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Title: Acoustic Imaging of Delaminations and Cracks Using Time Reversal and Nonlinear Spectroscopy Techniques

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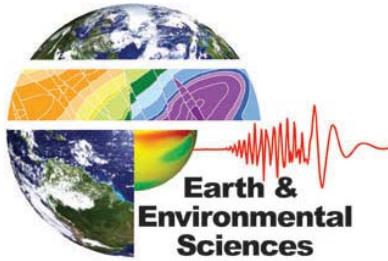
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# Acoustic Imaging of Delaminations and Cracks Using Time Reversal and Nonlinear Spectroscopy Techniques

**LANL EES-17 Acoustics Team:**

**Brian E. Anderson**

**James A. Ten Cate**

**Timothy J. Ulrich**

**Pierre-Yves Le Bas**

# Motivation for Our Work

- China Lake rocket motors (solid fuel) - delaminations between fuel and outer casing.
- Mock propellant manufactured delamination sample.

- We inspect samples at low vibration levels (doesn't further damage the samples).
- We look for delaminations and cracks.
- We're developing a noncontact source to use with our noncontact sensor for inspection of samples.



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# Imagine Reversing the Ripples in a Pond

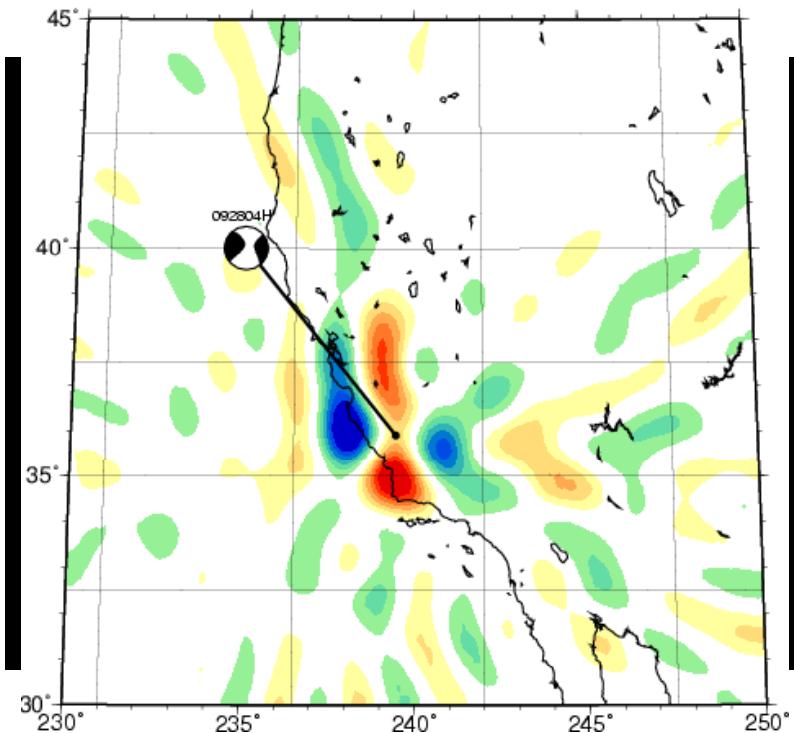
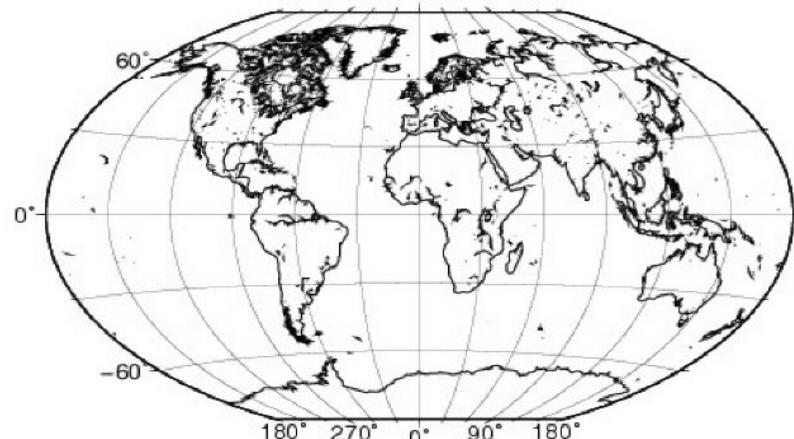
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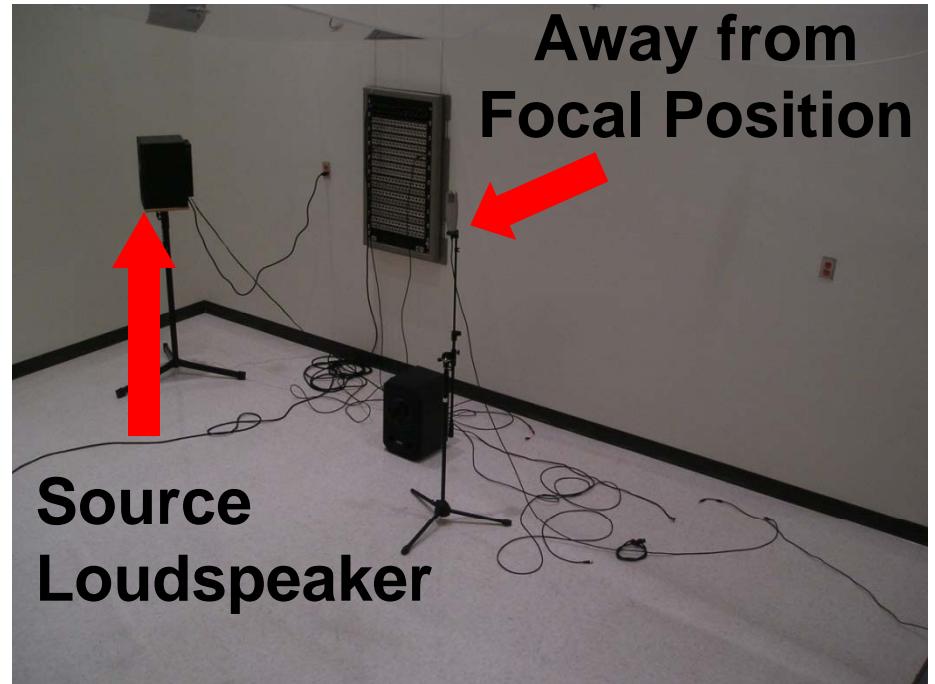
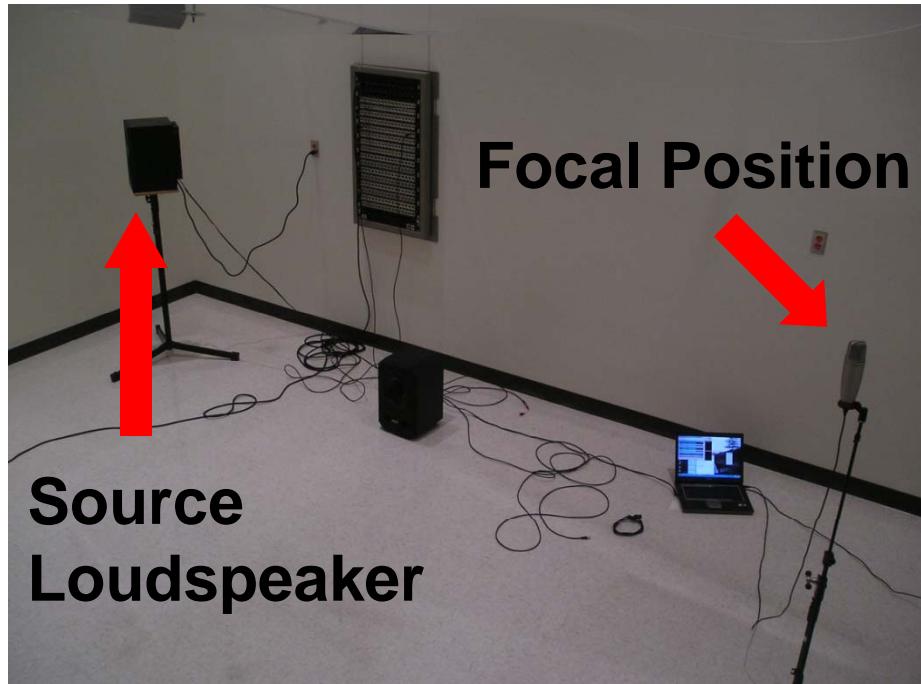
Larmat *et al.*, Geophys. Res. Lett., (2009).  
Anderson *et al.*, Acoust. Today, (2008).

## Time Reversal of Earthquakes

Time : 4914 s



# Audio Demonstration for Speech Privacy



Clap



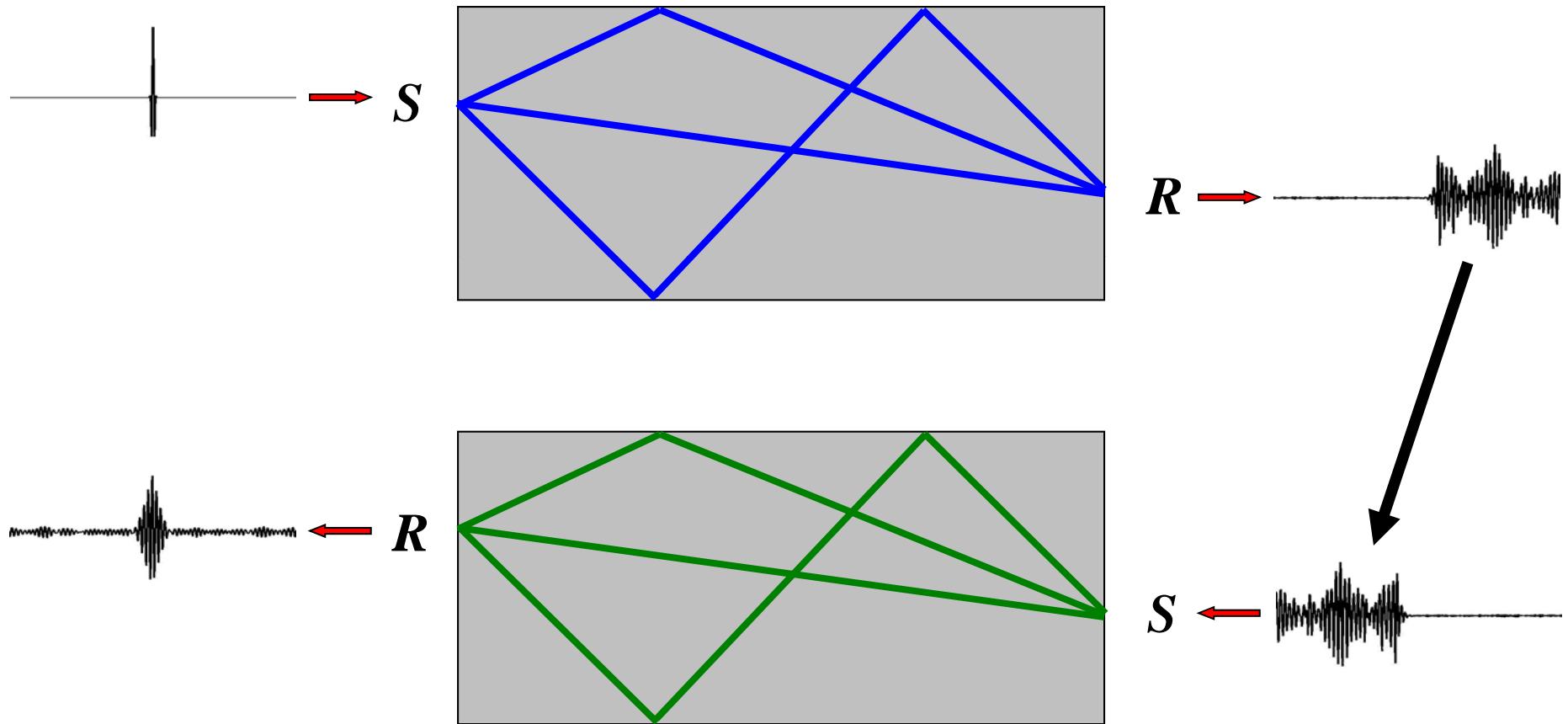
Away



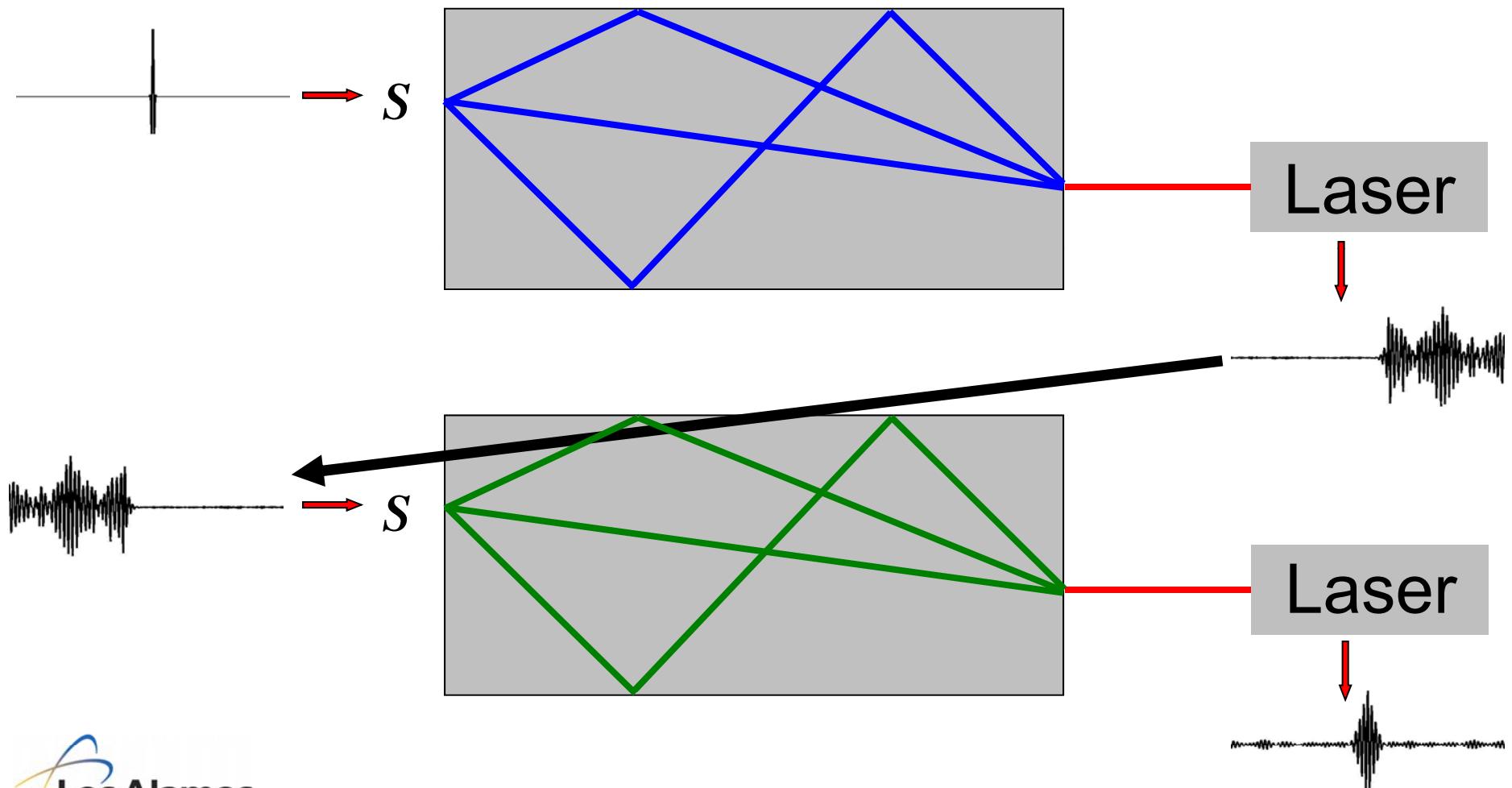
Focus



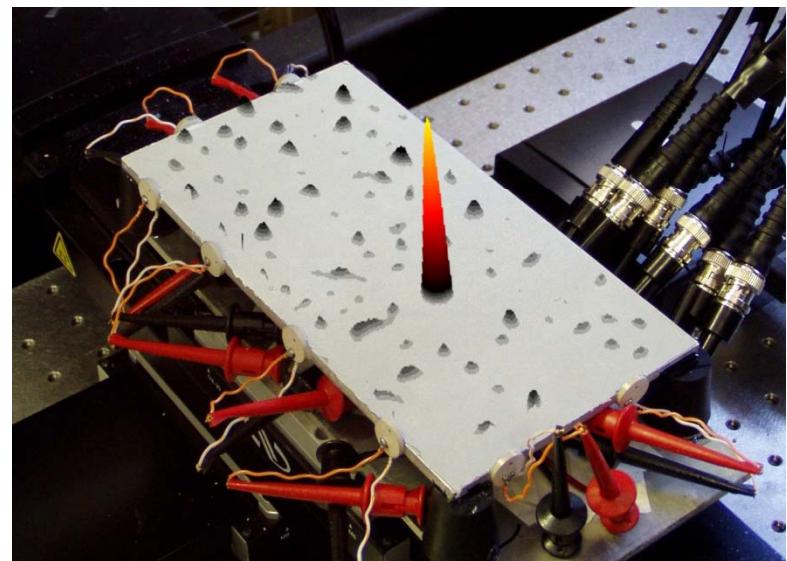
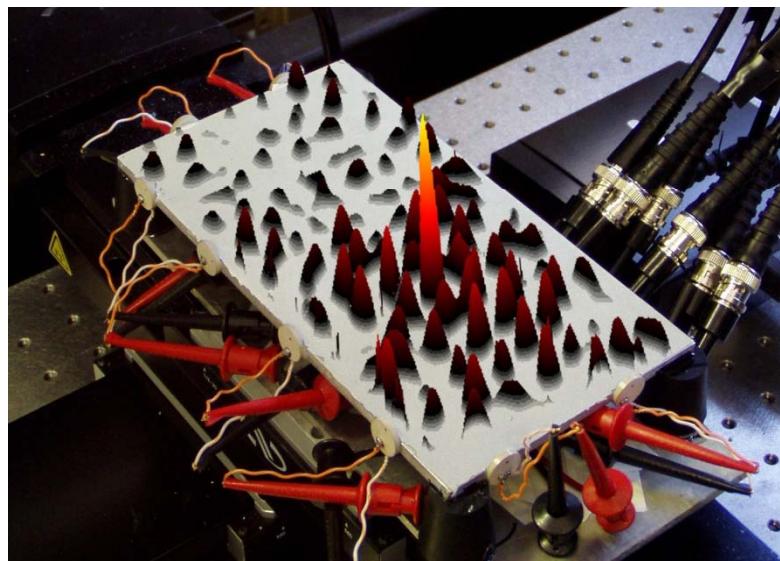
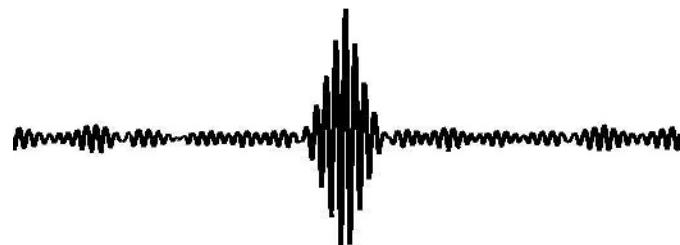
## Standard Time Reversal (Source Reconstruction)



## Reciprocal Time Reversal (High Amplitude Focusing)

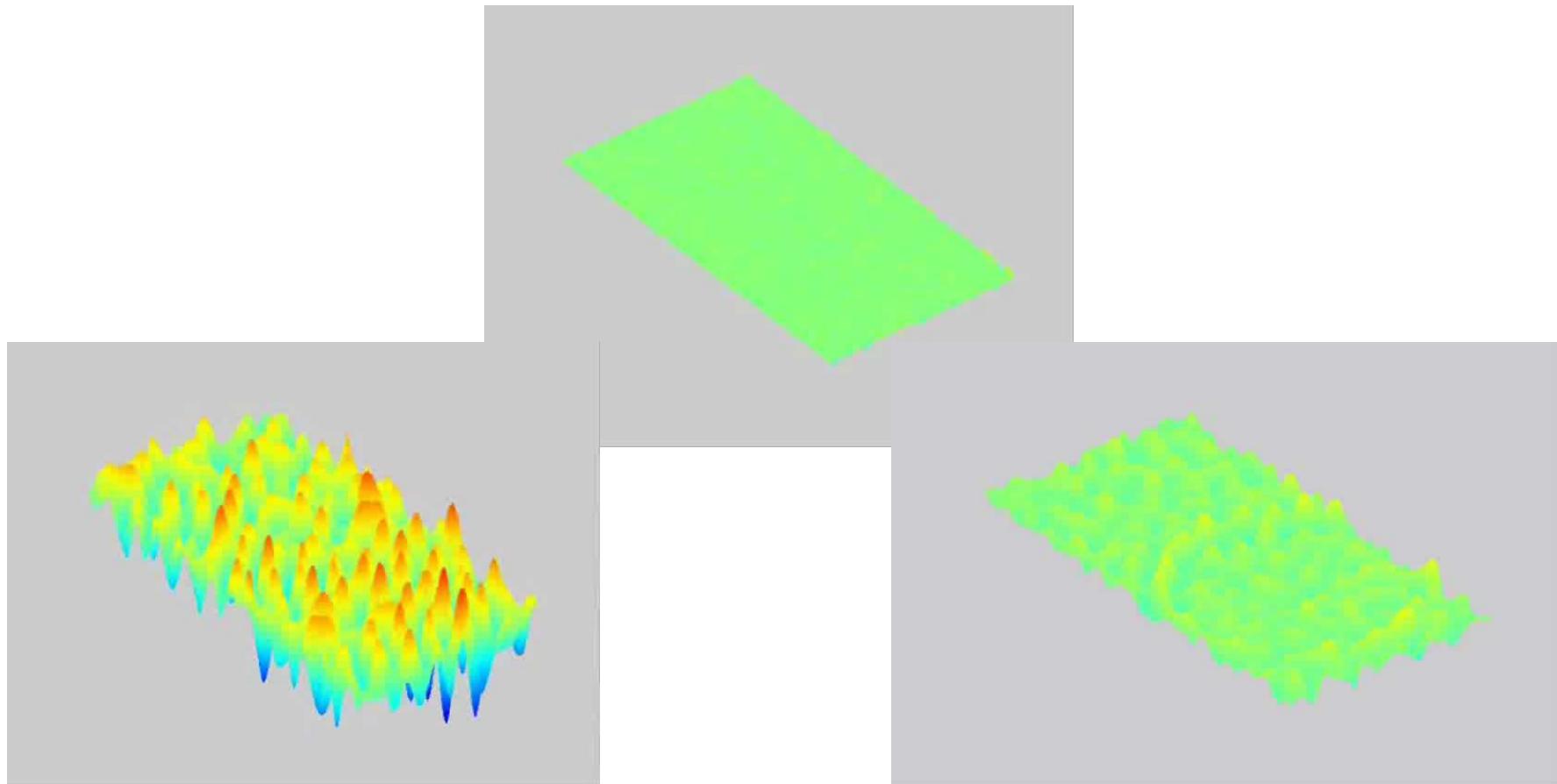


## Comparison of Time Reversal w/ and w/o Deconvolution

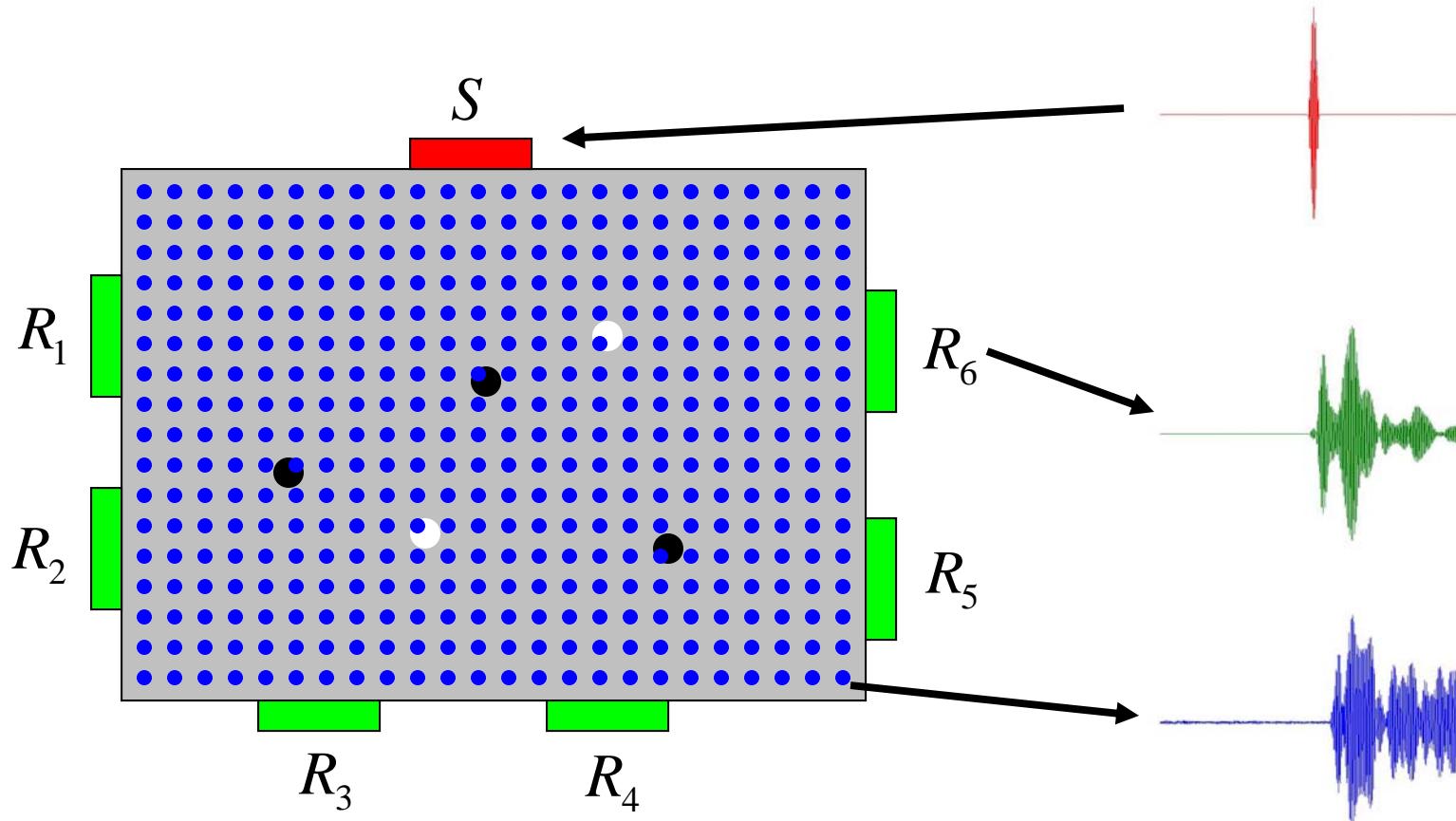


# Time Reversal – Wave Propagation Movies

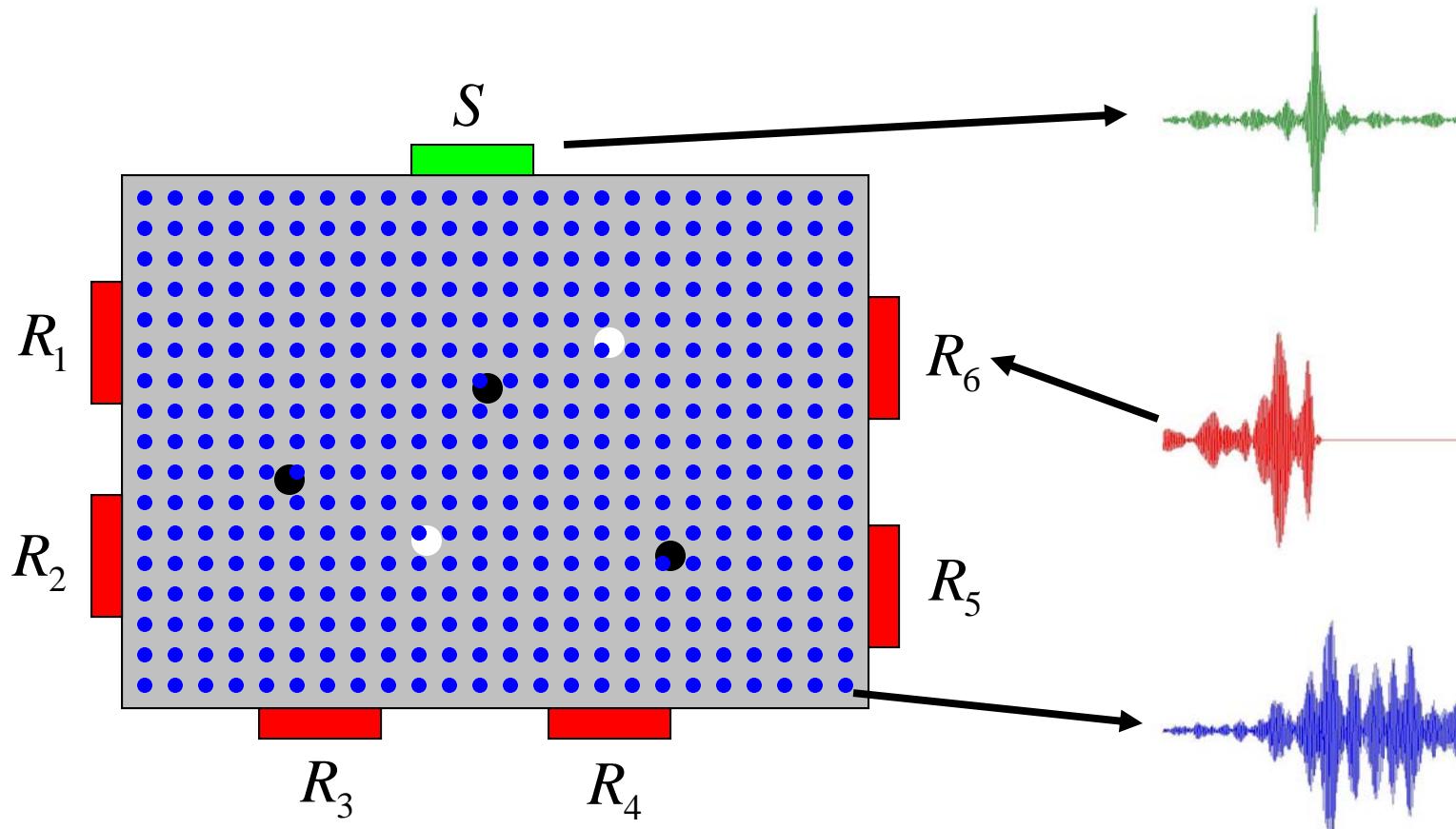
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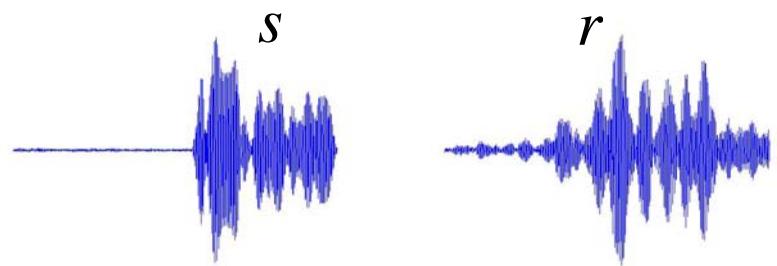
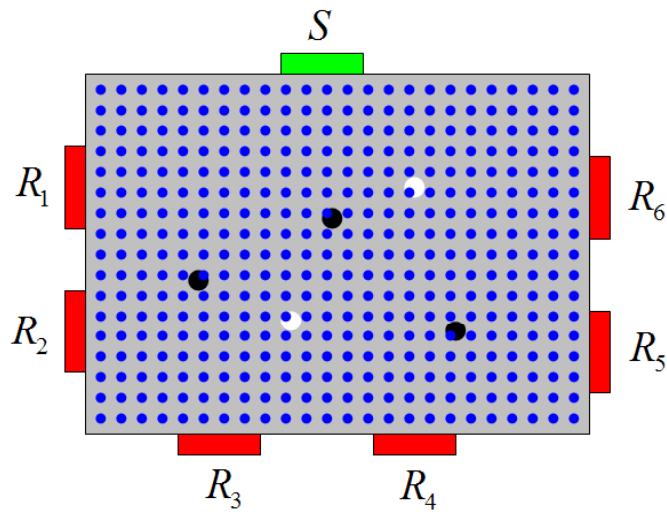
## Reverse Time Migration to Image Delaminations



## Reverse Time Migration to Image Delaminations



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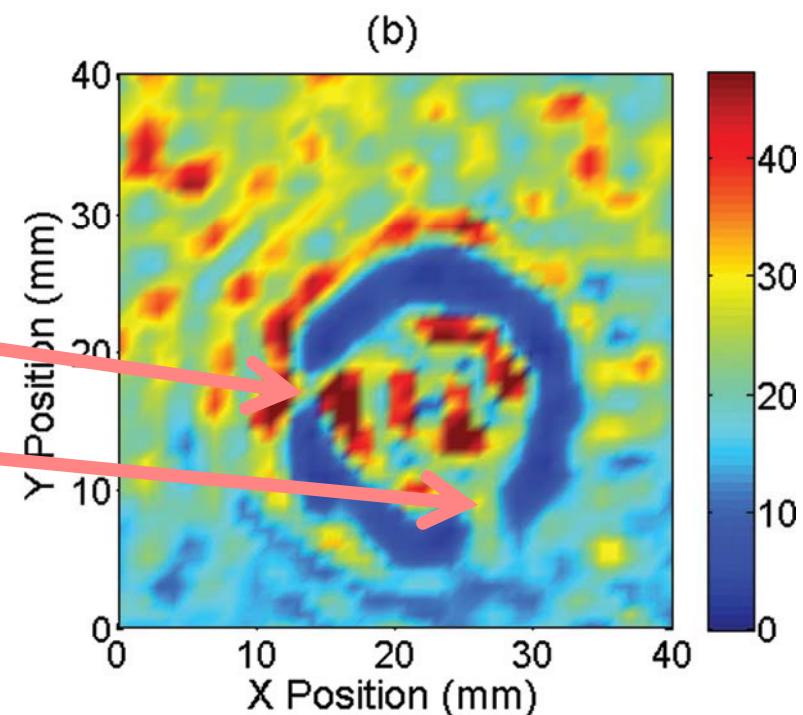
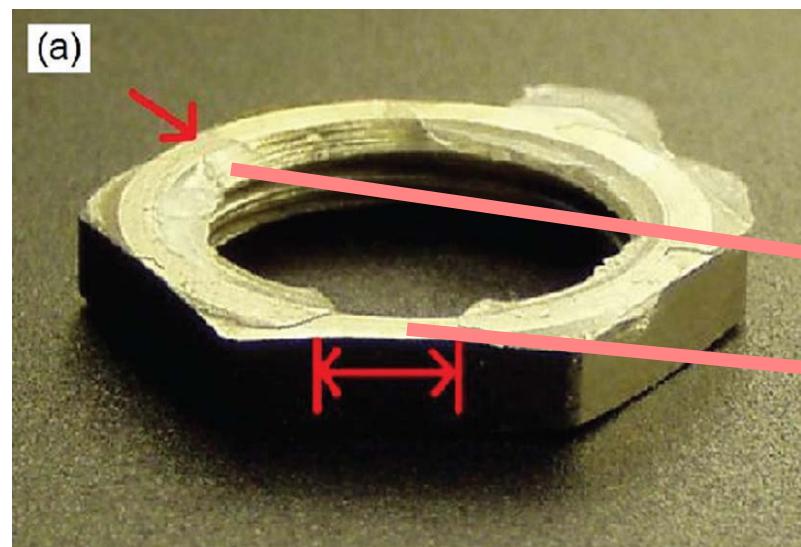
$$IC = \{s(x_s, y_s, t) \otimes r(x_s, y_s, t)\}_{t=0}$$

$$IC = \sum_{i=f_L}^{f_H} |S(x, y, \omega_i) \cdot R(x, y, \omega_i)|$$

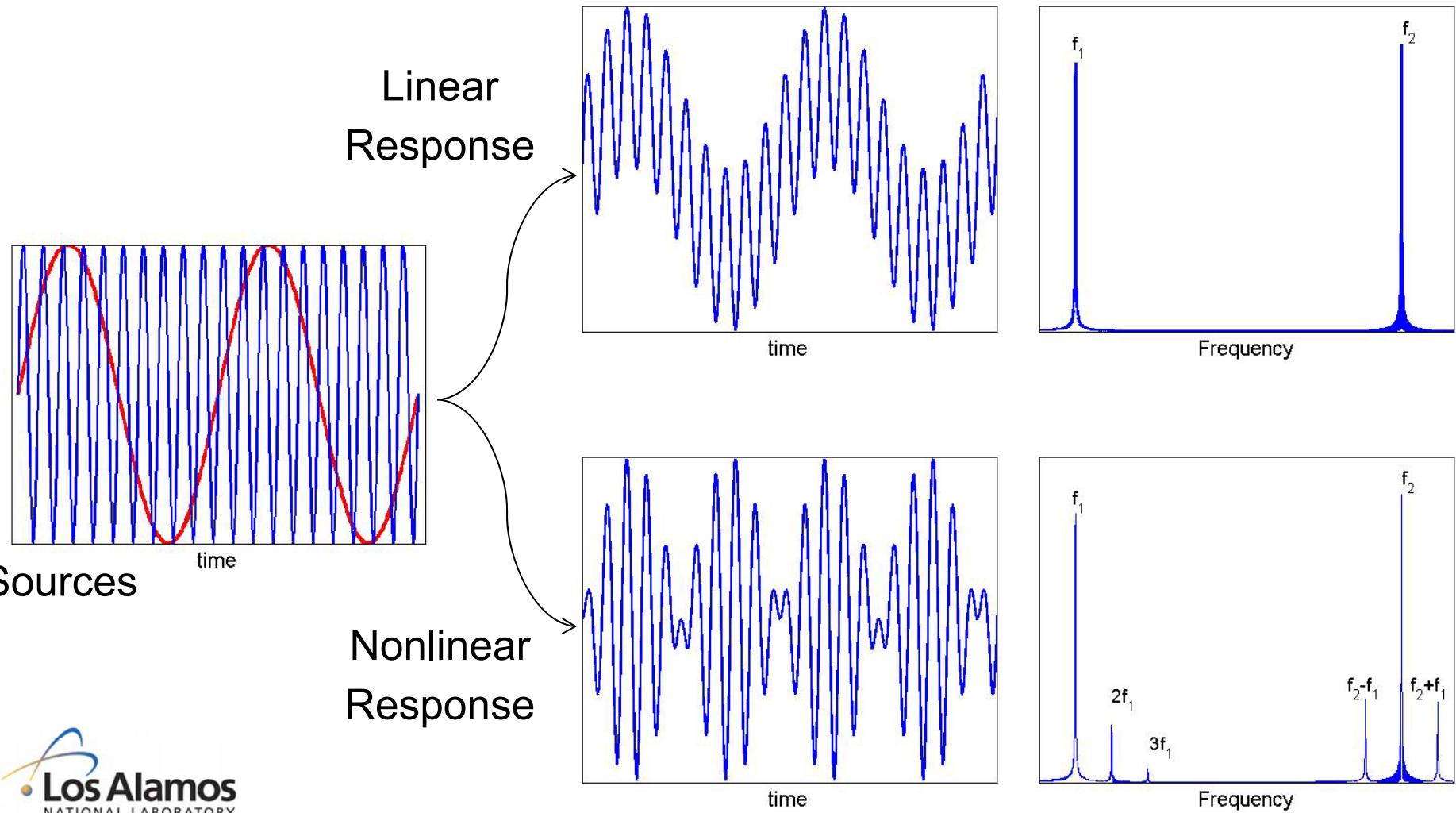
High Impedance Scatterers  $\rightarrow$  Minima

Low Impedance Scatterers  $\rightarrow$  Maxima

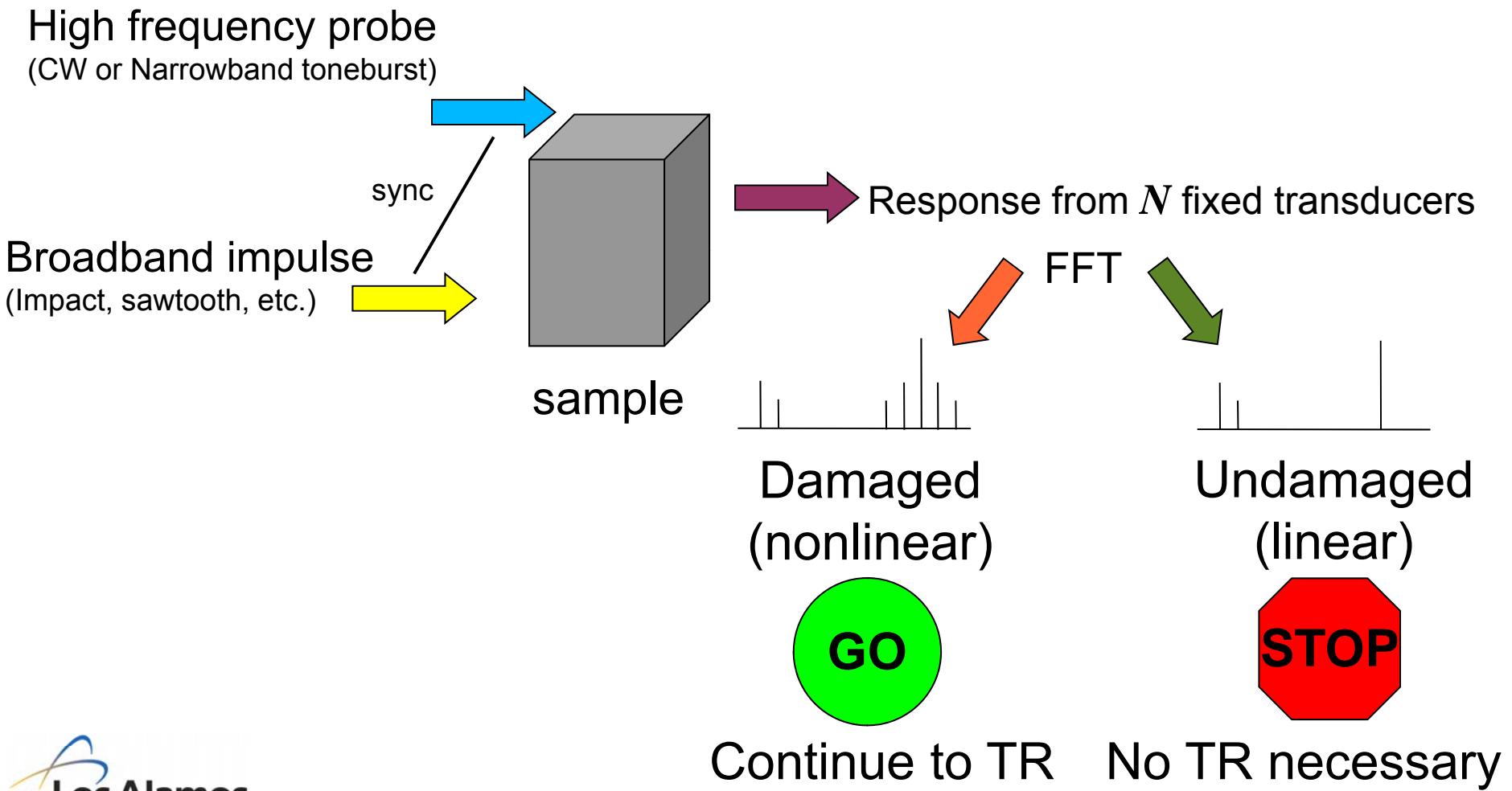
## Reverse Time Migration to Image Delaminations



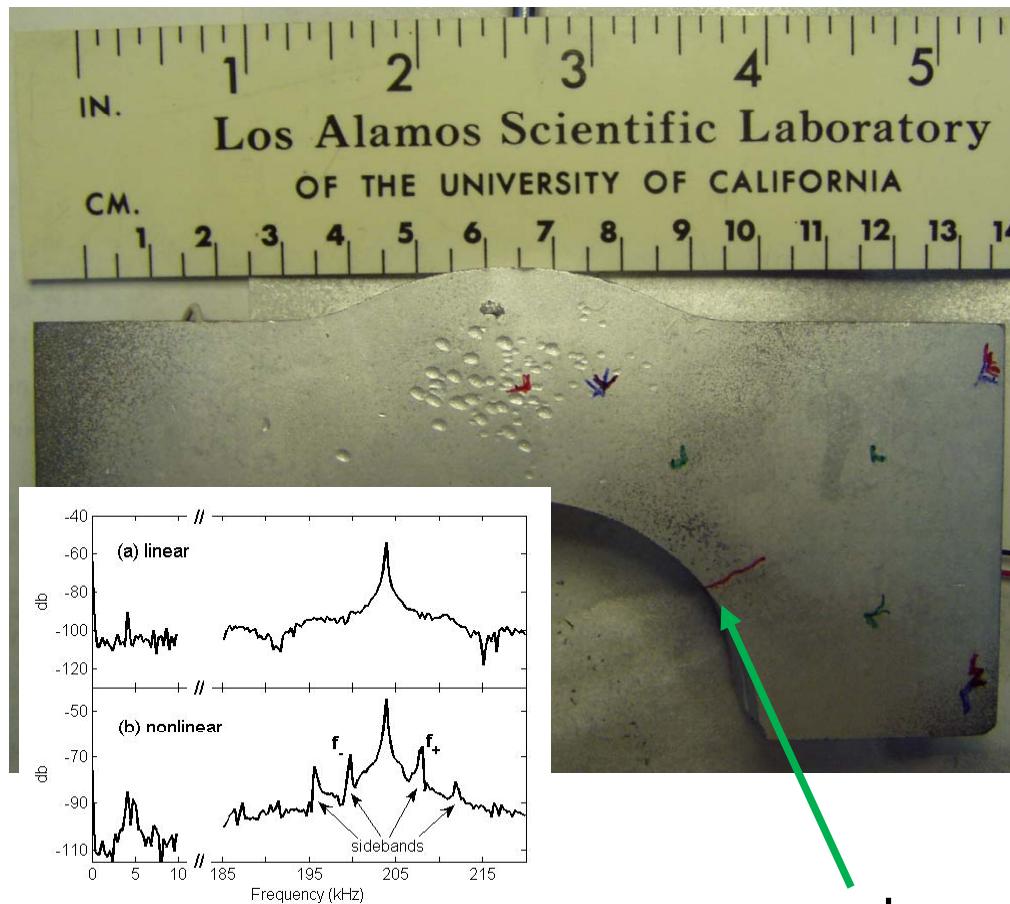
# Nonlinear Wave Modulation & Harmonic Generation



# Damage Diagnosis through Nondestructive Evaluation (Nonlinear Techniques)

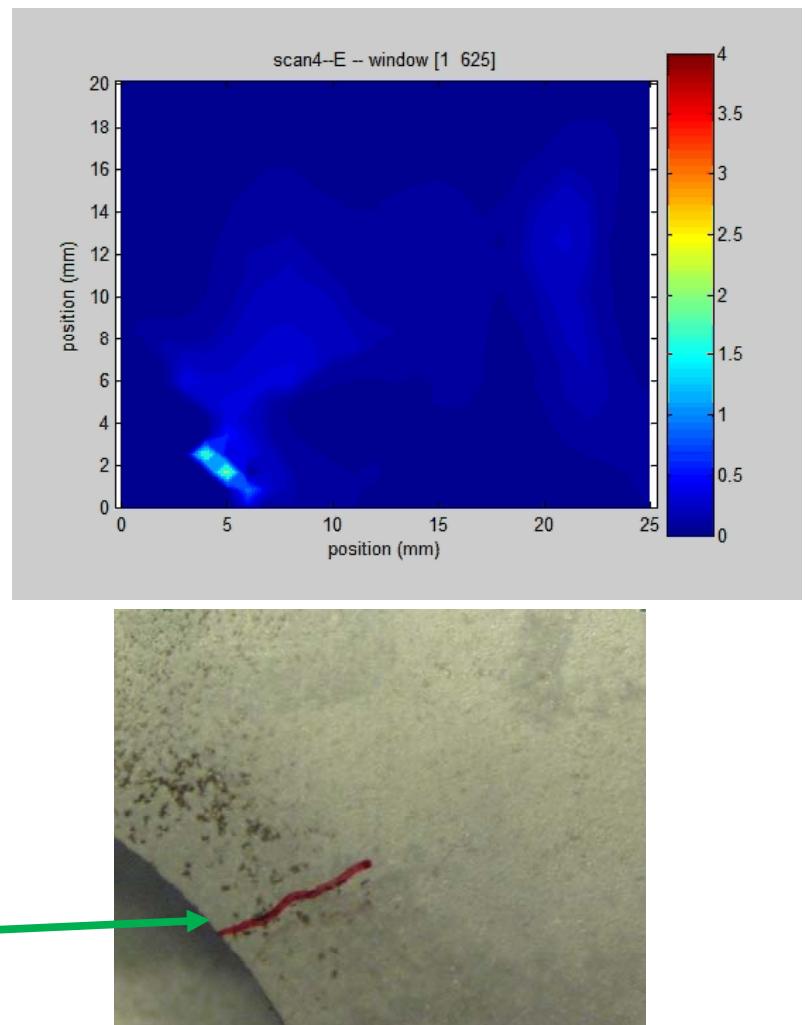


## Imaging of a Crack Using Time Reversal



Operated by Los Alamos National Security, LLC for the U.S. Department of Energy's NNSA

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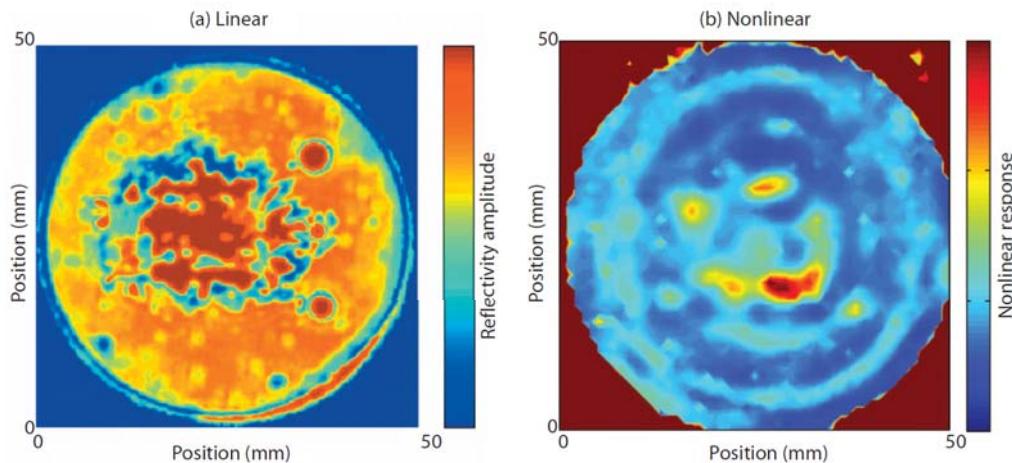


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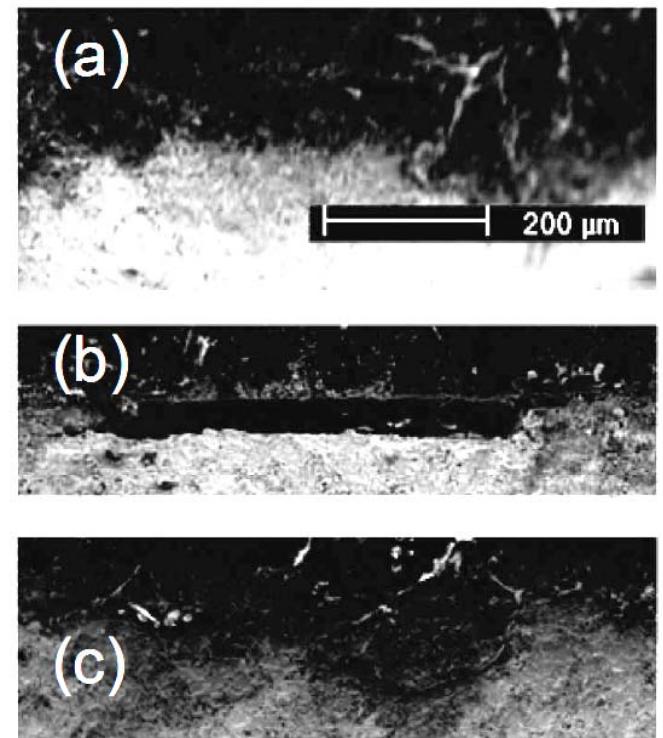


# Imaging of Delamination Edges Using Time Reversal and Nonlinear Spectroscopy

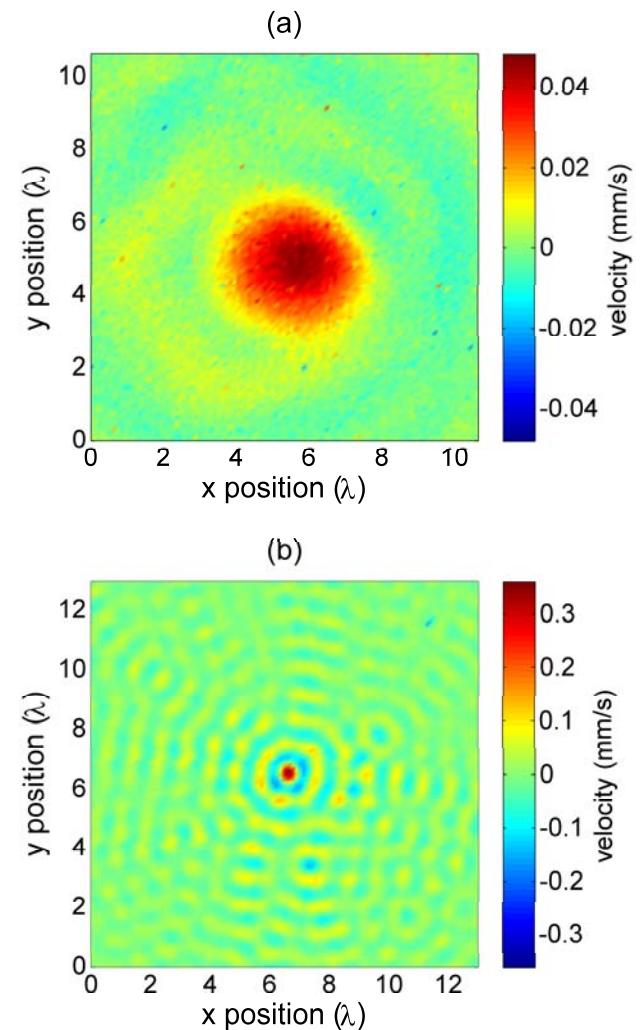
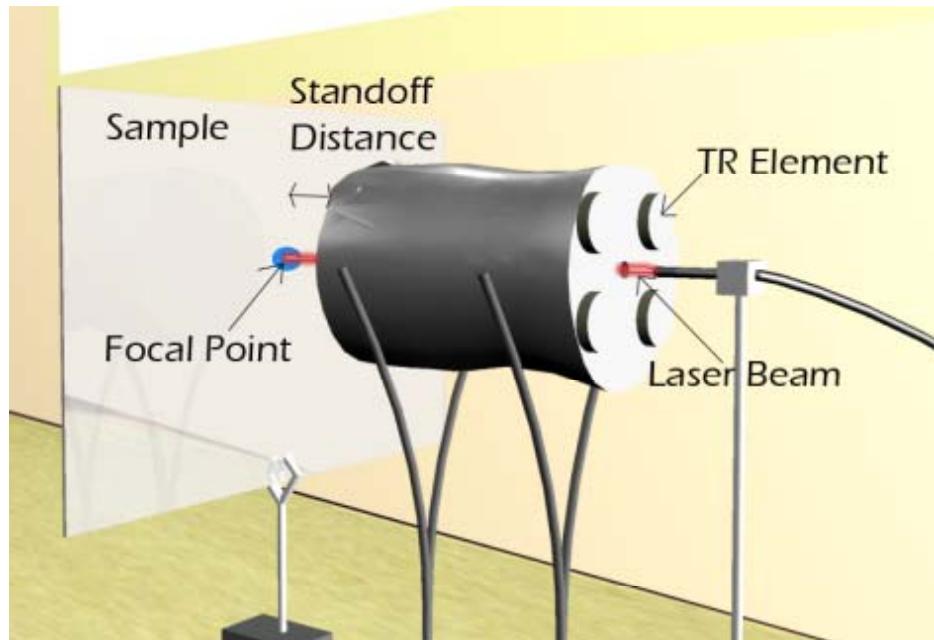
- Two metal disks were diffusion bonded together.
- A linear C-scan imaged voids.
- A nonlinear TR scan imaged edges.
- Small cores were taken to verify findings.



SEM Photos

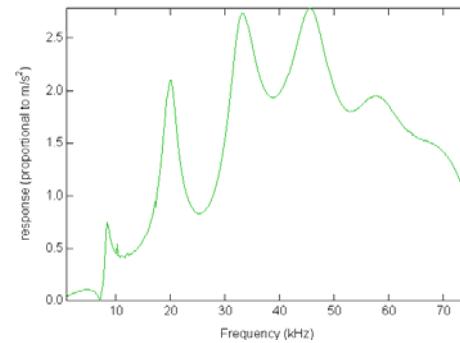


## Time Reversal Acoustic Noncontact Source



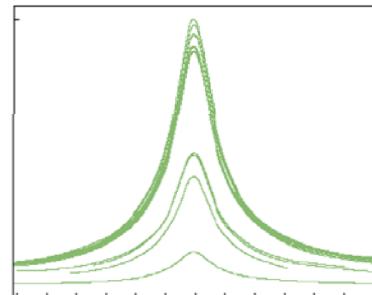
# Material Property Determination: RUS & NRUS

- We measure elastic properties of samples using Resonant Ultrasound Spectroscopy (RUS).

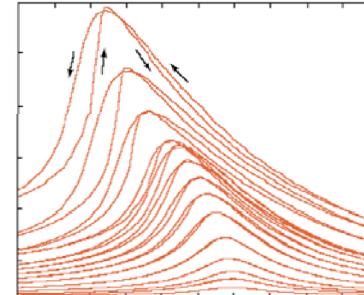


- We also measure the nonlinearities in a sample (crack density, damage indicator, etc.) using Nonlinear Resonant Ultrasound Spectroscopy (NRUS).

Linear  
(undamaged)



Nonlinear  
(damaged)



$f$  ←  $\Delta f$  ←  $f$   
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# Conclusions

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- Time reversal yields source localization and source characterization, or it may be used to focus high amplitude sound for damage interrogation.
- We use linear and nonlinear acoustic techniques to locate delaminations and cracks.
- Our nonlinear techniques are very sensitive to damage detection.
- Noncontact acoustic source allows sample inspection without contact.
- The goal is to be able to inspect samples for delaminations and cracks without touching them.