Time reversal methods for the detection and monitoring of CO_2/brine leakage pathways in wellbore systems

FWP-FE-634-15-FY15

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LA-UR-18-27503

U.S. Department of Energy

National Energy Technology Laboratory

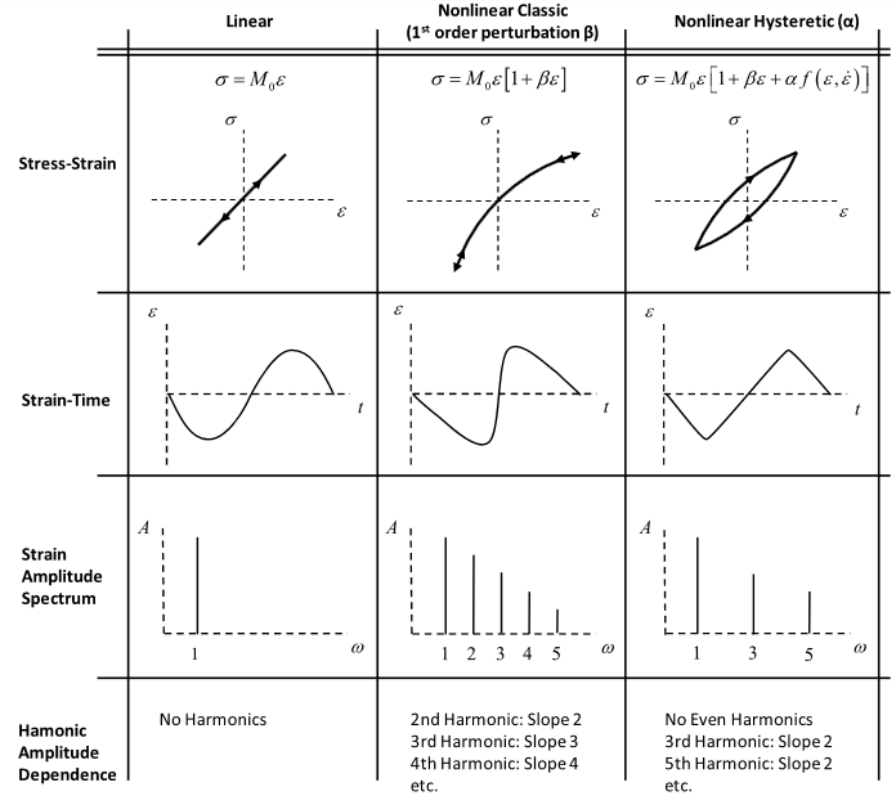
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 13-16, 2018

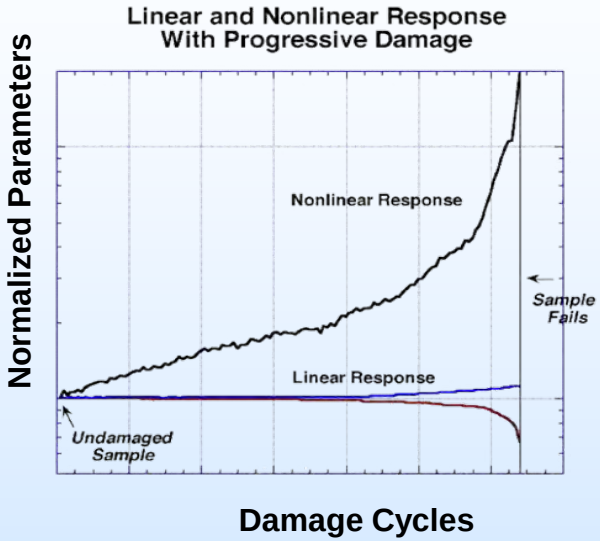
Presentation Outline

- Background
  - Nonlinear Elastic Waves
  - Time Reversal
- Objectives
- Flat Samples
- Wellbore Sections
- Synergies
- Summary

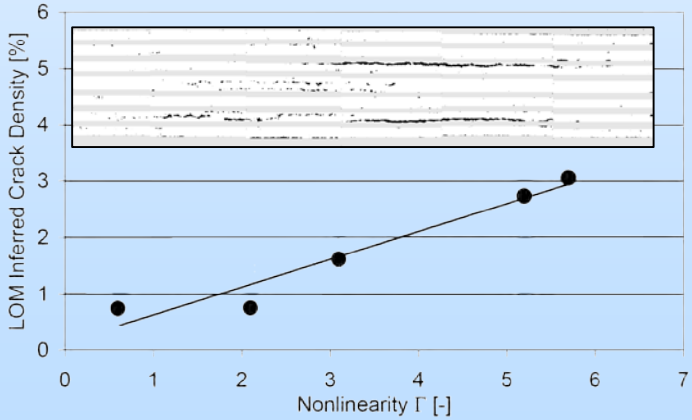
Nonlinear Elastic Wave Propagation



Van Den Abeele et al. (2000)



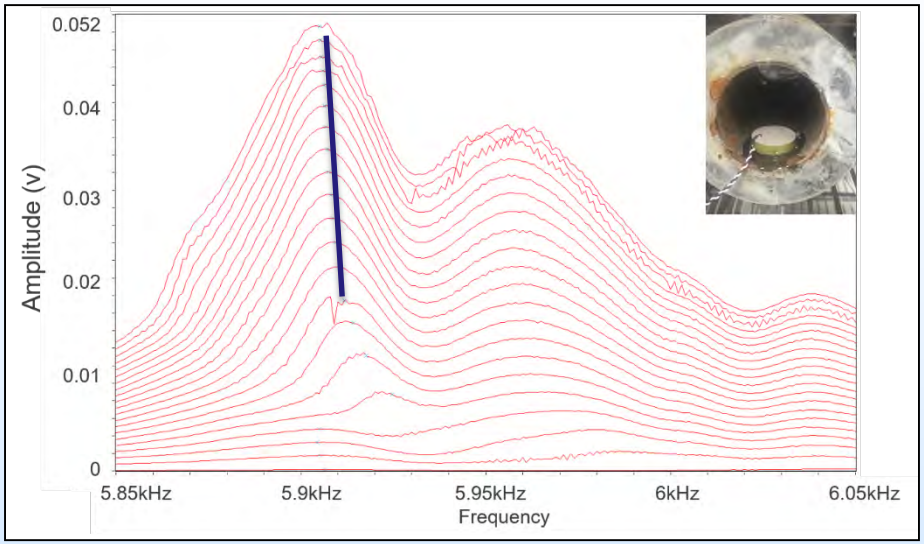
P. B. Nagy (1998)



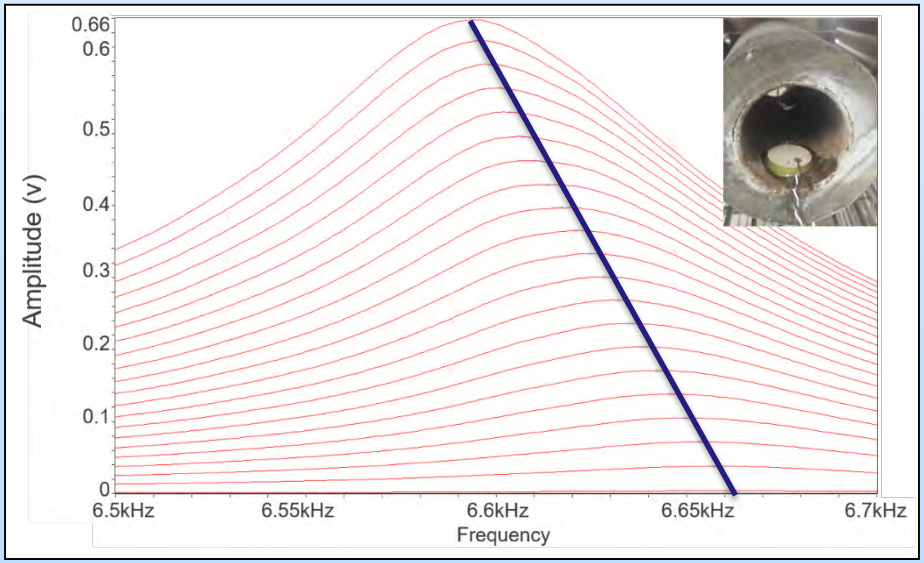
Van Den Abeele *et al.* (2009)

Nonlinear **R**esonant **U**ltrasound **S**pectroscopy

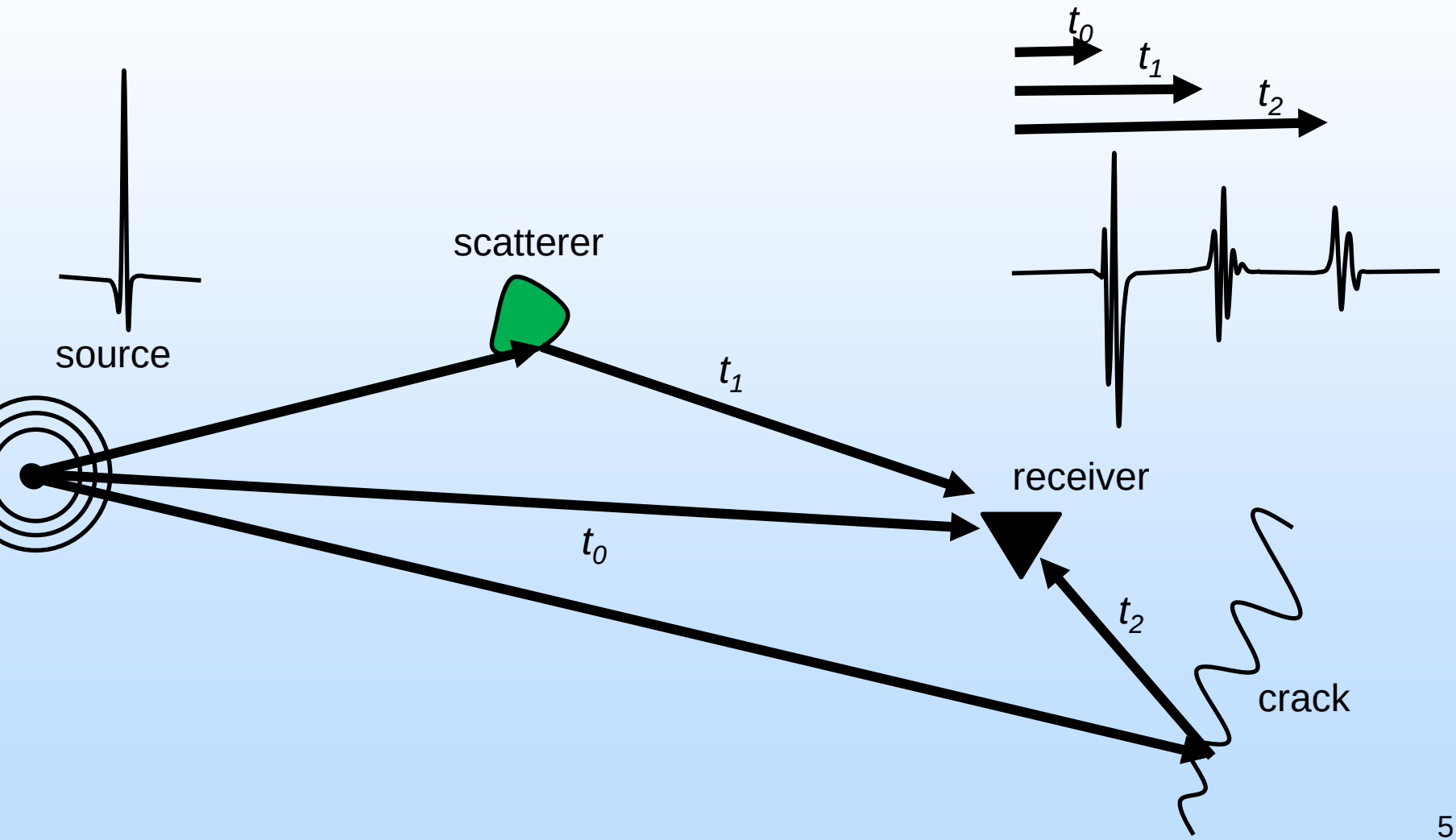
Intact



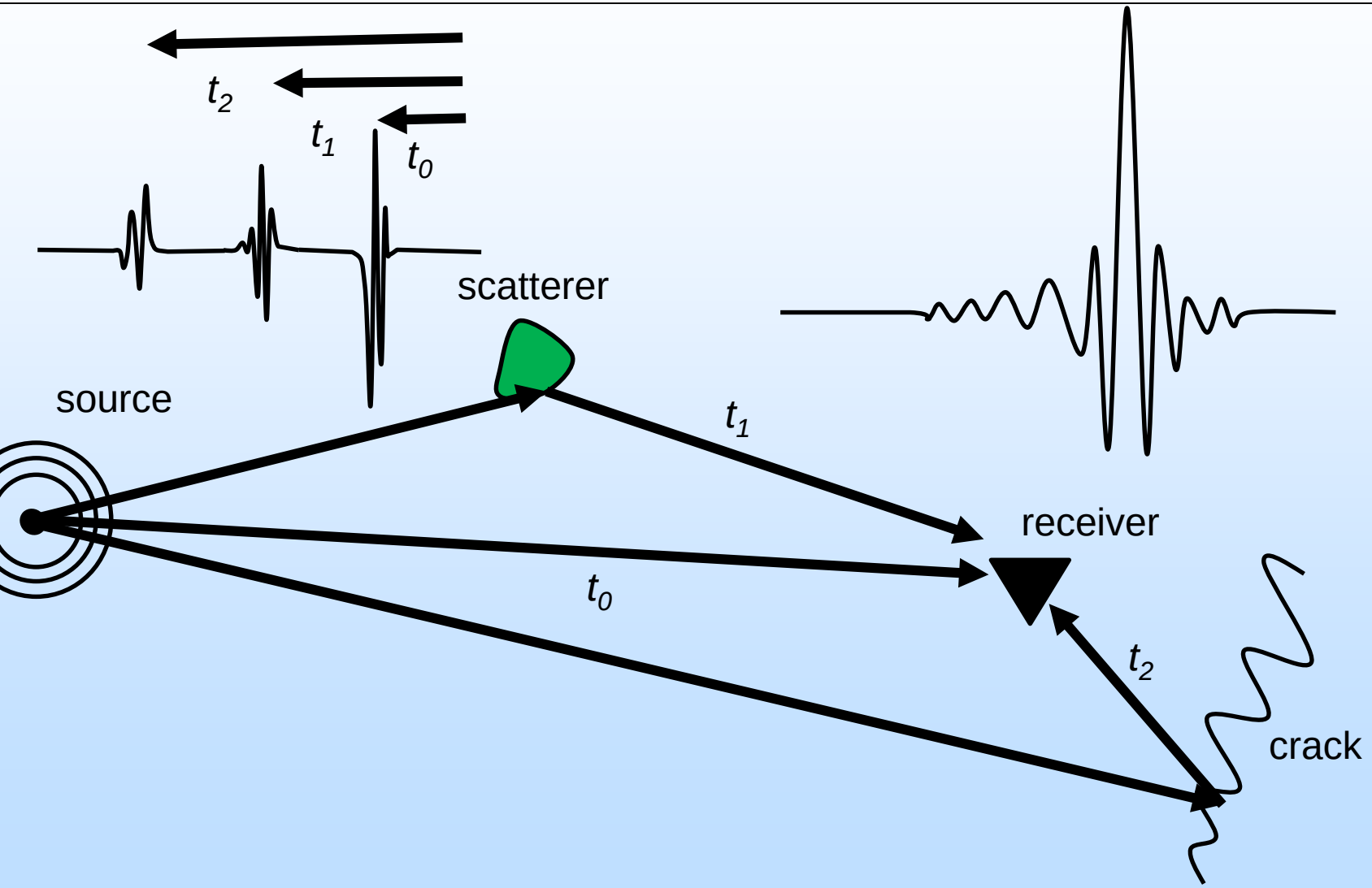
Damaged



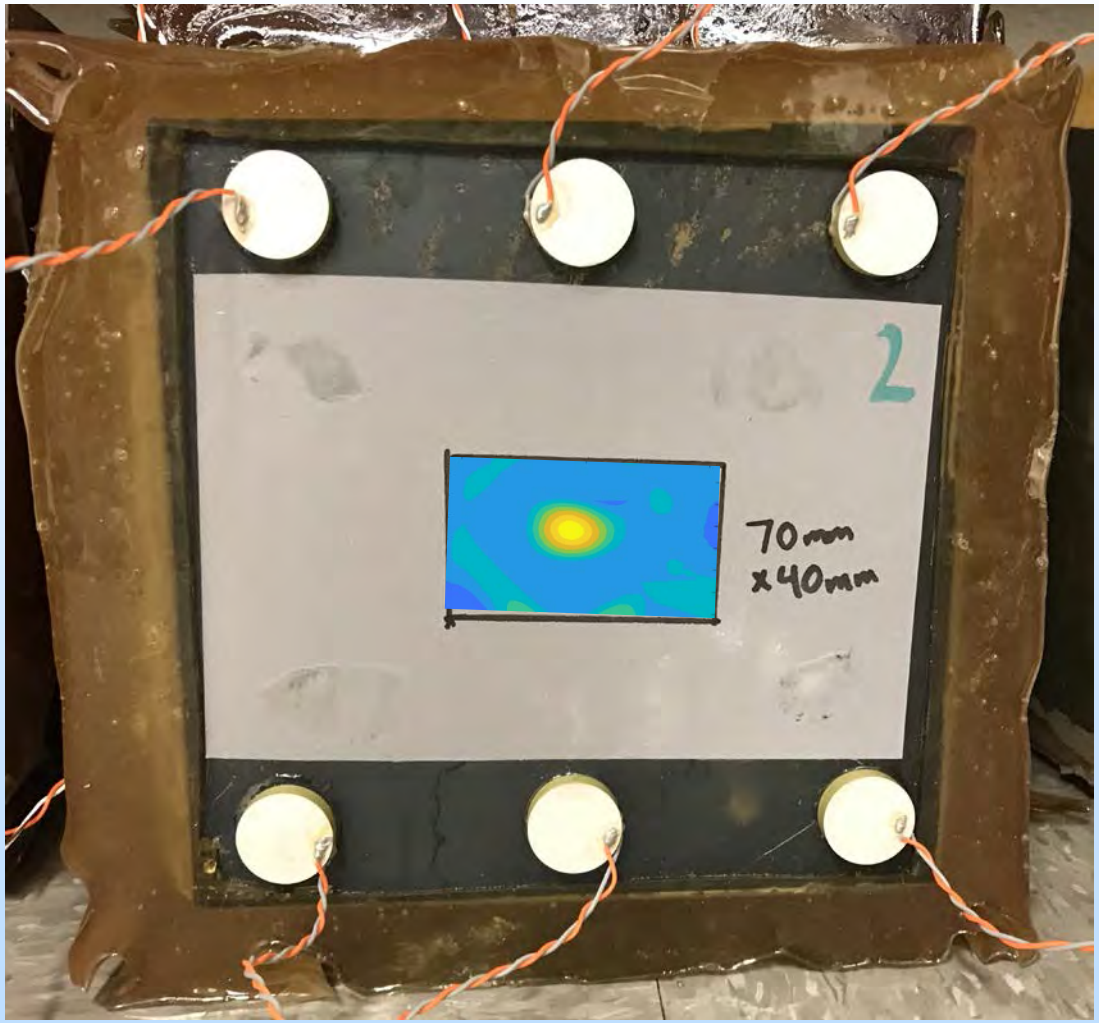
Time Reversal



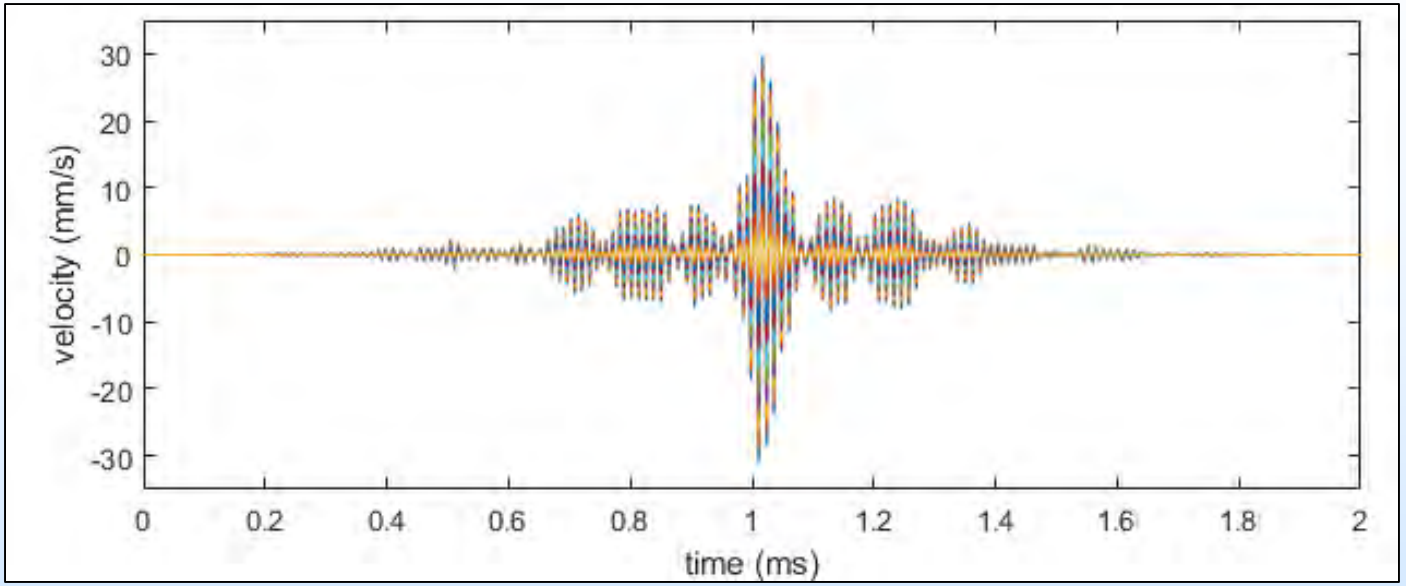
Time Reversal

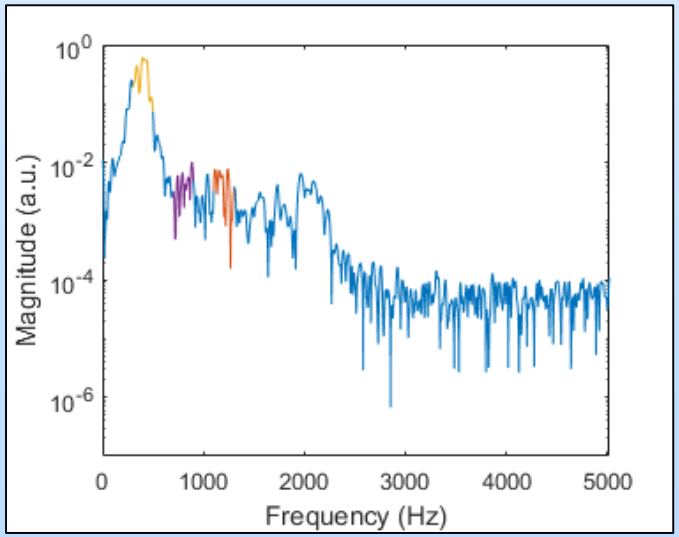


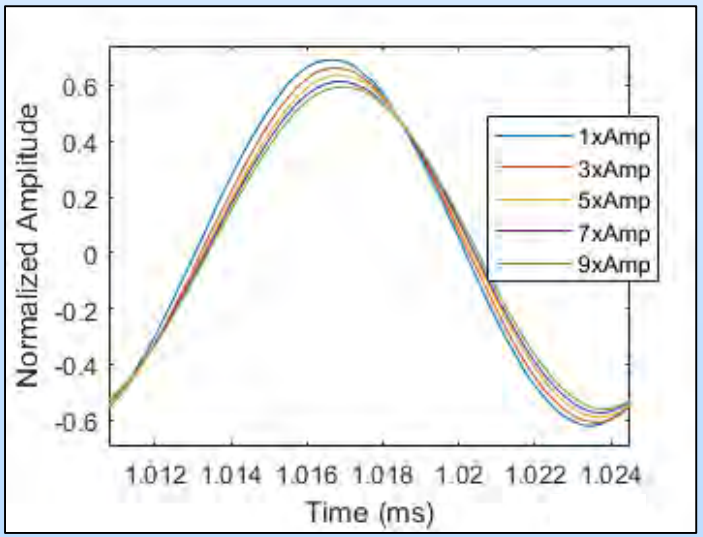
Time Reversal



Time Reversal Elastic Nonlinear Diagnostic





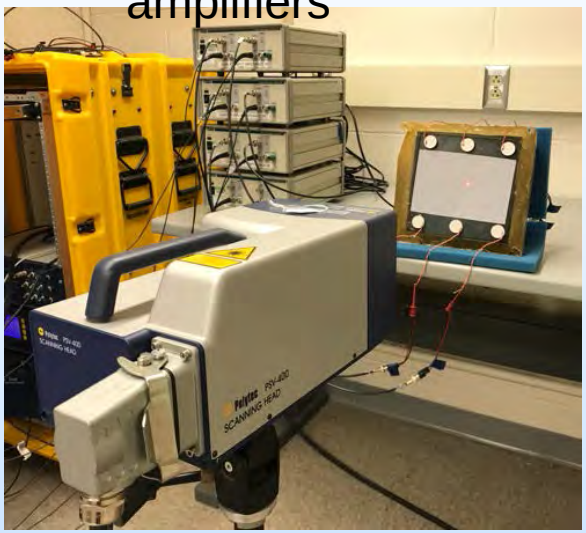


Objectives

- Can we use Time Reversal and nonlinear elastic wave measurement to determine damage in wellbores?
  - Are single point measurements a good indicator of local or global damage?
  - What types of damage can be resolved in a wellbore? Debonding? Corrosion? Cracking?
  - How does the acoustic signal change as a function of confining pressure and fluid type (e.g., gas, oil, water)? Does it change if the fluid is in motion?

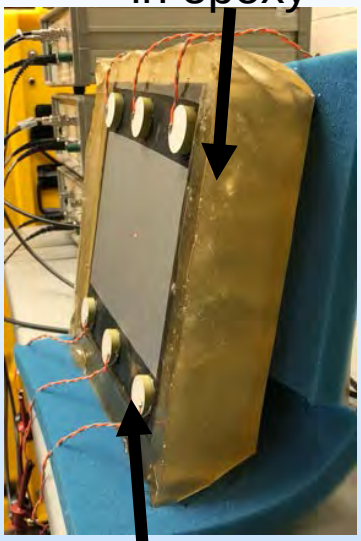
Flat Samples: Experimental Setup

amplifiers

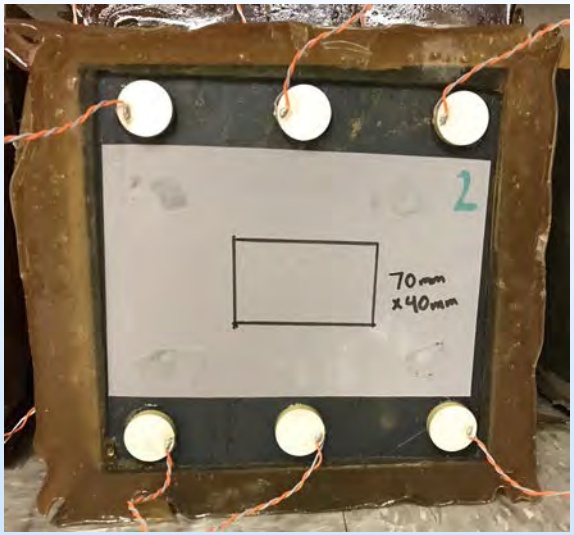


scanning laser vibrometer

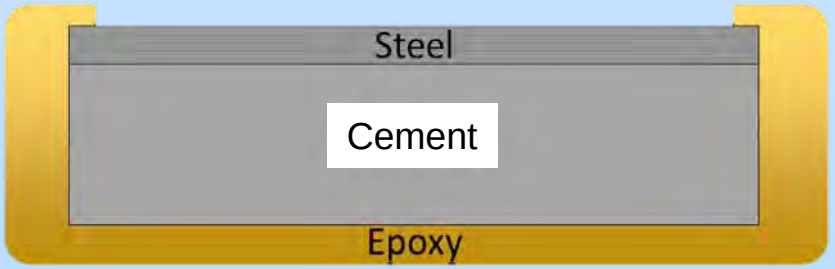
sample encased in epoxy



piezo transducers

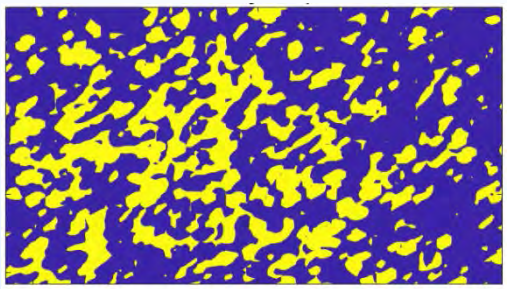


Sample

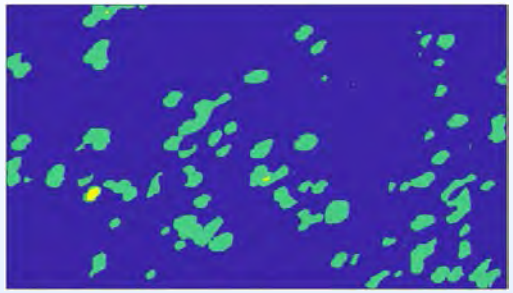


Peak Delay: Intact vs Debonded

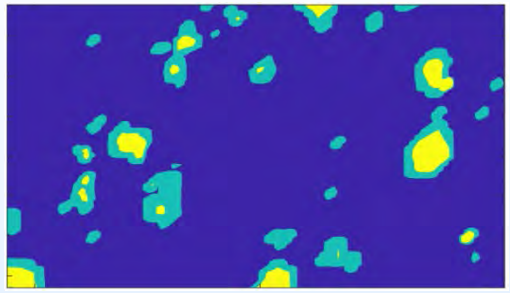
Sample 2 Intact

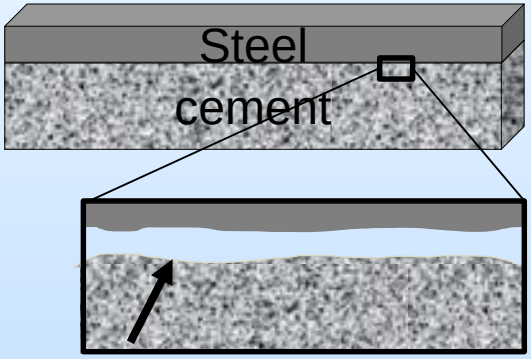


Sample 5 Intact



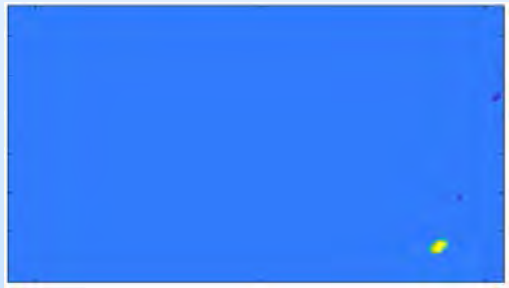
Sample 7 Intact





Debonded

Sample 1 Debonded

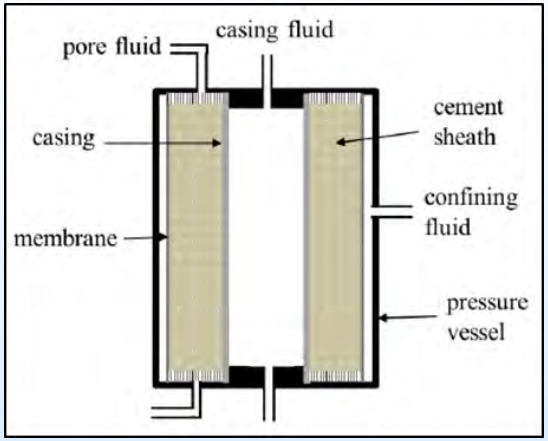


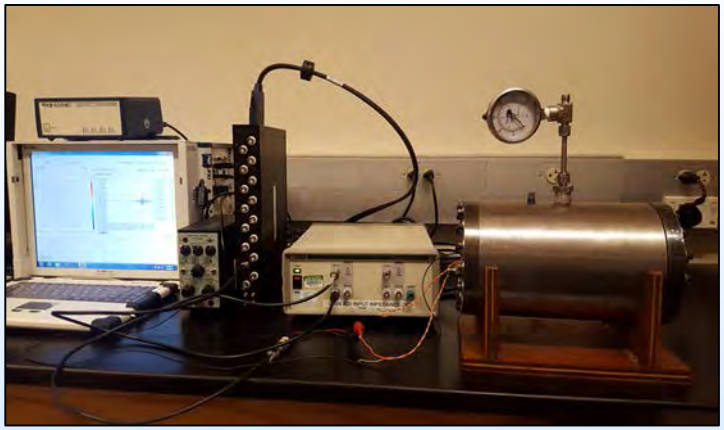
Sample 8 Debonded

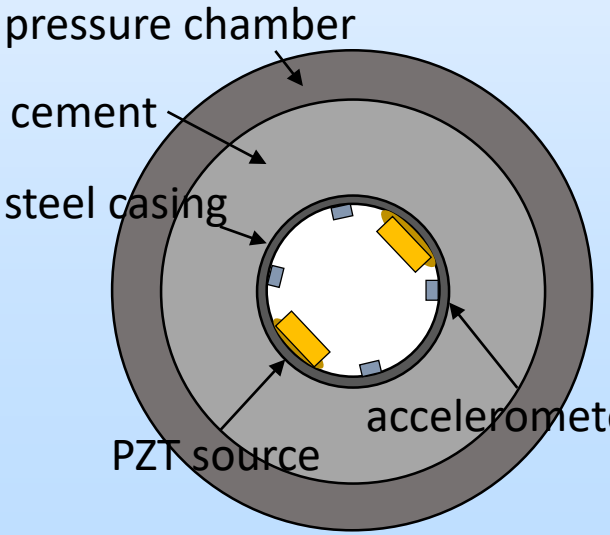
Lessons Learned

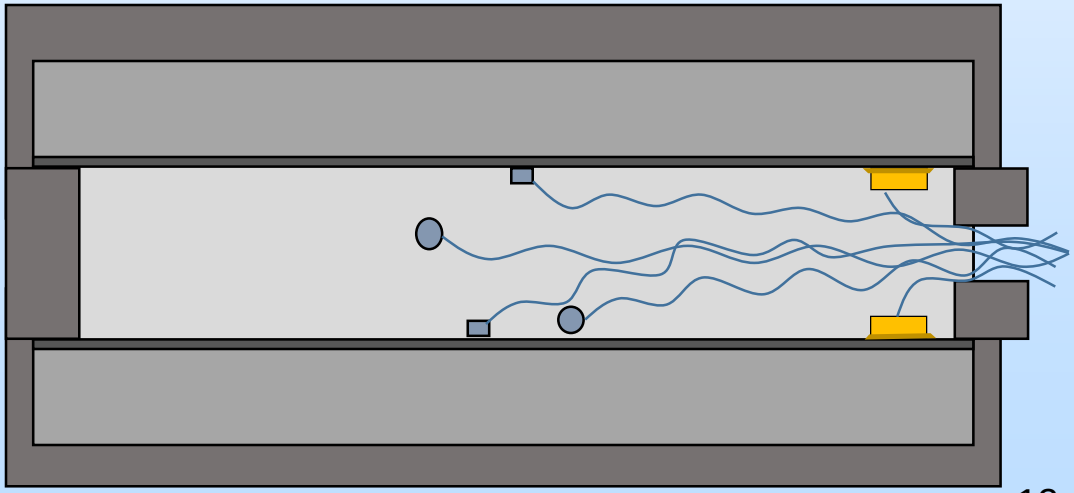
- Imaging via higher harmonics generation did not provide distinction in the samples
- Difficult to create samples that have other types of damage, e.g. corrosion, cracks
- Unable to inspect steel/cement interface without destroying the interface

Wellbore Sections



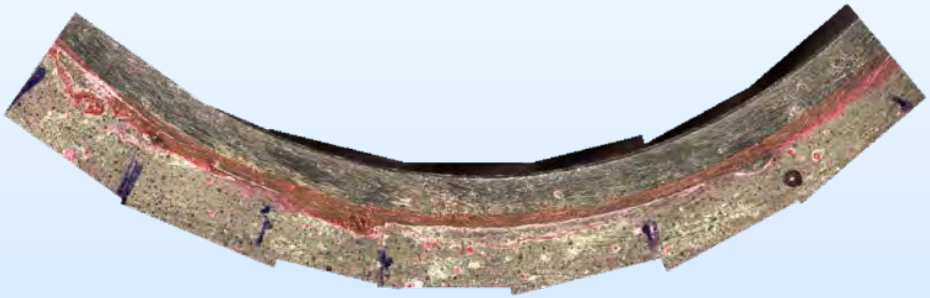




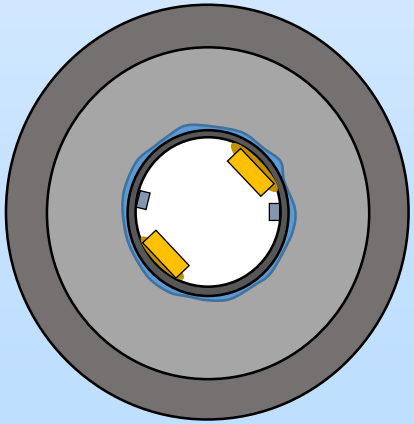


Wellbore Sections

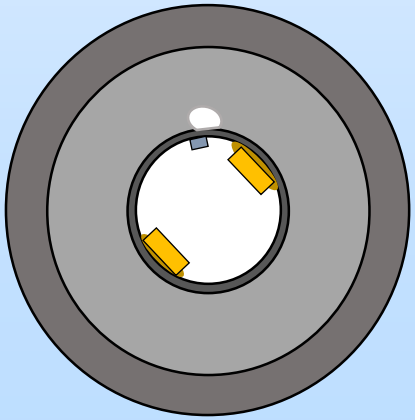
- Measure nonlinear parameters for range of pressures and flow.
- Various defects can be created in wellbore samples.
- Measure using accelerometers adhered to the interior surface.
- Wellbore samples with microannuli are injected with dyed epoxy, then specimen is sliced. Microphotographs are taken around entire circumference and "pieced" together.



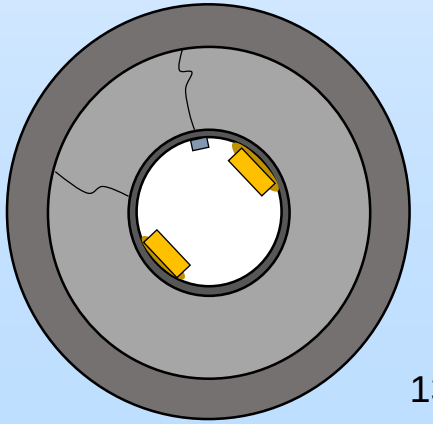
Thermal Debonding



Apertures



Cracks



Accomplishments to Date

- Measured eight flat samples with various damage
- Able to determine if a flat sample is intact or debonded based on nonlinear acoustic signature
- Completed experiments setup to measure nonlinear parameters under pressure and flow, in the process of creating more samples

Lessons Learned

- Different defects cannot be reliably made in flat samples other than debonding.
  - The corroded specimens we tested used a corroded plate and then cement was poured on top. It did not corrode in place, so the bond between the corroded steel and the cement was still good. Need to come up with a better way of making a sample that is similar to a pipe that corrodes in the field.
  - It was also difficult to create cracked flat samples that were similar to those field samples. When we manually cracked them, they also debonded.

- New experimental setup is required for scanning inside a wellbore sample. Fiber optic laser cannot be twisted, or else it misaligns. We have changed to using accelerometer instead, even though it will only be a single point measurement.

Synergy Opportunities

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

- SubTer: *Autonomous Monitoring of Wellbore Integrity Applying Time Reverse Nonlinear Elastic Wave Spectroscopy (TR NEWS) and Fiber Optic Sensing and Communication*

Project Summary

- Time reversal and nonlinear elastic wave measurements can be combined to image flat samples of steel and cement
- We can successfully and repeatedly distinguish between debonded and intact flat samples
- Cylindrical wellbore sections will be tested that are debonded, cracked, and have small apertures
- The wellbore sections will be tested under confining pressure, and with fluid flow to determine how the nonlinear elastic wave measurements change with increasing pressure and with different fluids

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

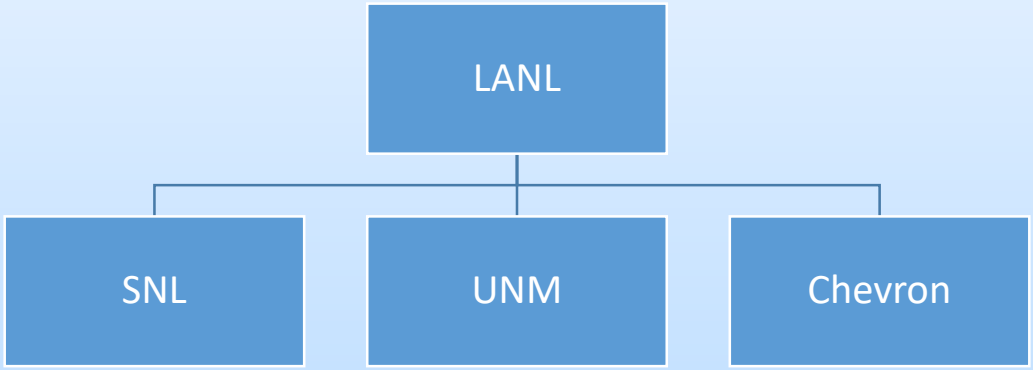
Goals and Objectives

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

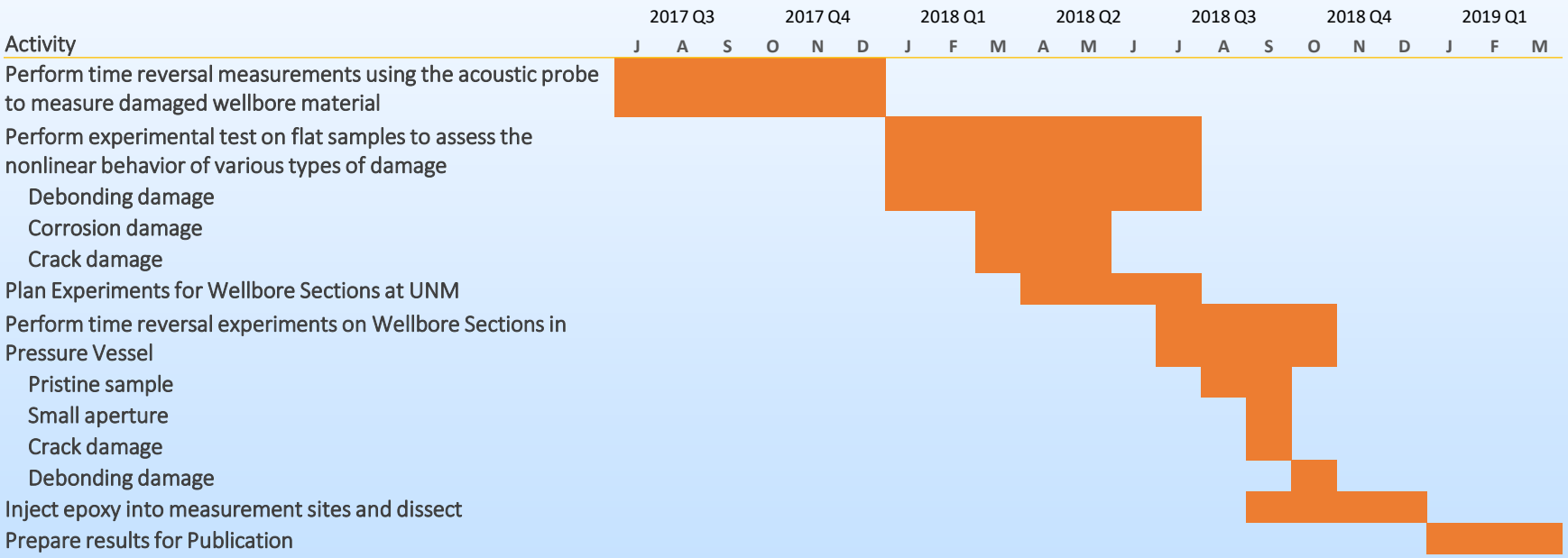
- Goal is to
  - Use of nonlinear acoustics to quantify cracks
  - Use of time reversal with nonlinear acoustics to estimate the orientation of cracks
  - Experiments first on well characterized intact samples then on damaged samples
  - Field experiments to validate the whole method

Organization Chart

- Communication plan:
  - Monthly progress meeting with all participants
  - Regular visits of LANL personnel to UNM and vice versa



Gantt Chart


2017 Q3
2017 Q4
2018 Q1
2018 Q2
2018 Q3
2018 Q4
2019 Q1
Activity
J A S O N D J F M A M J J A S O N D J F M
Perform time reversal measurements using the acoustic probe to measure damaged wellbore material
Perform experimental test on flat samples to assess the nonlinear behavior of various types of damage
Debonding damage
Corrosion damage
Crack damage
Plan Experiments for Wellbore Sections at UNM
Perform time reversal experiments on Wellbore Sections in Pressure Vessel
Pristine sample
Small aperture
Crack damage
Debonding damage
Inject epoxy into measurement sites and dissect
Prepare results for Publication

Bibliography

- State of the art paper with GSCO2 partner has been submitted
- Planning on a second paper based off of the results from pressure chamber