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Title:	Time Reversal and Nonlinear Elastic Wave Spectroscopy: Methods, Technologies and Applications
Author(s):	Timothy J. Ulrich II
Intended for:	Collaborative workshop between LANL and IPGP, sponsored by EES, held in Santa Fe

Los Alamos
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EST. 1943

Form 836 (7/06)

Time Reversal and Nonlinear Elastic Wave Spectroscopy: Methods, Technologies and Applications

Over the last 15 years Nonlinear Elastic Wave Spectroscopy (NEWS) has emerged as the most sensitive set of techniques for early detection of mechanical damage. Another recent focus in acoustics research is a technique called Time Reversal (TR) for focusing and/or locating sources of wave energy. Combining the abilities of TR and NEWS provides new capabilities to detect, locate and image defects such as cracks, delaminations and disbonds with high precision. The work reviewed here comprises the results from several studies focused on the combination of TR and NEWS and various methods and technologies spawned from these studies. Additionally, current and potential applications in fields of medicine, biology, seismology, engineering and others will be discussed.

Timothy James (TJ) Ulrich II obtained is Ph.D. in Physics at the University of Nevada Reno (UNR) after an M.S. degree in Physics and a B.S. in Materials Science and Engineering, also at UNR. Ulrich came to LANL in 2005 as a post-doc, and later became a staff member (Research Scientist) in 2008. His work includes developing new acoustics-based experimental tools and techniques for materials characterization and nondestructive evaluation as well as developing instrumentation, software and performing experiments in support of laboratory mission projects. He is widely recognized as one of the main developer of experimental techniques for nonlinear acoustic, time reversal and combinations of the two. He has been recognized as a Mackenzie scholar of Physics, a Regents scholar and a NASA Space Grant Student Fellow while at UNR. Since coming to LANL Ulrich has been invited numerous times (2005, 2006, 2007) by the Center National de la Recherche Scientifique - CNRS in Paris as a visiting scholar. His work has been recognized at LANL in multiple LANL Achievement Awards for his scientific contributions (2008 - 2010), including awards for "demonstrated excellence through peer-reviewed publications" and "technological advances in acoustic sensing and imaging."

Photo:

Time Reversal and Nonlinear Elastic Wave Spectroscopy

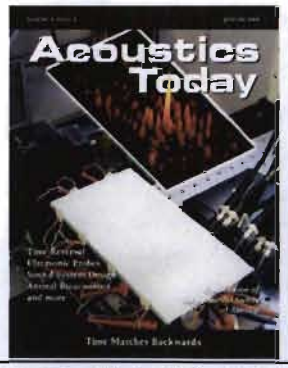
Methods, Applications and Technologies

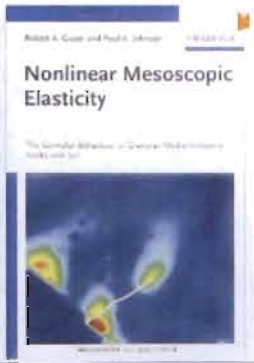
TJ Ulrich

May 3, 2011

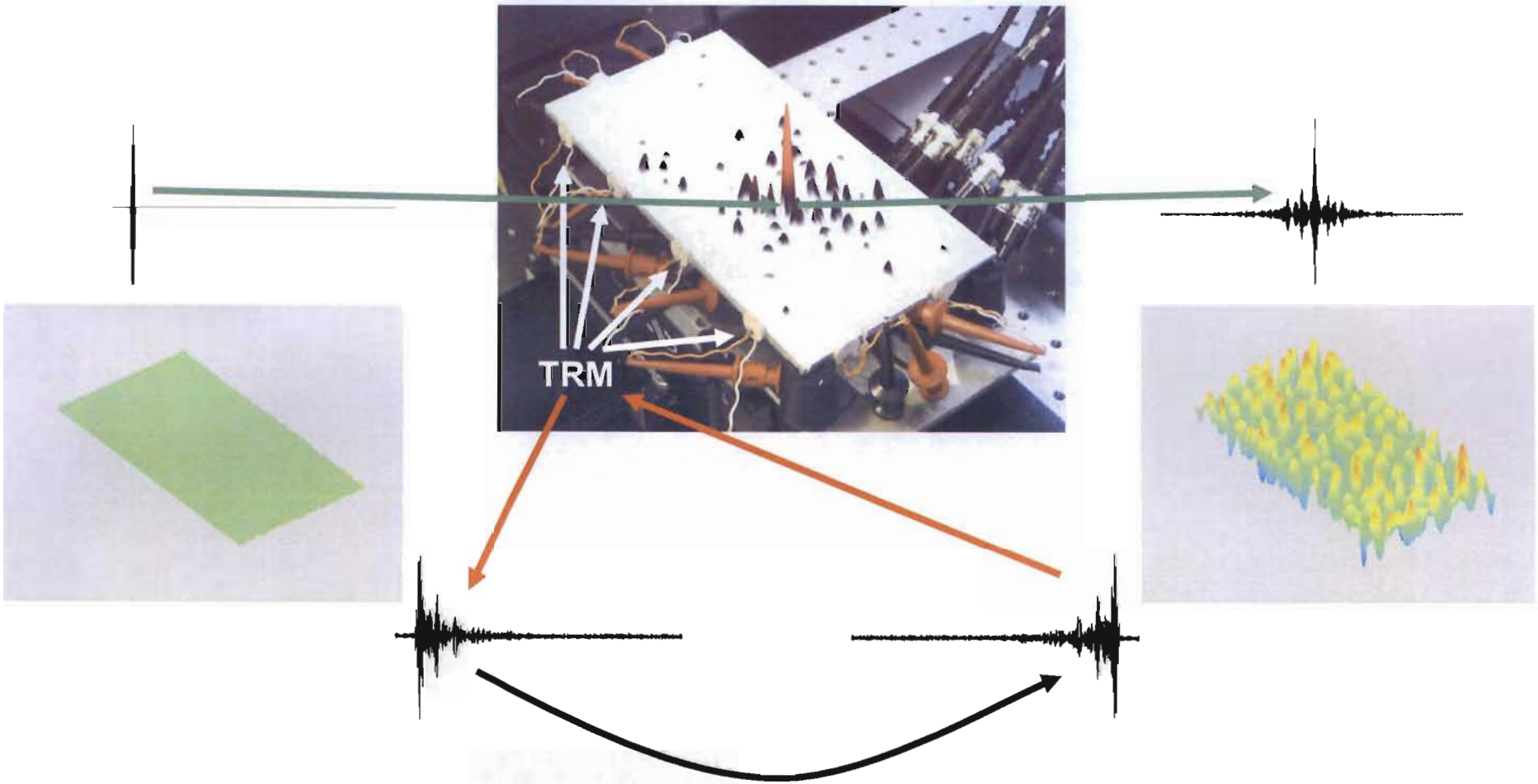
TR Team & Collaborators

- **EES-17**
  - Pierre-Yves Le Bas
  - Carene Larmat
  - Michele Griffa (now @ ETH Zurich)
  - Brian Anderson (now @ BYU)
  - James TenCate
  - Robert Guyer (also @ UNR)
  - Paul Johnson
- **University Paris VI**
  - Jacques Rivière
  - Pascal Laugier
- **KU Leuven (Kortrijk)**
  - Koen Van Den Abeele
- **Polytecnico di Torino**
  - Marco Scalerandi
  - Antonio Gliozzi



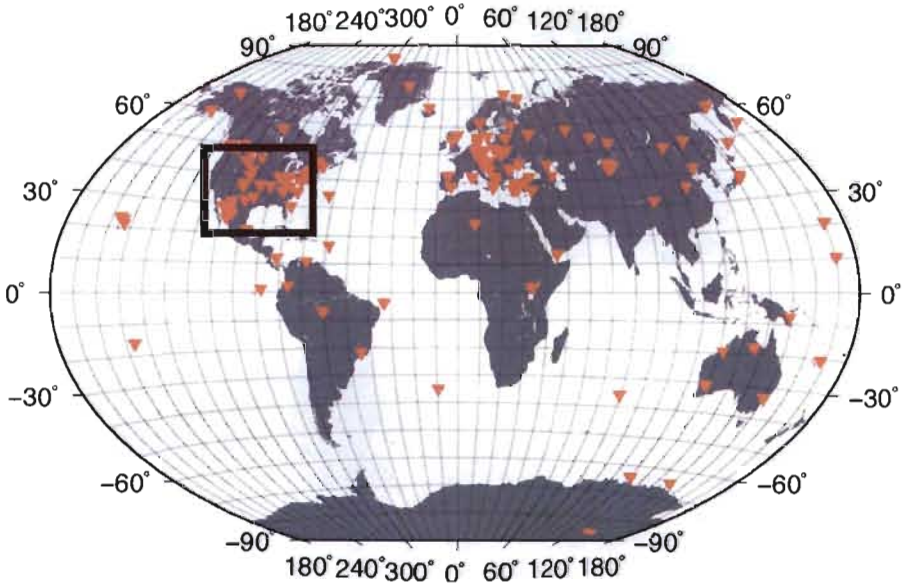


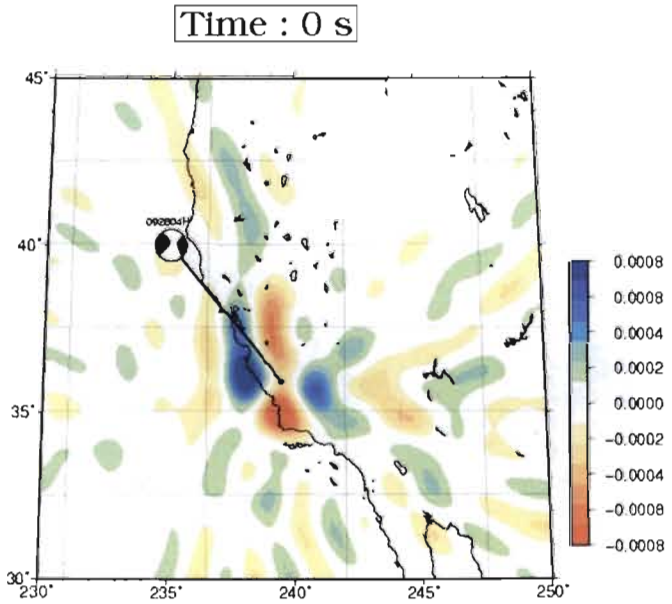
What is Time Reversal?



Seismology

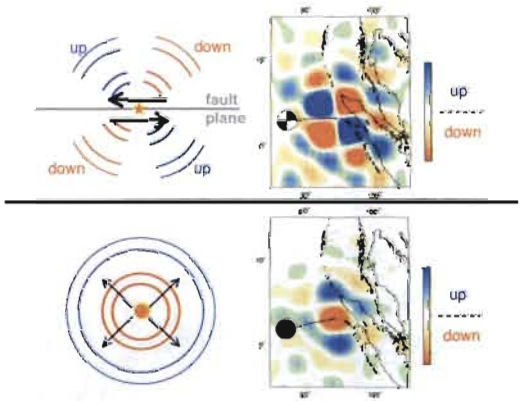
2004 Parkfield, CA Earthquake





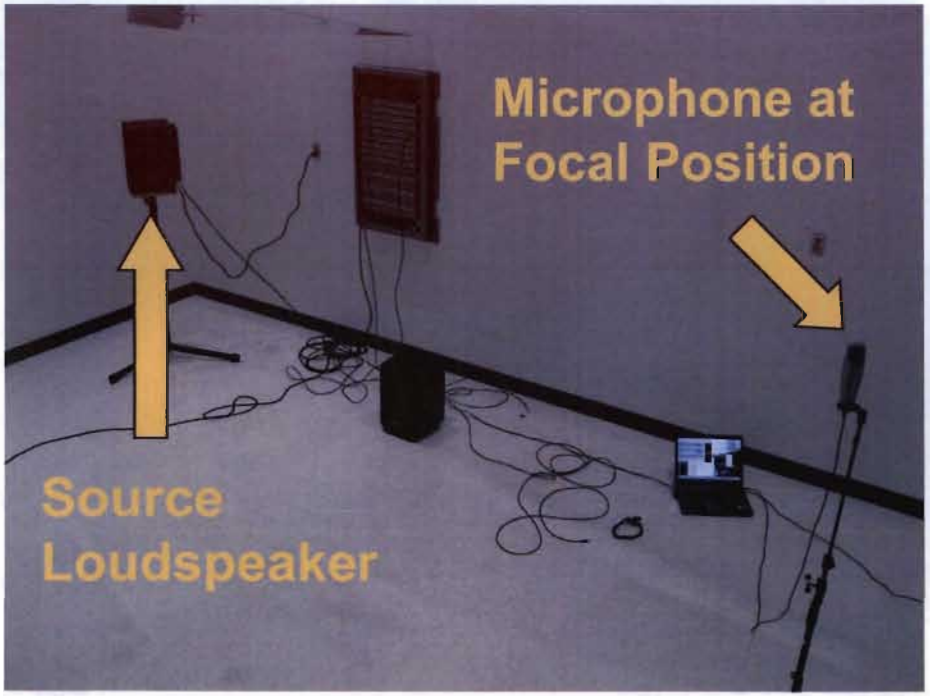
Advantages:

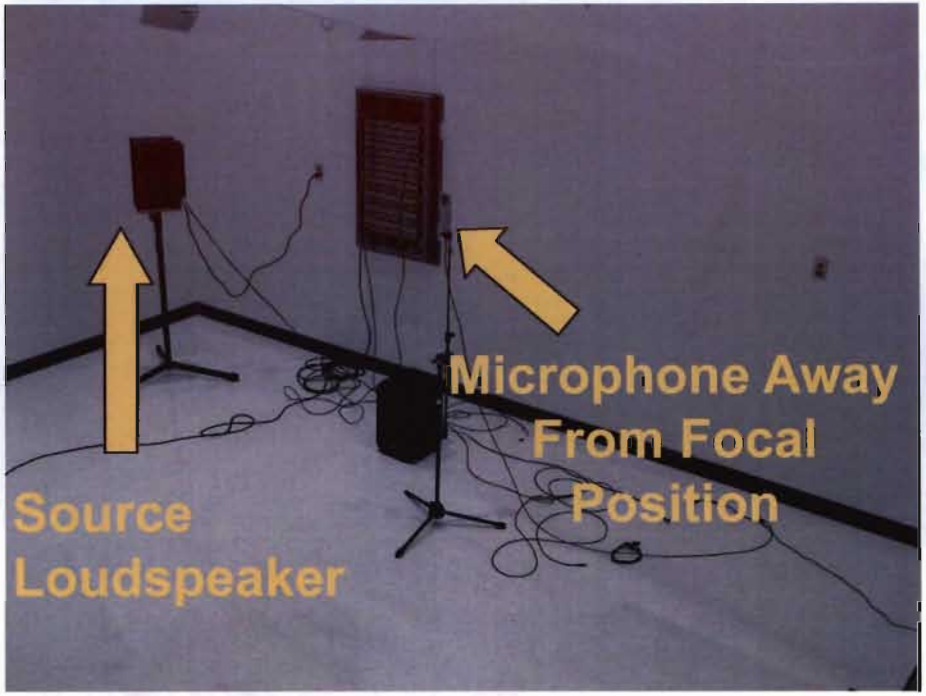
- Improved localization (time & space)
- Obtain source time functions
- Obtain Radiation Patterns



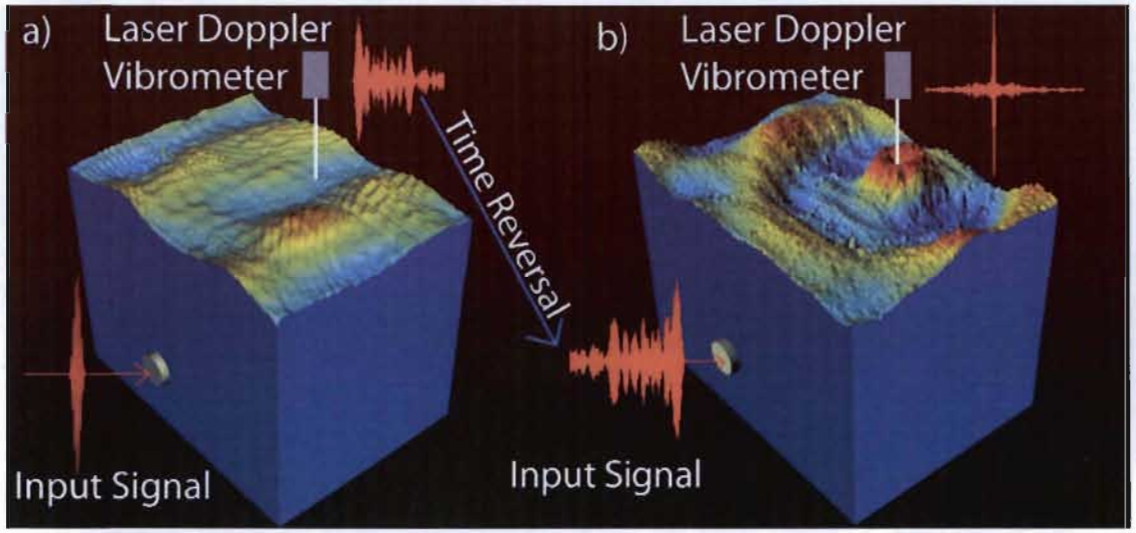
Communications

Chamber dimensions – 28.6 x 18.6 x 18.8 ft

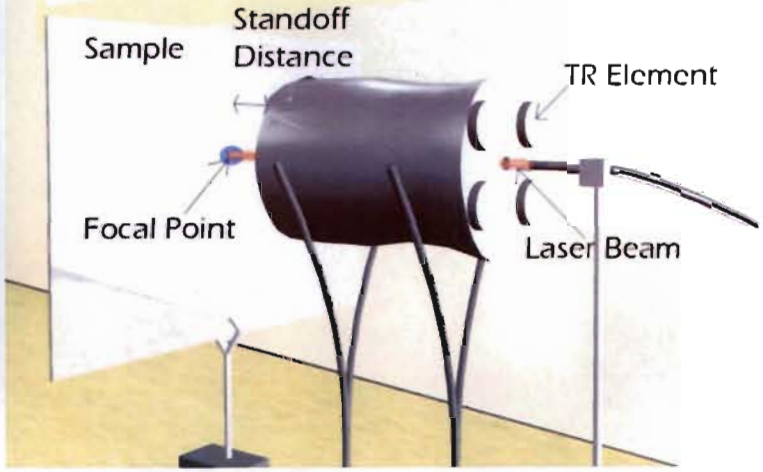




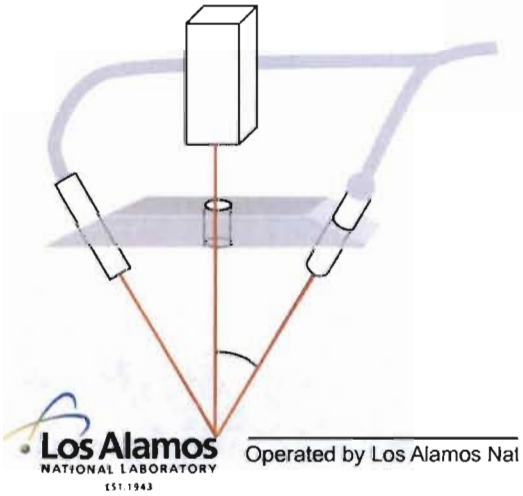
Reciprocal TR … Creating Virtual Sources

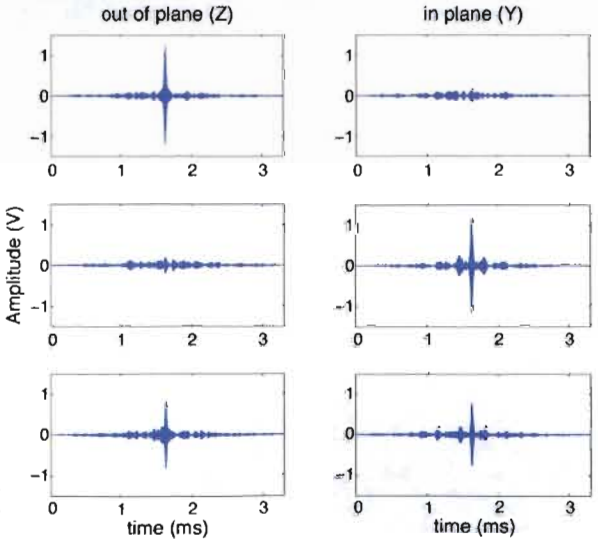


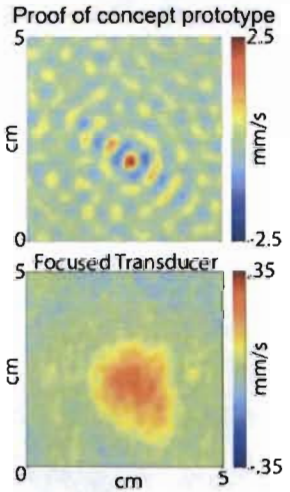
Noncontact

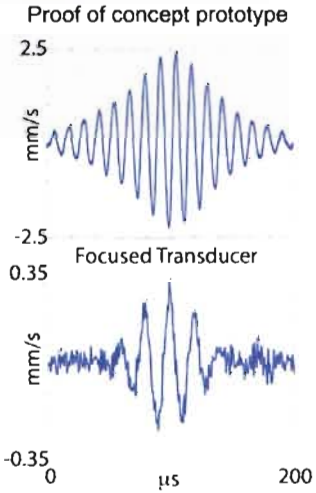


3-D









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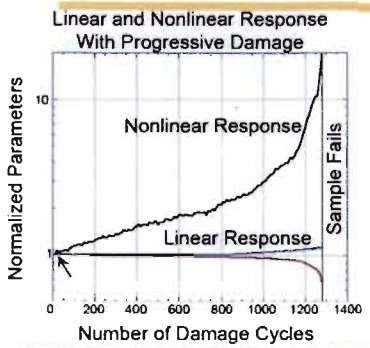
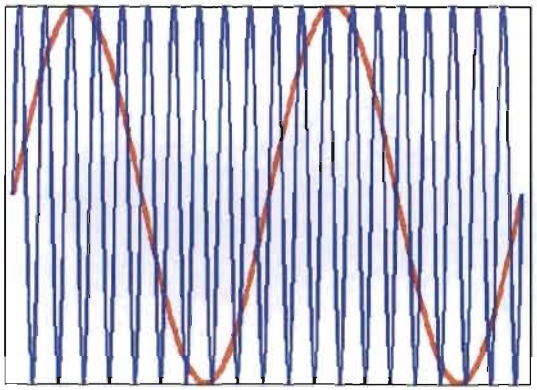
NNSA

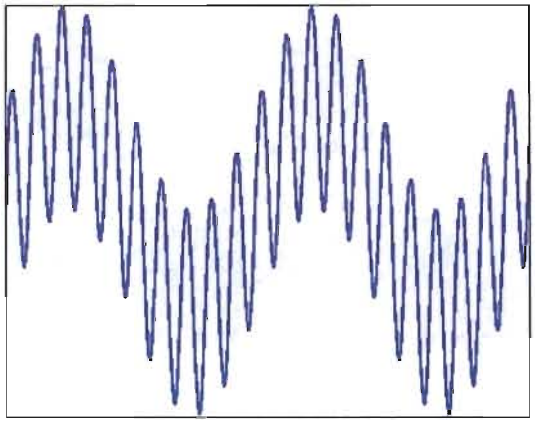
Nonlinear Elastic Wave Spectroscopy

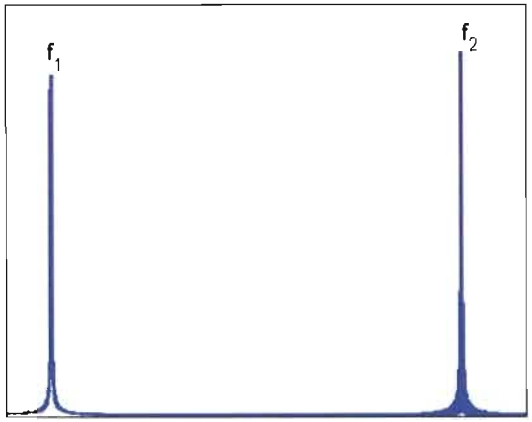




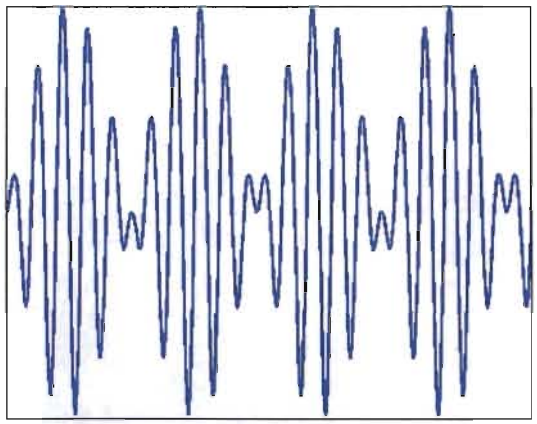
Sources

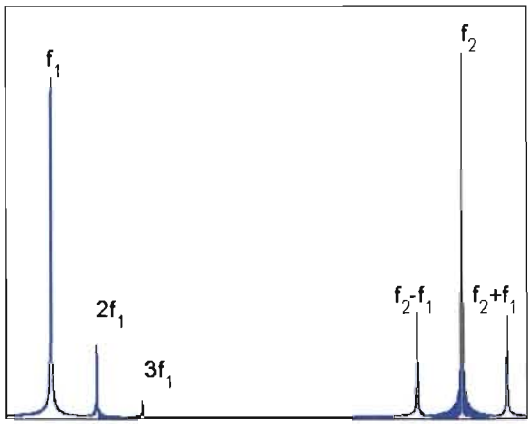
Linear Response





Nonlinear Response

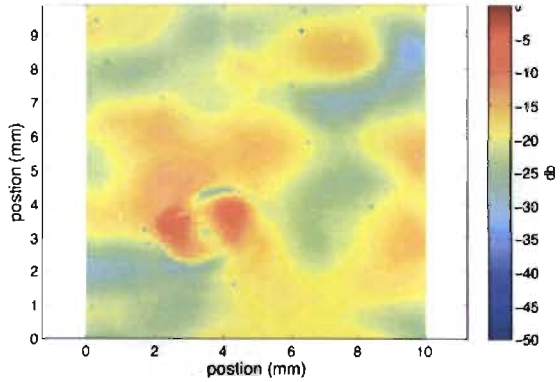




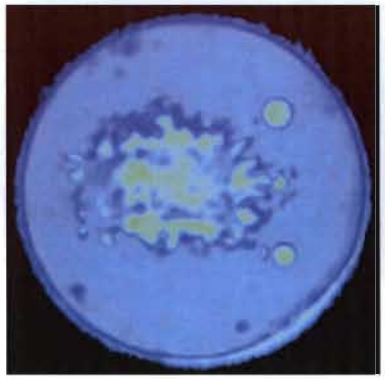
Imaging – Time Reversed Elastic Nonlinearity Diagnostic (TREND)

Linear

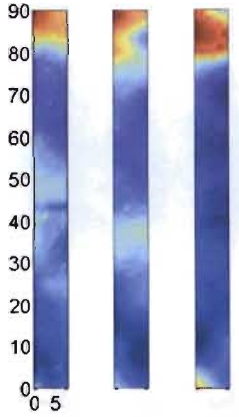
Impact damage (glass)



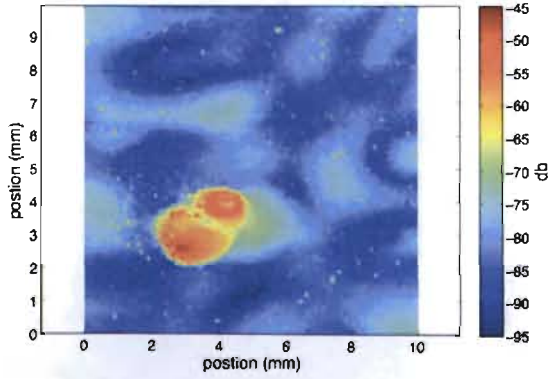
Diffusion bond defects (Cu-Au)

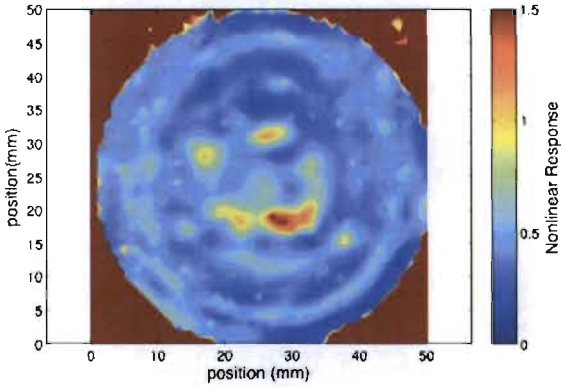


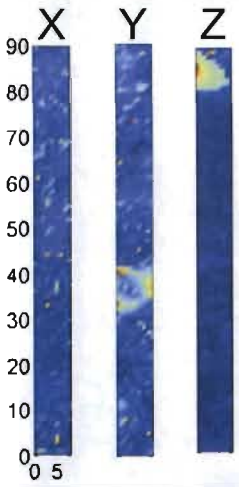
Defect Orientation (3-D TR)



Nonlinear





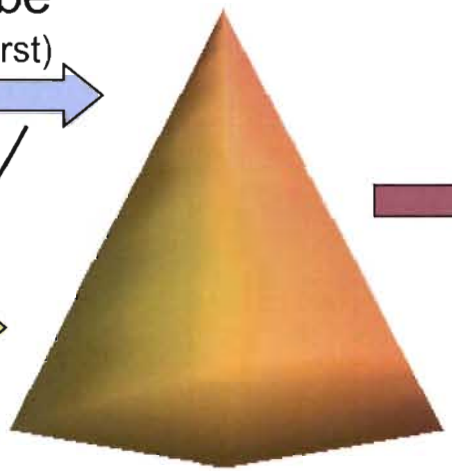


Imaging – TR NEWS

High frequency probe
(CW or Narrowband toneburst)

sync

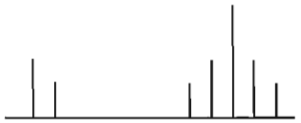
Broadband impulse
(Impact, sawtooth, etc.)



sample

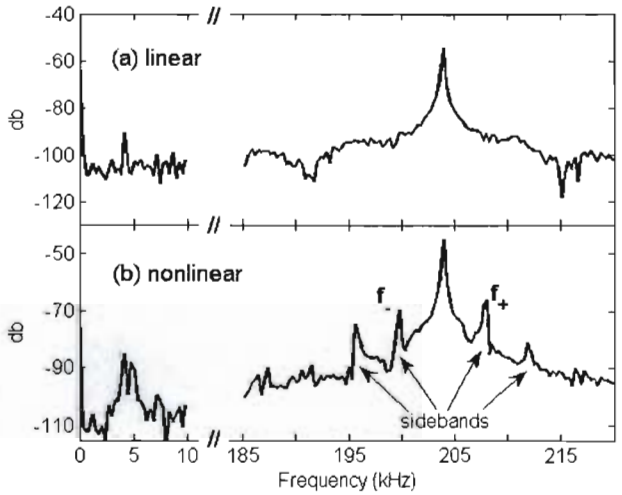
Response from N fixed transduce

FFT



Damaged
(nonlinear)

Undamaged
(linear)



GO

Continue to TR

STOP

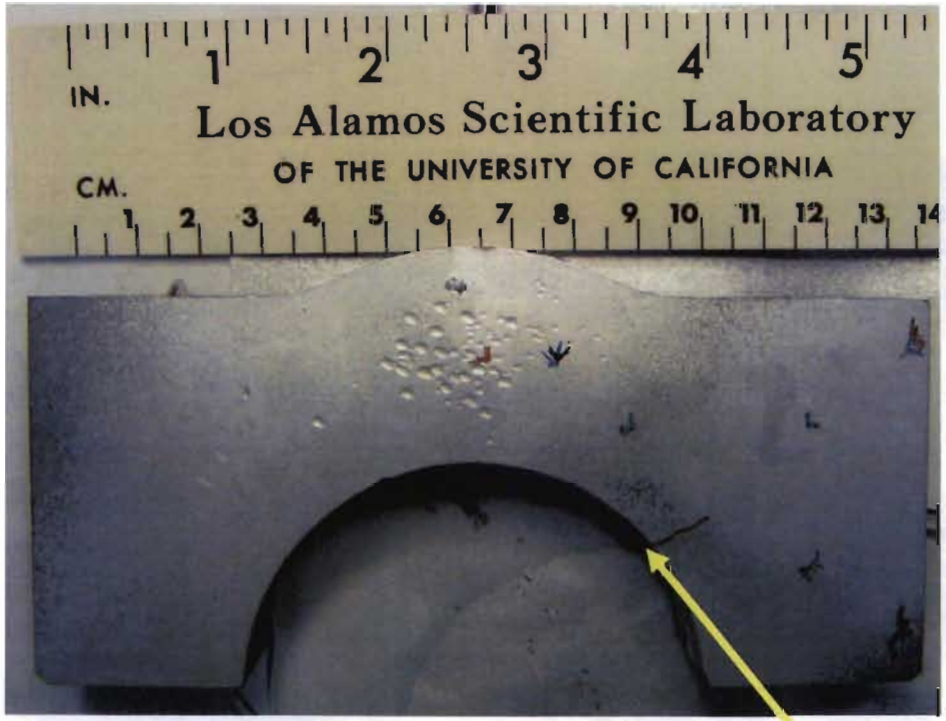
No TR necessary

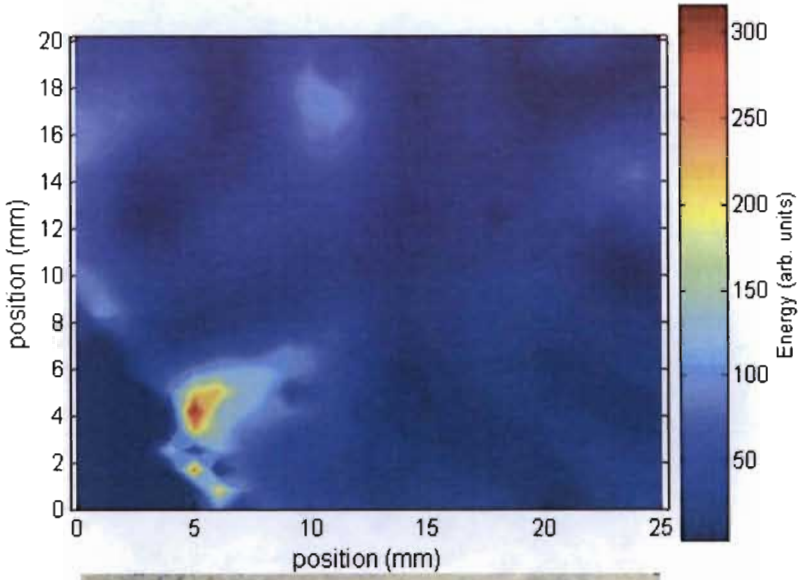
Imaging – TR NEWS

Sources:

broadband -- hammer tap (excite 4 kHz)

probe – 204 kHz, CW





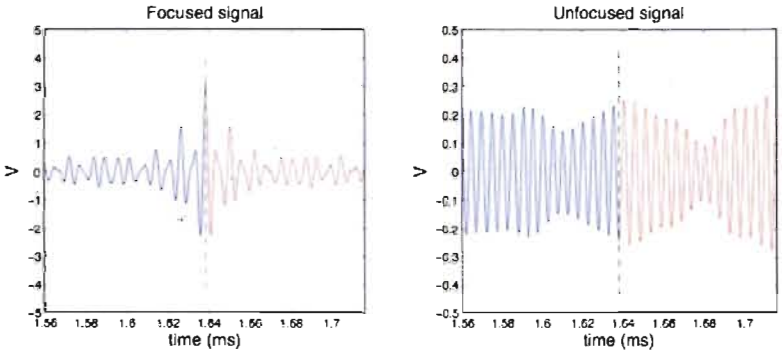
3-D sample:

13.5 cm X 6.5 cm X 3.0 cm

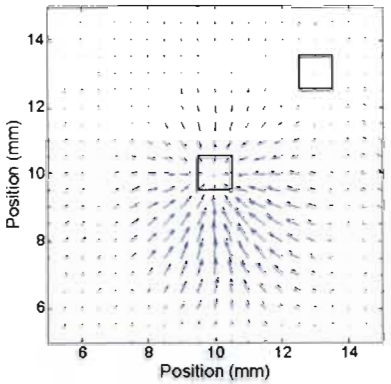
crack

Improved Imaging Metrics

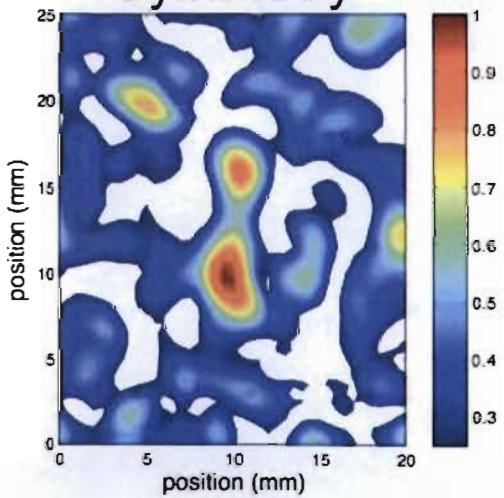
Symmetry



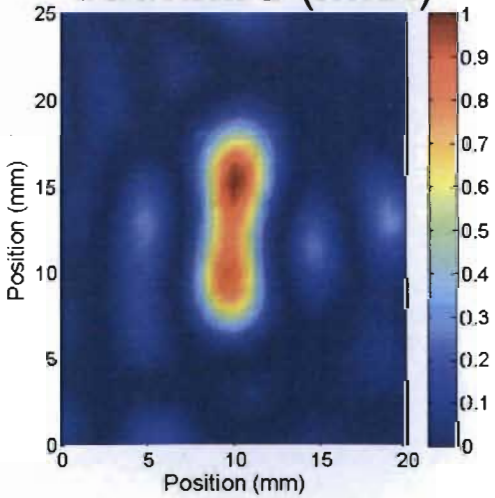
Energy Flux



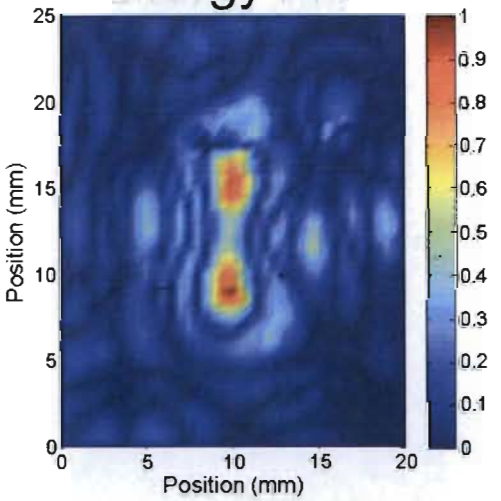
Symmetry



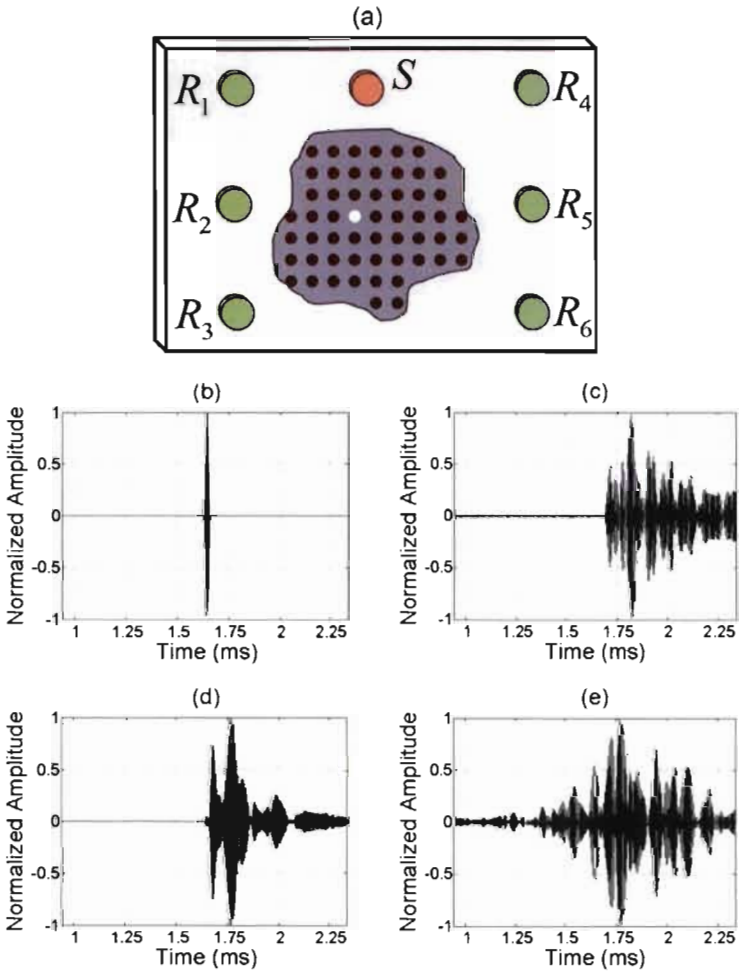
Standard (Max)

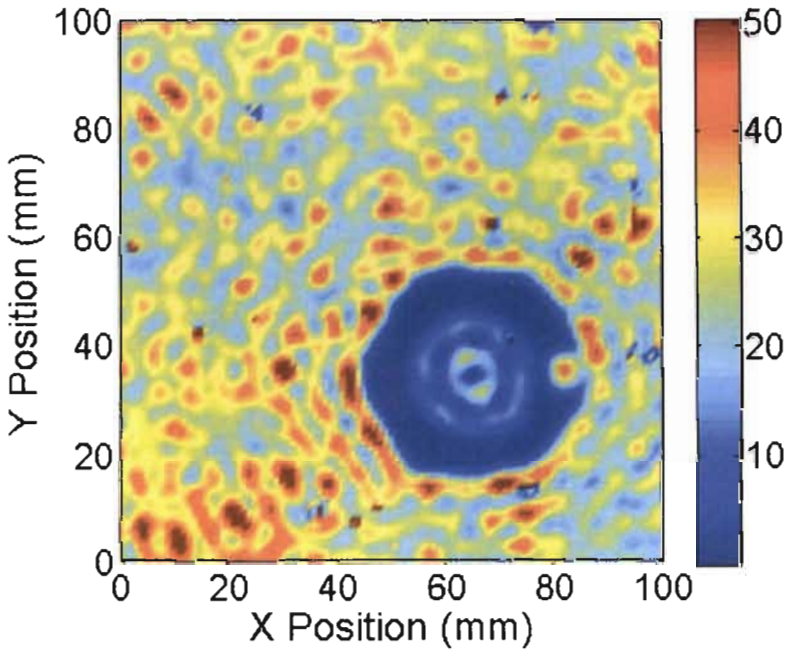


Energy Flux



Alternative Imaging Method - Reverse Time Migration





Potential Applications

- **NDE**
  - Damage quantification
  - Locate and image defects
  - Progressive damage monitoring
- **Medical Ultrasound**
  - Osteoporosis diagnostics
  - Monitoring fractures (progressive damage and/or healing)
  - Implant placement quality.
- **Friction and Interface Mechanics**
  - Tribology & Wear
  - Earthquake Fault Mechanics