Nonlinear Acoustic Methods for the Detection and Monitoring of CO2/Brine Leakage Pathways in Wellbore Systems

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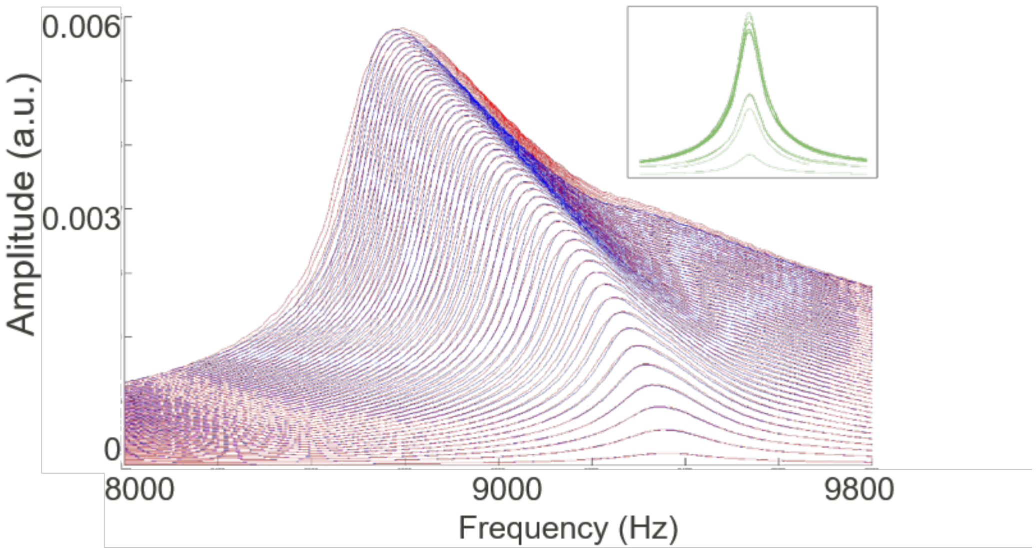
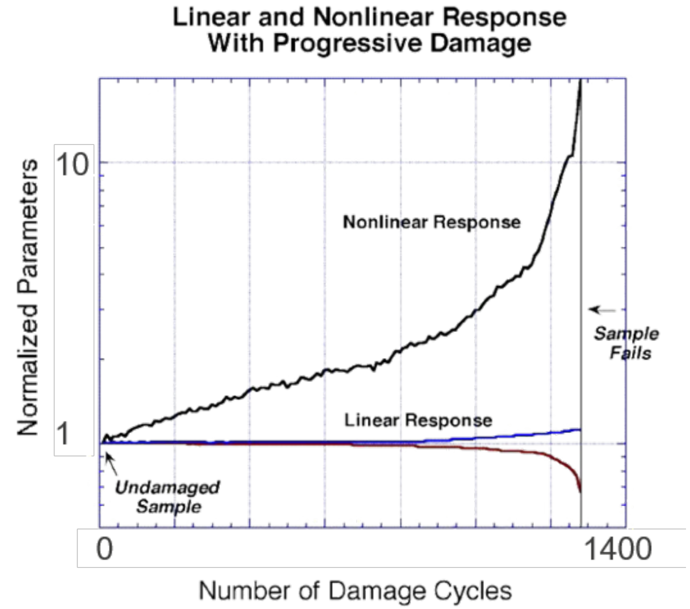
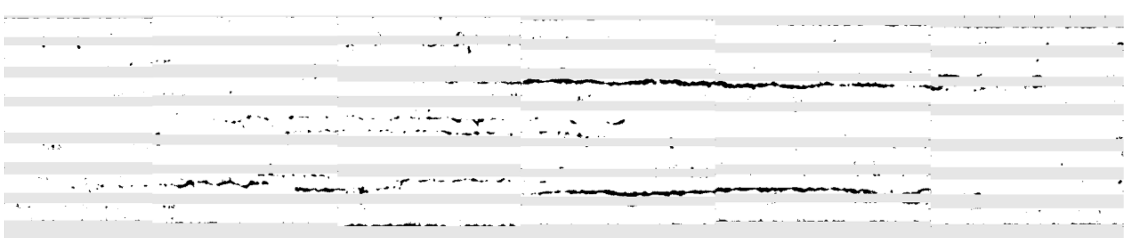
Outline

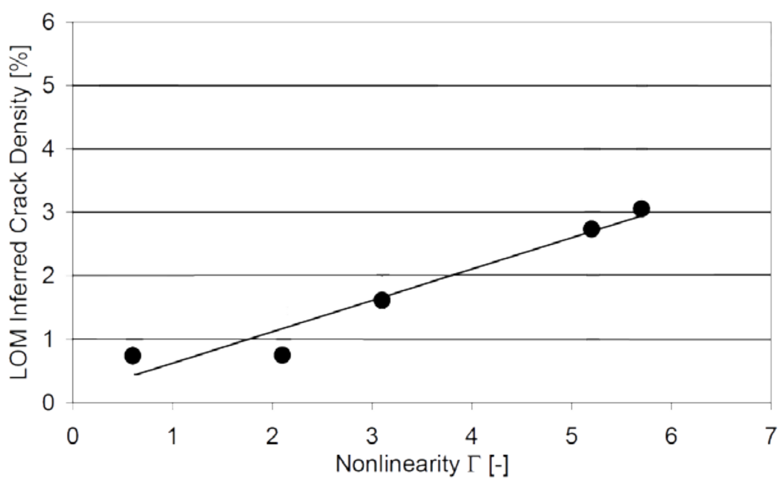
- Nonlinear acoustics
- Application to wellbore leakage pathway detection
- Micro-annulus detection
- In Borehole Measurements
- Synergies
- Summary

Methodology: Nonlinear Acoustics



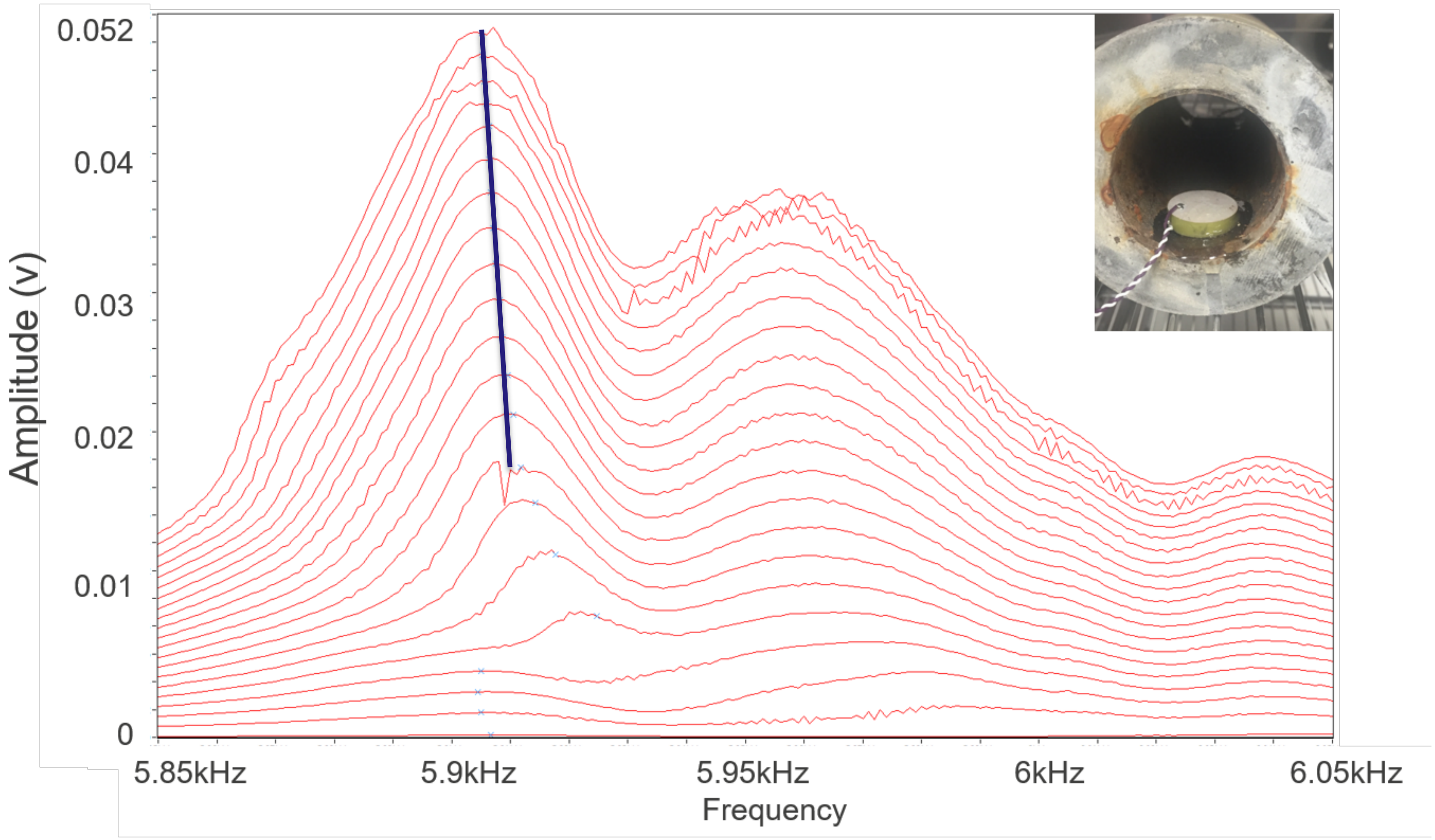




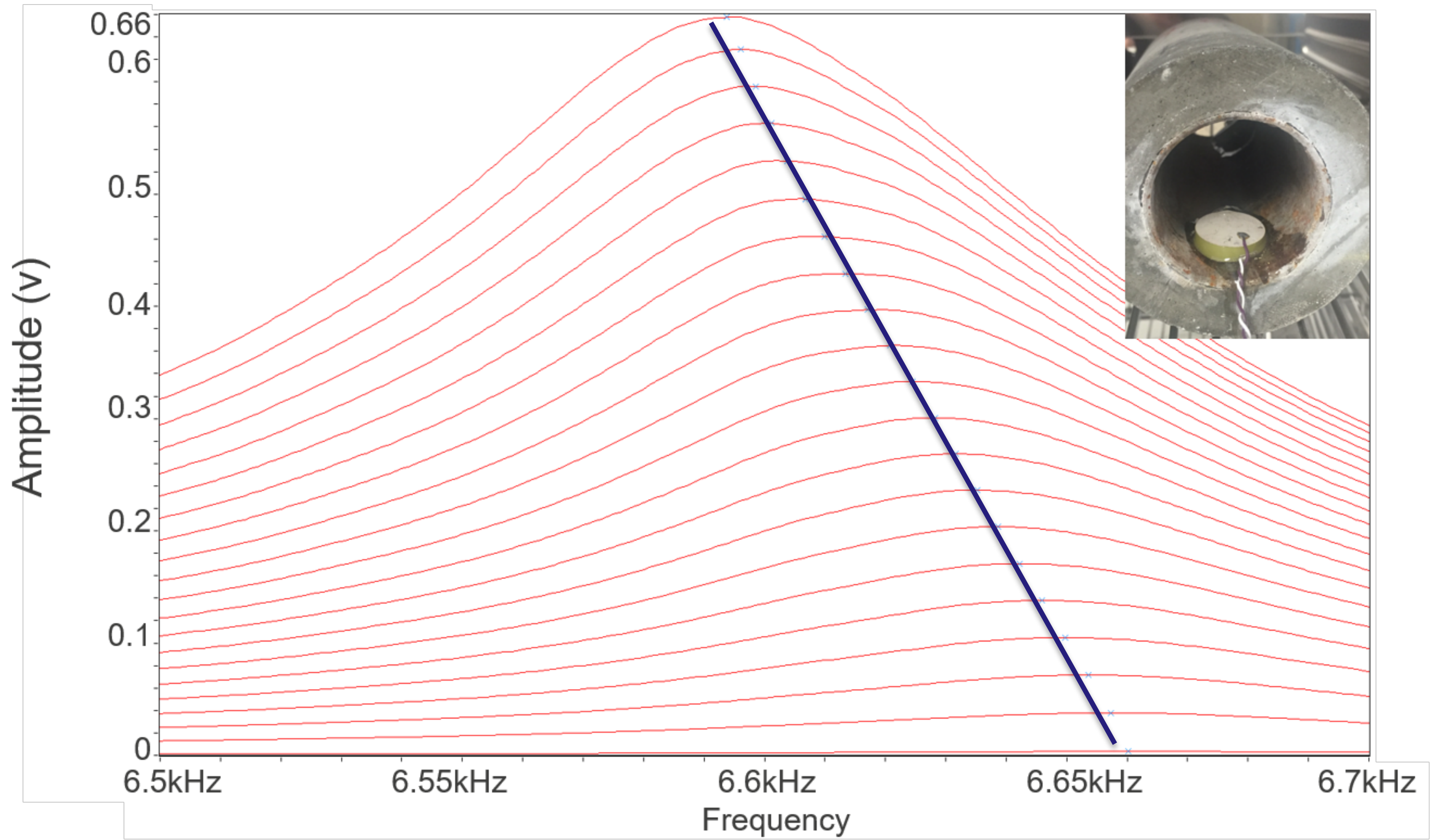


Samples

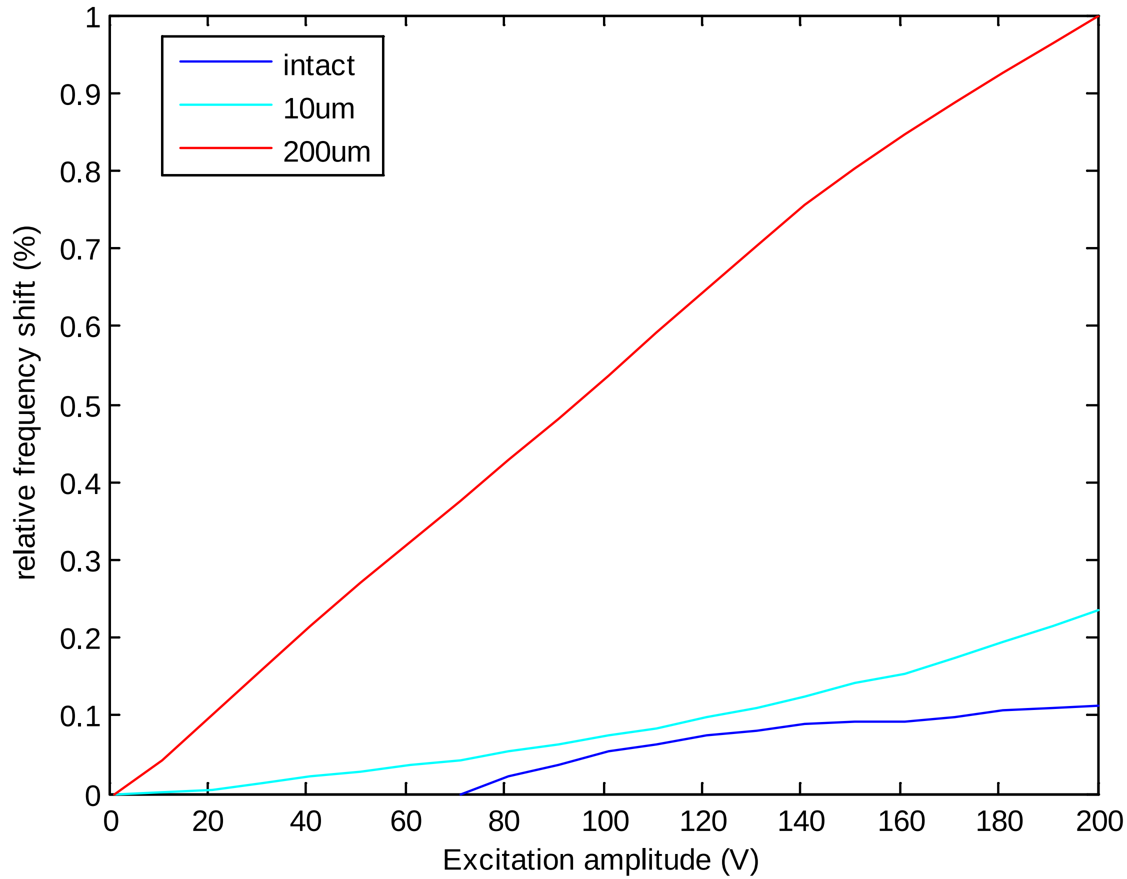
Intact sample



Damage Sample



Comparison



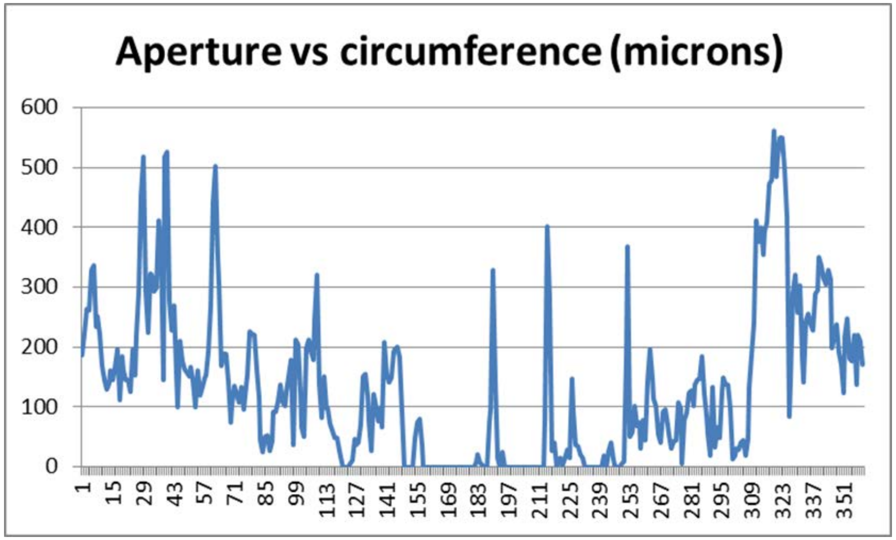
Sample	Slope (Nonlinearity)
Intact	$8\ 10^{-4}$
10 um	$1\ 10^{-3}$
200um	$5\ 10^{-3}$

New Samples

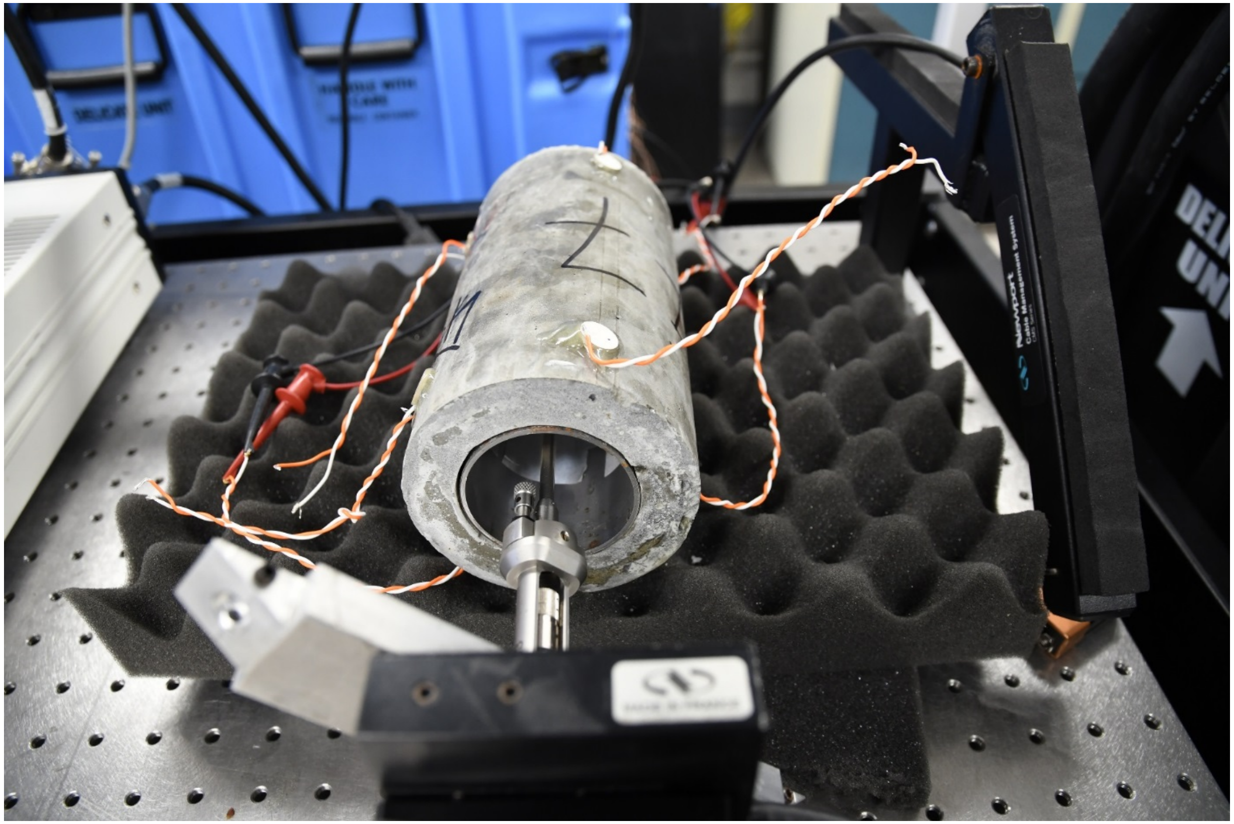
The microannulus aperture is highly variable, and a significant portion of casing and steel interface may be in full contact (zero aperture).

Wellbore samples with microannuli are injected with dyed epoxy, then specimen is sliced. Microphotographs are taken around entire circumference and "pieced" together.

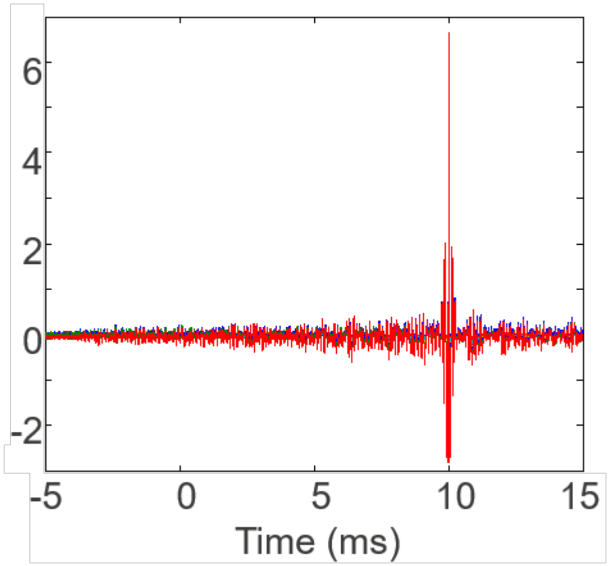
Image analysis of microphotographs are used to construct the aperture distribution around circumference.

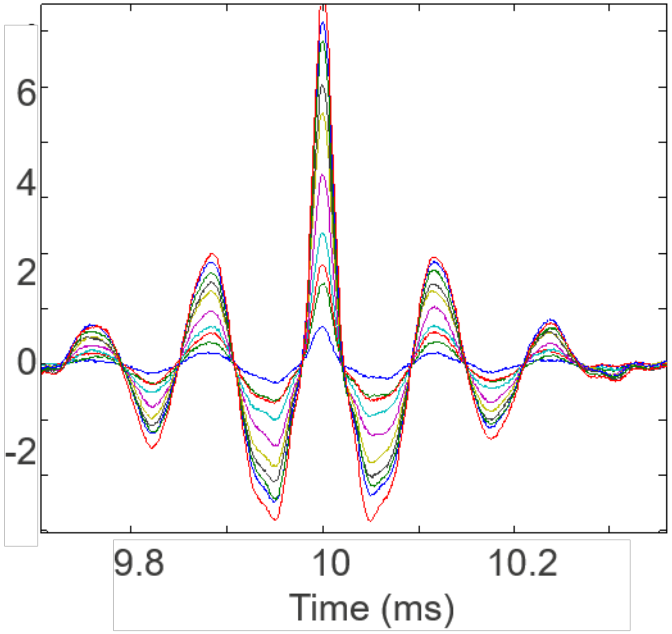


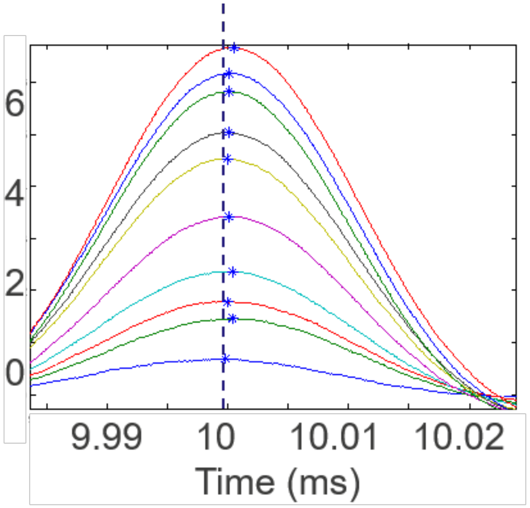
Setup



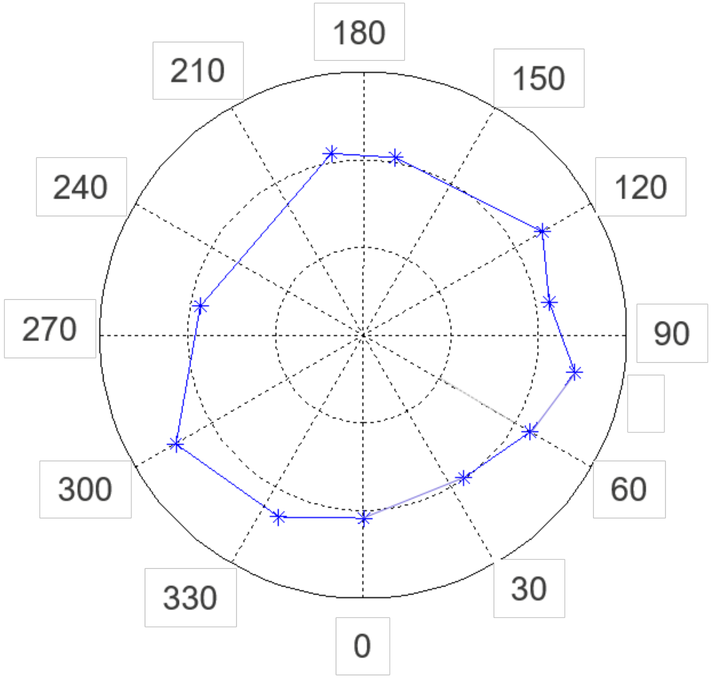
Typical signals



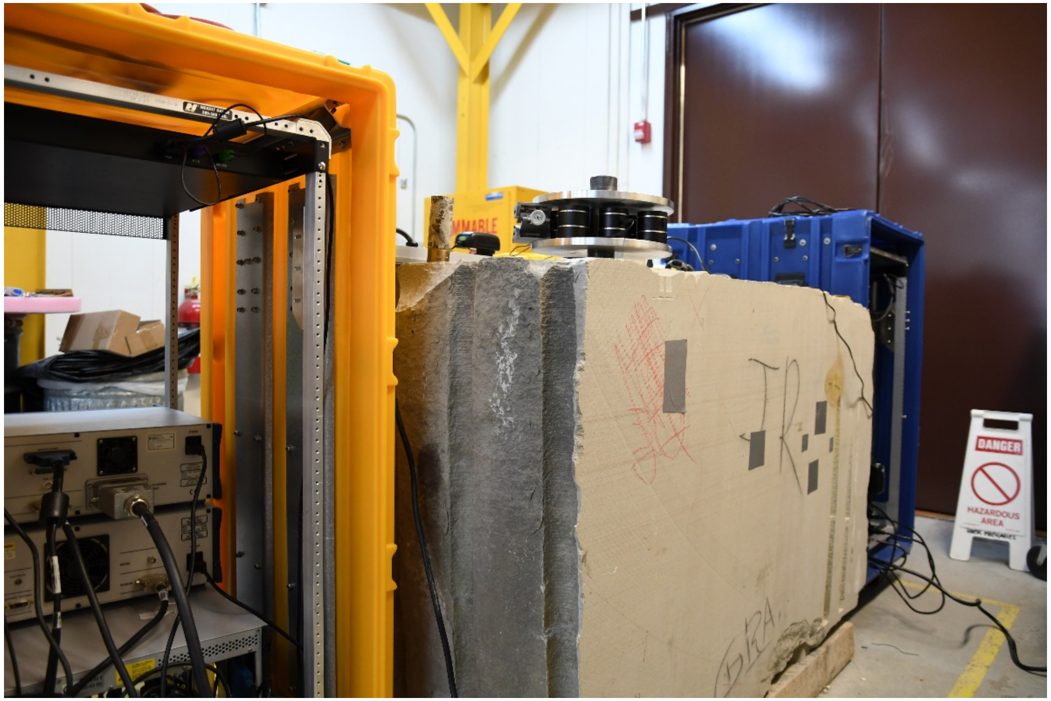




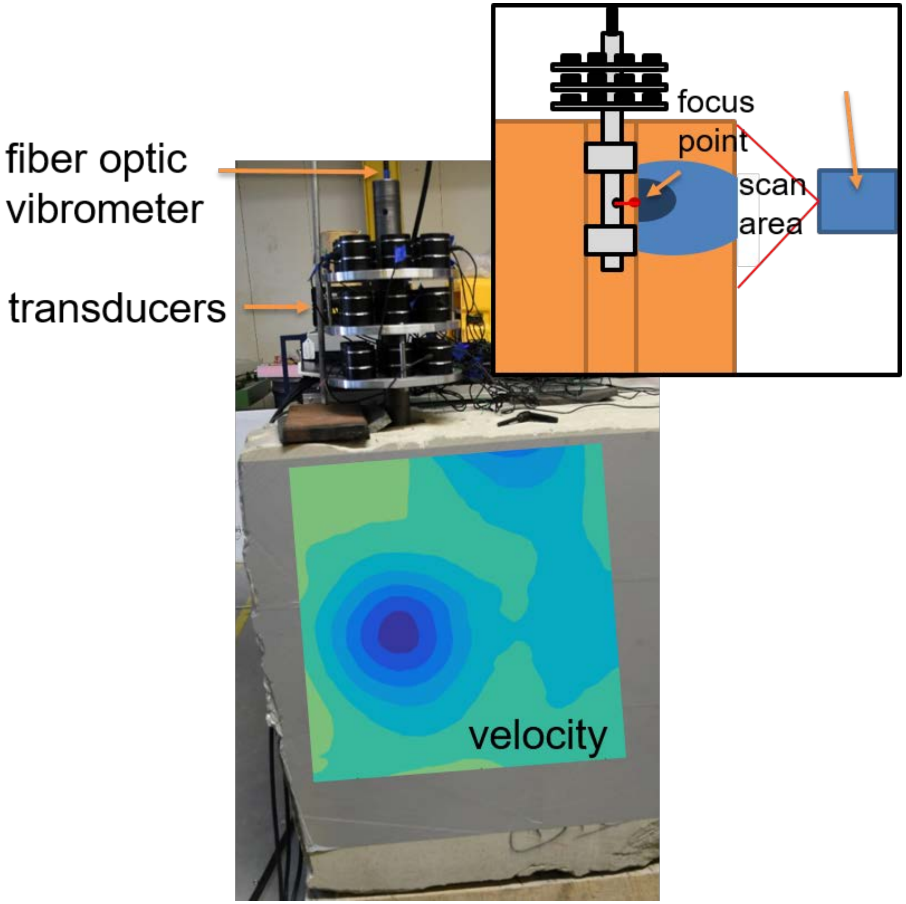
Analysis

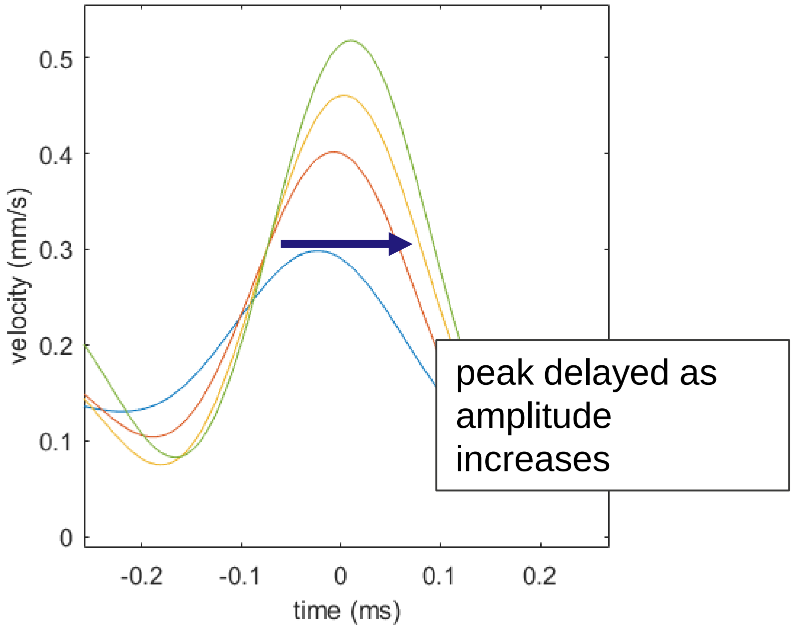


Time Reversal in Borehole



Time Reversal in Borehole





Accomplishments to Date

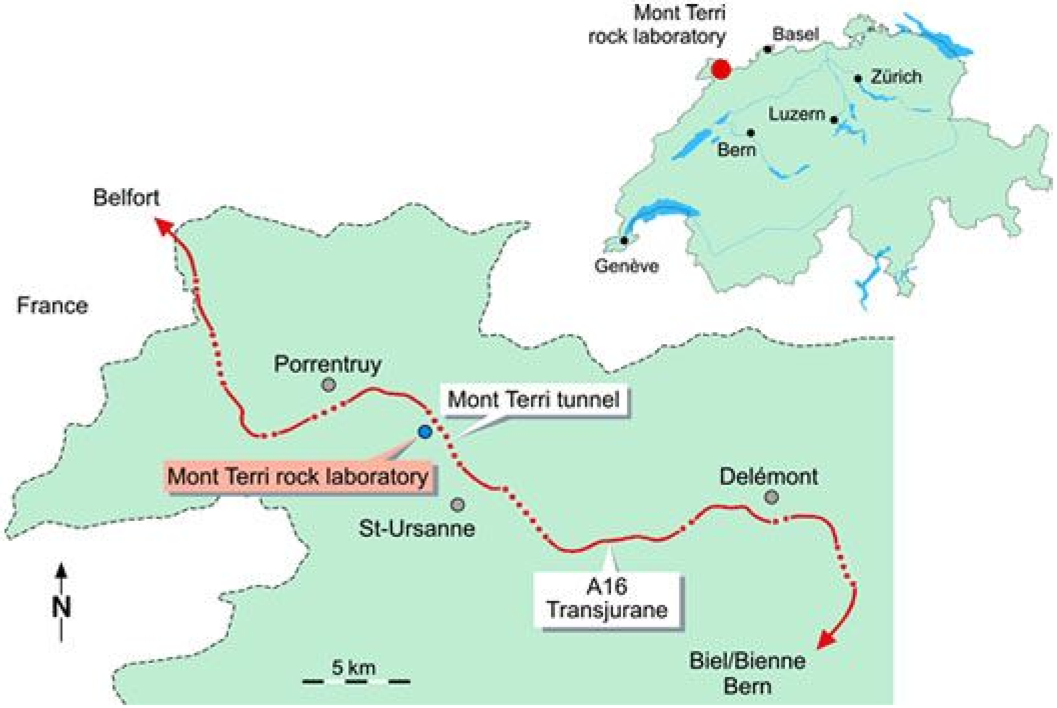
- **Proof of concept tool for in-borehole measurement**
- **Validation of the sensitivity of nonlinear parameters to micro-annulus**

Lessons Learned

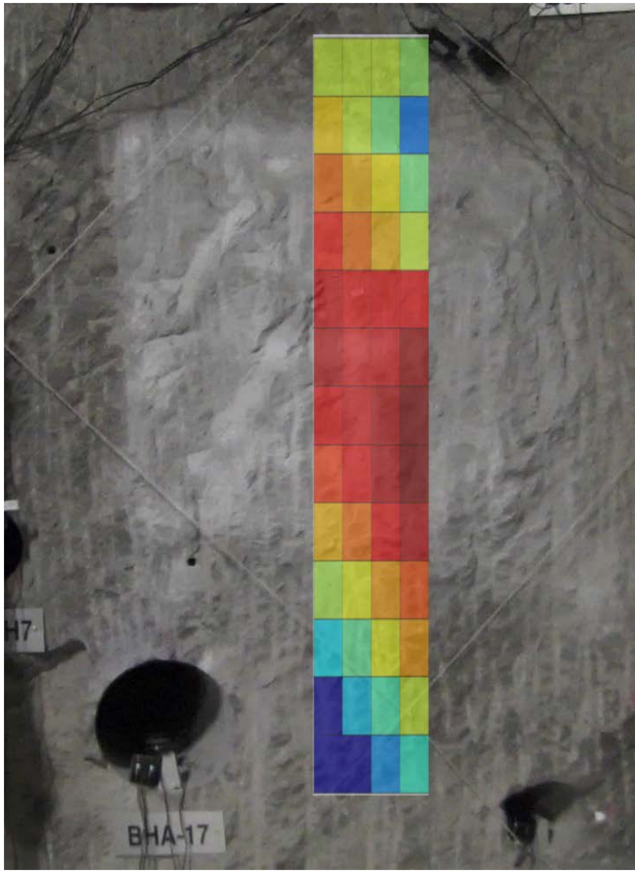
- **Large gap might not have a nonlinear signature: need to couple with other technology**
- **Need for an expected crack size/frequency/amplitude balance**

Synergy: Mont Terri

Another project involving Chevron shows opportunities for in-situ measurements

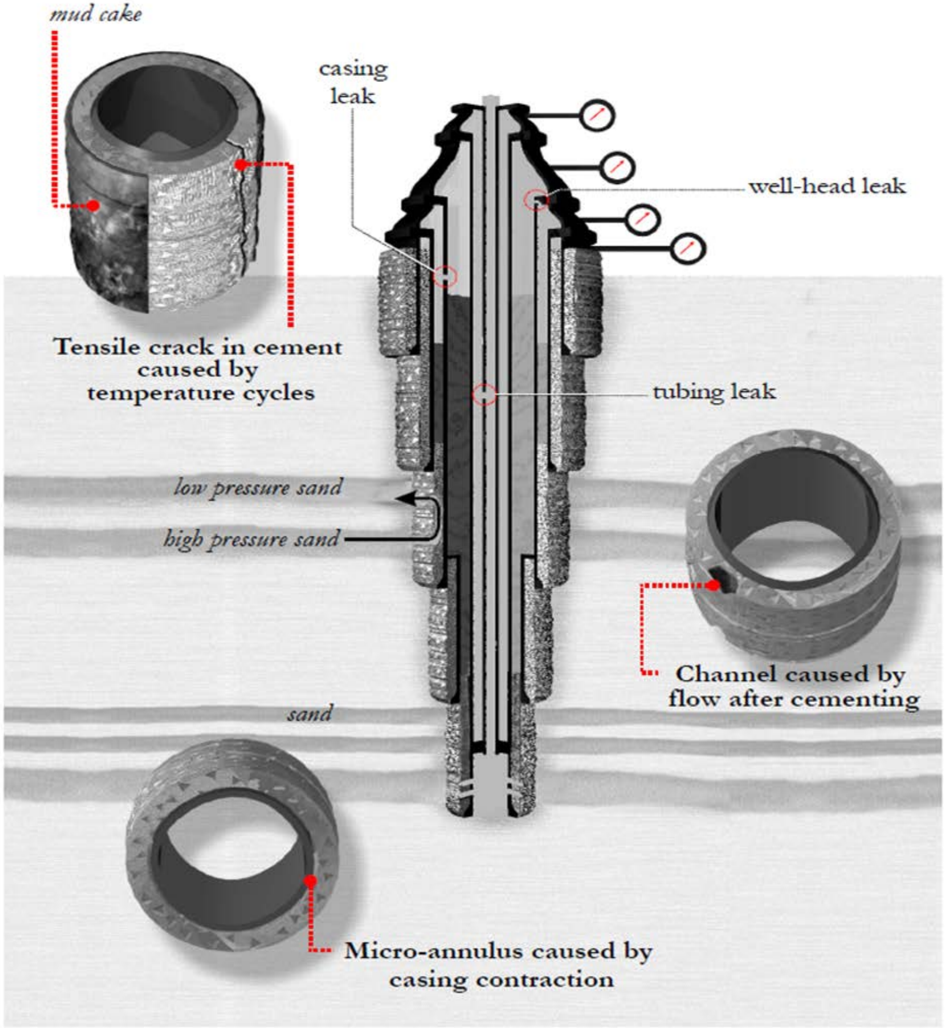


Synergy: Mont Terri



Synergy: Mont Terri

CSA experiment



Synergy: $GSCO_2$

- The Center for Geologic Storage of CO_2 ($GSCO_2$) is an integrated multidiscipline and multi-institution research center focused on recognized challenges for commercial scale storage of carbon dioxide (CO_2) storage.

- LANL is now part of the $GSCO_2$ center for characterizing the effect of CO_2 on the nonlinear behavior of rocks

Project Summary

Project lead by LANL in collaboration with UNM and SNL. Chevron is cost share

Goal is to

- **Use of nonlinear acoustics to quantify cracks**
- **Use of time reversal with nonlinear acoustics to estimate the orientation of cracks**
- **Experiments first on well characterized intact samples then on damaged samples**
- **Field experiments to validate the whole method**

Currently,

- **Sensitivity of nonlinear parameters to micro-annulus has been validated**
- **Proof of concept tool for field deployment done**

Path Forward

- **Refined measurement and analysis of nonlinear parameters**
- **Compare with other micro-annulus characterization techniques**
- **Try to test and deploy at Mont Terri**

Questions?

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Appendix

Benefit to the Program

- **Develop and validate technologies to ensure 99 percent storage permanence (goal 1) by Identifying and characterizing wellbore leakage path (area of interest 2)**

- **This will lead to improved prediction, identification, and quantification of wellbore leakage risk.**

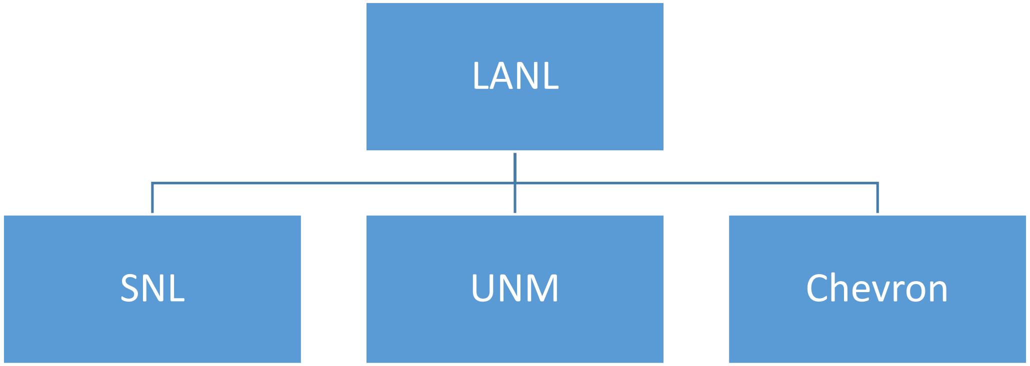
Project Overview: Goals and Objectives

- **GOAL:** Improve detection of leakage path near well bore using a combination of nonlinear acoustics and time reversal

- **Objectives:**
  - development of a time-reversal acoustic probe,
  - testing on representative wellbore materials,
  - generating a variety of damaged wellbore materials and wellbore materials exposed to carbon dioxide (CO_2) for the experiments,
  - conducting *in situ* field measurements at the Mont Terri, Switzerland underground laboratory

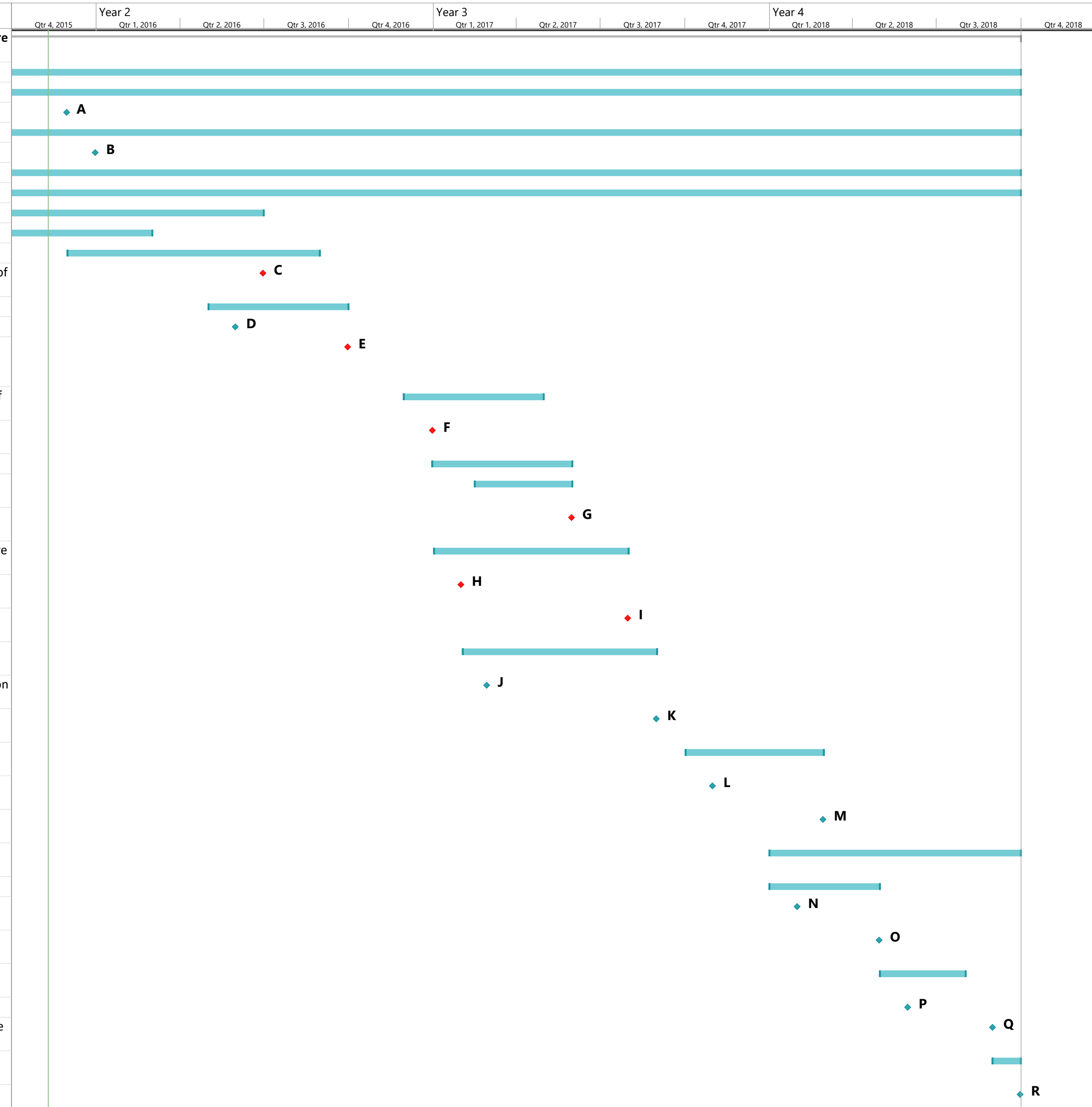
Organization Chart/ Communication Plan

- **Communication plan:**
  - Monthly progress meeting with all participants



Proposed Schedule

ask Name
lonlinear Acoustics Methods for Detection and Monitoring of CO2/Brine Leakage Pathways in Wellbore ystems
1.0 Project Management Plan (PMP)
1.1 Project Management Plan (PMP)
A. Updated Project Management Plan
1.2 Meetings
B. Kickoff Meeting
1.3 Reportings
1.4 Project Management
2.0 Design Laboratory Wellbore Materials, Assemble, and Characterize Baseline Properties
2.1 Design Laboratory Wellbore Materials, Assemble
2.2 Characterize Baseline Properties of Laboratory Wellbore Materials
C. Quick-look report summarizing the results of the baseline characterization property measurements of the wellbore materials.
3.0 Generate Thermal- and Mechanical-induced Damage to Wellbore Materials and Characterize
D. Plan for the induced damage and characterization of the damaged wellbore material.
E. Quick-look report summarizing the laboratory-induced damage experiments including the conditions of the damage events and characterization measurements of the damaged wellbore materials.
4.0 Assemble Acoustics Probe and Perform Time-Reversal Characterization of the Nonlinear Behavior of Damaged Wellbore Materials at Laboratory Conditions
F. Plan for performing time-reversal measurements using the acoustic probe to characterize the damaged wellbore material.
4.1 Assemble Acoustics Probe for Time-Reversal Measurements
4.2 Perform Assessment of the Nonlinear Behavior of Damaged Materials using Time Reversal techniques
G. Quick-look report summarizing the time-reversal acoustic probe measurements of the damaged wellbore materials.
5.0 Perform Time-Reversal Caracterization of Wellbore Material Exposed to Carbone Dioxide to Measure Elastic Property Changes
H. Plan for performing time-reversal characterization of wellbore material exposed to carbon dioxide (CO2) to measure elastic property changes.
I. Quick-look report summarizing the time-reversal acoustic probe measurements of the wellbore materials exposed to CO2 in a controlled environment.
6.0 Develop Analytical Framework for Three-dimensional (3D) Nonlinear Acoustics Behavior in relationship to Known Fracture Distribution
J. Plan for the experimental investigation of extracting wellbore material fracture density and orientation with the time-reversal acoustic probe method.
K. Quick-look report summarizing the experimental results of extracting wellbore material fracture density and orientation with the time-reversal acoustic probe method.
7.0 Develop Pulse-Echo Doppler Method to Acoustically Measure Flow Rates and Correlate with Direct Permeability Measurements in Wellbore Materials
L. Plan for the experimental investigation and development of a pulse-echo Doppler method to acoustically measure flow rates.
M. Quick-look report summarizing the experimental results of the pulse-echo Doppler method to acoustically measure flow rates in wellbore materials.
8.0 Proof-of-Principle Time-Reversal Measurements at Laboratory Experimental Downhole Conditions and In Situ at the Mont Teri, Switzerland Facility
8.1 Time-Reversal Measurements at Laboratory Experimental Downhole Conditions
N. Plan for performing the experiments and measurements in the laboratory at downhole conditions.
O. Quick-look report summarizing the results of the time-reversal measurements at laboratory experimental downhole conditions.
8.2 Time-Reversal Measurements at Experimental Downhole Conditions In situ at Mont Terri, Switzerland Facility
P. Plan for performing the measurements in situ at the Mont Terri, Switzerland facility.
Q. Quick-look report summarizing the results of time-reversal measurements at experimental downhole conditions in situ at Mont Terri, Switzerland facility.
8.3 Summary of Field Operating Performance for Time-Reversal Acoustic Probe for Detection of Damaged Wellbore Materials
R. Fact Sheet “Nonlinear Acoustic Probe for Wellbore Damage Detection” containing field operating conditions, performance, and cost for use.



Appendix: Bibliography

2 papers in preparation:

- State of the art paper with $GSCO_2$ partner
- Micro annulus detection using nonlinear acoustics