Time reversal of ultrasound in granular media*

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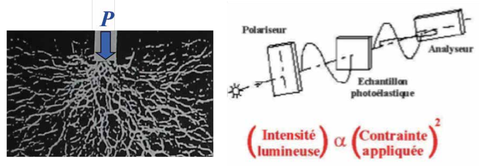
Context

Granular media

Natural athermal media

Grain size : from 1µm (powders) to 100m (geological media)

Contact force network

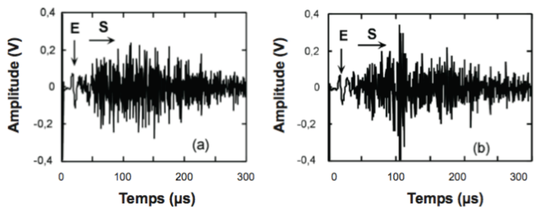


P. Dantu, Ann. des Ponts et Chaussés 4 (1957)

Waves in granular media

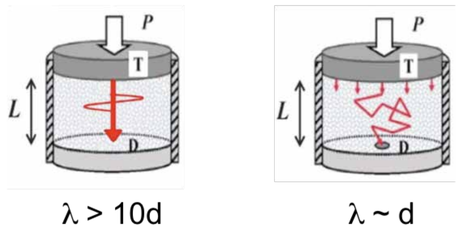
C-h. Liu & S. Nagel , PRL 68 (1992)
X. Jia, C. Caroli, and B. Velicky, PRL 82 (1999)
X. Jia, PRL 93 (2004)

Transmitted waves



Coherent wave
Very robust to configuration changes

Scattered wave
Highly dependent on configuration changes

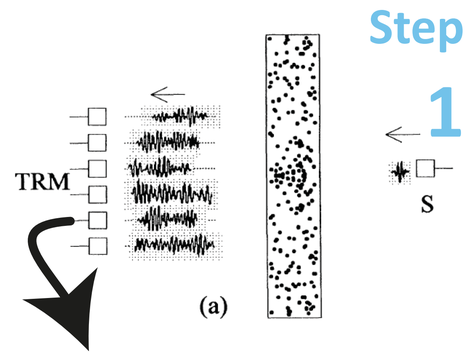


λ > 10d

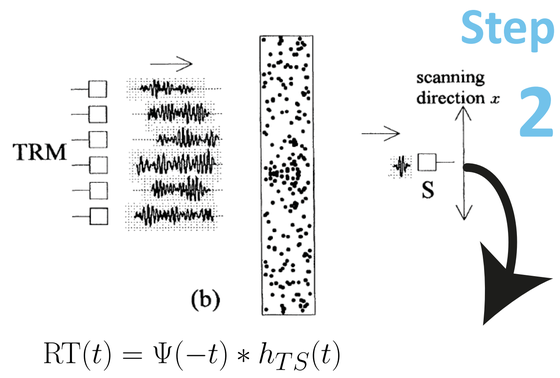
λ ~ d

Time reversal

M. Fink, Physics Today 50 (1997)
A. Derode, P. Roux, M. Fink, PRL 75 (1994)
A. Tourin, A. Derode, M. Fink, PRL 87 (2001)



$$\Psi(t) = \delta(t) * h_{ST}(t)$$



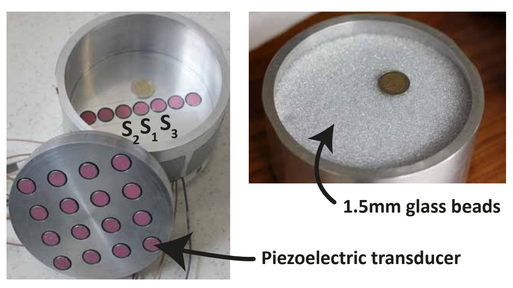
$$\begin{aligned} \mathrm{RT}(t) &= \Psi(-t) * h_{TS}(t) \\ &= \delta(-t) * h_{ST}(-t) * h_{ST}(t) \end{aligned}$$

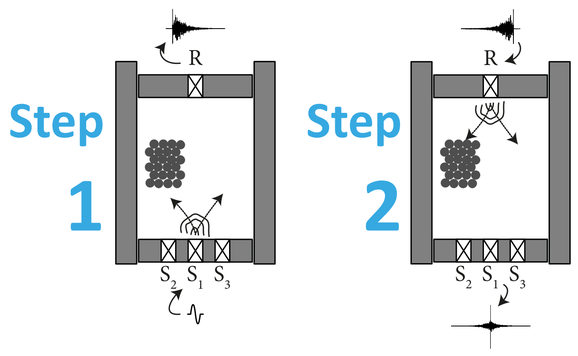
Recompressed signal is maximal at t=0

Based on **spatial reciprocity** : $h_{ST}(t) = h_{TS}(t)$

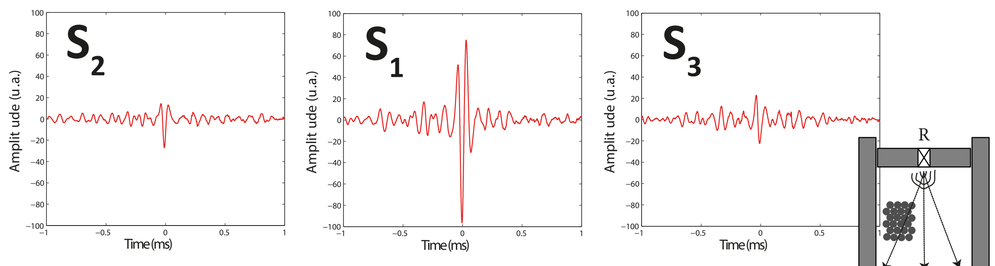
Experiments

Linear time reversal

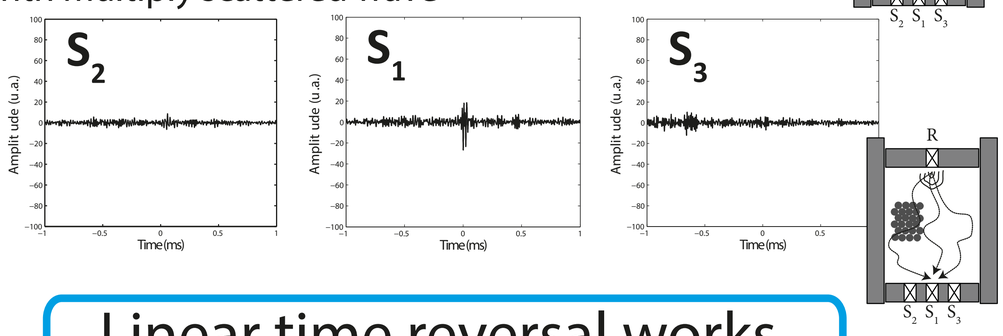




TR with coherent wave

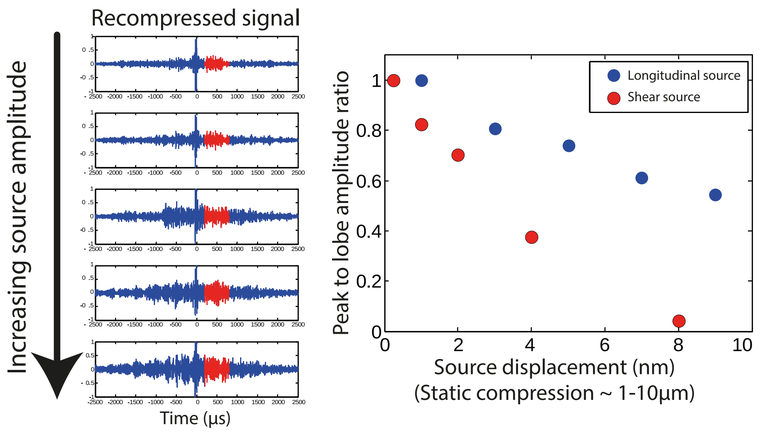


TR with multiply scattered wave



Linear time reversal works and focal spot is smaller with multiply scattered wave

Non-linear time reversal

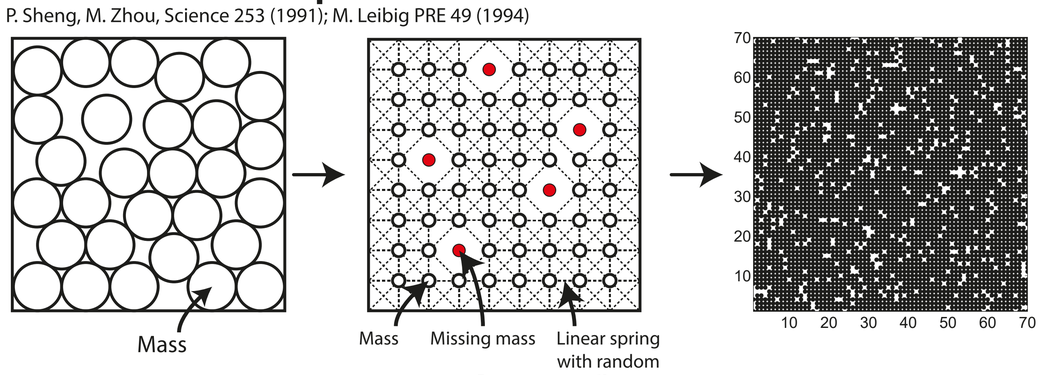


Failure of time reversal at high amplitudes due to **rearrangements in the network of contacts!**

Simulations

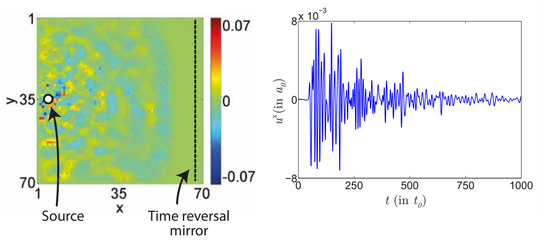
Model: amorphous network

P. Sheng, M. Zhou, Science 253 (1991); M. Leibig PRE 49 (1994)

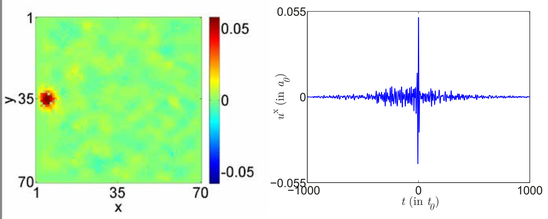


Linear time reversal

Step 1: forward propagation



Step 2: backward propagation



It works!

Non-linear time reversal

Our model for the **rearrangements**

- A rearrangement is a **new random picking in the distribution of the stiffnesses**
- Rearrangements occur only if **vibrational displacement exceeds 2% of static displacement**

Step 2: backward propagation

Failure of time reversal!

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