Seismic observations on the moon: seismic interferometry and moonquakes

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Outline

- Seismic Interferometry
- LOFAR
- US array
- Moonquakes
- Seismic observations on the moon

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- **Seismic Interferometry**
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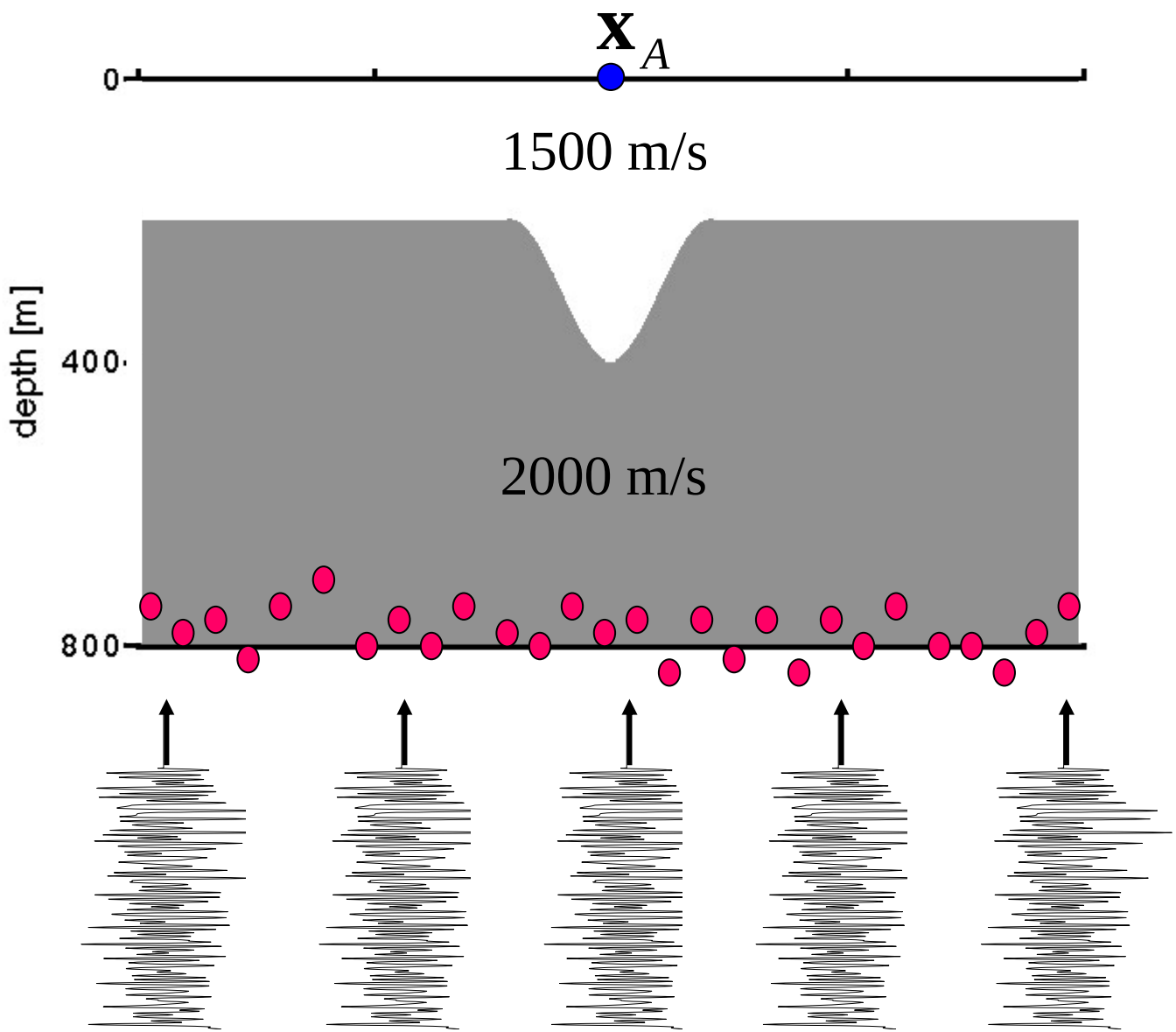
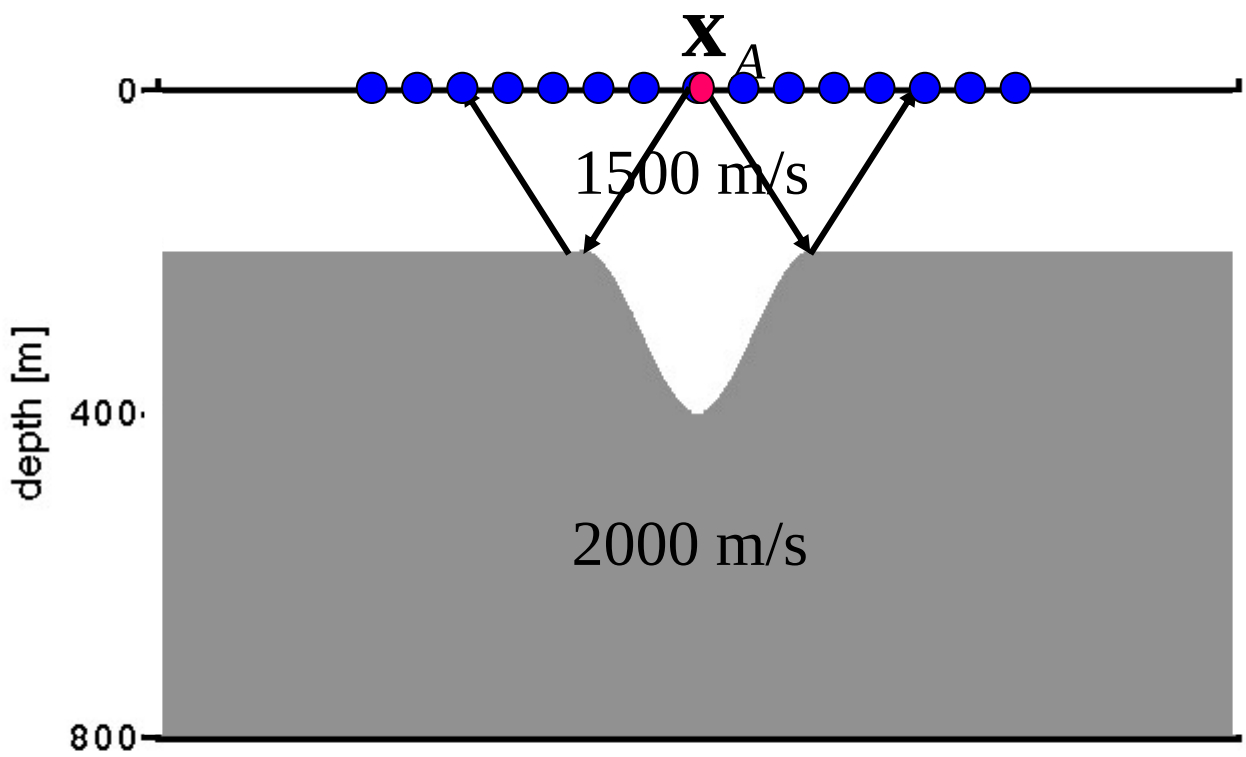
Seismic Interferometry

- Pioneering work by K. Wapenaar

- Currently validation on earth:
  - works for direct surface waves
  - works for active (man-made) sources
  - works for scattered waves ??
  - works for passive sources ??


x A
0
1500 m/s
depth [m]
400
2000 m/s
800


x
A
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2000 m/s
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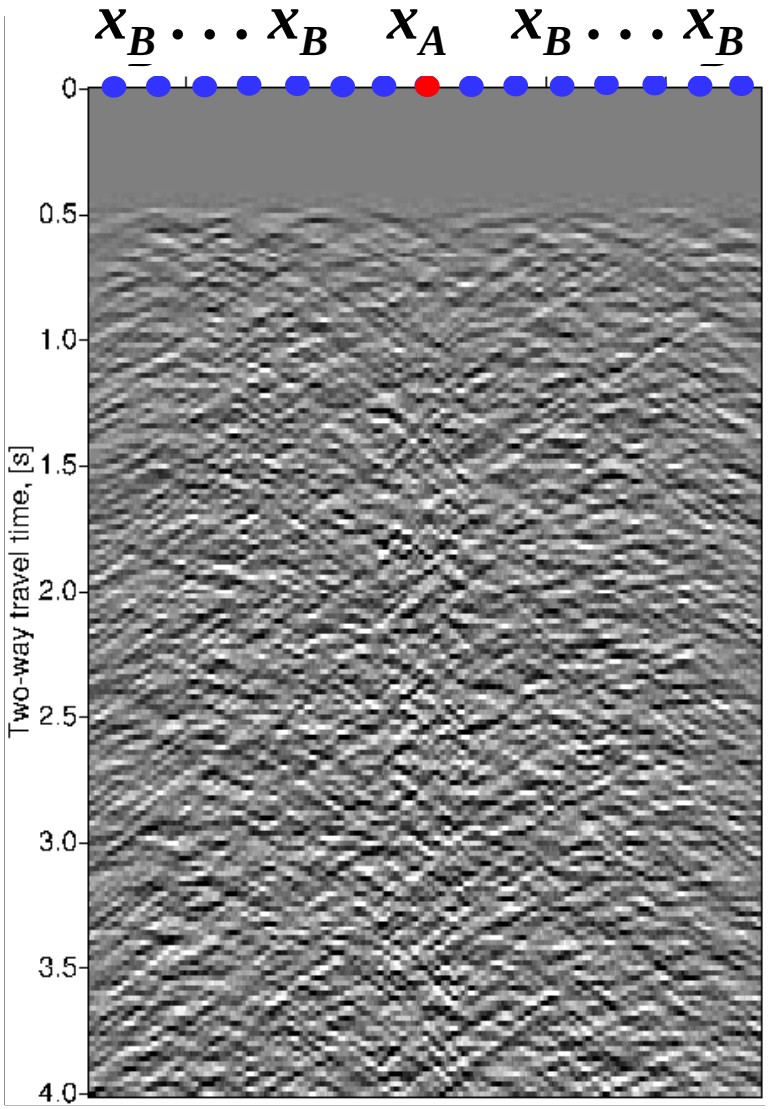
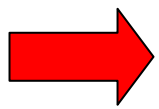
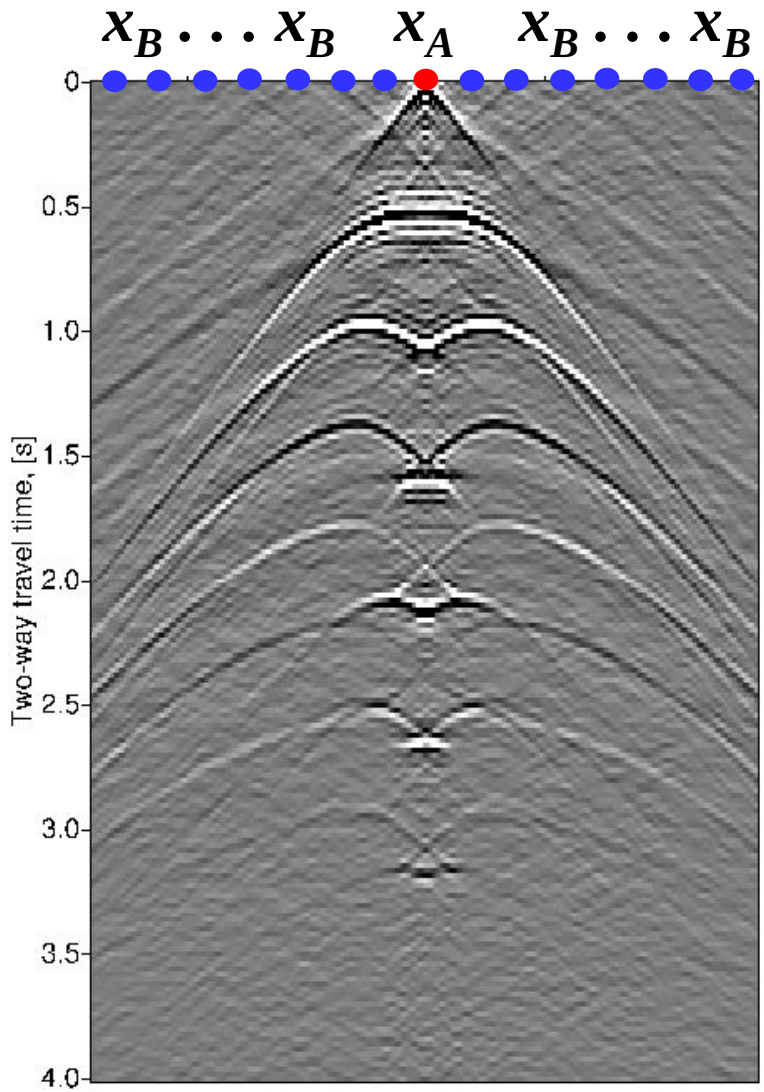
Seismic Interferometry

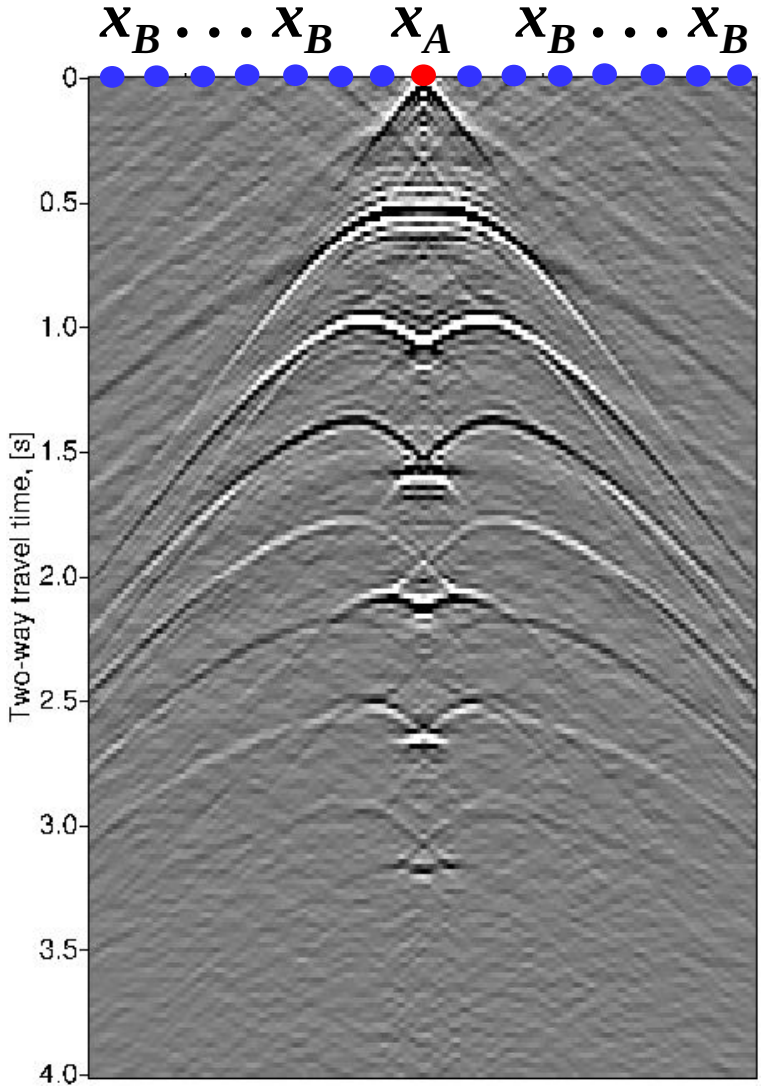






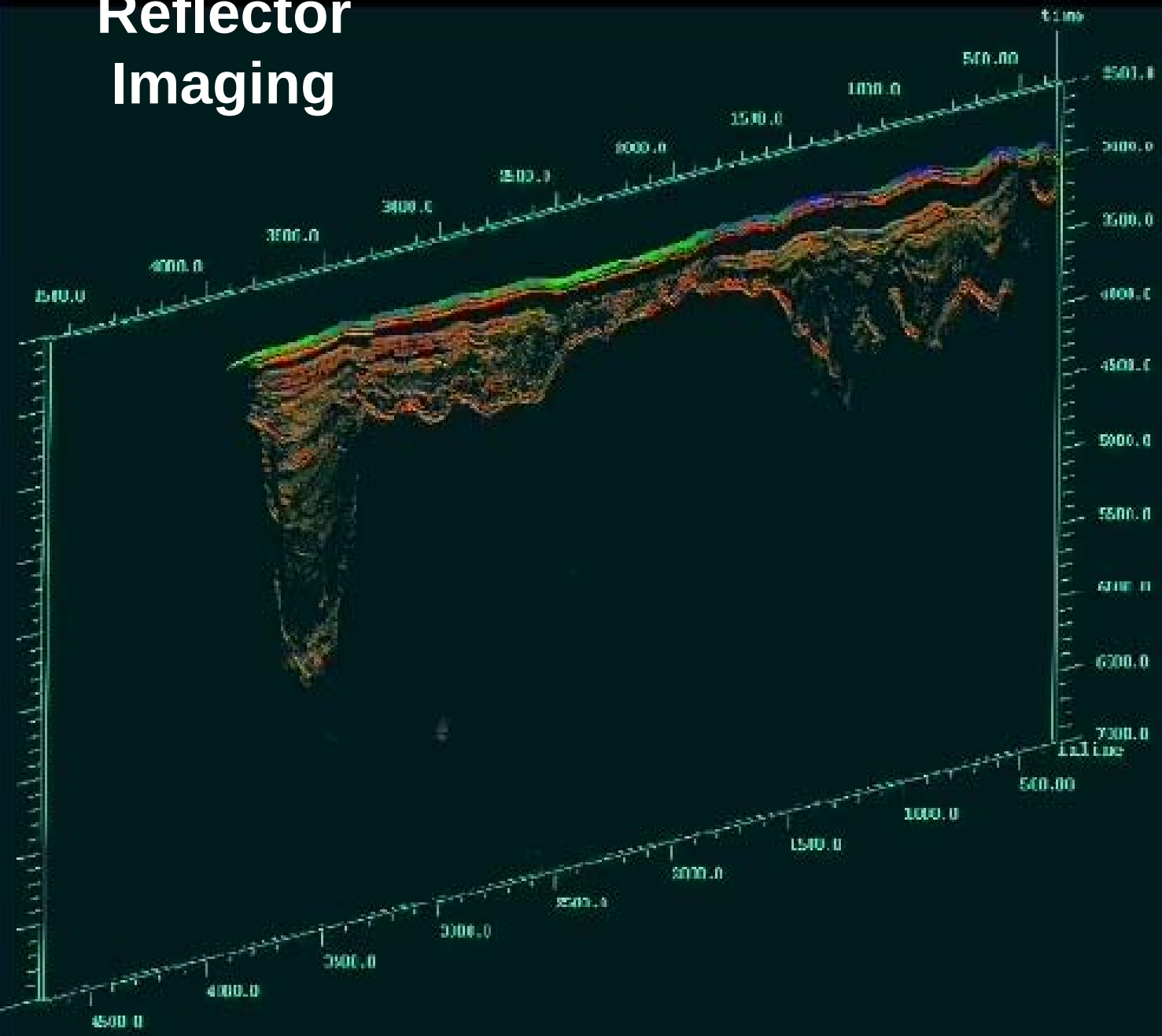
Transmission measurements **correlation** **Reflection measurements**

Reflector Imaging



Reflection measurements

Reflector Imaging



Interferometry:
Differences with astronomy:

- **Strongly inhomogeneous propagation model**
- **Reflection instead of source imaging**
- **Sky moving while earth static (losing 1 dimension)**

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- **LOFAR: crust scale**
- US array: earth scale
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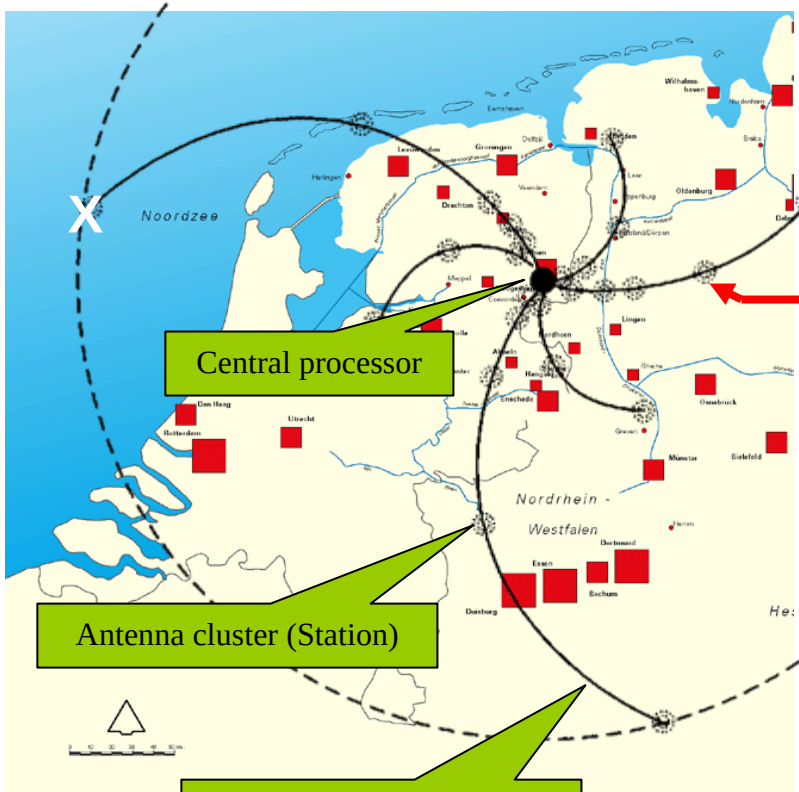
LOFAR: LOw Frequency ARray

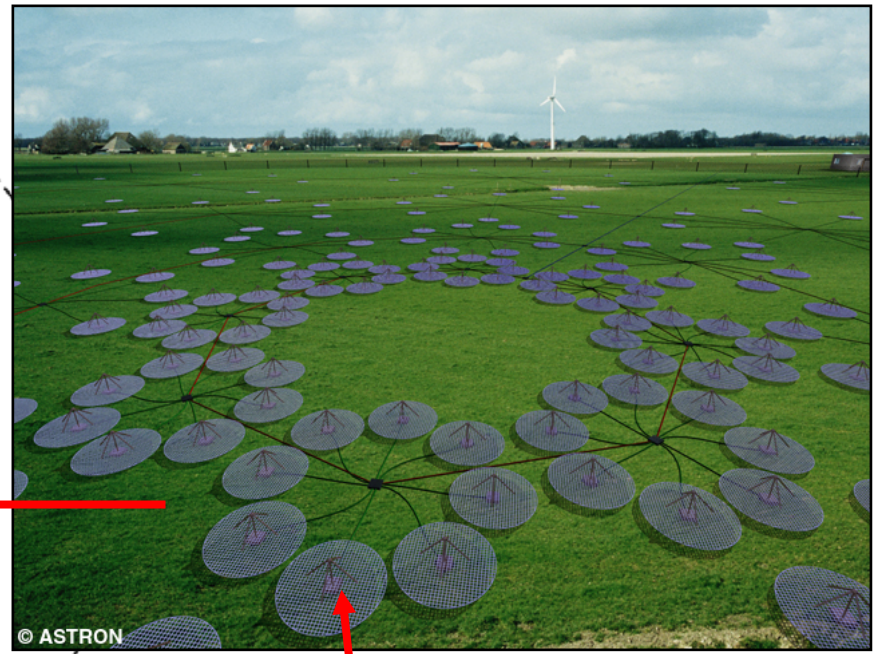
25% of antennas in central core



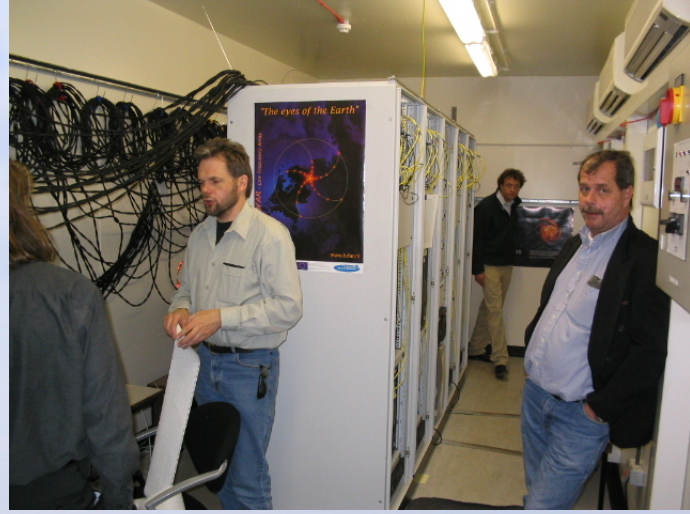
Central processor

Antenna cluster (Station)

High speed data transport

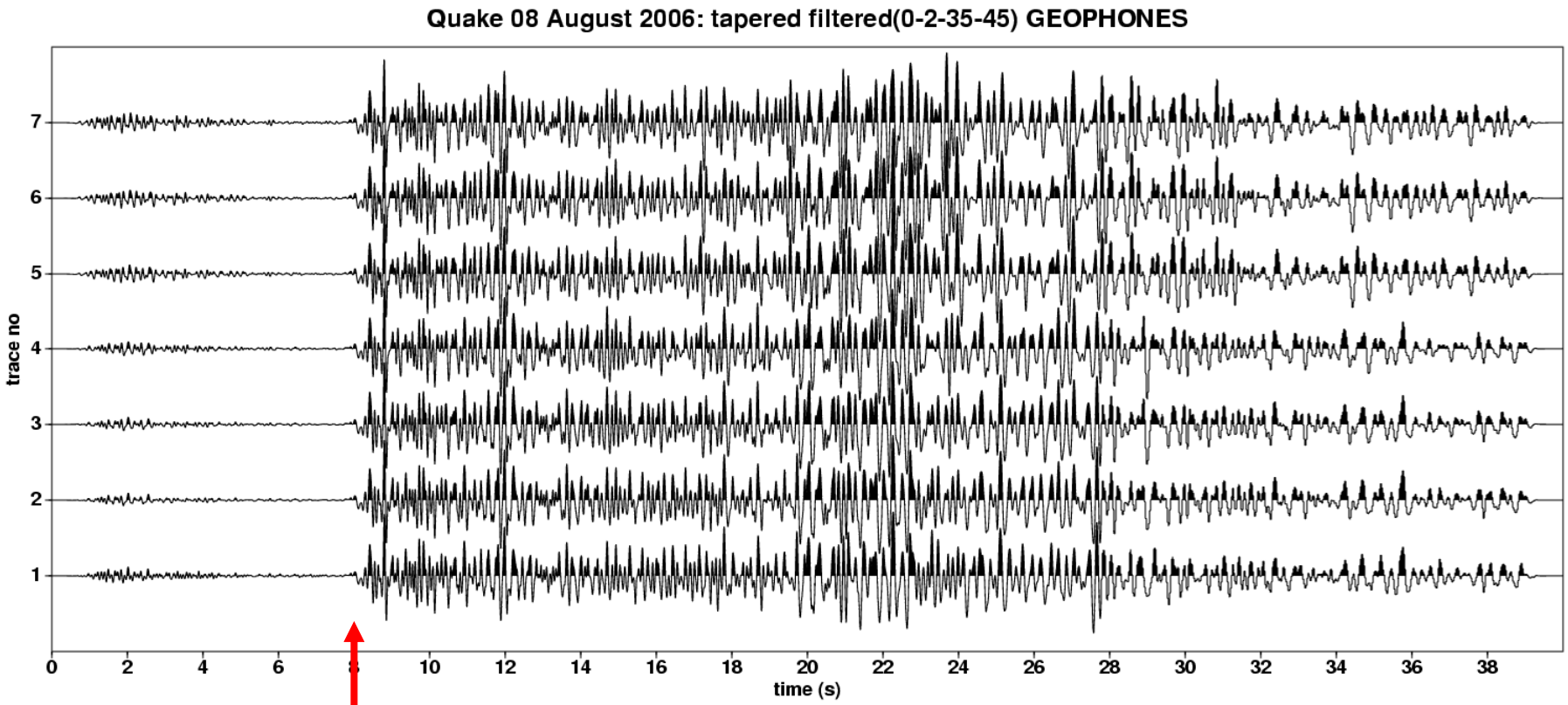


Test-site Exloo



Test-site Exloo

ISES



(Vertical component of geophones)

First arrival

Earthquake 08 August 2006, Recording at LOFAR test-site

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- **US array: earth-scale**
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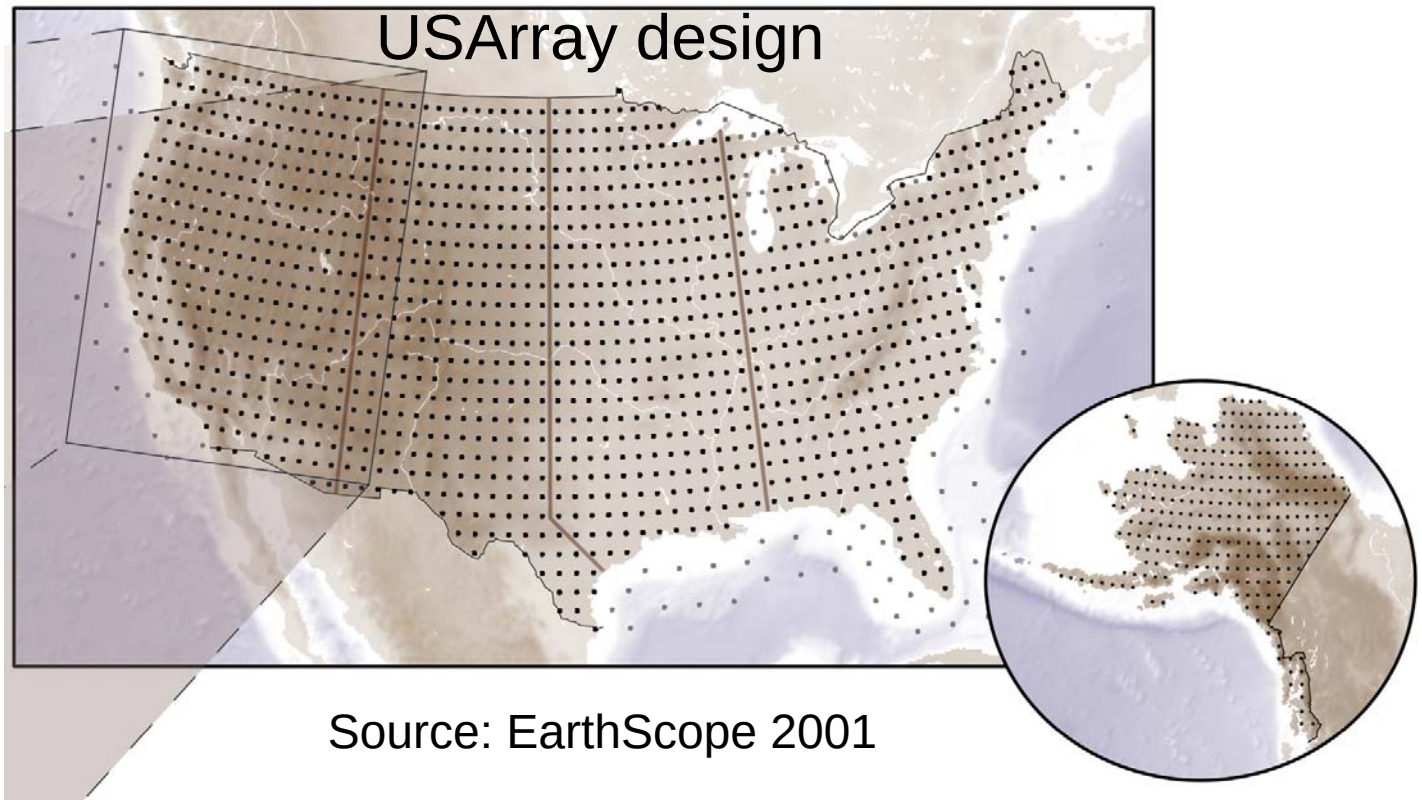
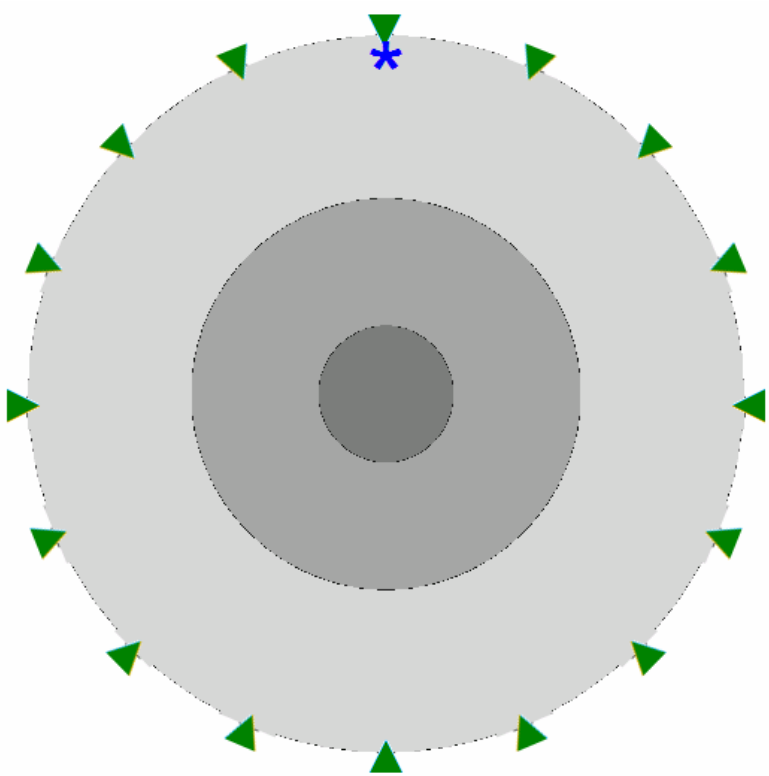
US array

Seismic Interferometry on global-scale seismology



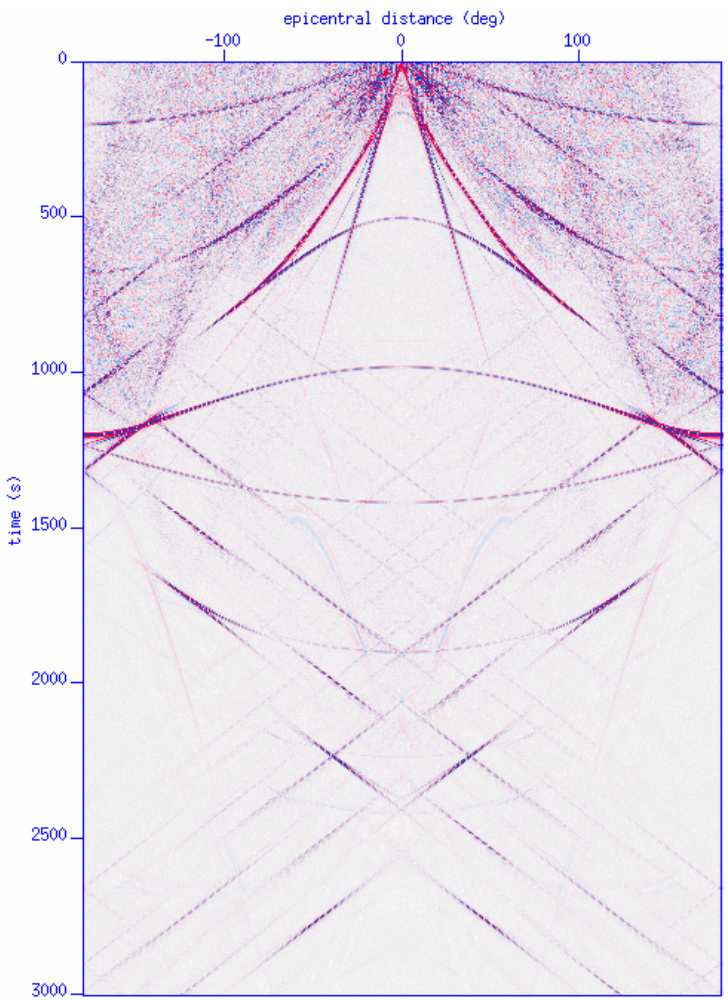
Source: EarthScope 2001

All epicentral distances

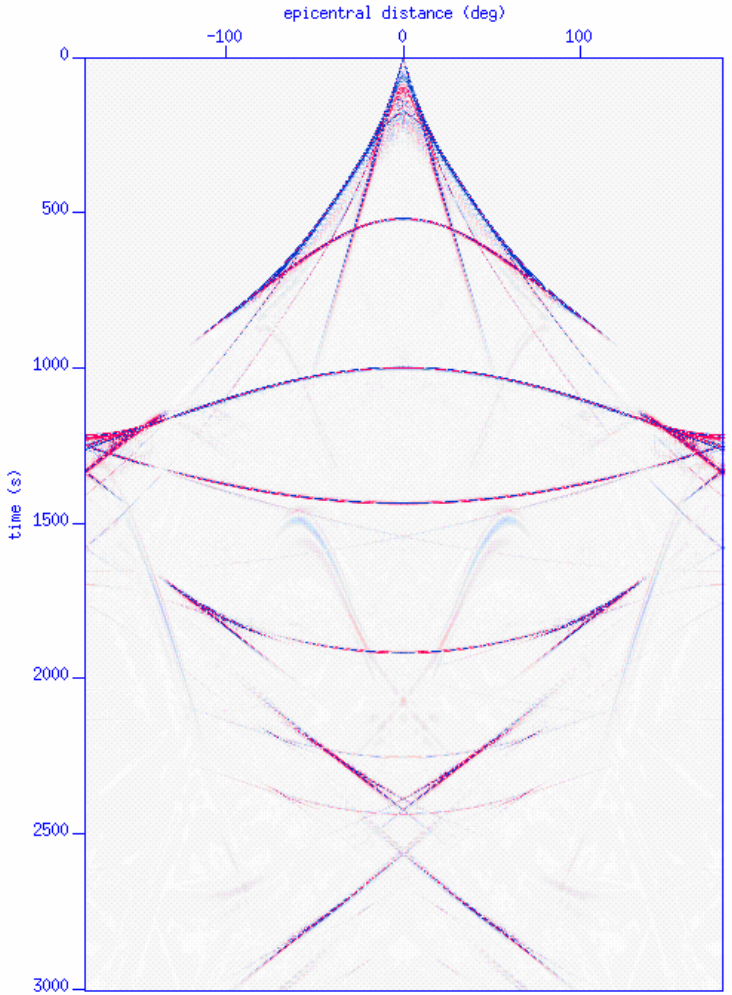


Causal result

Reconstructed



Directly modeled $G_0^{p,f}(\mathbf{x}, \mathbf{x}_B, t)$



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- **Moonquakes**
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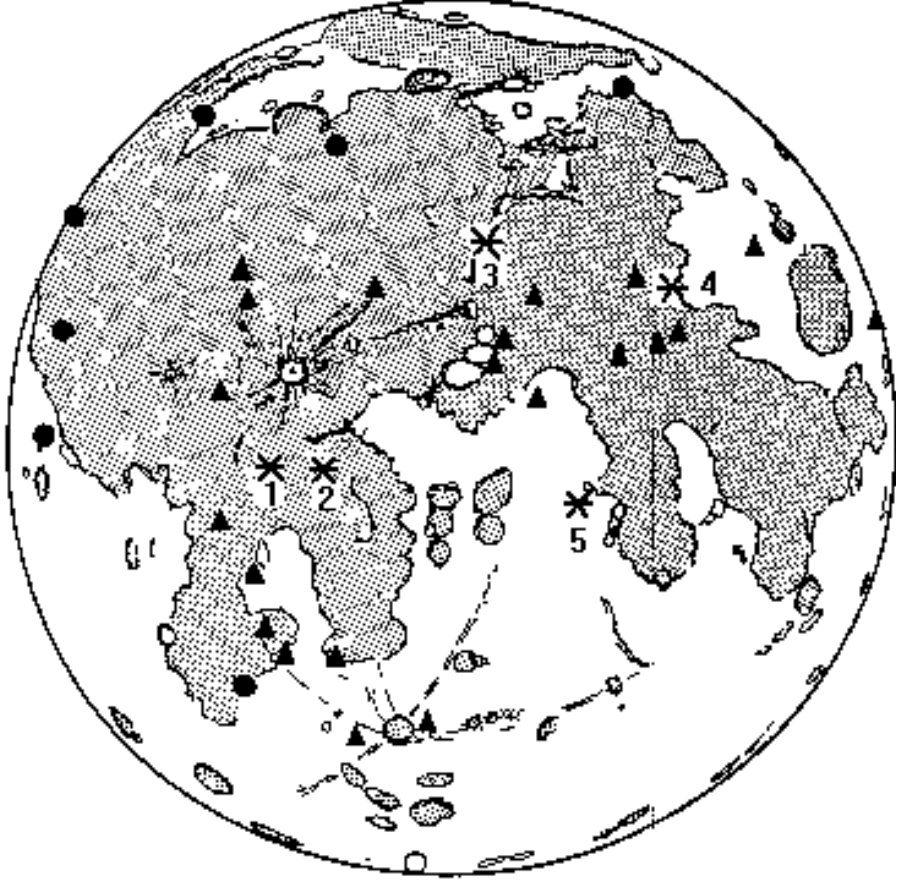
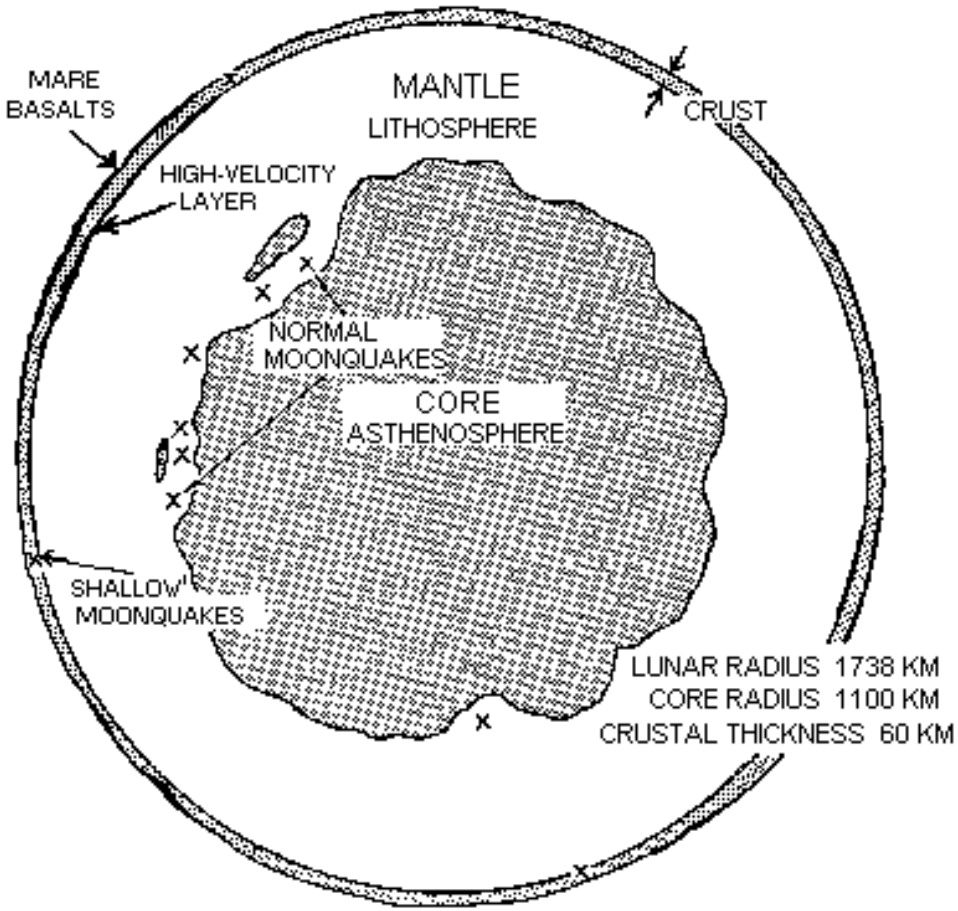




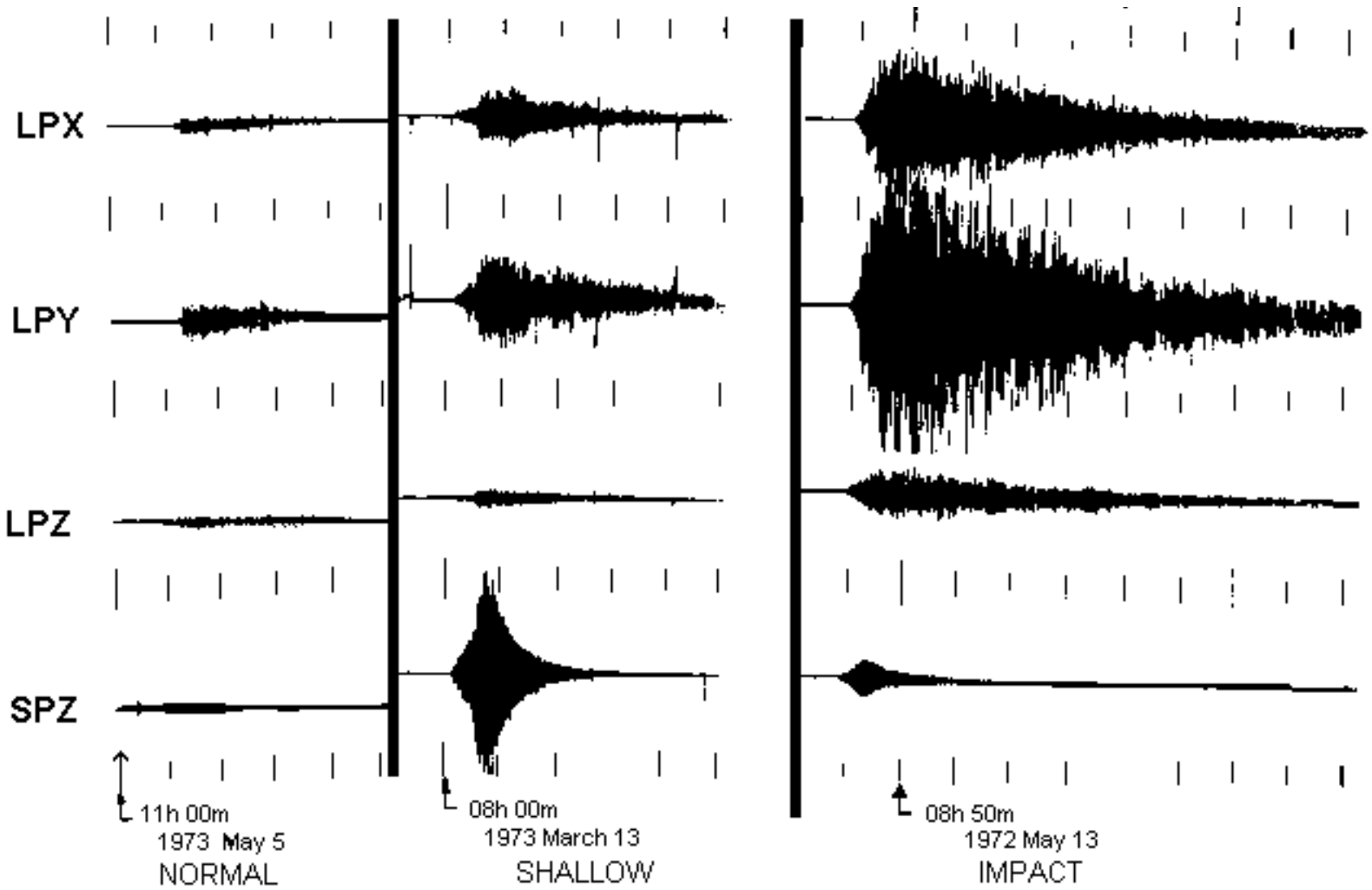
Some background on the seismology of Moonquakes.
G.A. EIBY: "EARTHQUAKES"

Three causes of lunar seismicity:

- Impacts
- Shallow: 0-60 km (crustal stresses)
- Deep : 600 – 900 km (tidal forces)

Features:

- ‘High’ frequency (0.1 – 1.0 Hz)
- Small amplitudes (0.5 – 1.3 Richter)
- Low damping
- Long reverberations (~ 60 minutes)


LPX
LPY
LPZ
SPZ
11h 00m
1973 May 5
NORMAL
08h 00m
1973 March 13
SHALLOW
08h 50m
1972 May 13
IMPACT

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Idea:

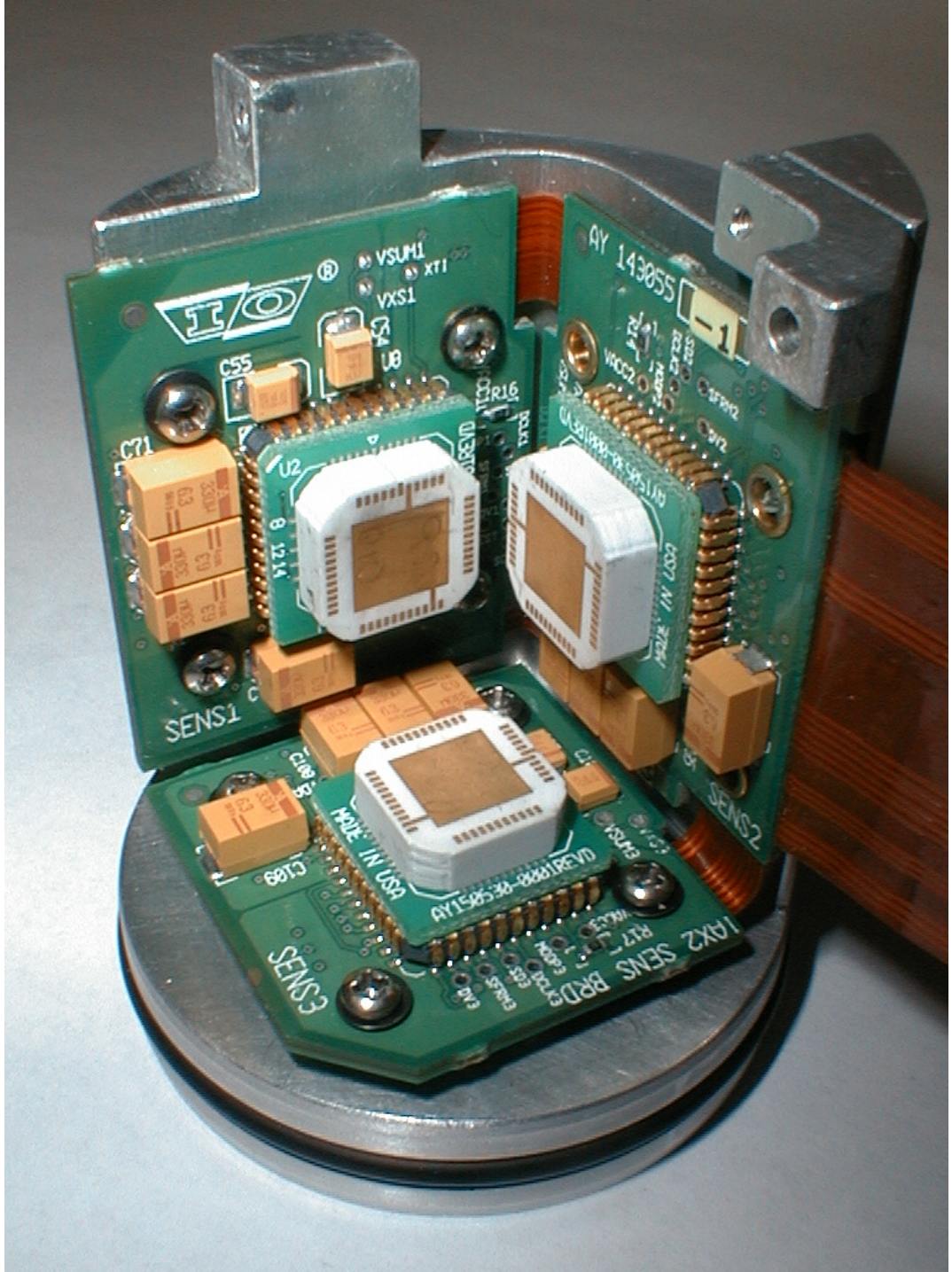
- Not a few but *many* stations: only then structure can be imaged

- Light-weight low-power sensors:

- Micro-machined sensors

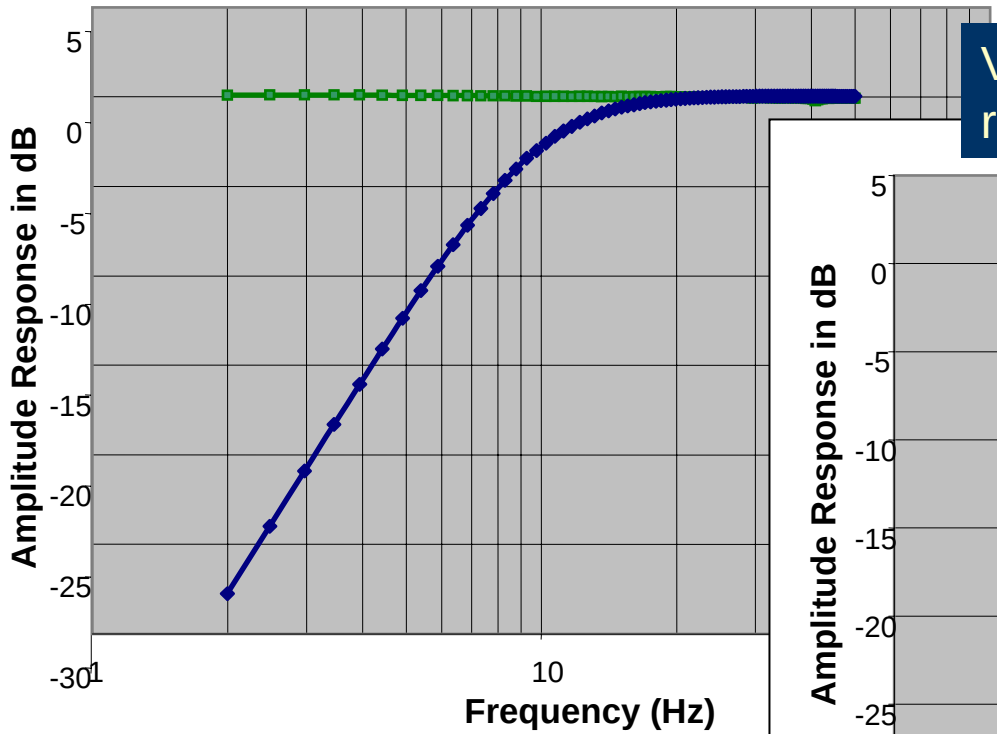
VectorSeis® Digital Sensor

- No tilt limitations

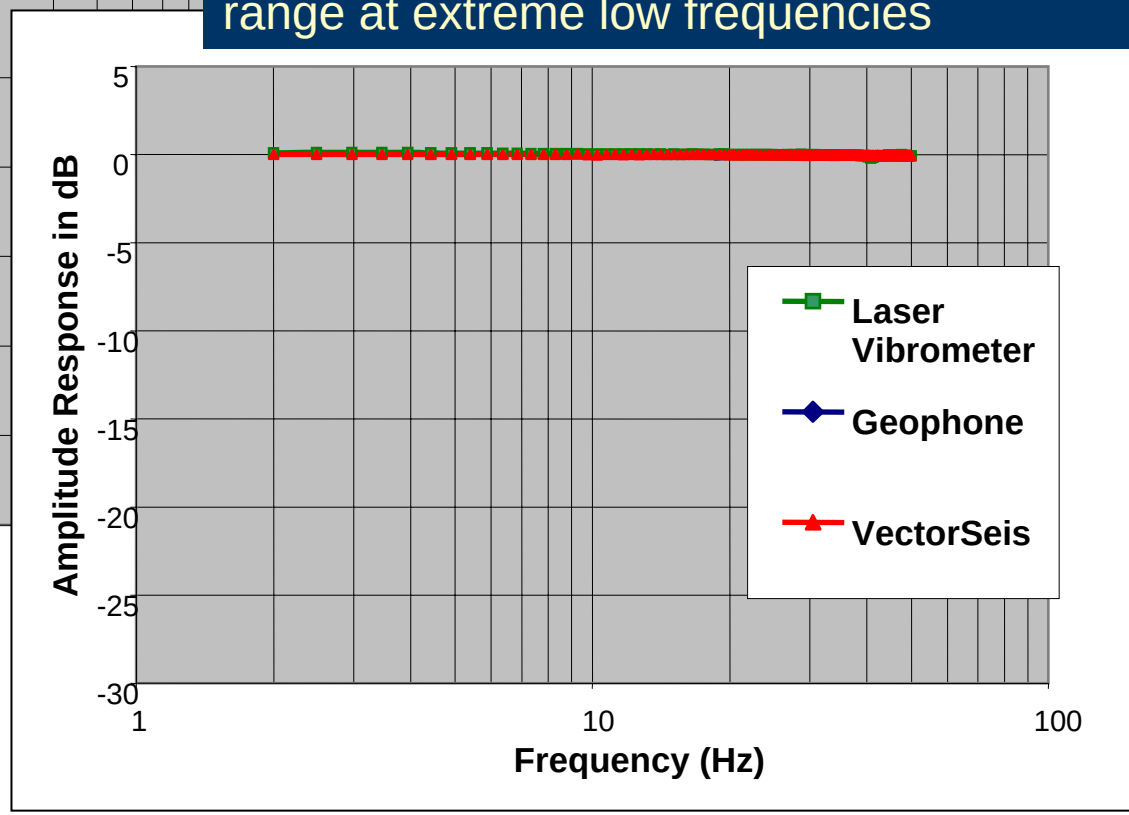


Frequency Response

Geophone & **VectorSeis**® simultaneously shaken, table motion measured by Laser Vibrometer, Geophone and VectorSeis outputs normalized to Vibrometer



VectorSeis sensor maintains dynamic range at extreme low frequencies



Thank you for your attention