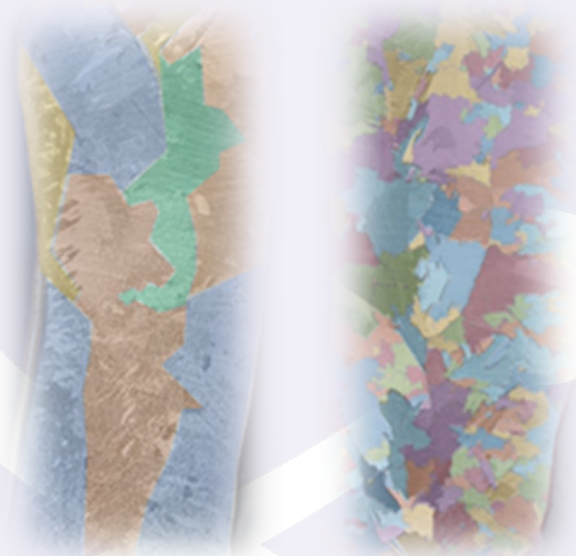
Our research - Applied Acoustics

Building and Sustaining Capabilities

Development of instrumentation, methods and sensors with a focus on difficult and challenging conditions (high pressure, high temperature, corrosive media, radiation, etc.)



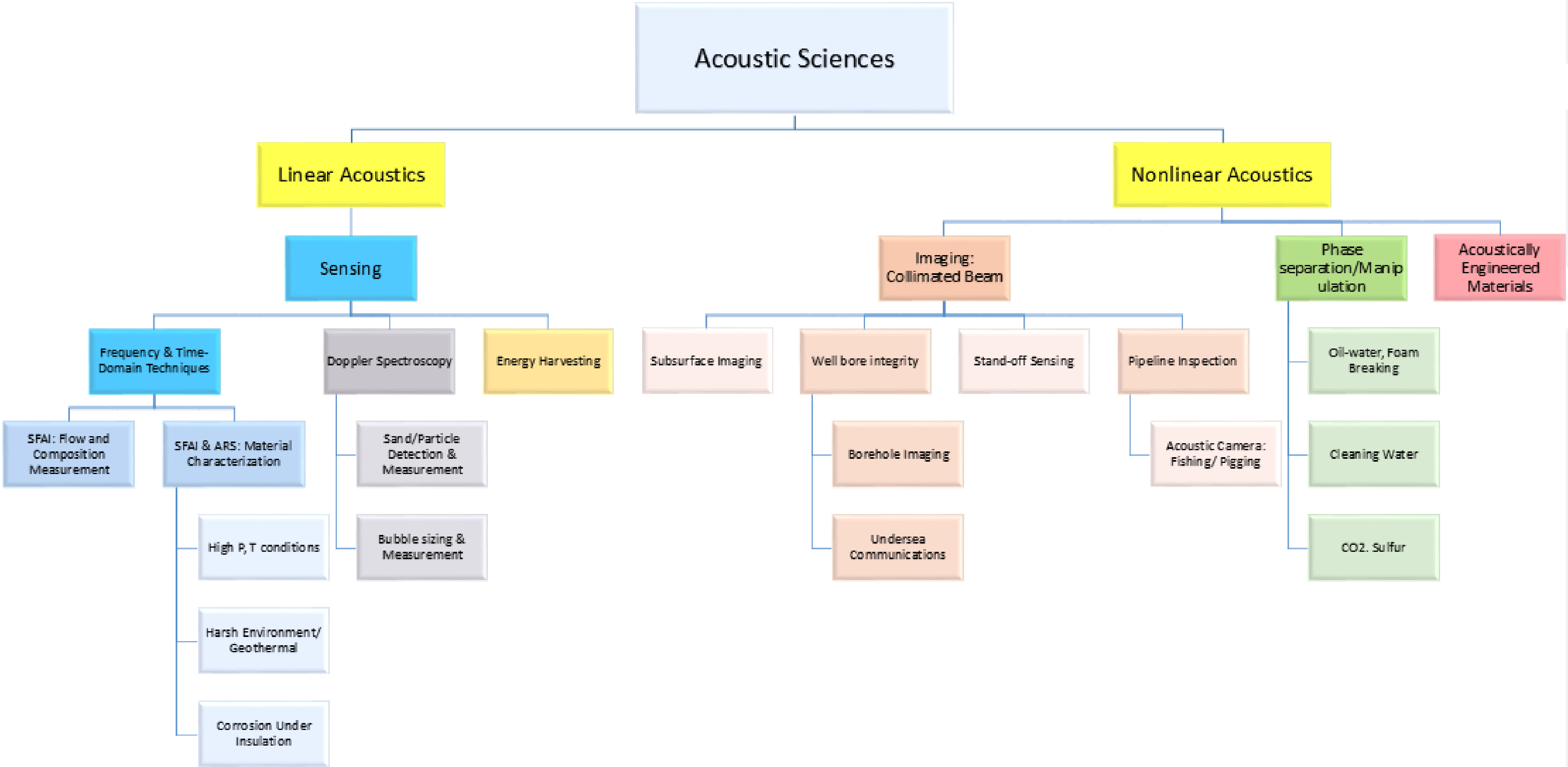




Sensing

Manipulation with sound

Applied Acoustics Lab Capabilities

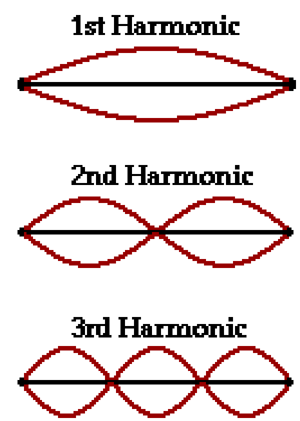


Standing Waves and Resonances in a Fluid medium inside a cavity:

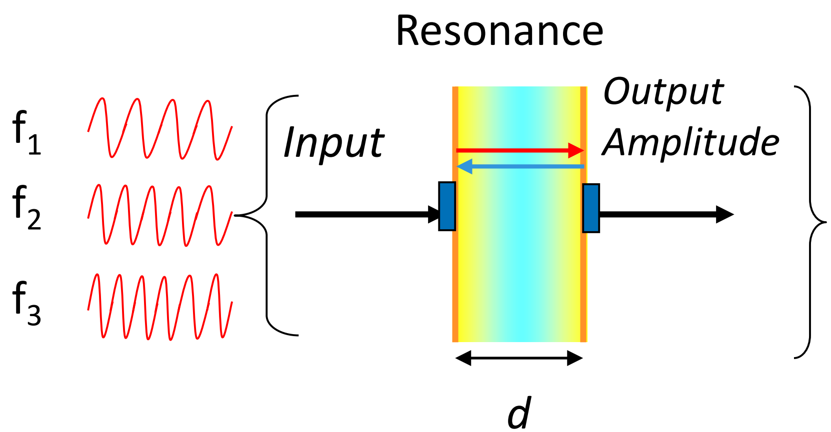
Resonance occurs when:

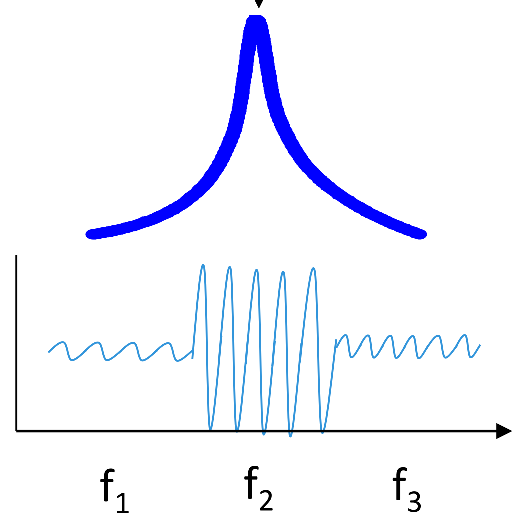
$d = n.(\lambda/2)$

n=1, 2, 3…
λ=wavelength



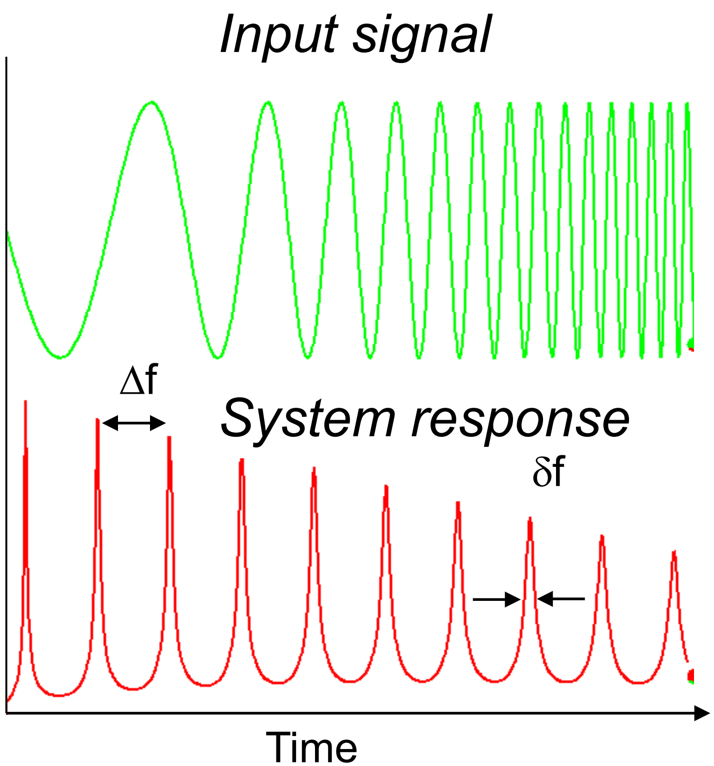
Examples of standing wave when resonance occurs





Resonance occurs when the forward sound wave and the reflected wave meet exactly in phase and interfere

How can fluid properties be determined using swept frequency and acoustic interferences?



Sound speed = $2d\Delta f$

Sound absorption $\sim \delta f$

Δf =frequency spacing

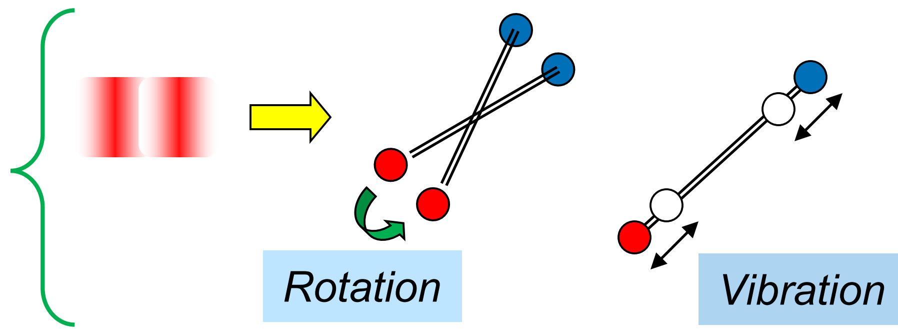
δf =peak width

There can be hundreds of such resonance peaks in a typical spectrum

Swept Frequency Acoustic Interferometry (SFAI)

Physical Parameters That Can Be Determined Using SFAI:

- **Sound speed** — $\sqrt{\text{Bulk Modulus}/\text{Density}}$
- **Sound attenuation** — Viscous drag, thermal effects, scattering
- **Molecular Relaxation**

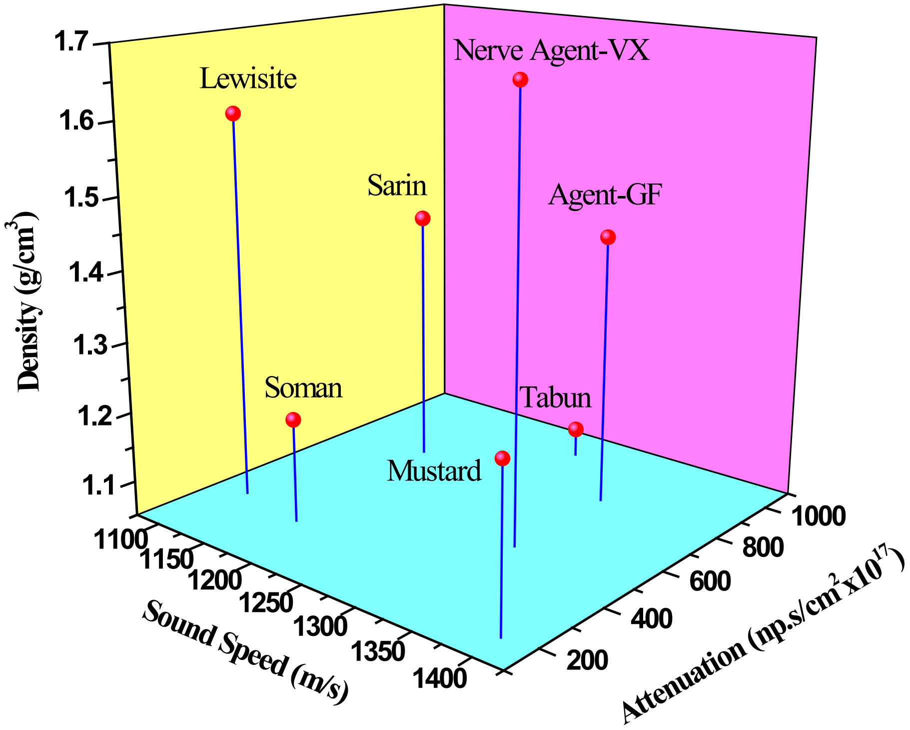


- **Density**
- **Viscosity**
- **Acoustic Nonlinearity** — Sound speed varies with pressure in liquids and solids.

Liquids, gases, mixtures, emulsions, suspension, etc.

Noninvasive Identification of CW Agents

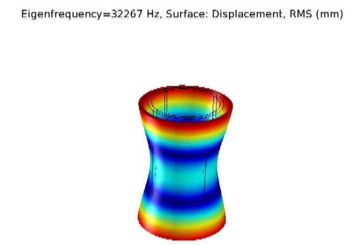
SFAI Measurements of CW Agent Physical Properties

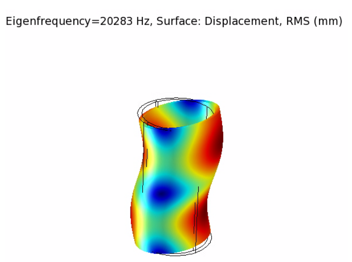


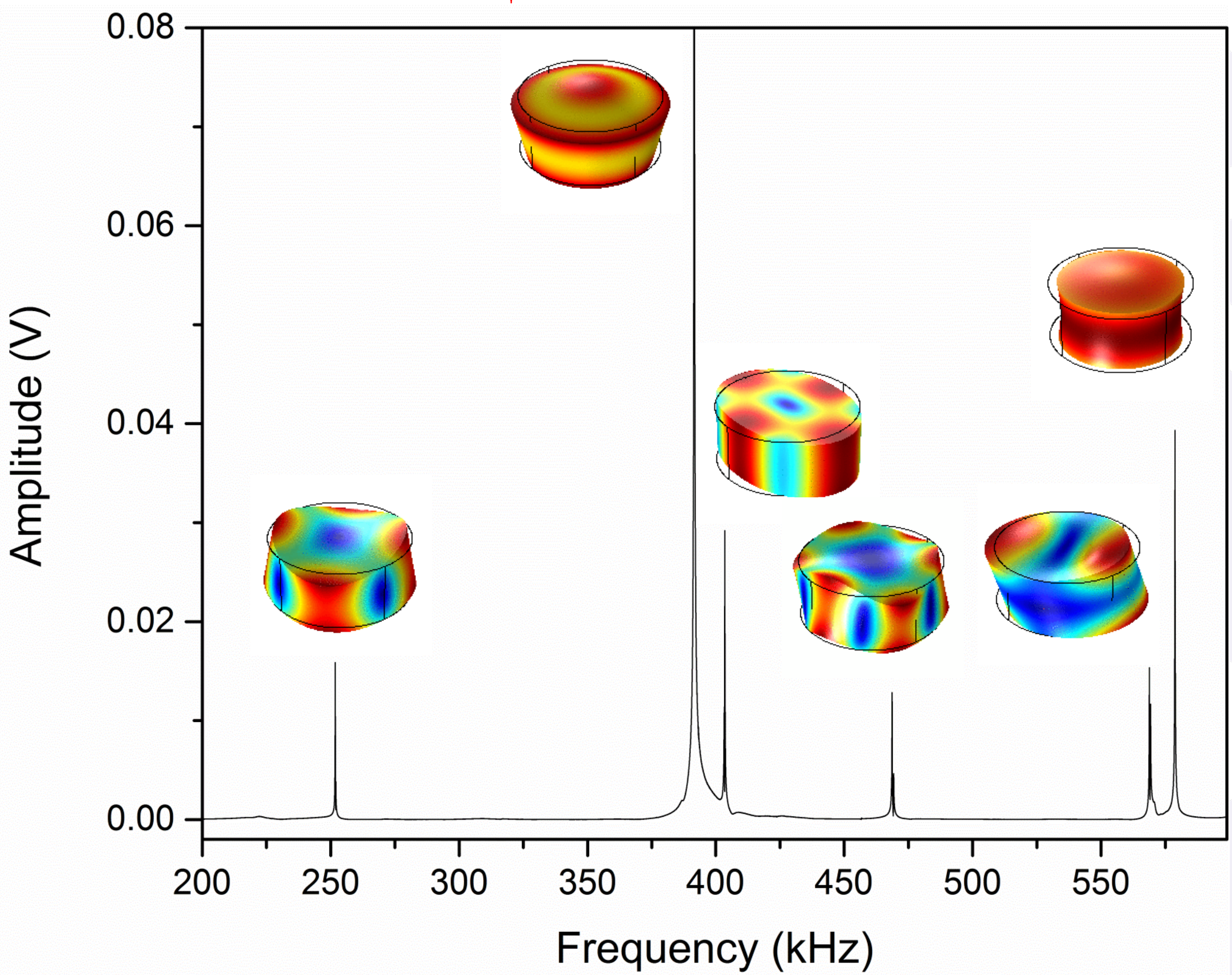
Elastic properties determination

Observe mechanical resonances of objects to determine physical properties of fluids and elastic properties of materials

Fluid inside pipe

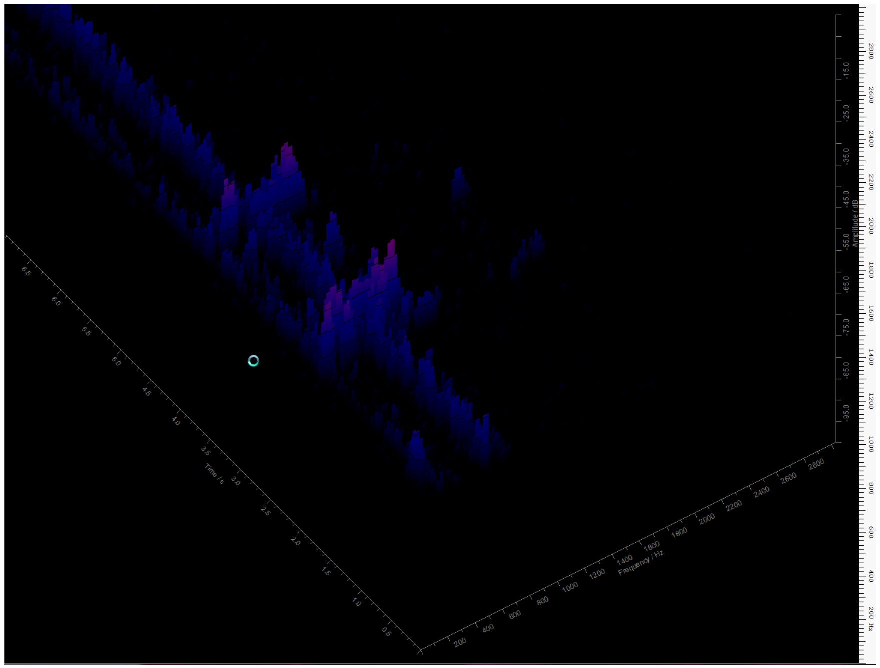






Particulate matter detection

Detect and quantify particulate matter, liquid droplets, and gas bubbles in flowing media through Doppler Spectroscopy



20-50 micron sand particles moving through mineral oil in a vertical metal pipe

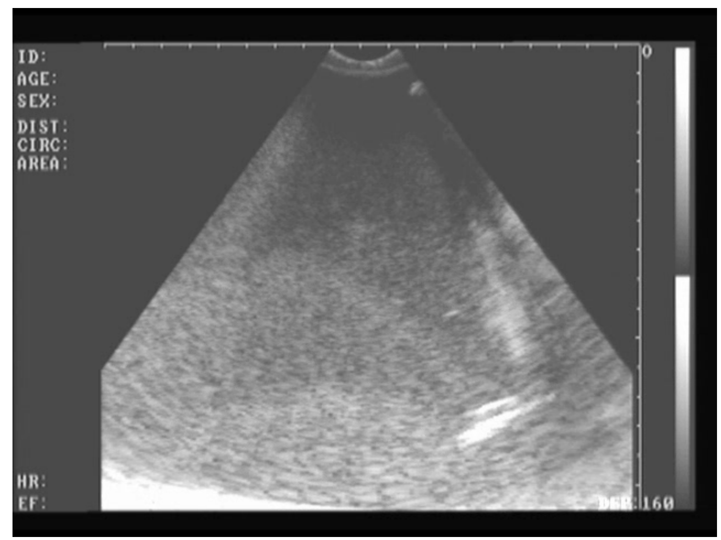
Doppler Spectroscopy

The spectrum contains information about particle size and concentration

Detection Sensitivity: ~ 5 grains of sand

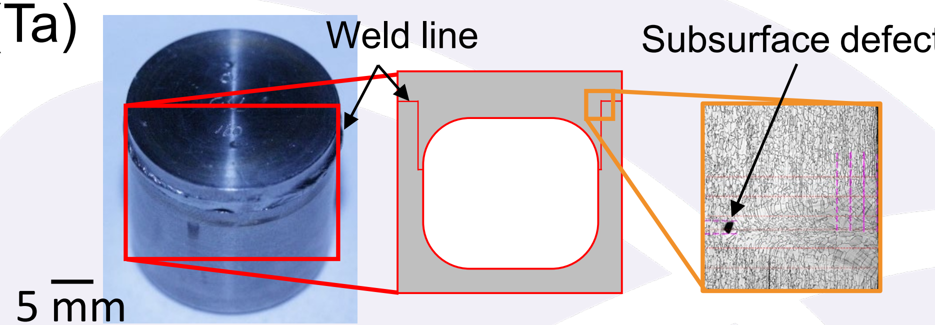
Size range: 1 – 100 micron

Ultrasonic Visualization of sand in water

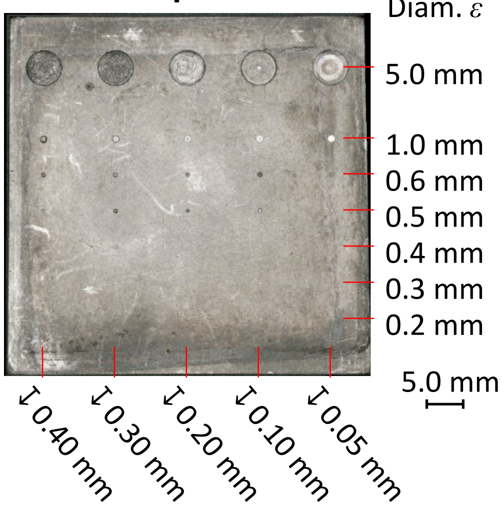


Acoustic weld defect detection

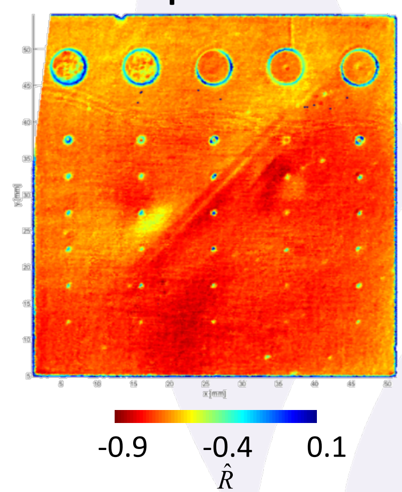
- Weld detection in dense materials (Ta) challenging for radiography
- Solution: scanning acoustic microscopy



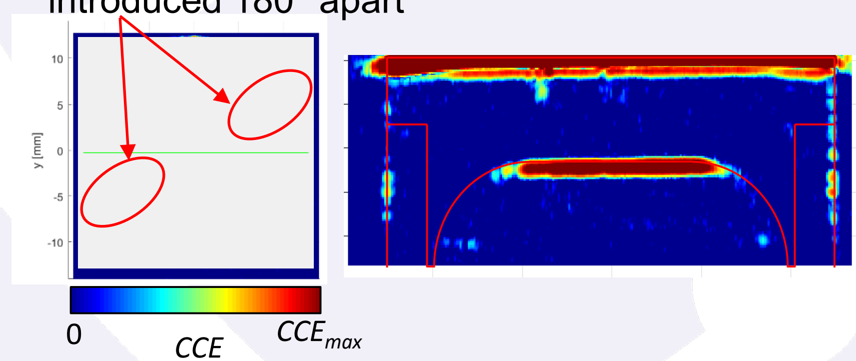
Optical microscopy of Ta plate



Acoustic microscopy of Ta plate



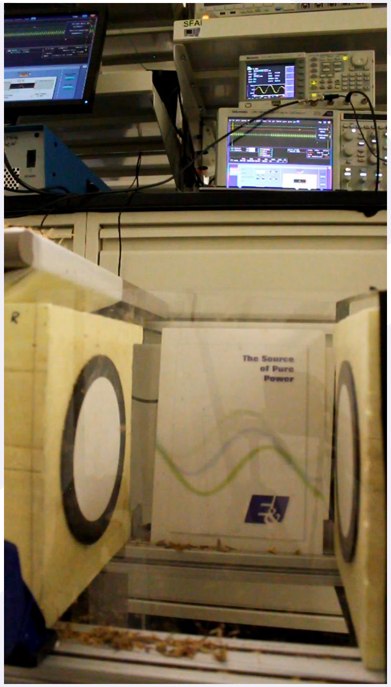
Inclusions intentionally introduced 180° apart

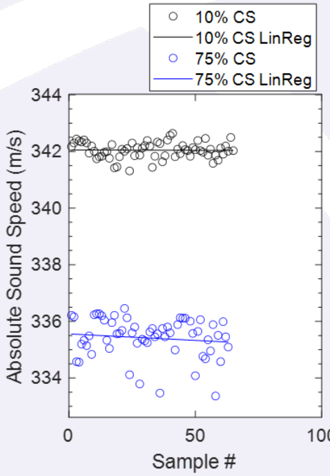


"Smart" Transfer Chutes with In-line Acoustic Sensors for Bulk-Solids Handling Solutions

- **Objective**: Develop innovative solids handling equipment (1) and unique in-line acoustic measurement sensors (2, 3) that improve operational reliability, safety, throughput, and yield of biorefineries.
- **Current limitations**
  - moisture sensing: cost, durability, complexity, reliability, sampling volume, and continuous monitoring.
  - no known commercial sensors for real-time monitoring of plug-screw feeder wear
  - no commercial chutes with the ability to change configuration to discard problematic feedstock.

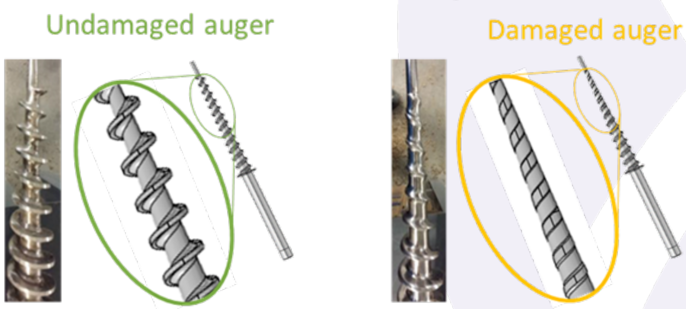
Moisture Sensor (corn stover)



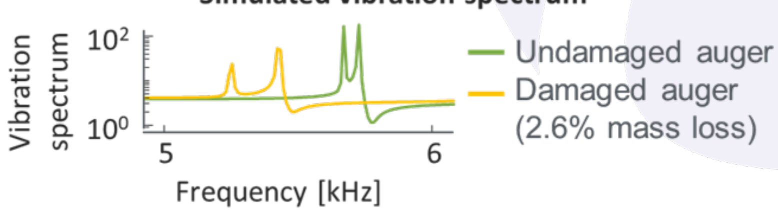


Wear Sensor

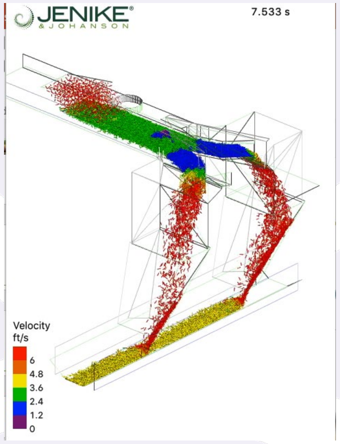
Real and simulated augers



Simulated vibration spectrum



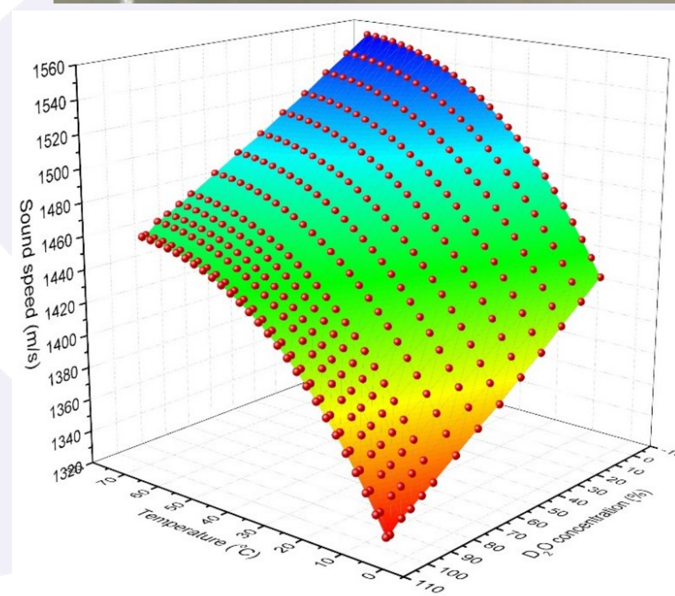
"Smart" Chute



Heavy Water Production Monitoring

A New Challenge for the IAEA

JCPOA-130 metric ton limit



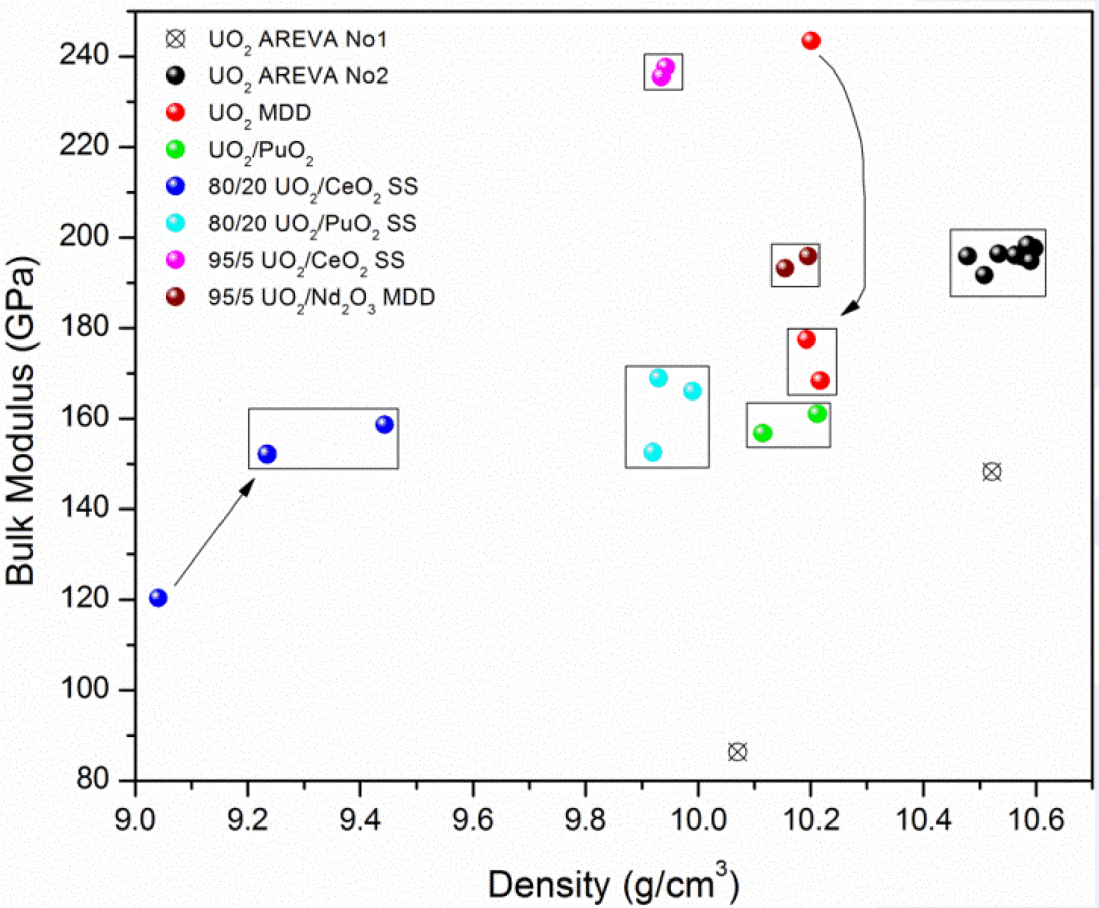
Arak Heavy Water Production Facility
Girdler sulfide process + distillation

We can measure accurate and precise sound speed, to the first decimal point

→ high precision/accuracy for D_2O concentration, ~ 0.1%

Nuclear materials identification

- **RUS - a nondestructive, very difficult to spoof, well-tested measurement method.**



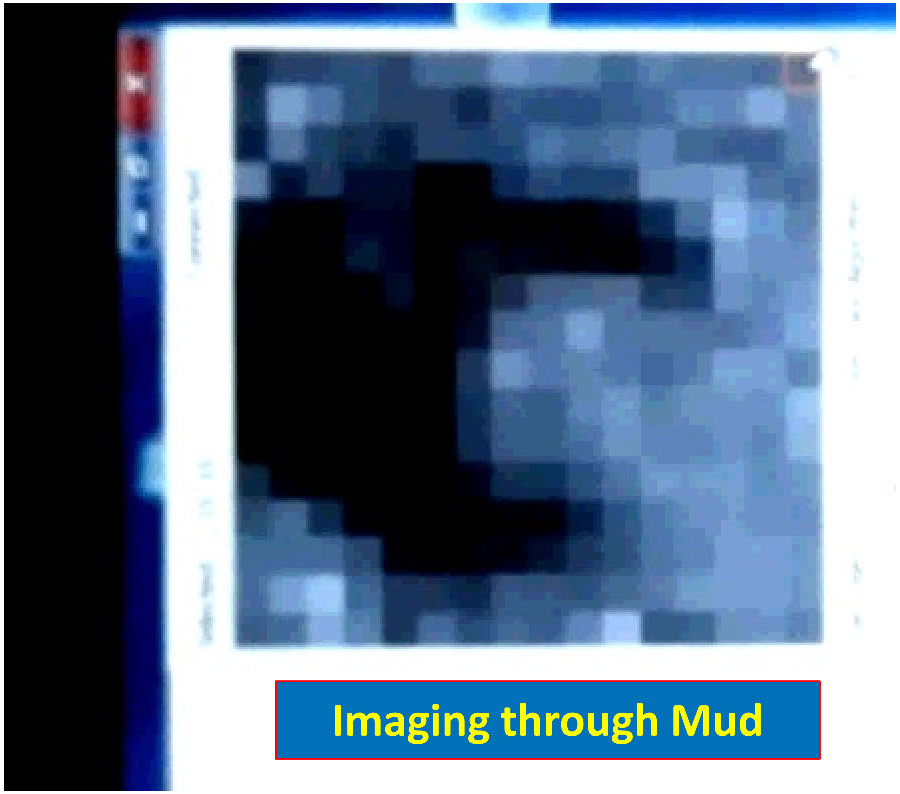
Good correlation between the elastic moduli and density for samples of different compositions/origins.

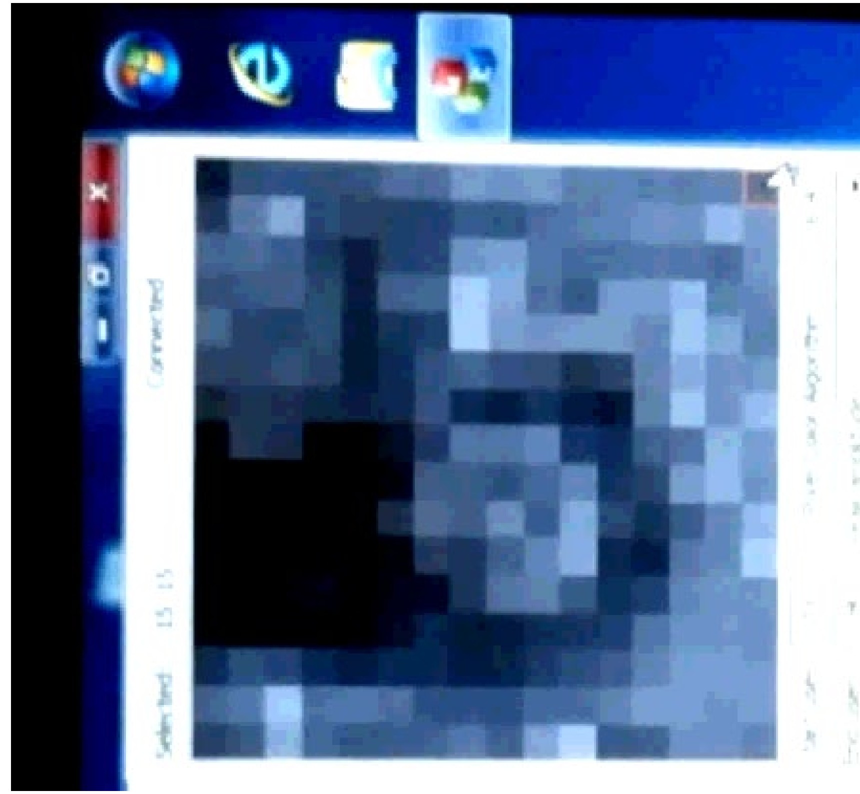
Able to identify nuclear material composition, fabrication method and source by measuring its RUS properties.

Acoustic Camera

Acoustic Camera: Seeing with Sound

Imaging through Highly Attenuating and Opaque Fluids





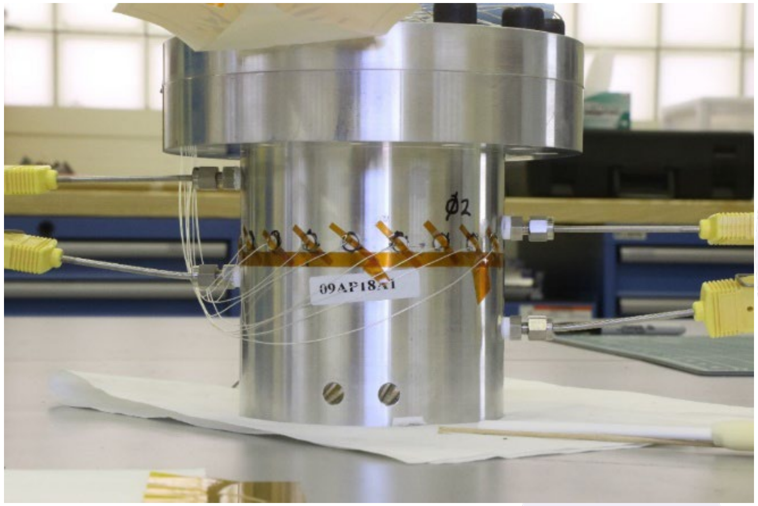
Current:

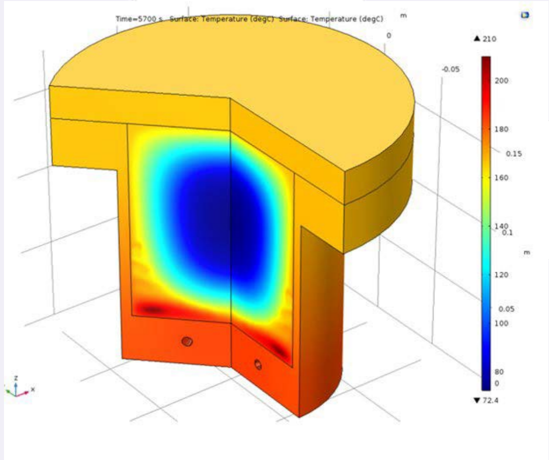
16 x 16 pixels

64 x 64; 128 x128 Pixels possible

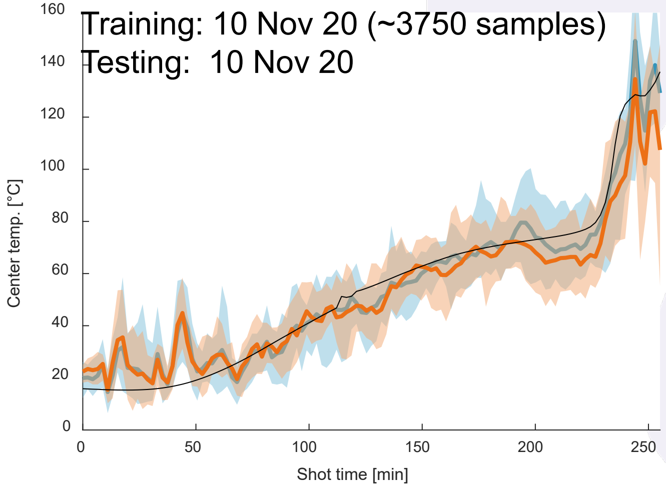
3DHEAT (3 dimensional high explosive acoustic temperature)

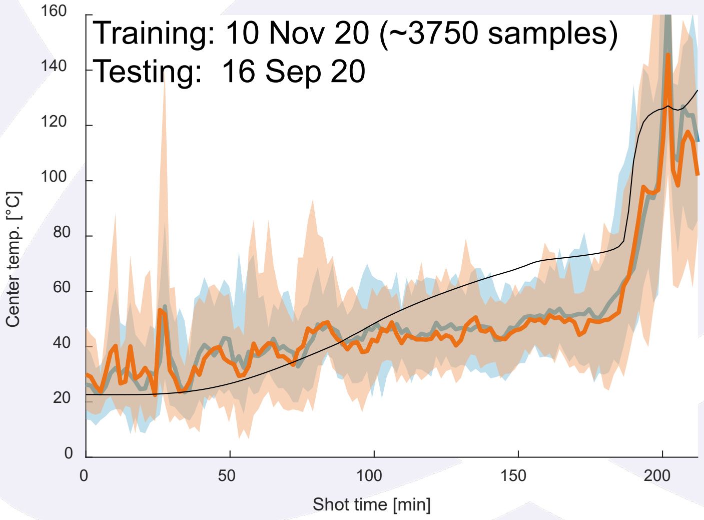
Acoustics diagnosis of thermal damage in Pentolite





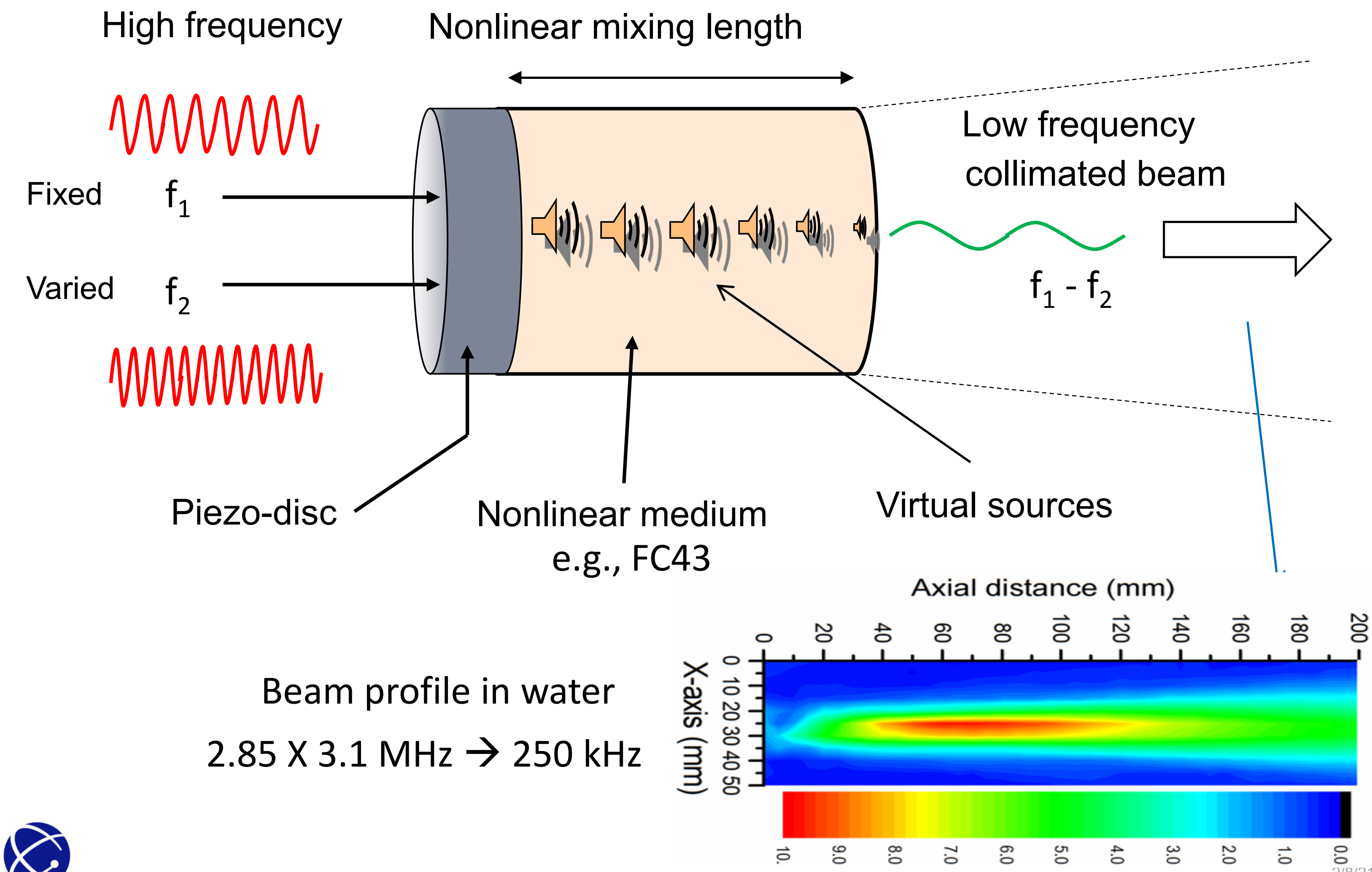
Machine learning, CNN (convolutional neural network)





Low Frequency Collimated Acoustic Beam

Mix sound waves in nonlinear media to create new form of sound waves that are very broad-band, lower frequency, and highly collimated



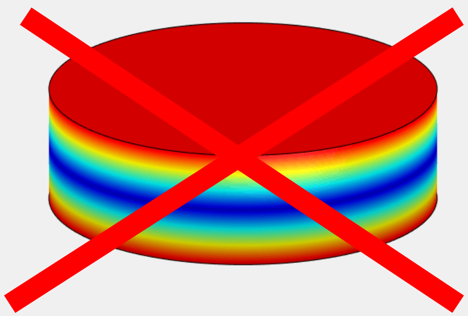
Beam profile in water

2.85 X 3.1 MHz → 250 kHz

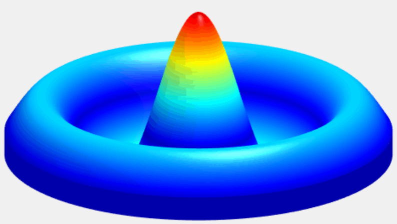
Low-Frequency Collimated Beam

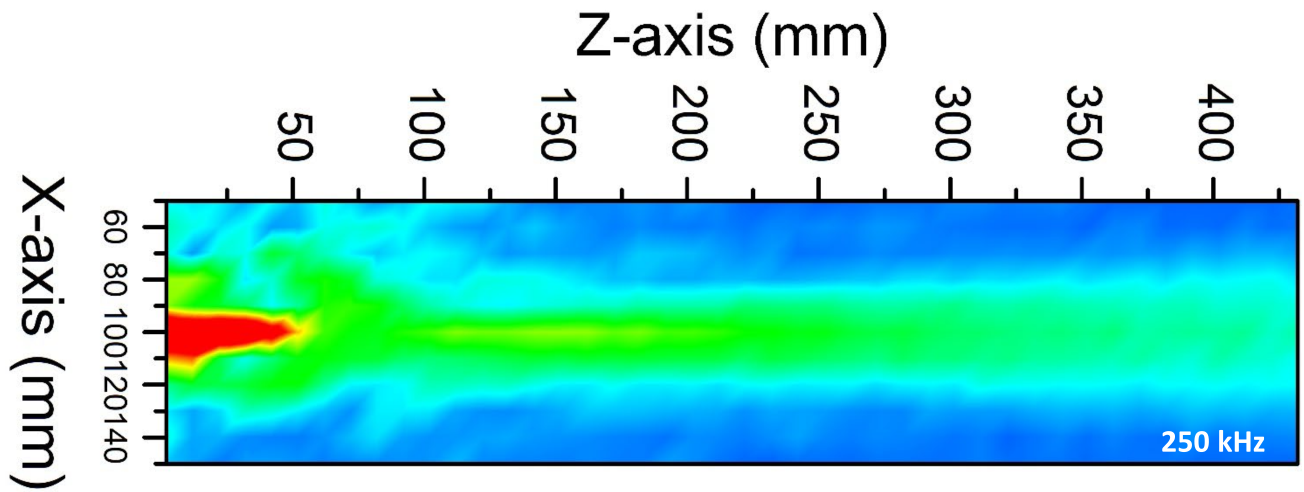
- **Bessel-like Acoustic Source (ACCObeam)**

Fundamental mode



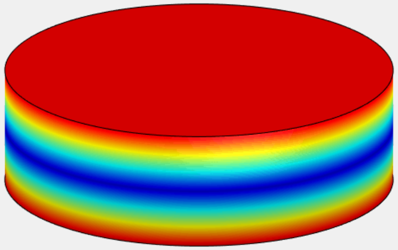
Radial mode



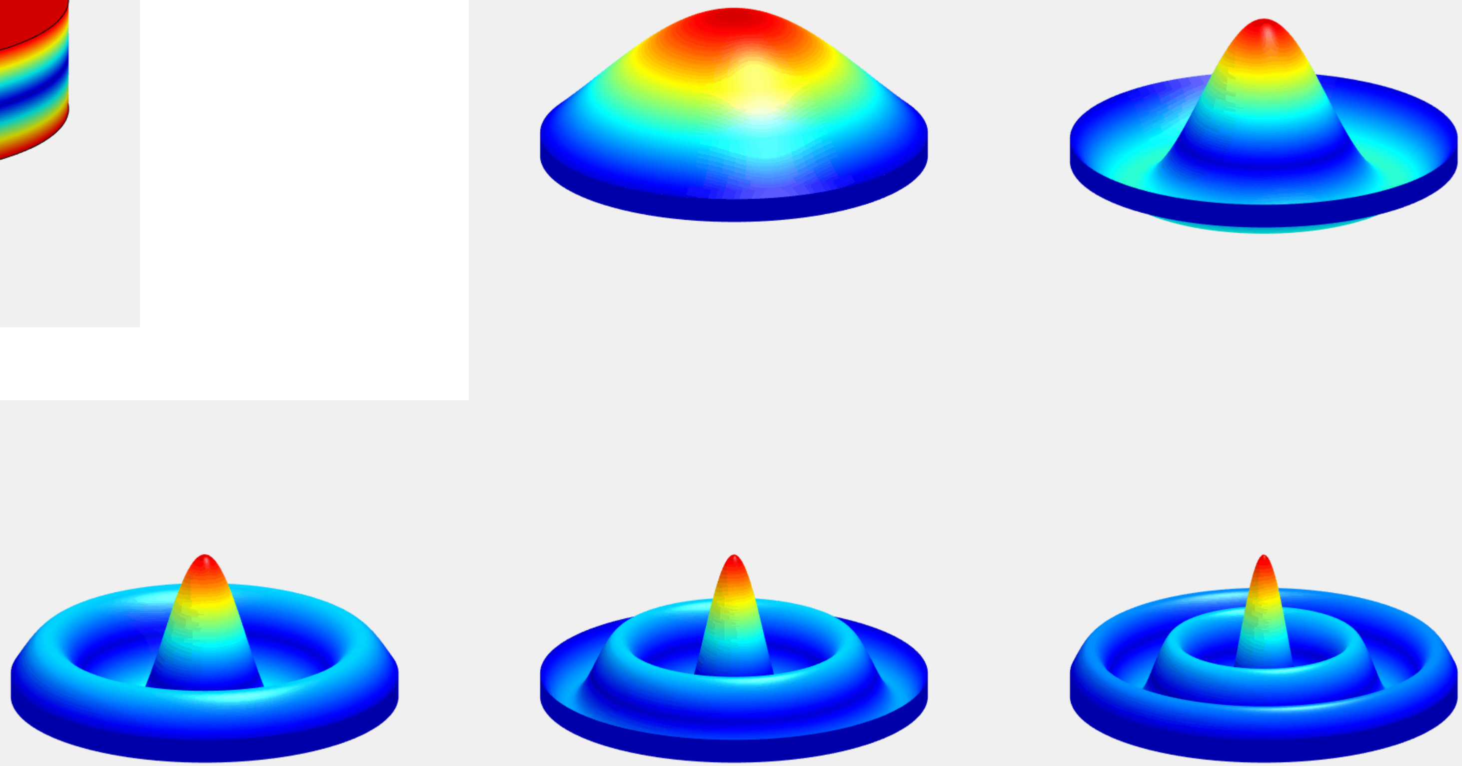


ACCObeam

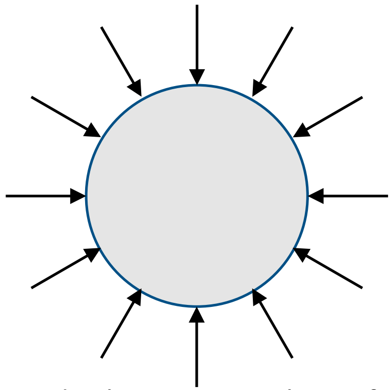
Fundamental mode



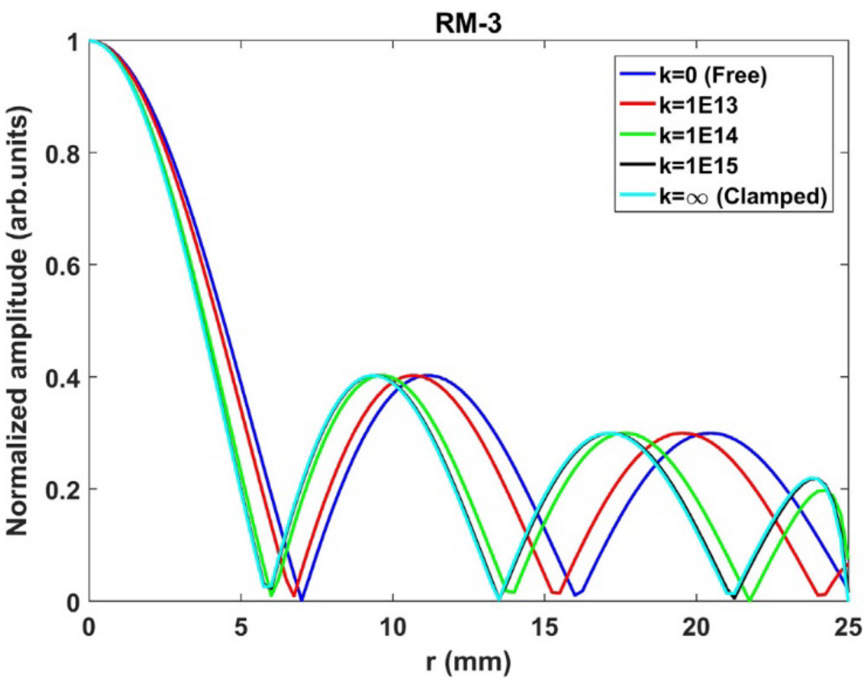
Radial modes



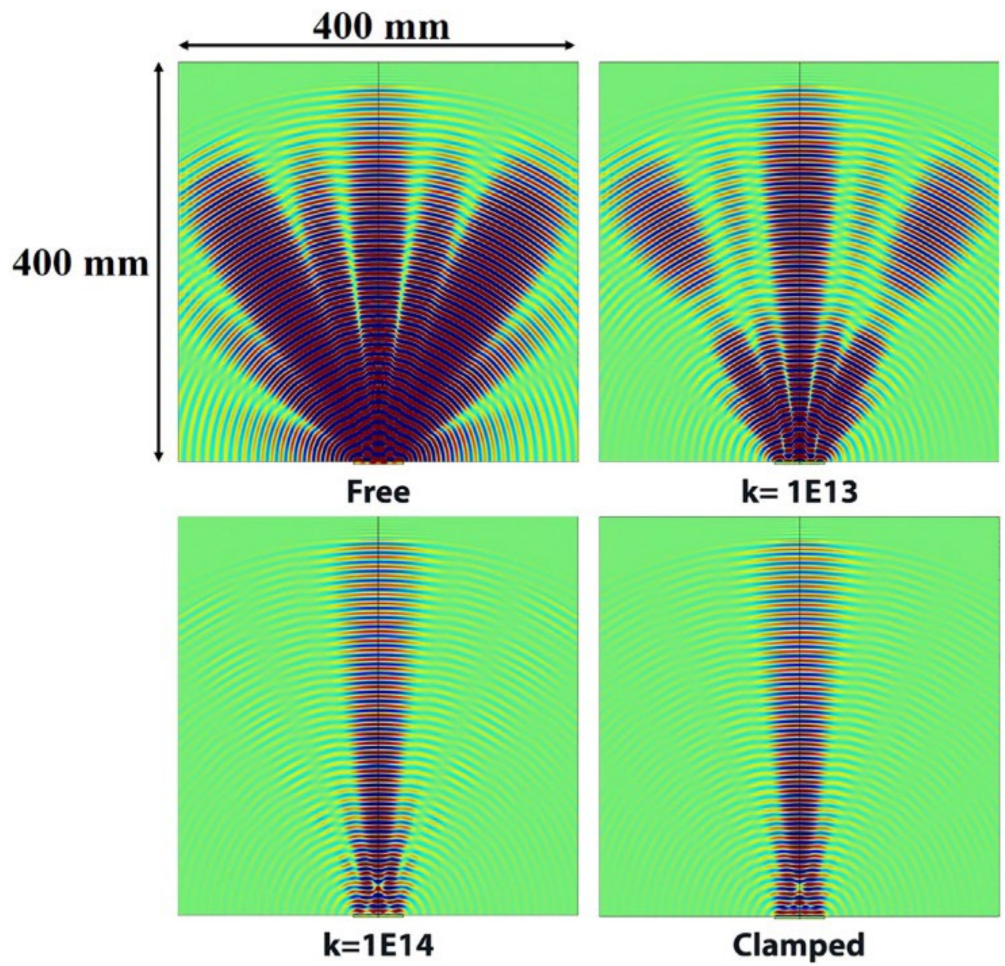
ACCObeam - Radial Modes Clamping



Normalized out-of-plane displacement on the surface of the disc for RM-3 for different lateral stiffness k (N/m3)



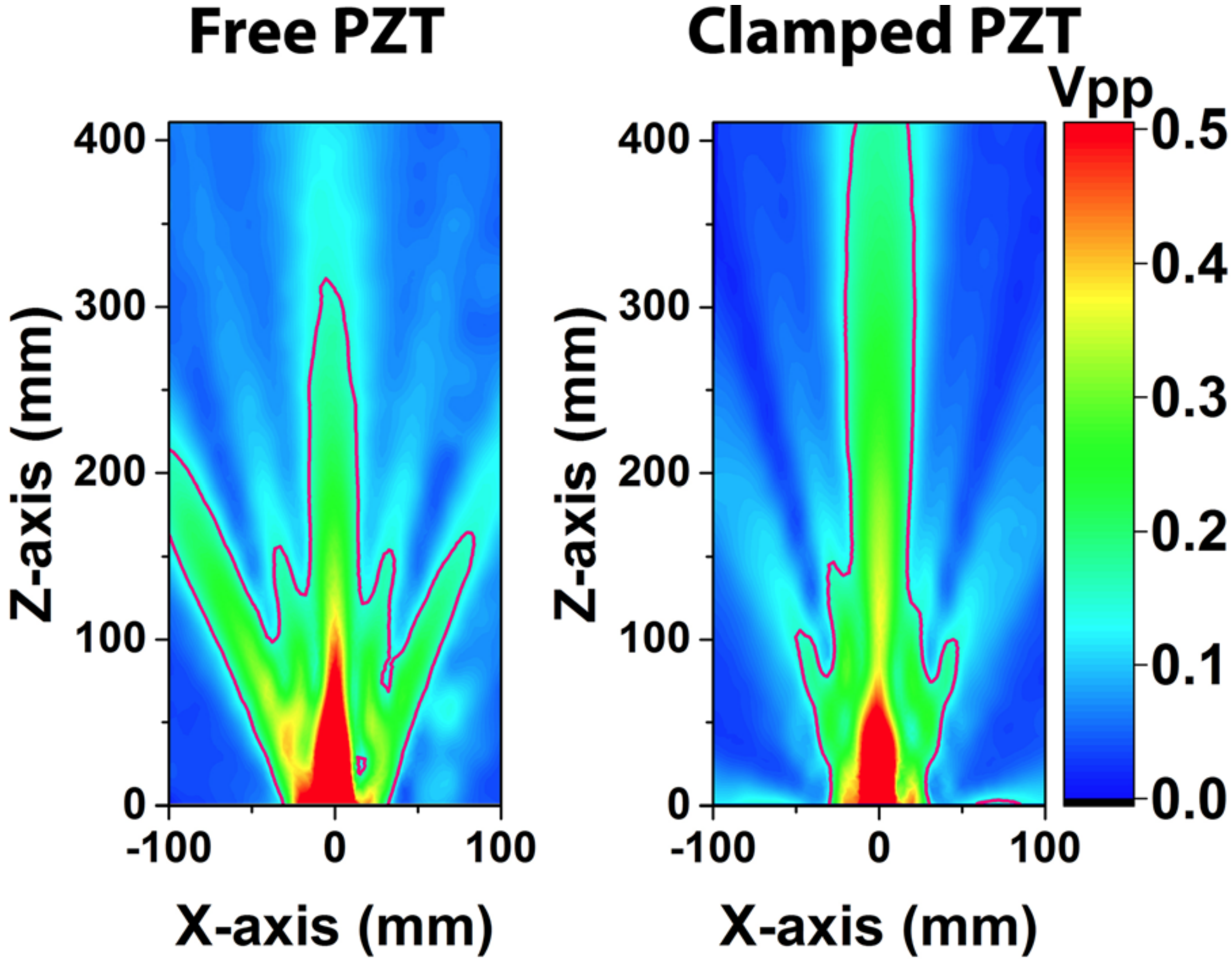
Ultrasonic beam profiles in water generated by RM-3 at 161.8 kHz for different lateral stiffness k



Wave Motion, vol. 76, (2018), pp. 19-27 and Proceedings of SPIE, vol. 10170, (2017), Article no. 1017024

ACCObeam - Radial Modes Clamping

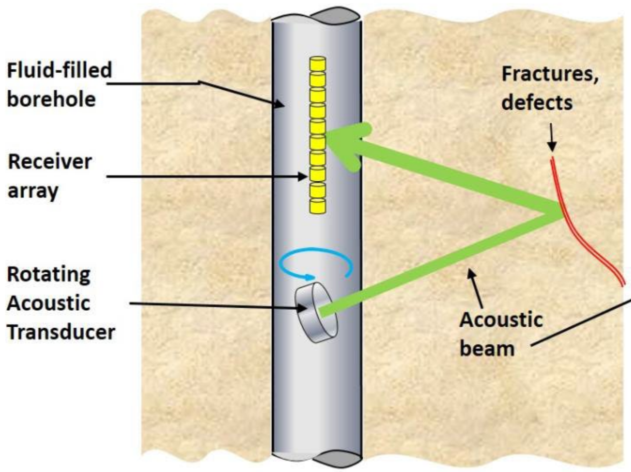
Beam profile in water for the 3rd radial mode RM-3;
free transducer (left) and clamped transducer (right)



Appl. Phys. Lett., vol. 110, issue 6, (2017), 064101

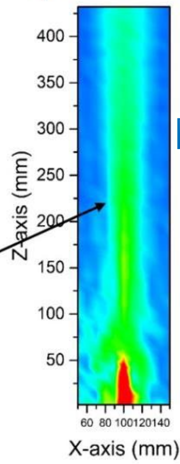
ACCObeam

Schematic representation of the 3D imaging system:

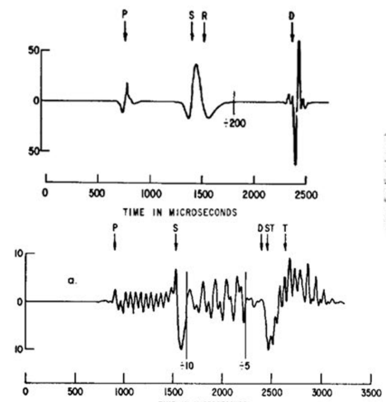


360 degree imaging

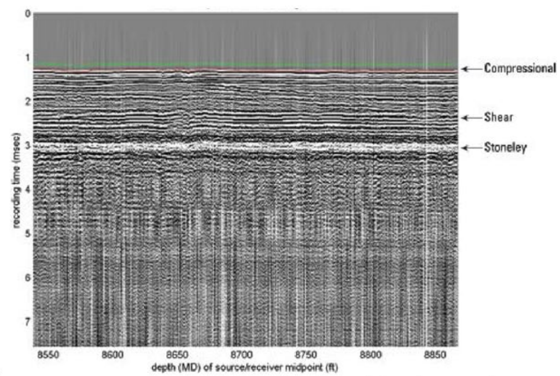
Low frequency Collimated beam (10-250 kHz)



No side-lobes



* from J.H. Rosenbaum, Geophysics, vol. 39, no. 1, (1974), p. 14-32



* from B.U. Jakob et al, First Break, vol. 28, Jul 2010

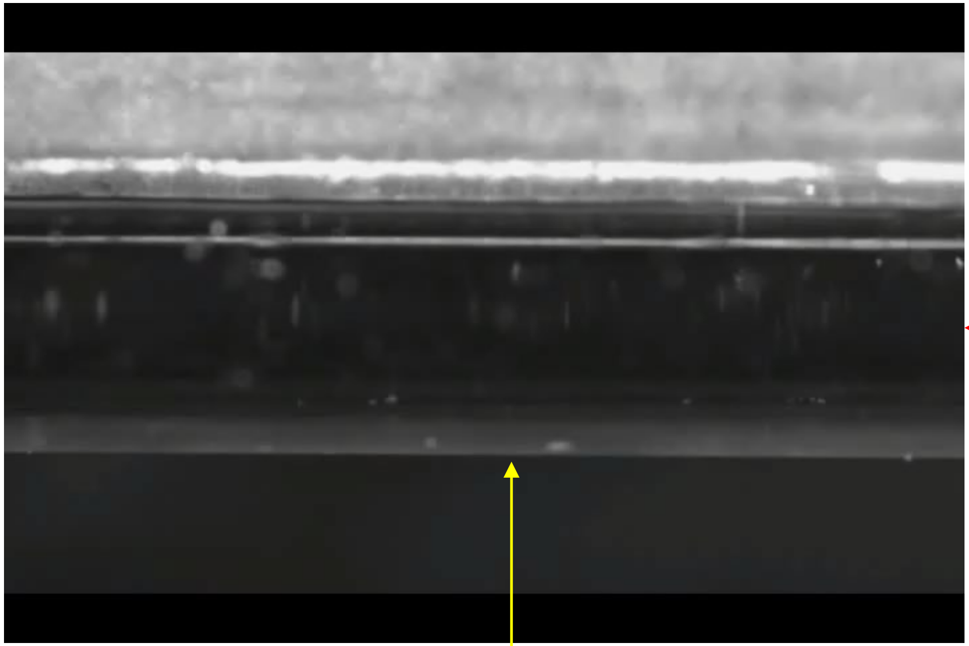
P – compressional wave
S – shear wave
R – pseudo-Rayleigh waves
ST – Stoneley wave
D – direct wave through fluid
T – tube wave

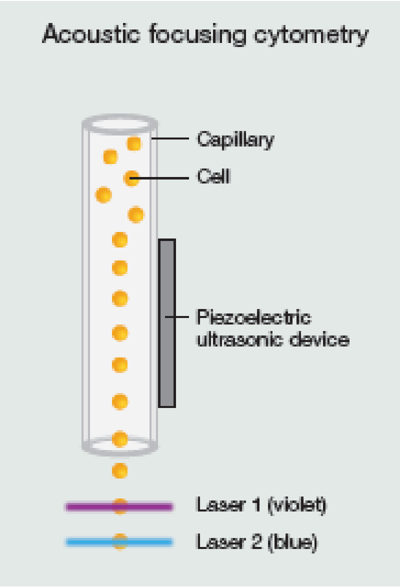
Concentration of Particles in a Tube

Sound field is turned ON and OFF.

Piezoelectric Transducer @ 1.5 MHz

Acoustic Flow Cytometer





600 μm capillary, Flow~ 200 μL/min

20 μm polystyrene beads

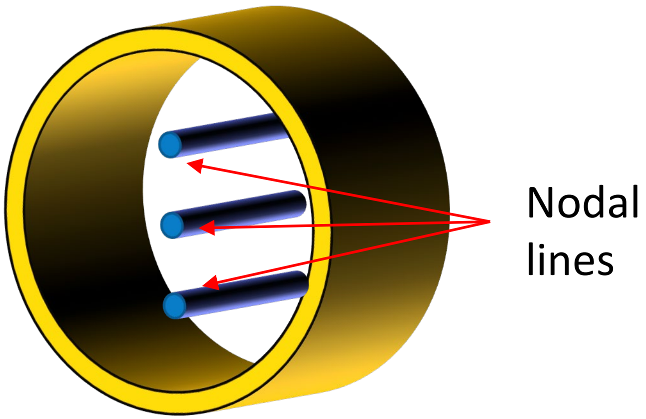
Real Time Video

Biological cell analysis

Thermo Fisher Scientific

Acoustic Separation of Humidified Air

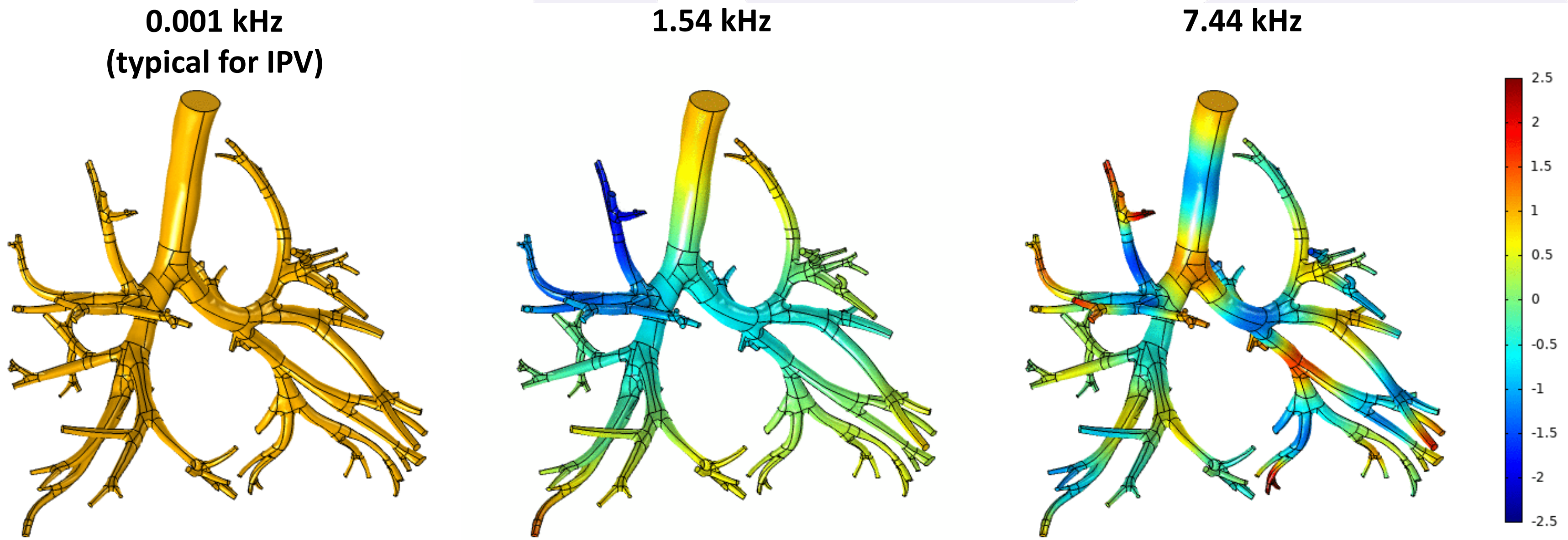
Acoustic Aerosol Concentration & Separation



The video (real-time) shows the separation of mist from humidified air and concentrating the mist acoustically inside a hollow cylinder using sound. Once the mist is concentrated, It can be taken out of the system. Various types of implementation are possible and this is simply a proof-of-concept to show what is possible with sound.

IPV – targeted excitation of lungs

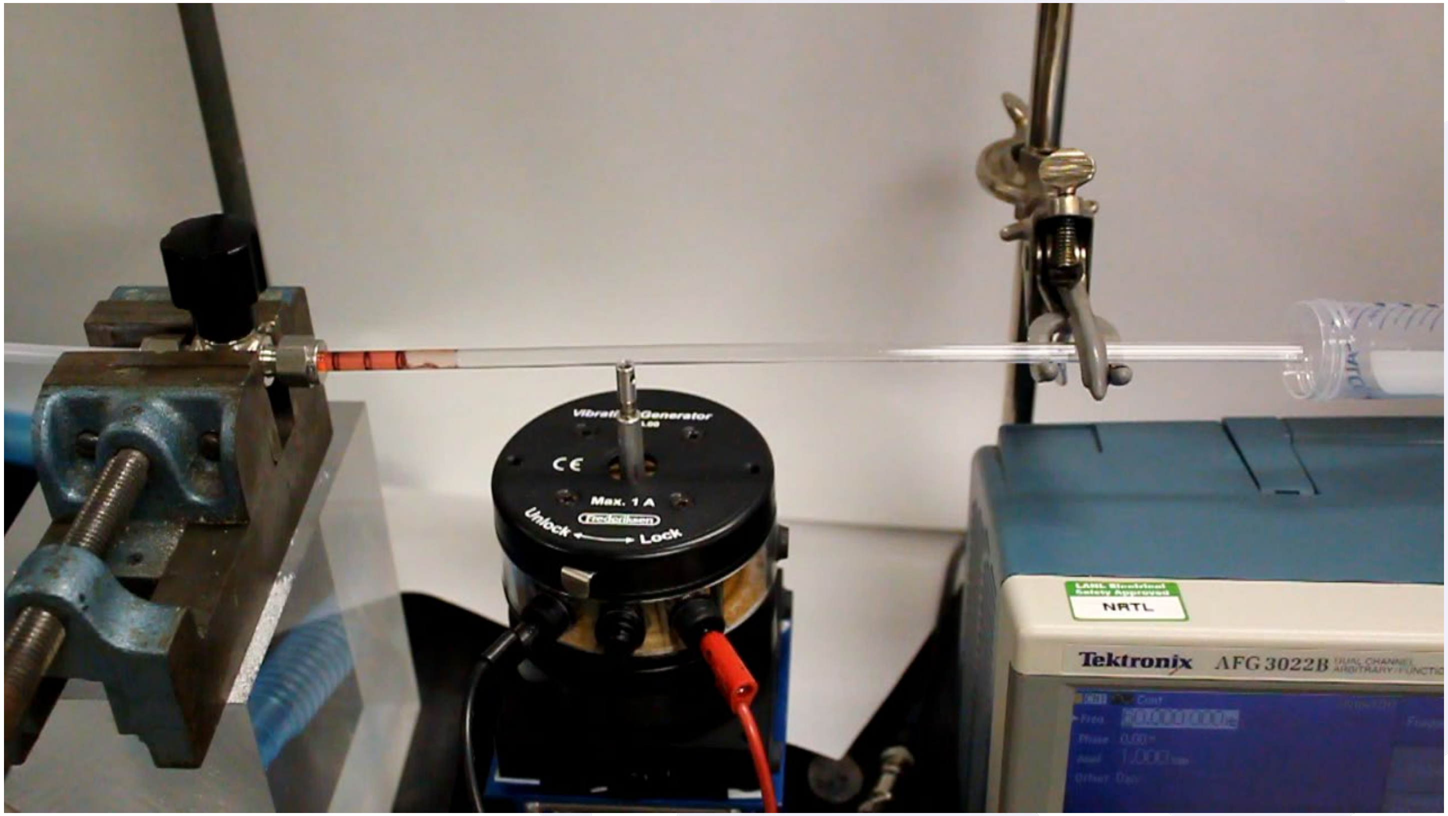
- Intrapulmonary percussive ventilation (IPV): Applies periodic bursts of air/aerosolized medication down the trachea to improve air absorption and mucus clearance
- Currently, no good understanding of optimal parameters (frequency)
- We simulate how frequency affects sound penetration in lung bronchi



Funded by DOE Office of Science through the CARES Act (the Coronavirus Aid, Relief, and Economic Security Act)

IPV – targeted excitation of lungs

- Proof-of-principle: use vibrations to improve mucus clearance from a channel

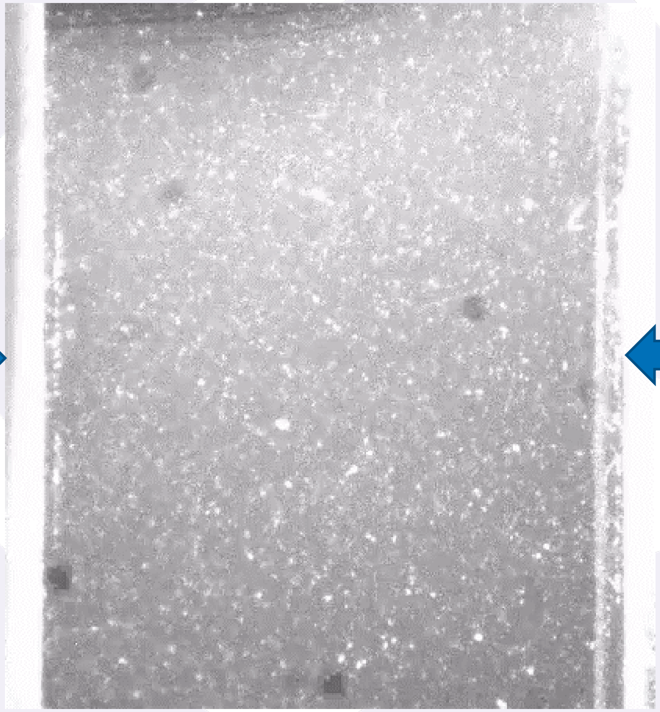


Acoustic Separation

Non-invasive mechanical separation of any two-phase system (e.g., liquid-liquid, liquid-solid, gas-liquid, etc.,) using sound

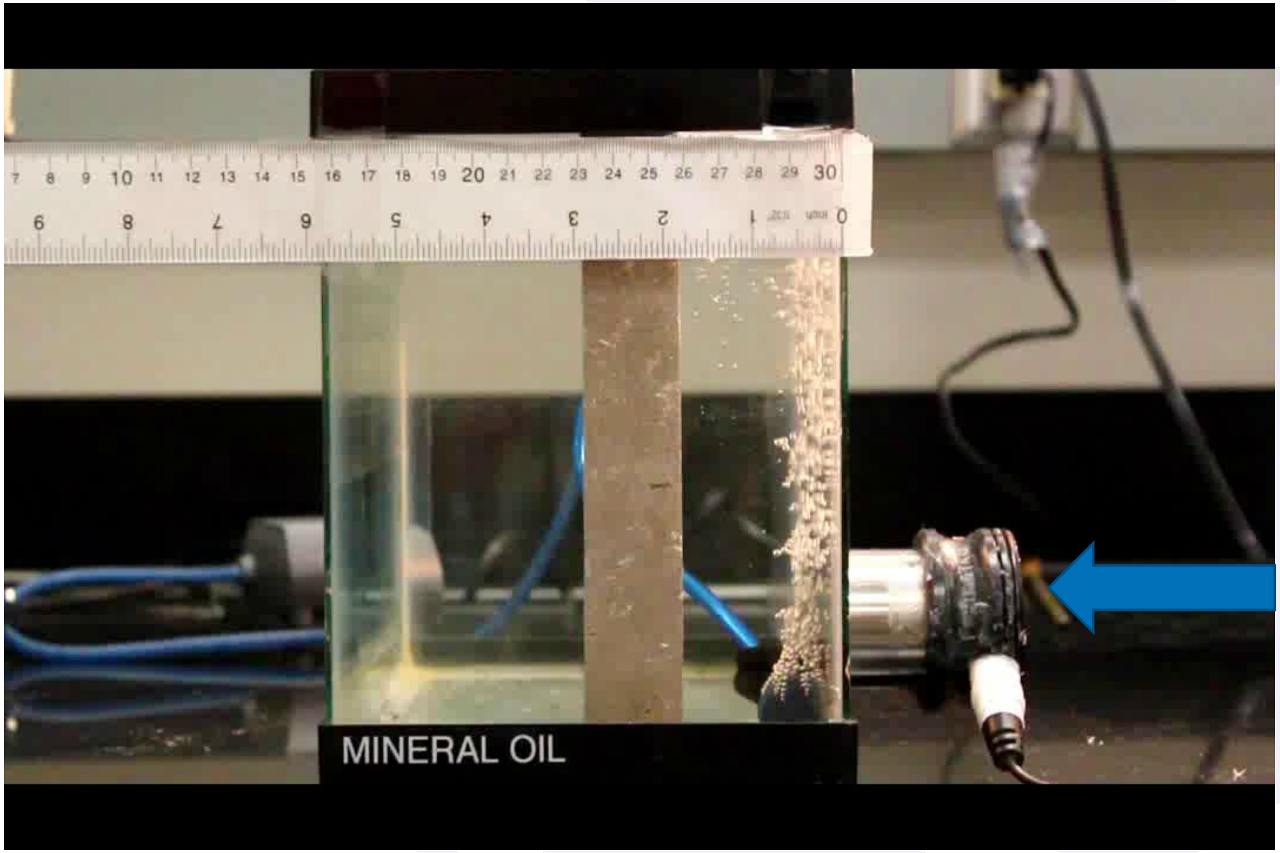
Liquid-Liquid

Solid-Liquid



Acoustic manipulation

Manipulation of gas bubbles, liquid droplets, and solid particles with sound



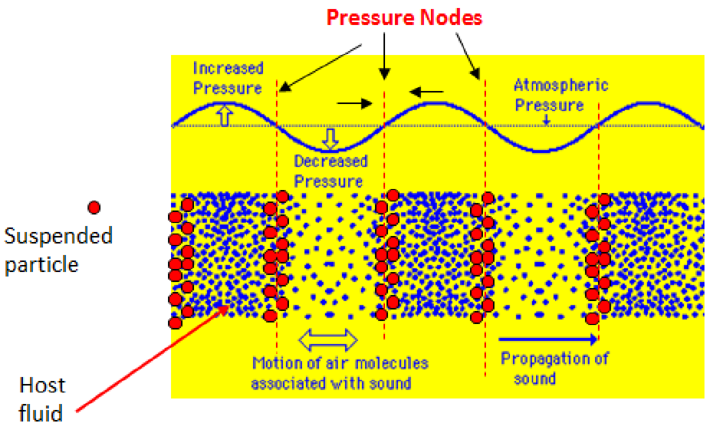
Ultrasonic Foam Mitigation

Particles/bubbles suspended in the liquid, will be moved to the nodes/antinodes of the standing waves by the **Acoustic Radiation Force**:

$$F_{ac} = \left[\frac{P_0^{\,2} V_p \beta_m}{2\lambda_m}\right] \varphi(\beta,\rho) \sin\left(\frac{4\pi z}{\lambda_m}\right)$$

$$\varphi(\beta,\rho) = \left(\frac{5\rho_p - 2\rho_m}{2\rho_p + \rho_m} - \frac{\beta_p}{\beta_m}\right)$$

V_p=volume of particle
β = compressibility
ρ = density
λ = wavelength of sound
P_0 = Peak acoustic pressure
z = distance from pressure node
m, p = medium, particle (subscripts)



Outcome of attracting bubbles

- coalesce instantly
  (most cases for bubble with close sizes)
- coalesce with time lag
  (R_i/R_j>2) 65-70%
- collect and co-exist
  (rare and only for big bubble size ratio)

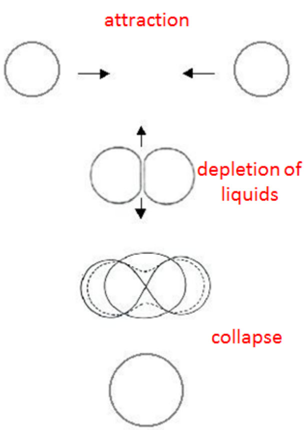
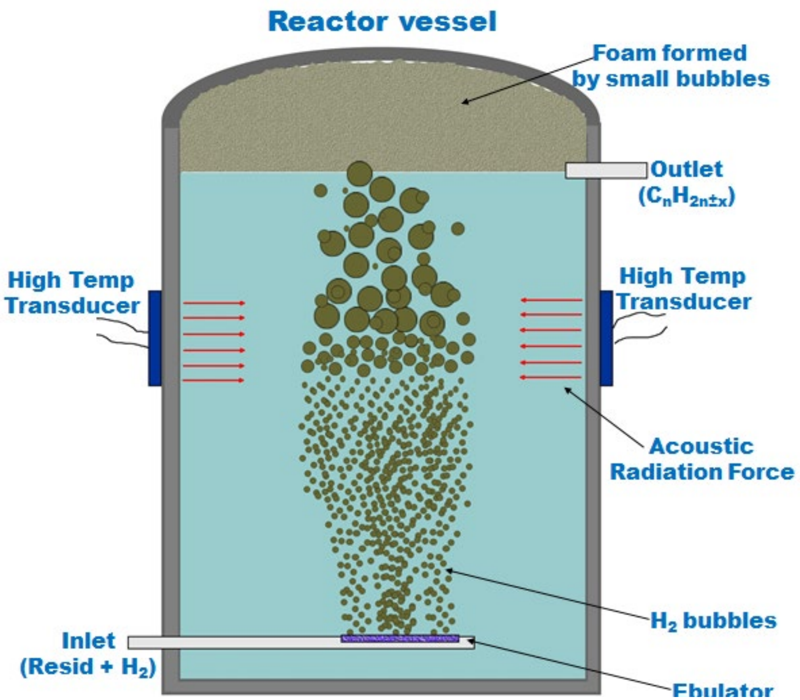


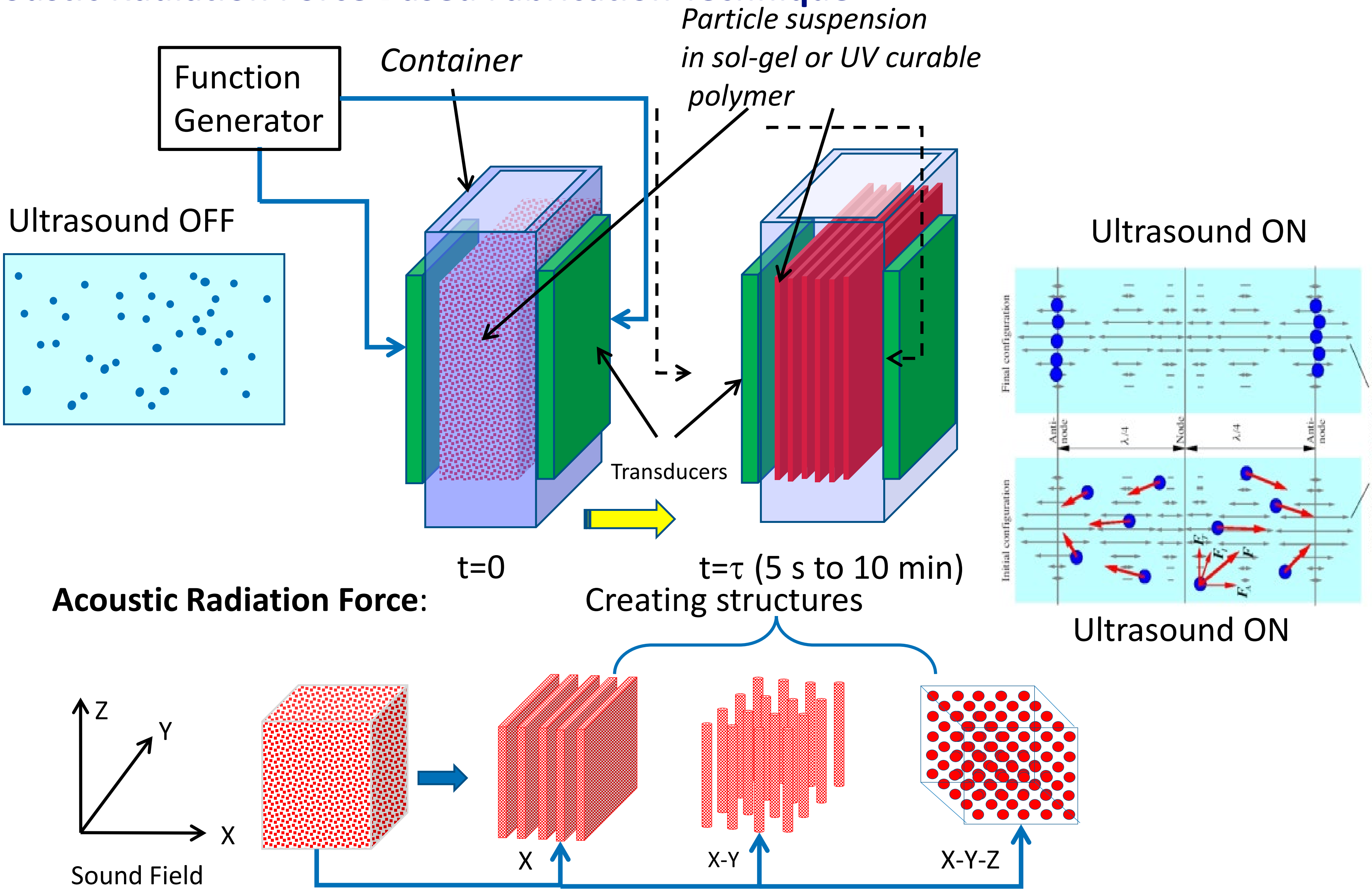
Illustration of foam mitigation concept in an industrial reactor vessel



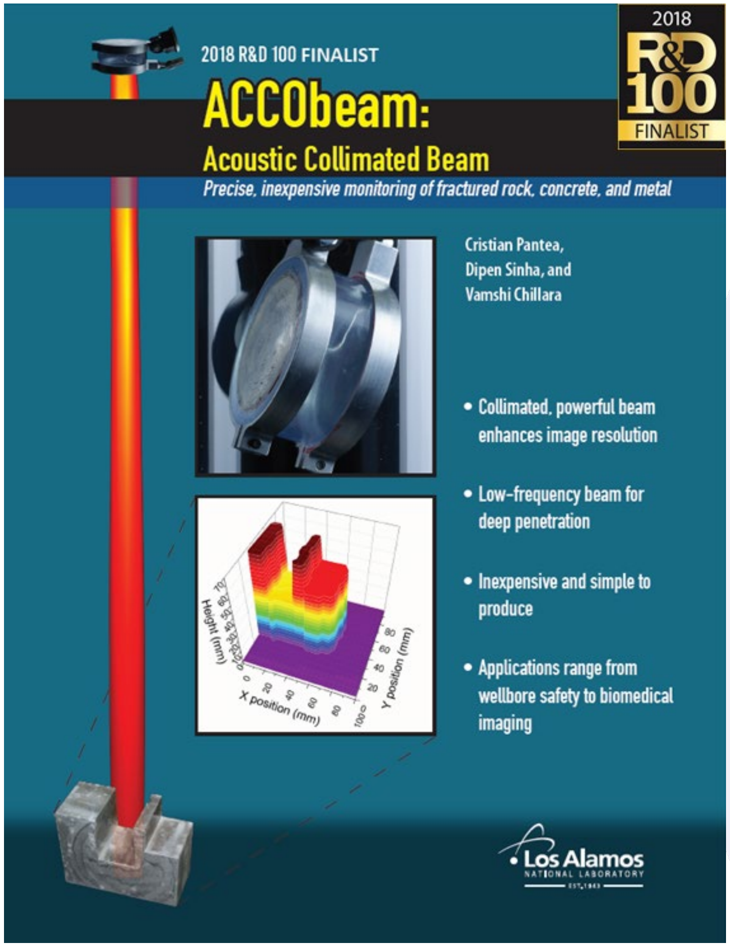
Underwater manipulation with sound

Acoustic Metamaterials

Acoustic Radiation Force Based Fabrication Technique



Thank you



2018
R&D 100
FINALIST
2018 R&D 100 FINALIST
ACCObeam:
Acoustic Collimated Beam
Precise, inexpensive monitoring of fractured rock, concrete, and metal
Cristian Pantea,
Dipen Sinha, and
Vamshi Chillara
Height (mm)
X position (mm)
Y position (mm)
• Collimated, powerful beam enhances image resolution
• Low-frequency beam for deep penetration
• Inexpensive and simple to produce
• Applications range from wellbore safety to biomedical imaging
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