A Microseismometer for Penetrator Deployment

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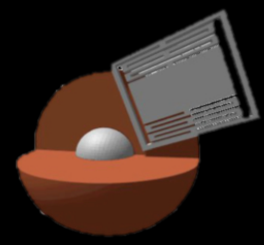

Contents

Science

- Internal structure of Europa and Ganymede
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- Science and engineering requirements for a penetrator-deployed microseismometer

Instrument

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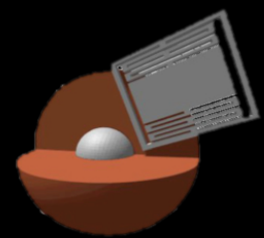
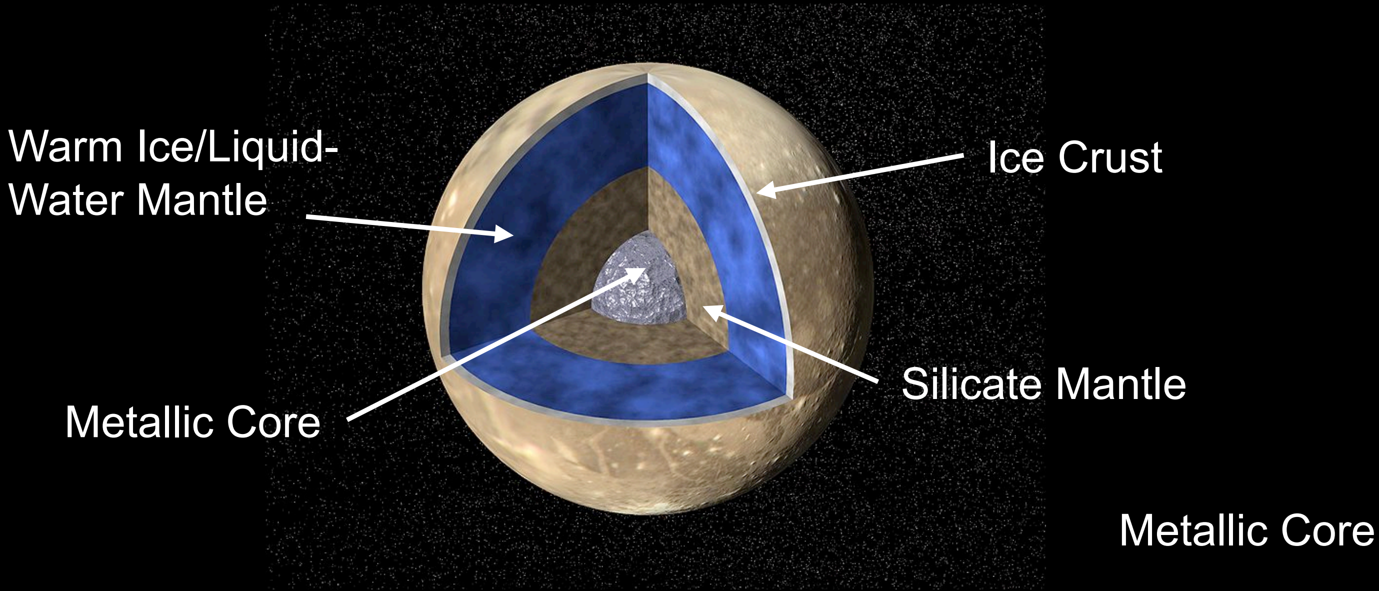
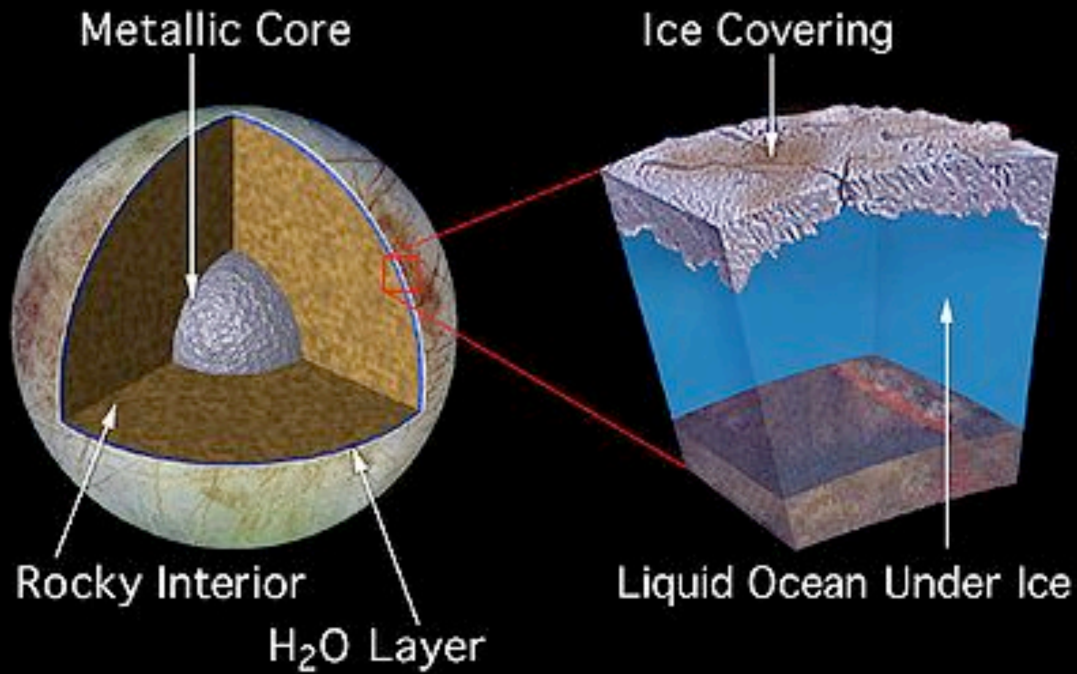


Interiors of Ganymede and Europa – current best models





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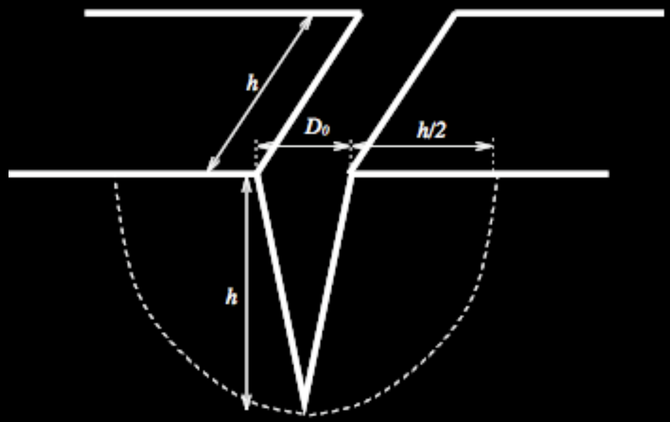
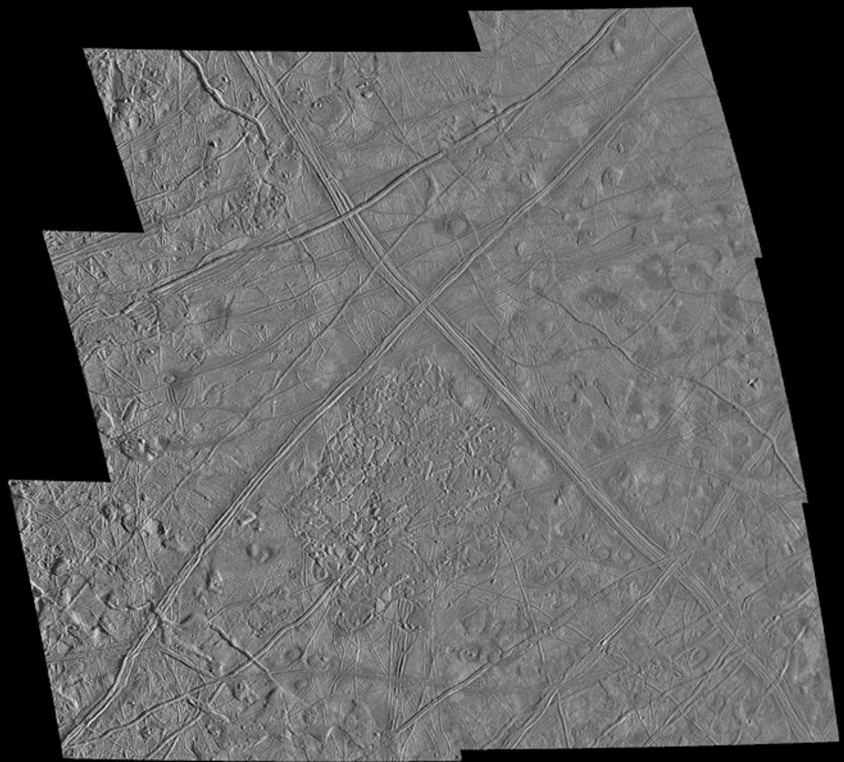
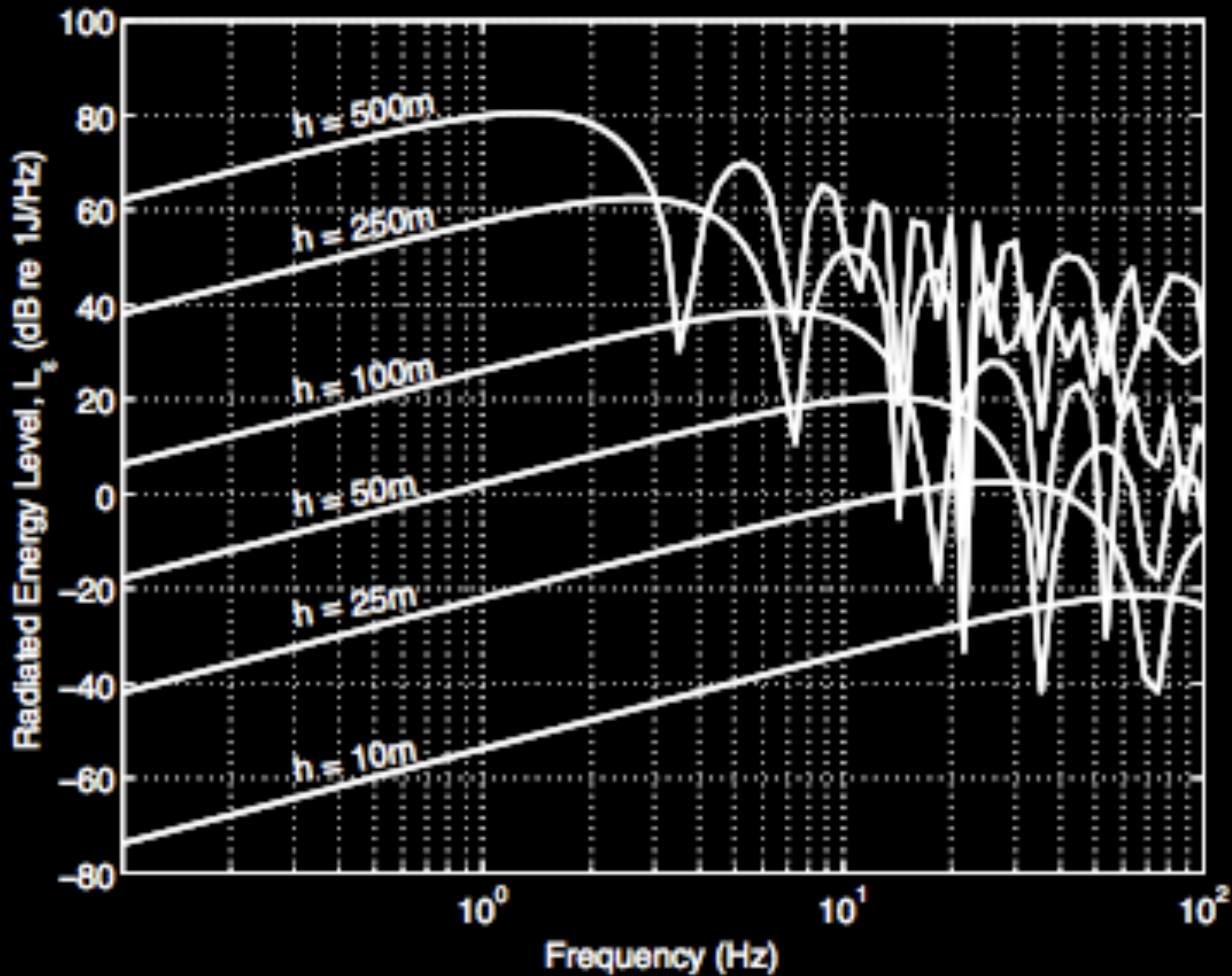
Ice cracks as seismic sources







Lee et al, 2003

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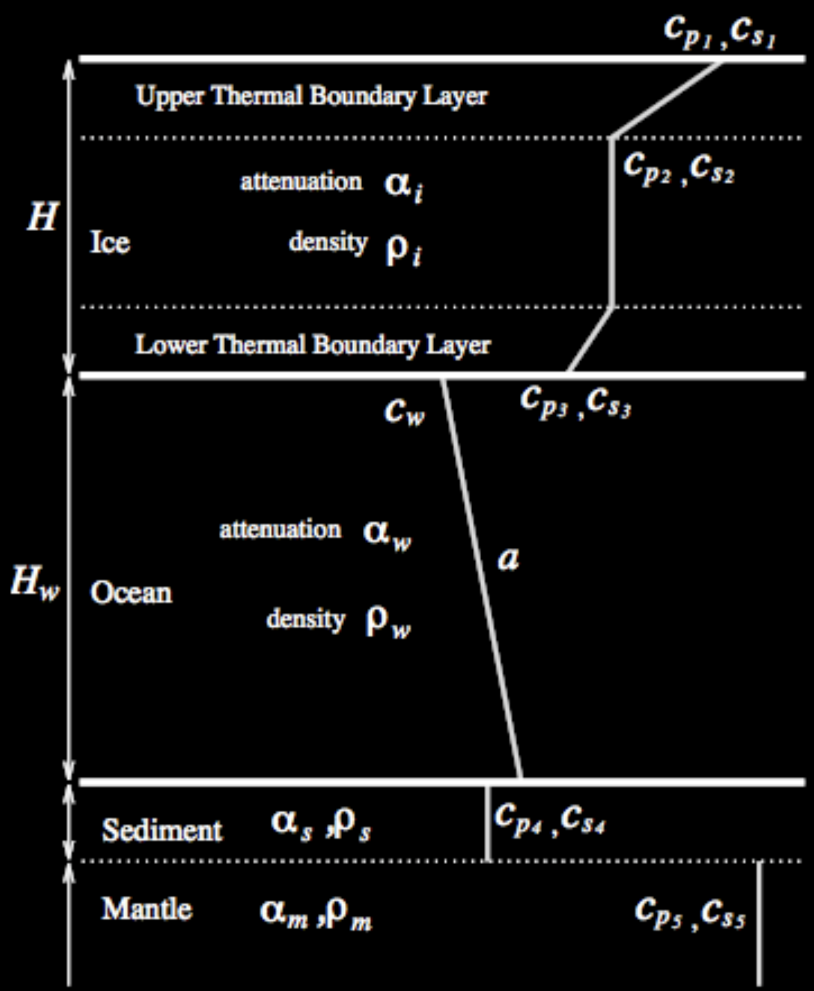
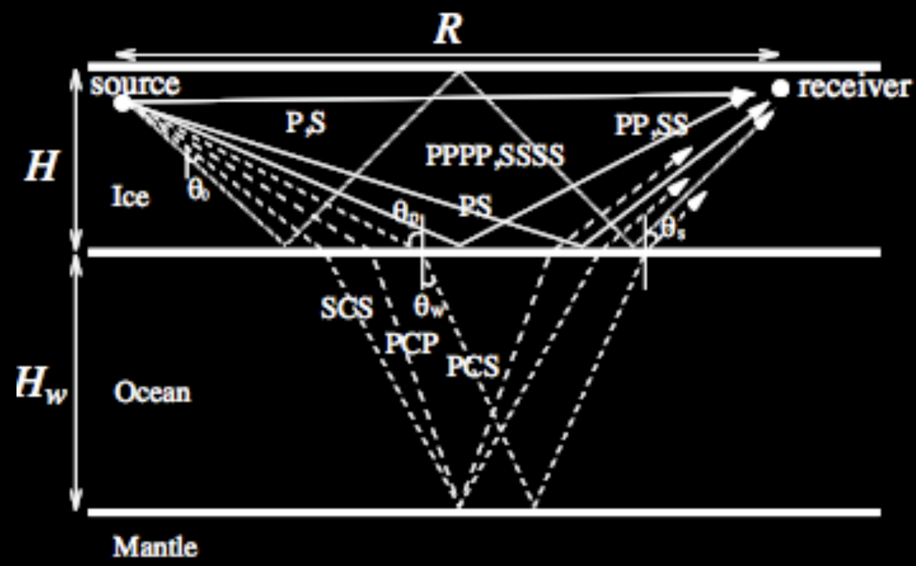
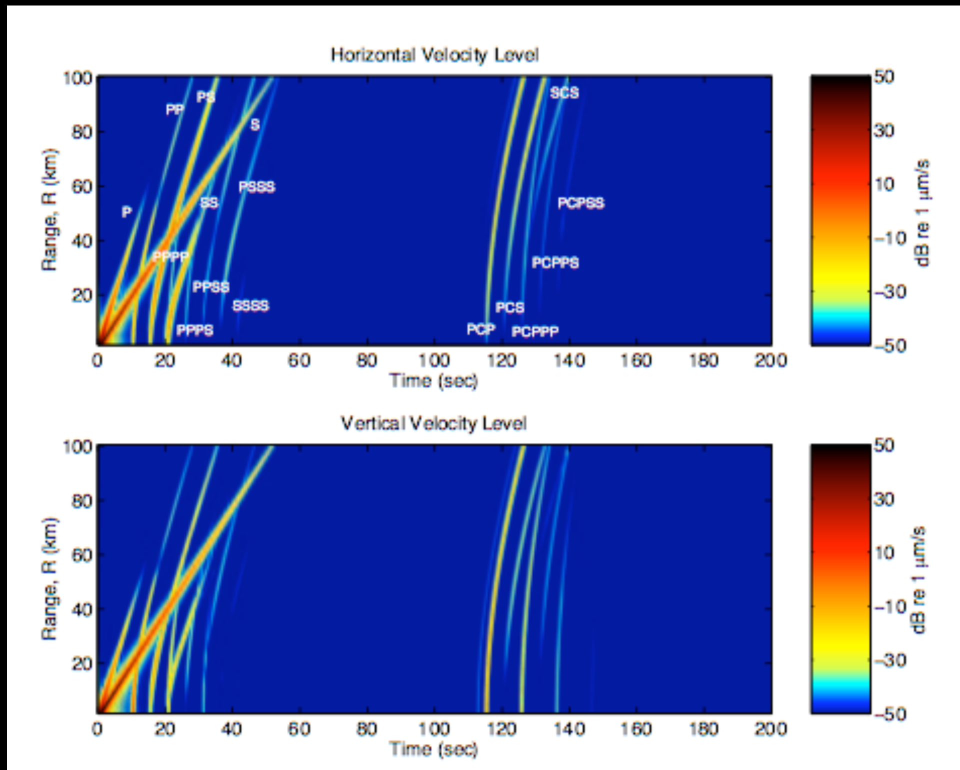
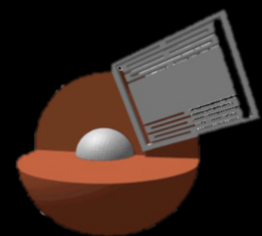
Unveiling the interior structure



Lee et al, 2003







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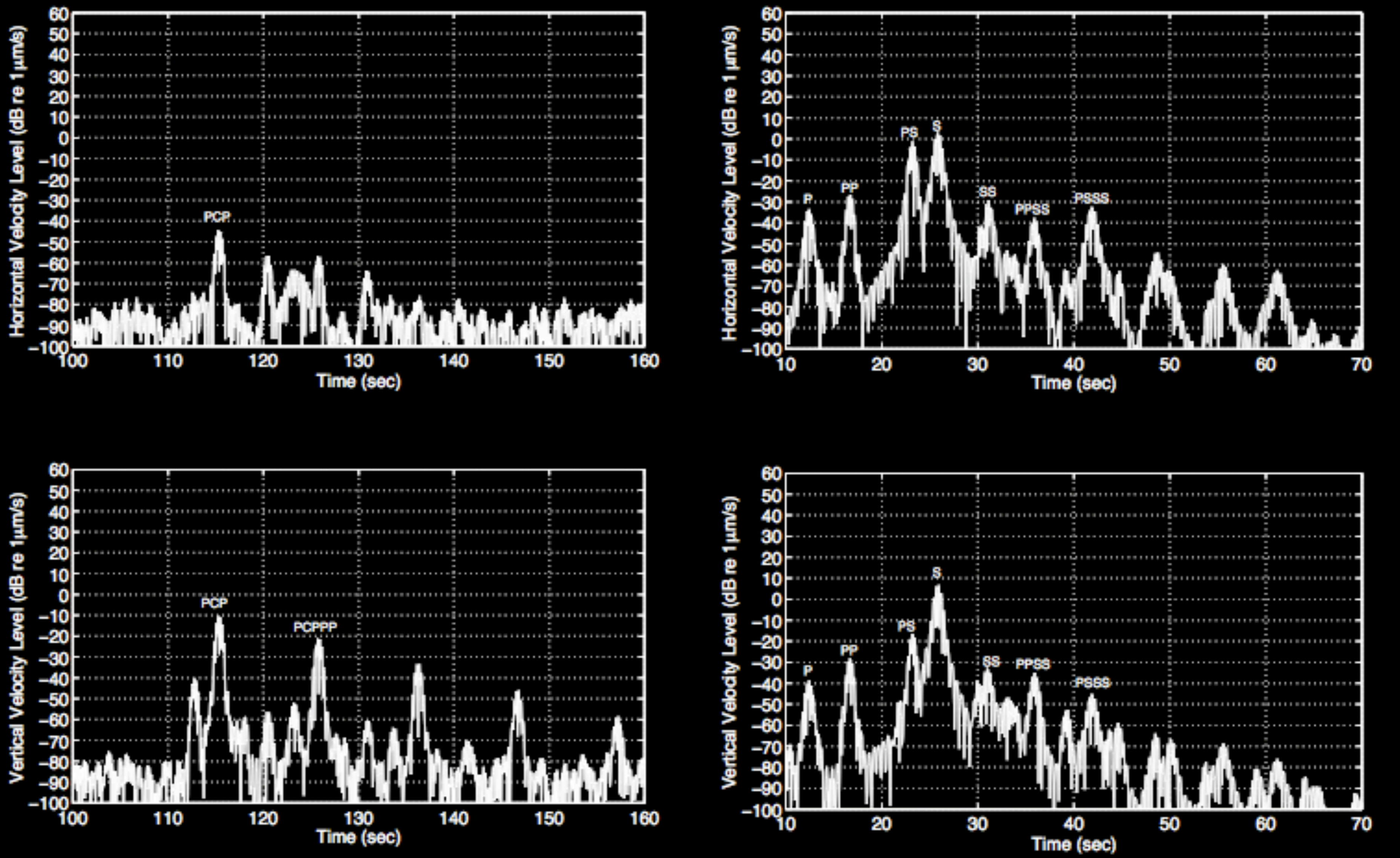
Synthesised Power Seismograms from Acoustic Sounding



Lee et al, 2003

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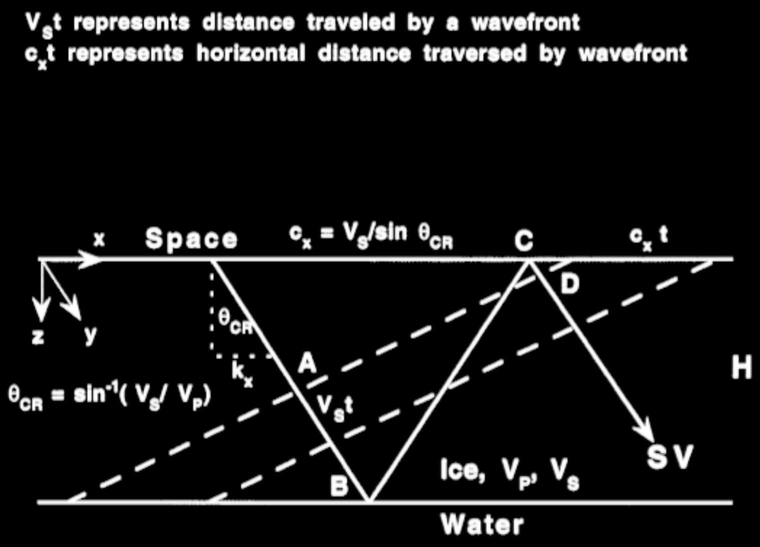
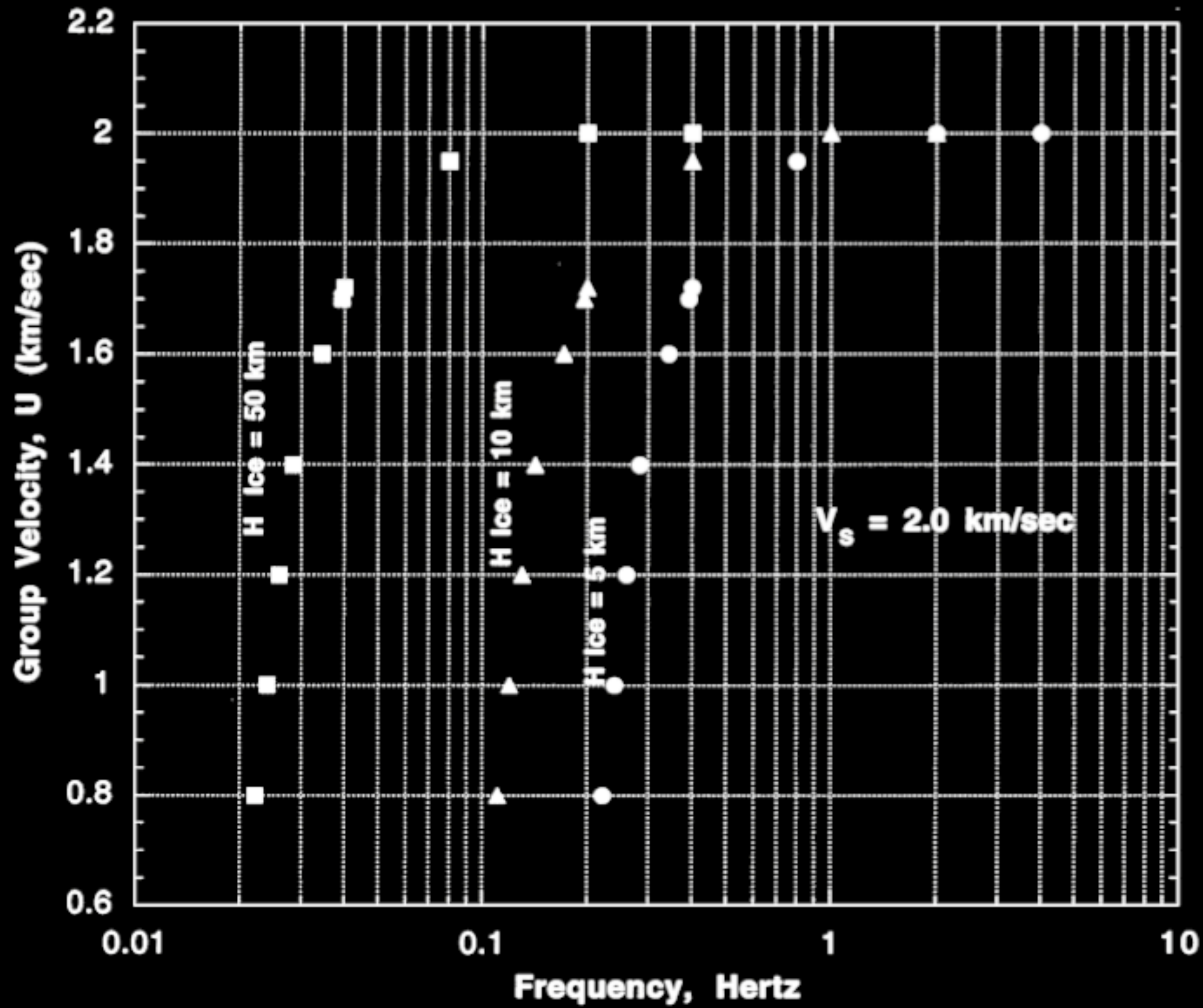
Love-wave propagation in an ice sheet

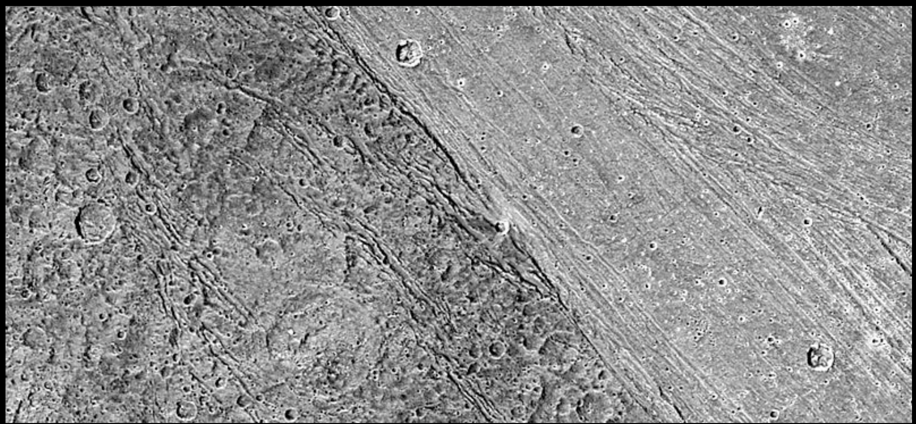




Kovach and Chyba, 2000

Science return from a single-station seismic deployment

- Characterisation of the ambient vibration spectrum of Ganymede and Europa
  - Stress evolution and release over diurnal cycle - certain
  - Level of tectonic activity (Ganymede) - certain
  - Micrometeorite impact rate - possible
- 1-D profile of the interior of the Ganymede and Europa:
  - Ice thickness - probable
  - Presence of interior ocean - probable
  - Depth of ocean - probable
  - Size of core – probable (Europa)/possible (Ganymede)



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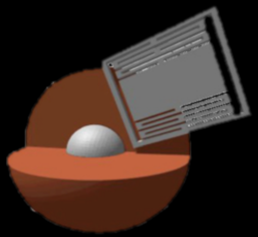


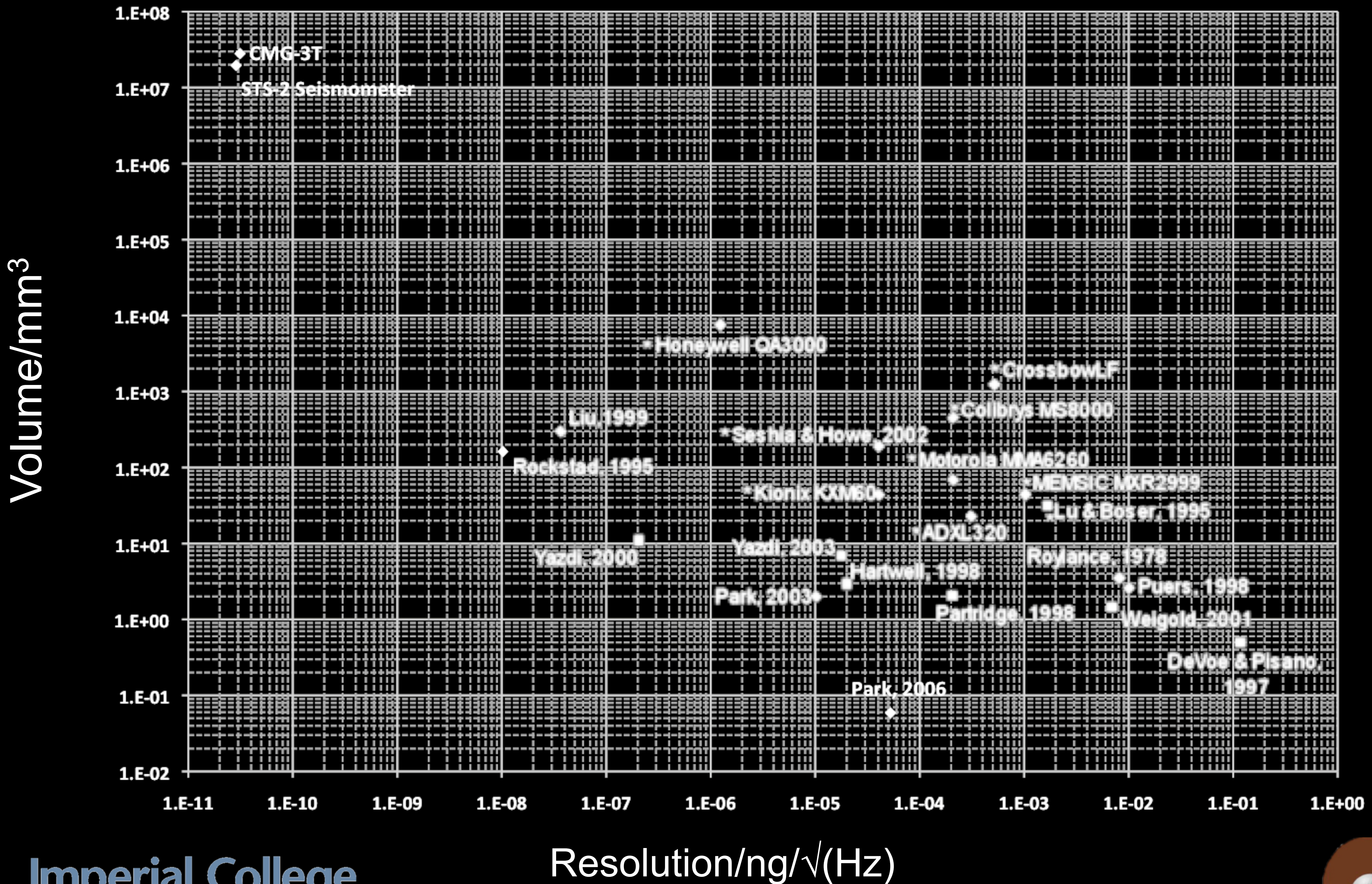
Instrument science requirements for a single-station seismic deployment

- Triaxial system
- Bandwidth from 0.02 to 100 Hz
- 10 nm/s sensitivity in bandwidth – 1 ng at 1 Hz
- 100 dB dynamic range, 16 to 18 bits or greater
- Several diurnal cycles lifetime

Engineering requirements for deployment and operation

- Low mass, and especially volume
- Low power
- Robust enough to withstand entry shock of up to 40,000 g
- Operation under any tilt conditions

Accelerometer performance vs volume



After Park, 2006 and others

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The limits to miniaturisation

Mechanical noise

For a suspension with loss mechanisms the mechanical acceleration noise floor is given by

$$a_n = \sqrt{\frac{4kT\omega}{mQ}}$$

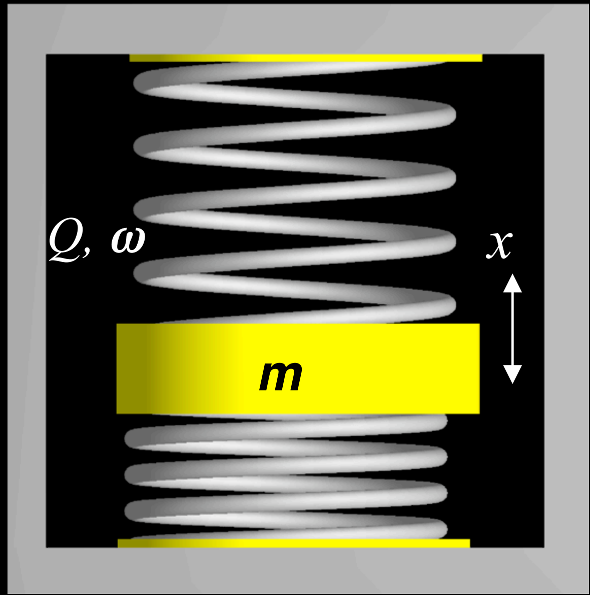
where

T is the temperature

Q is the quality factor of the suspension,

ω is the resonant frequency

m is the proof mass



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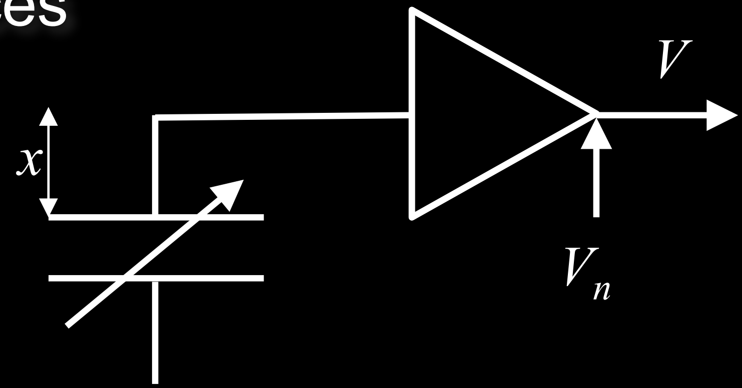
Electronics Noise

The voltage noise of the first amplifier of the position transducer also introduces acceleration noise

$$a_e = \frac{\omega^2}{\partial V / \partial x} V_n$$



where

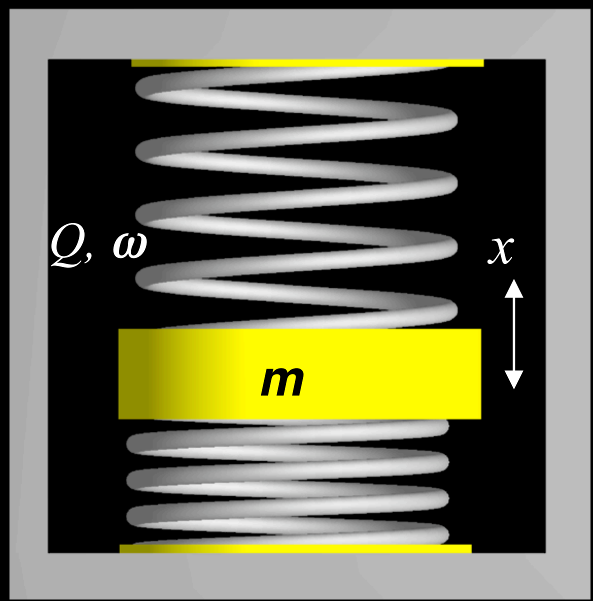
$\partial V/\partial x$ is the transducer gain

V_n is voltage noise of the amplifier

Gravity

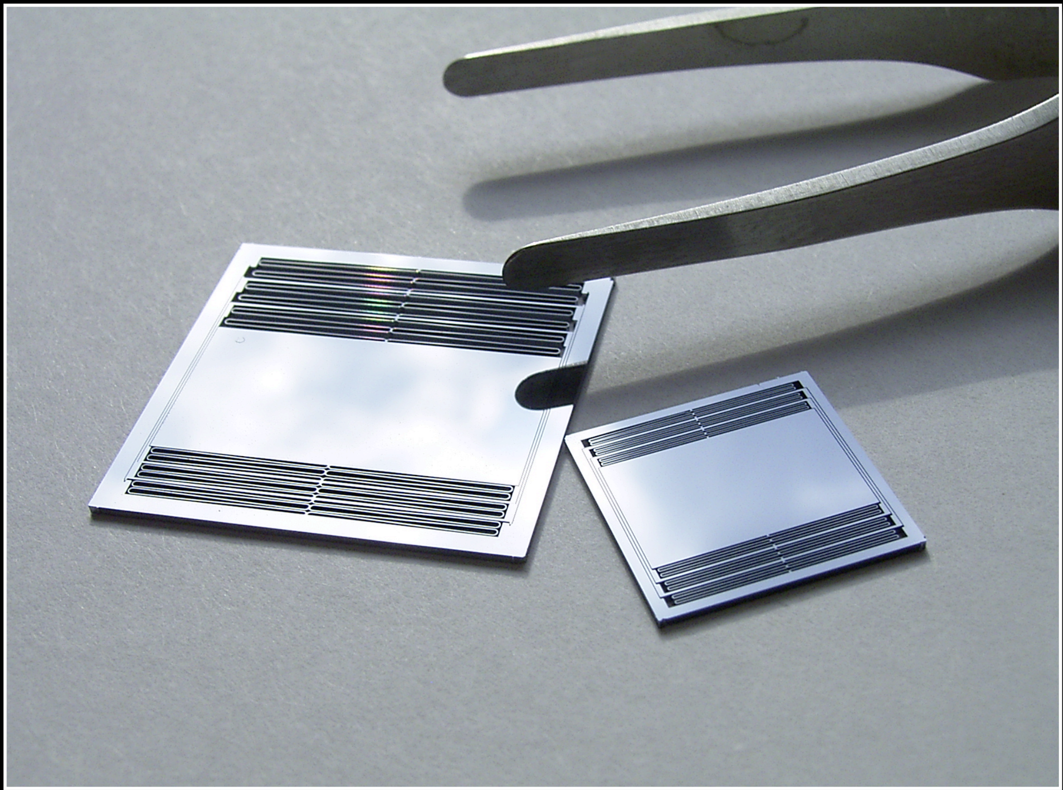
We need to measure the vertical component against a background acceleration of 0.13 or 0.15 g

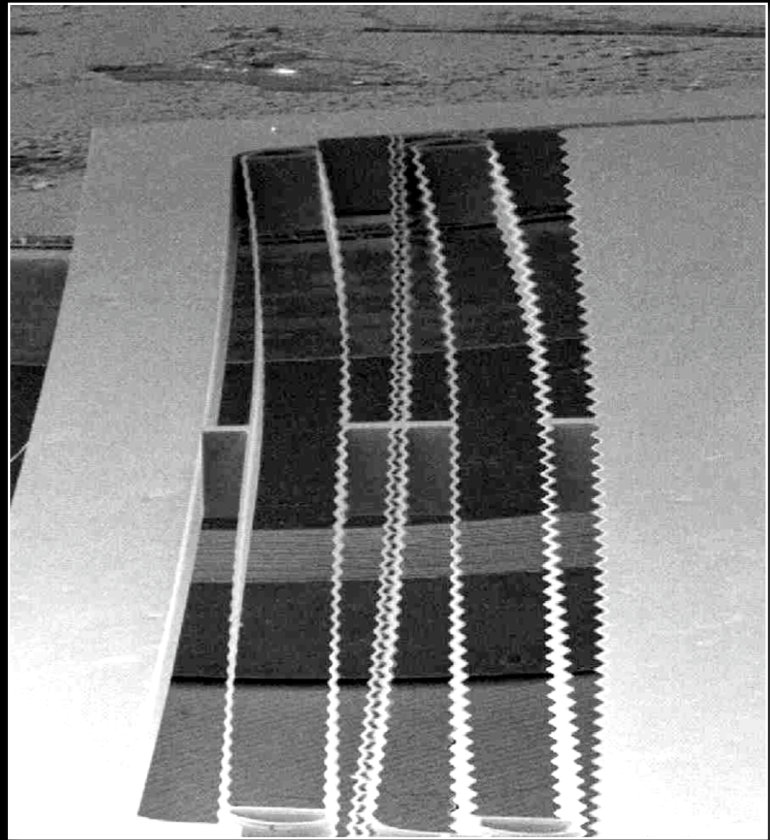
The suspension needs to have sufficient room to sag $x = g/\omega^2$

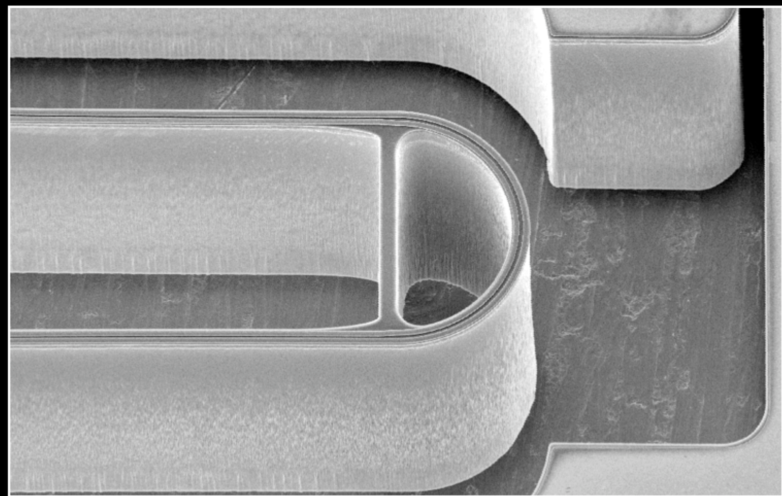


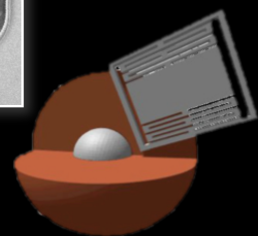
Suspension fabrication

Use deep reactive-ion etching (DRIE) to machine through silicon wafer to form the suspension, high m, low ω, *high* Q









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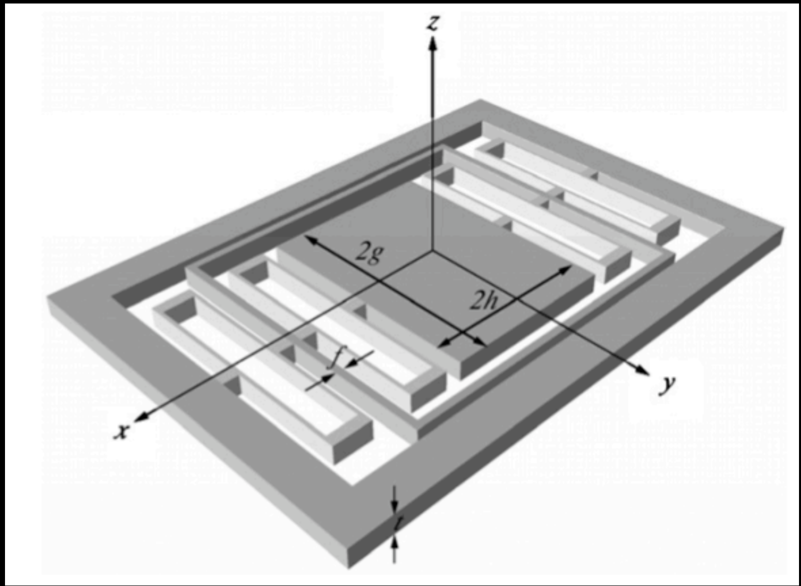
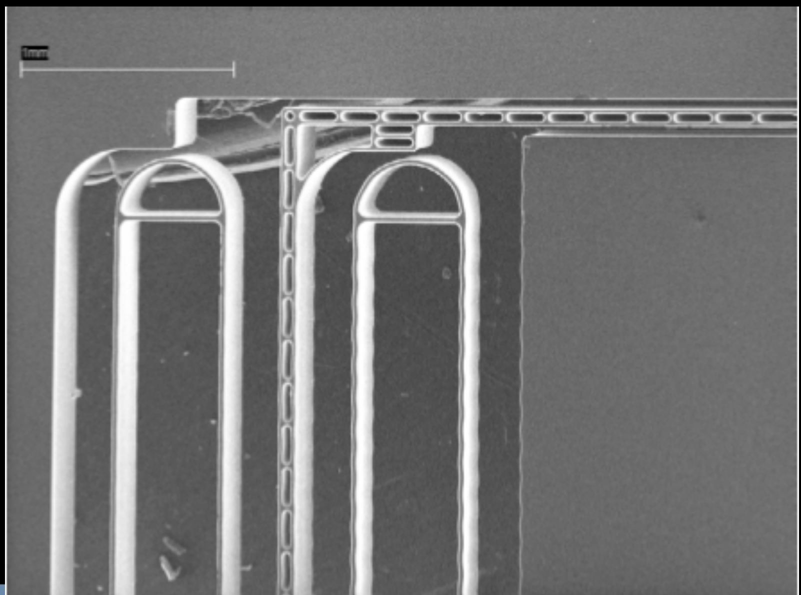
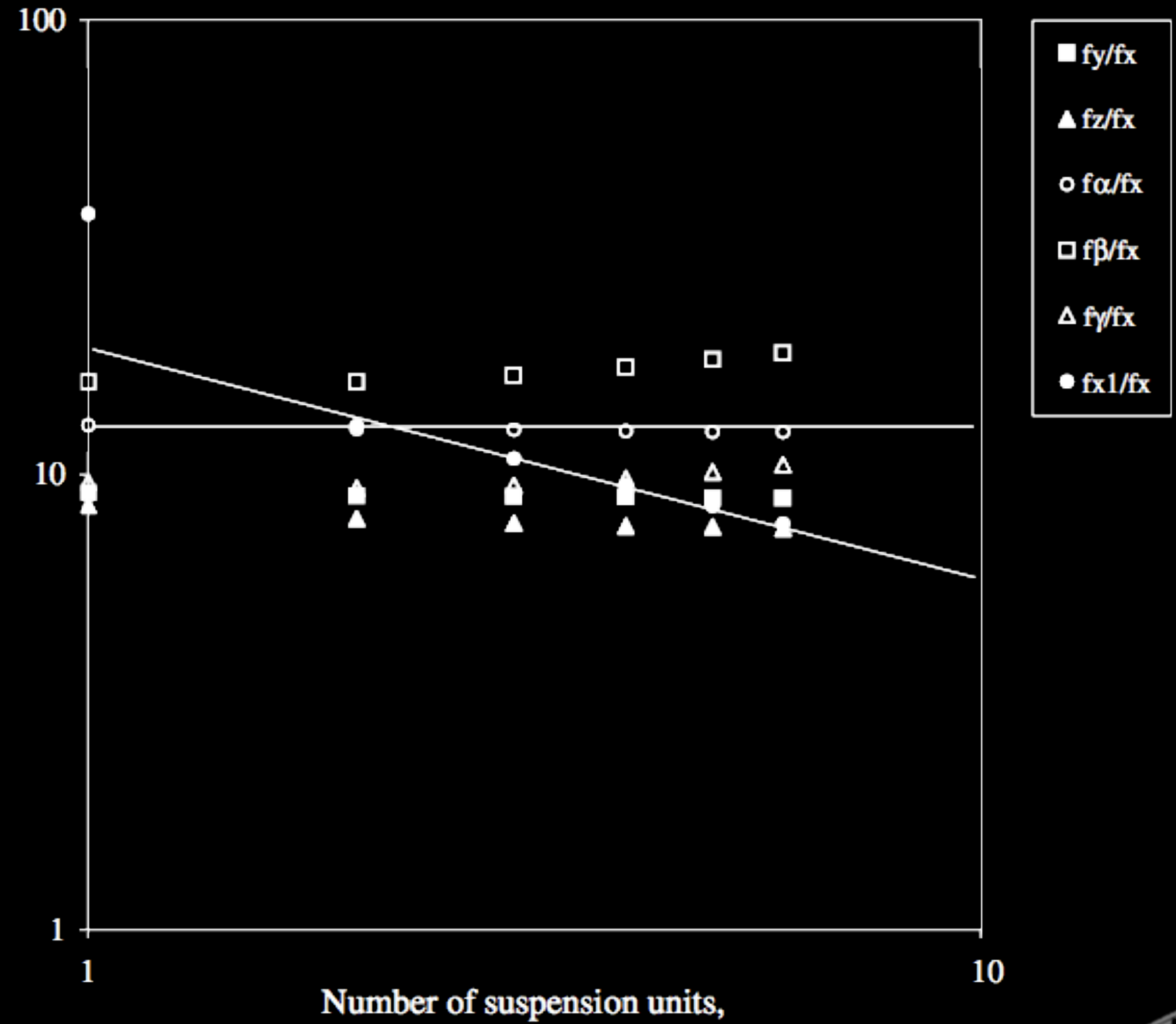
Suspension design – frames for rigidity at low ω





Rejection ratio of unwanted modes



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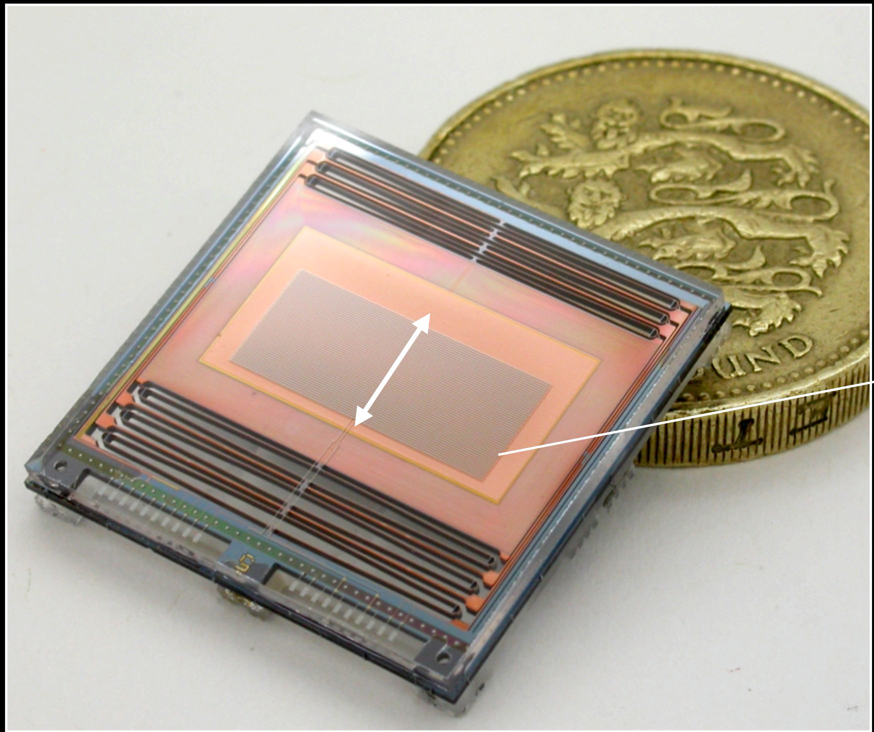
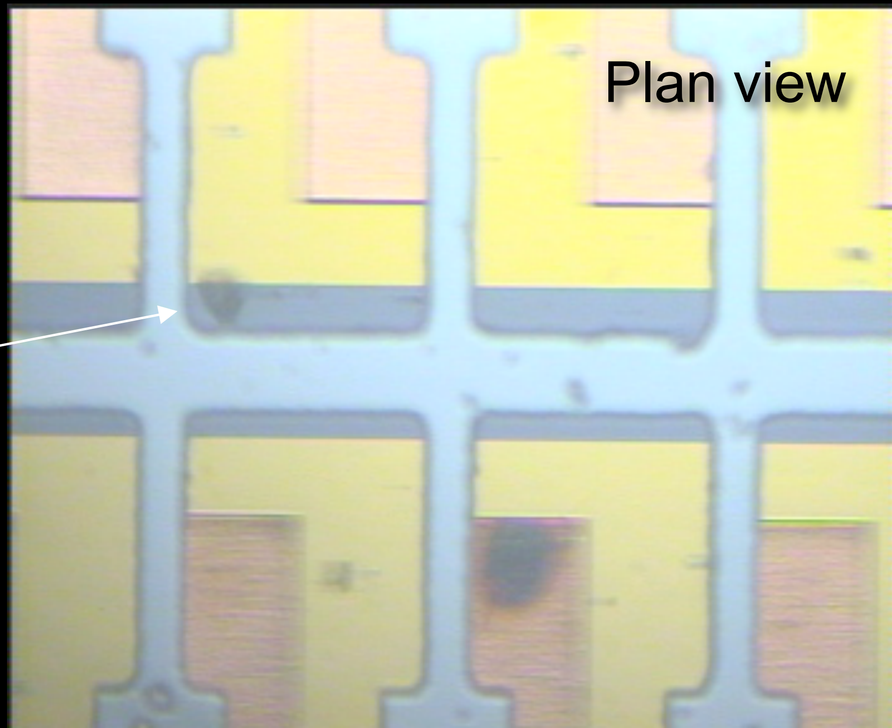
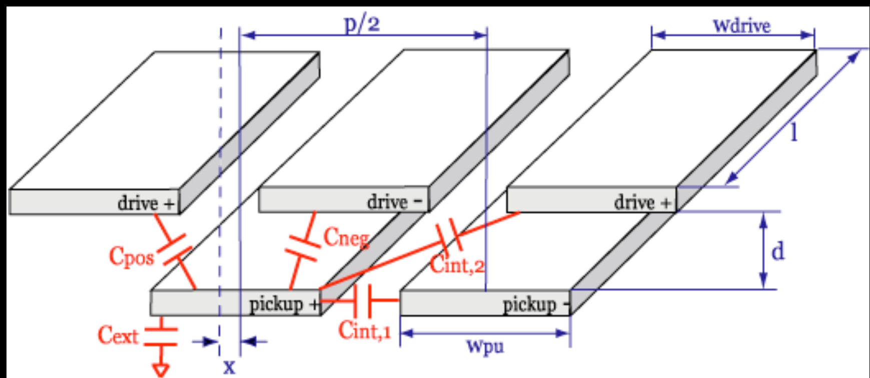
Displacement Transducer – Lateral Capacitive Array





Cross section



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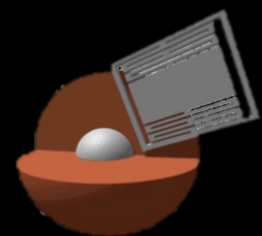
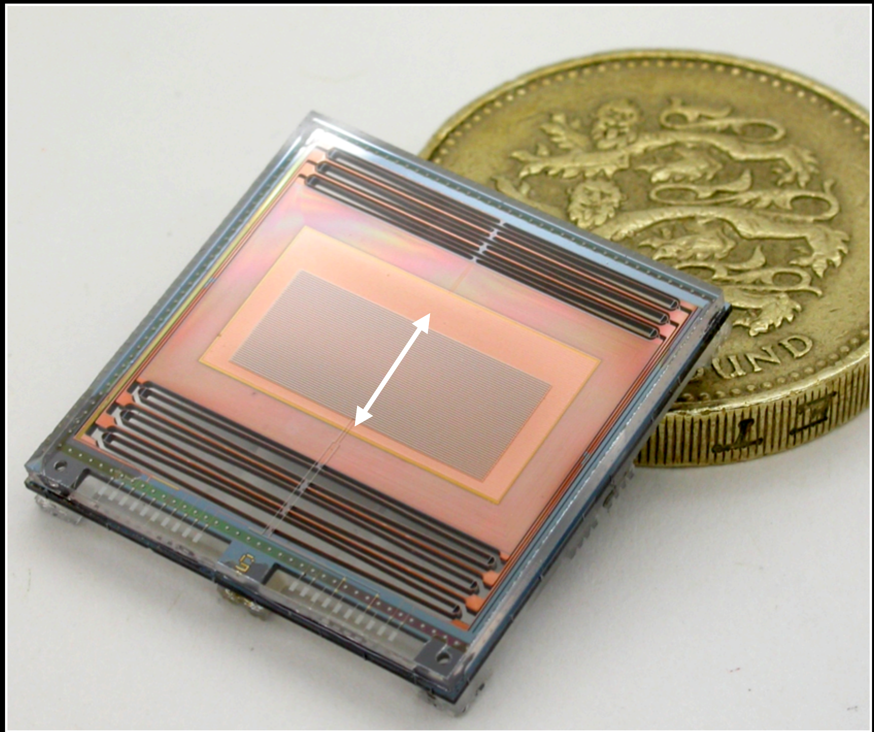
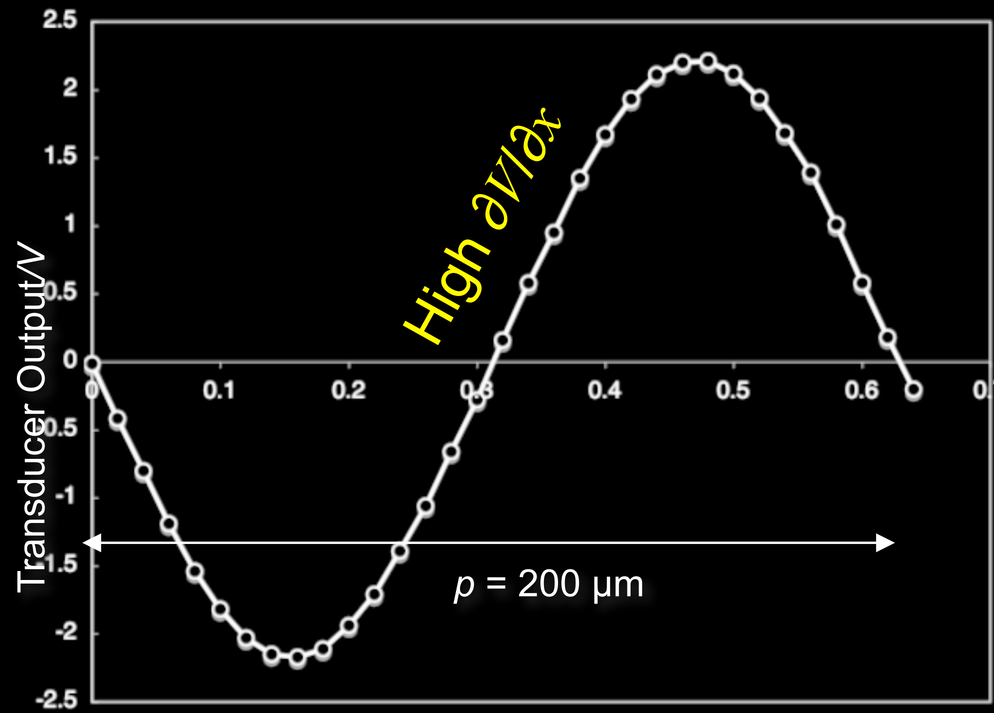
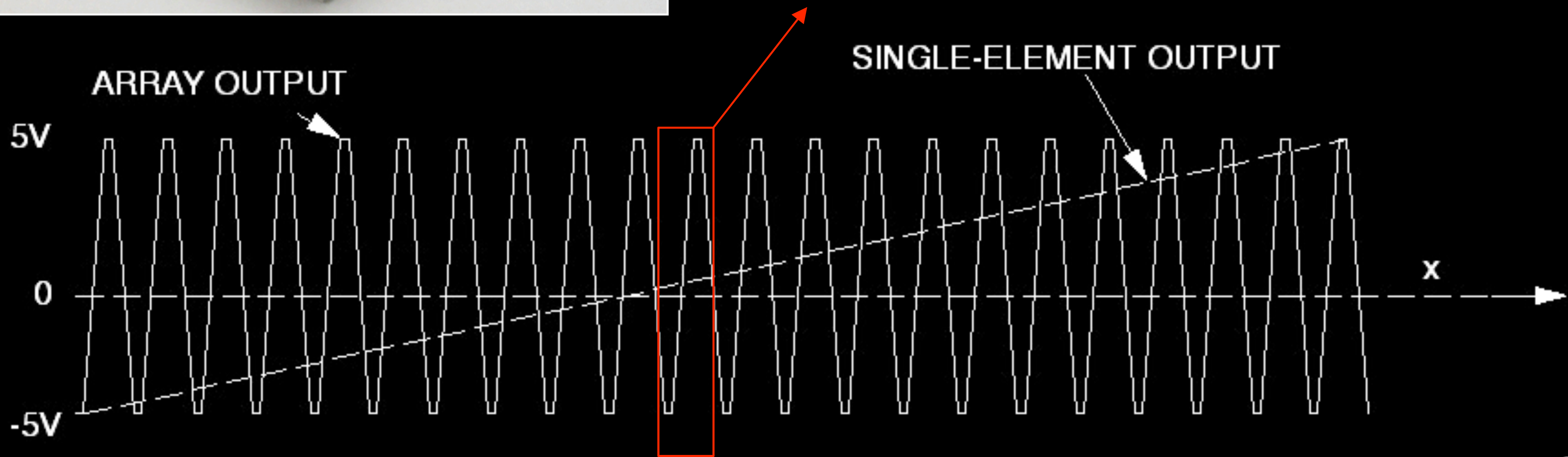


Displacement Transducer - Gain







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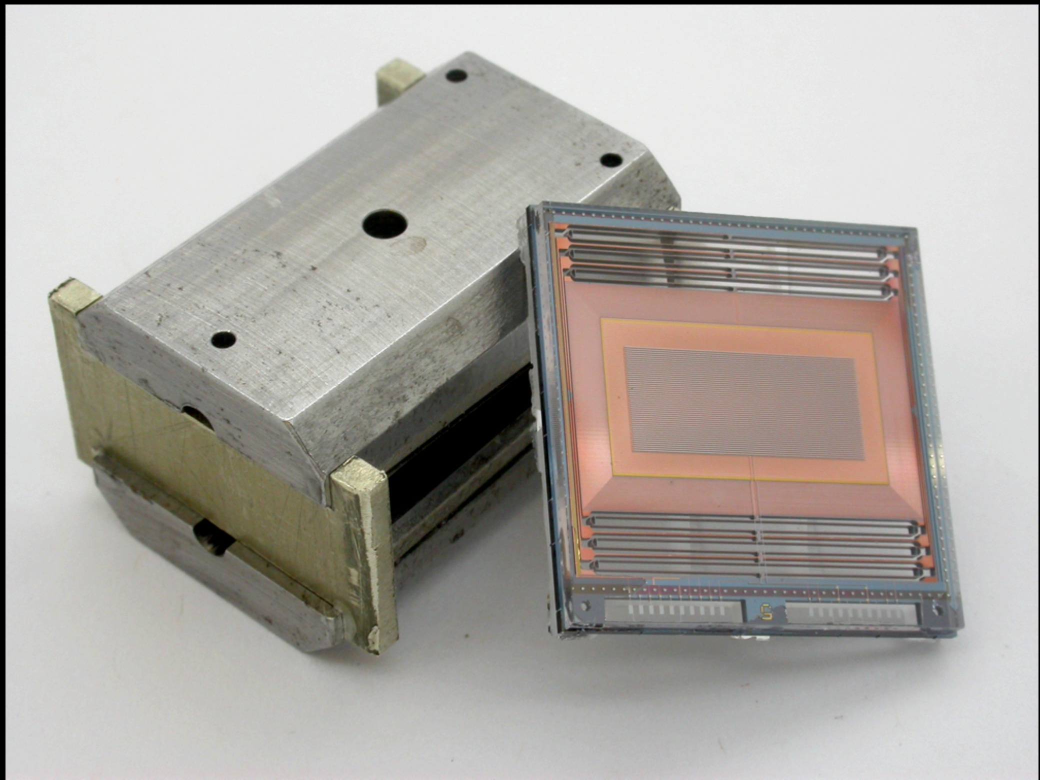
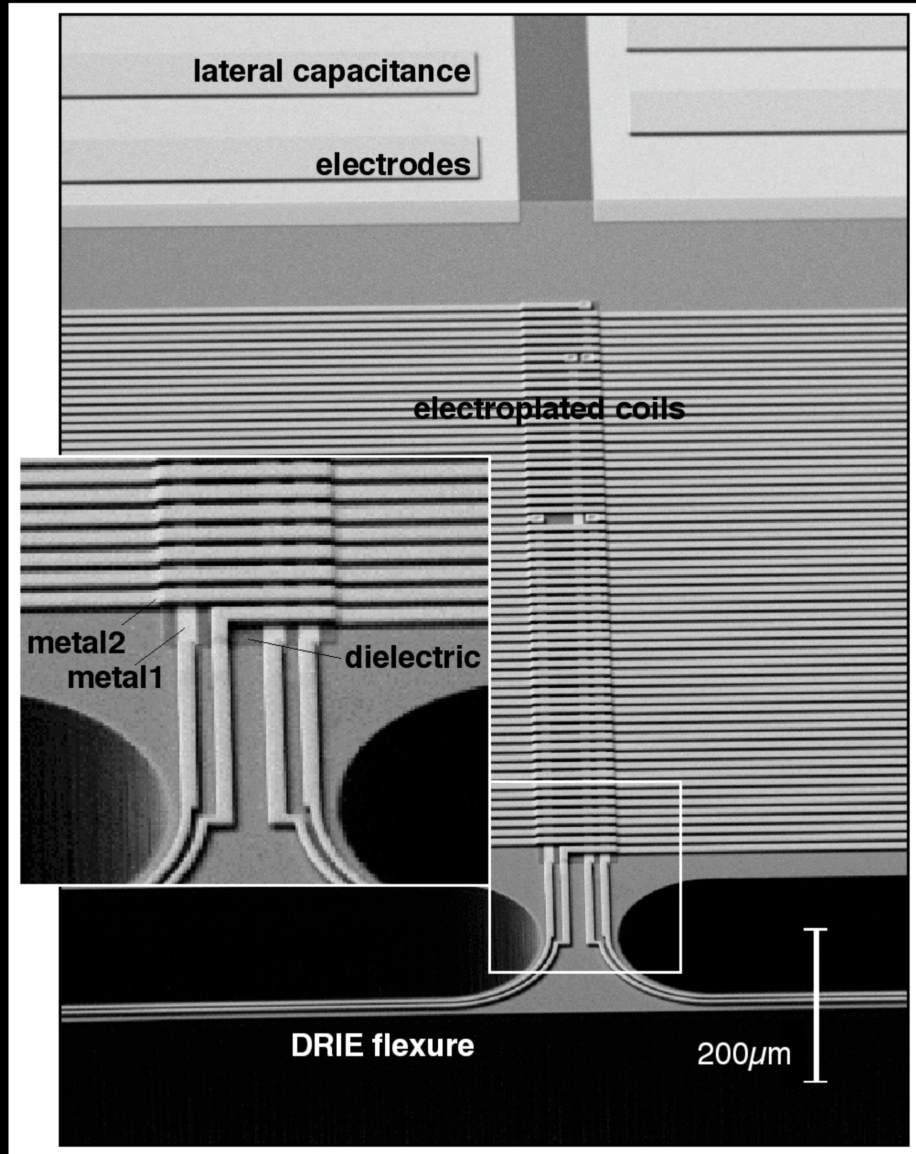
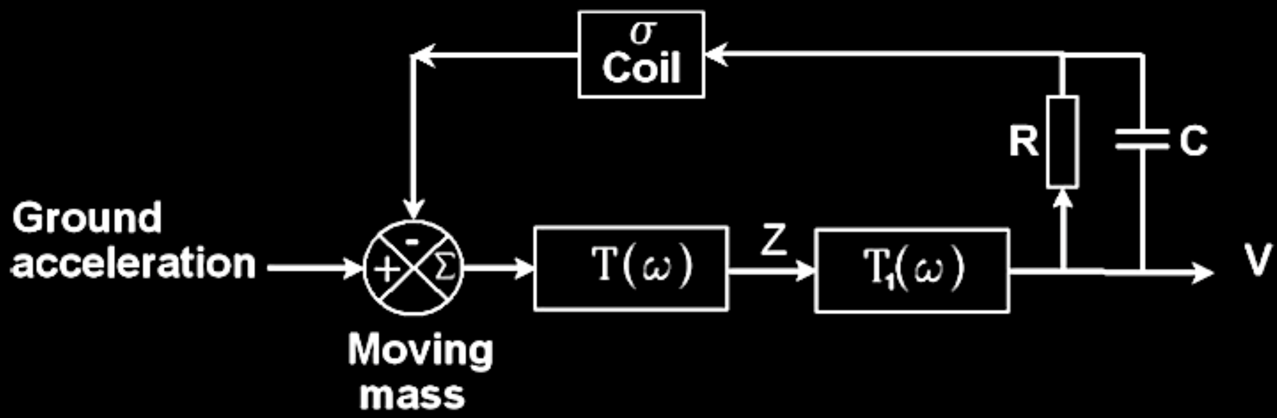
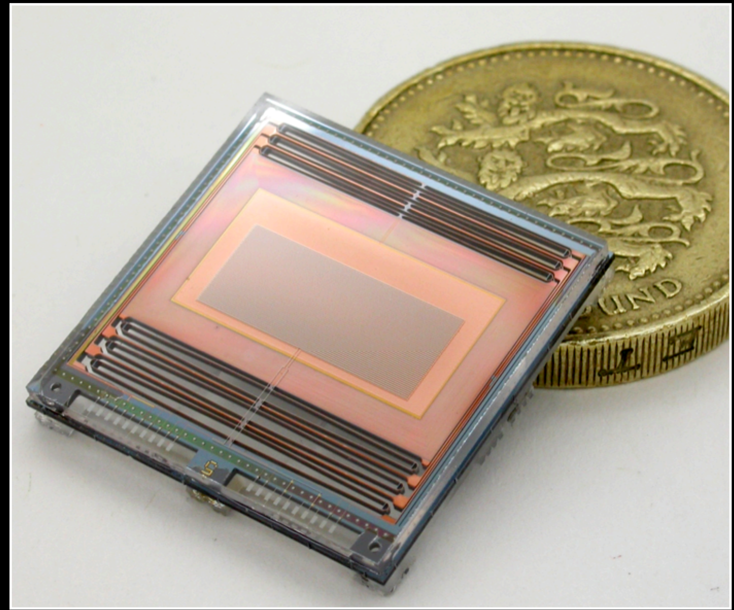
Electromagnetic feedback actuation – high m, Q



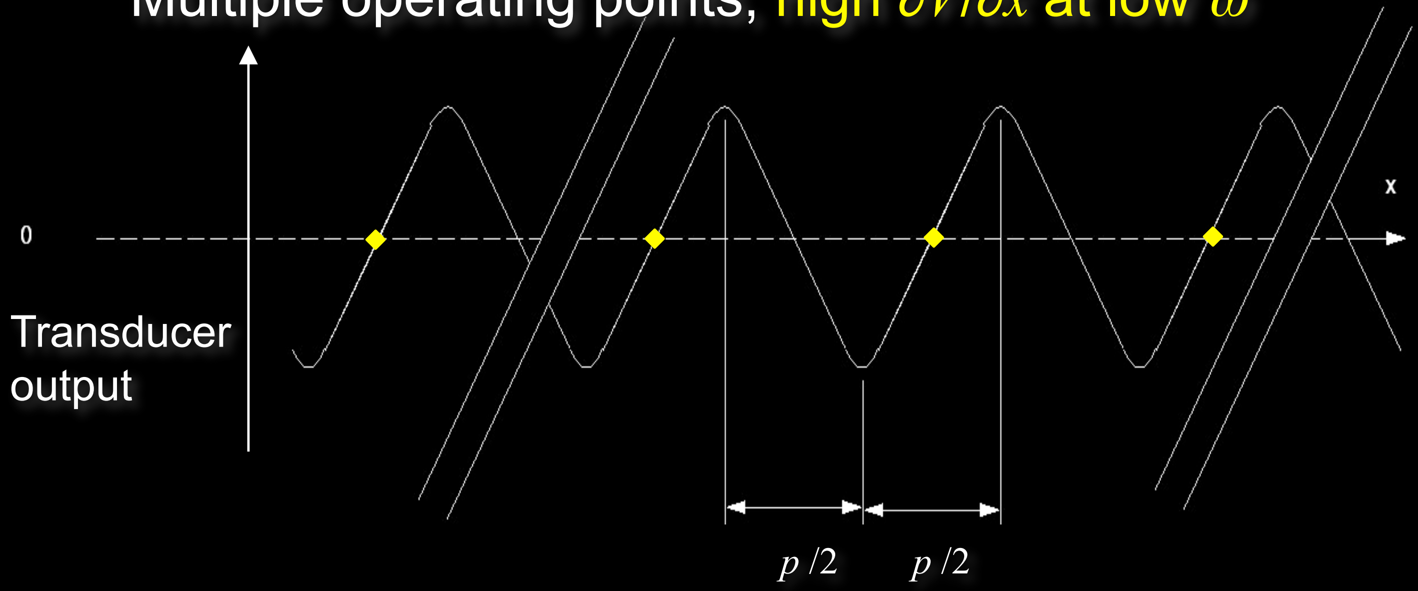


Feedback Control – selecting the operating point





Multiple operating points, high $\partial V/\partial x$ at low ω



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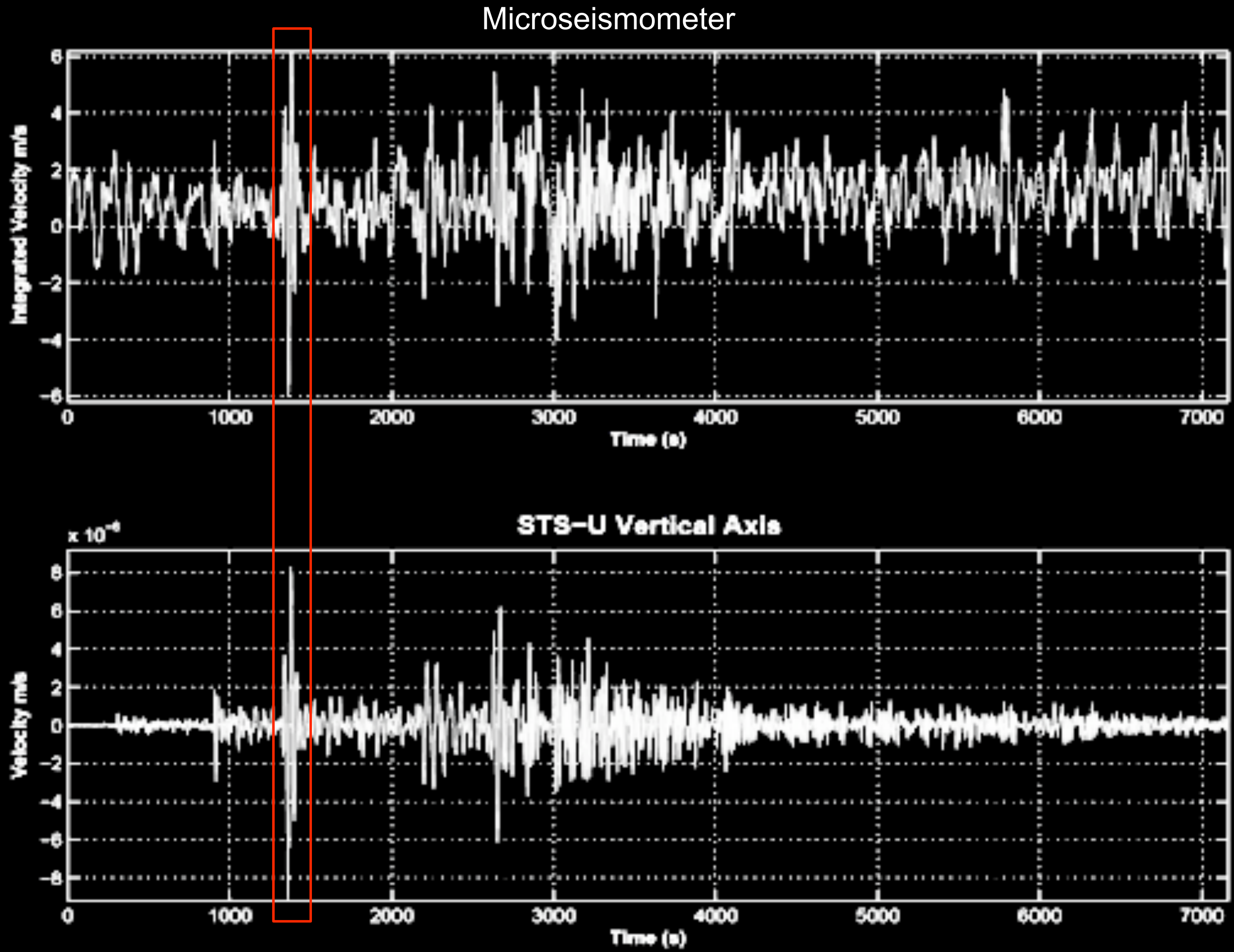
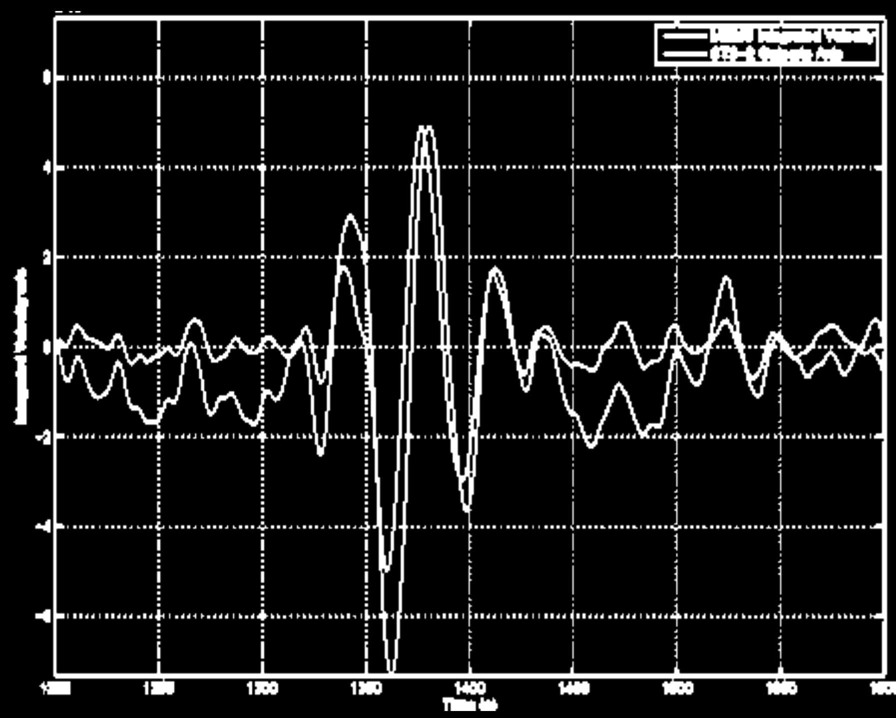
Performance – earthquake detection

First field testing of microseismometer in June 2008 at Kinemetrics, Pasadena
Detection of both local and teleseismic events (Sandwich Islands: Δ = 121° Mw = 7)



Filtered to equivalent bandwidth



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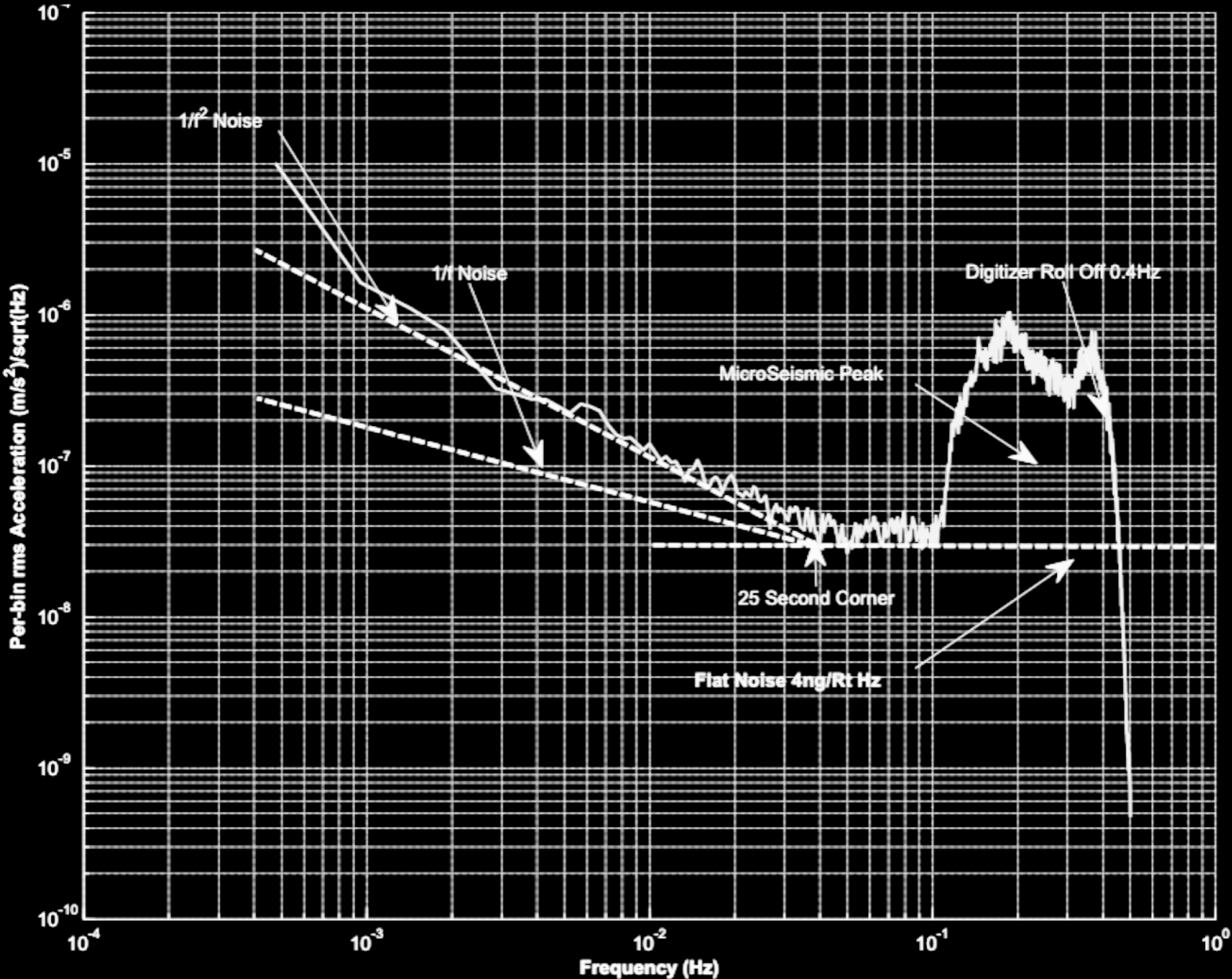
Resolution from ambient seismic noise



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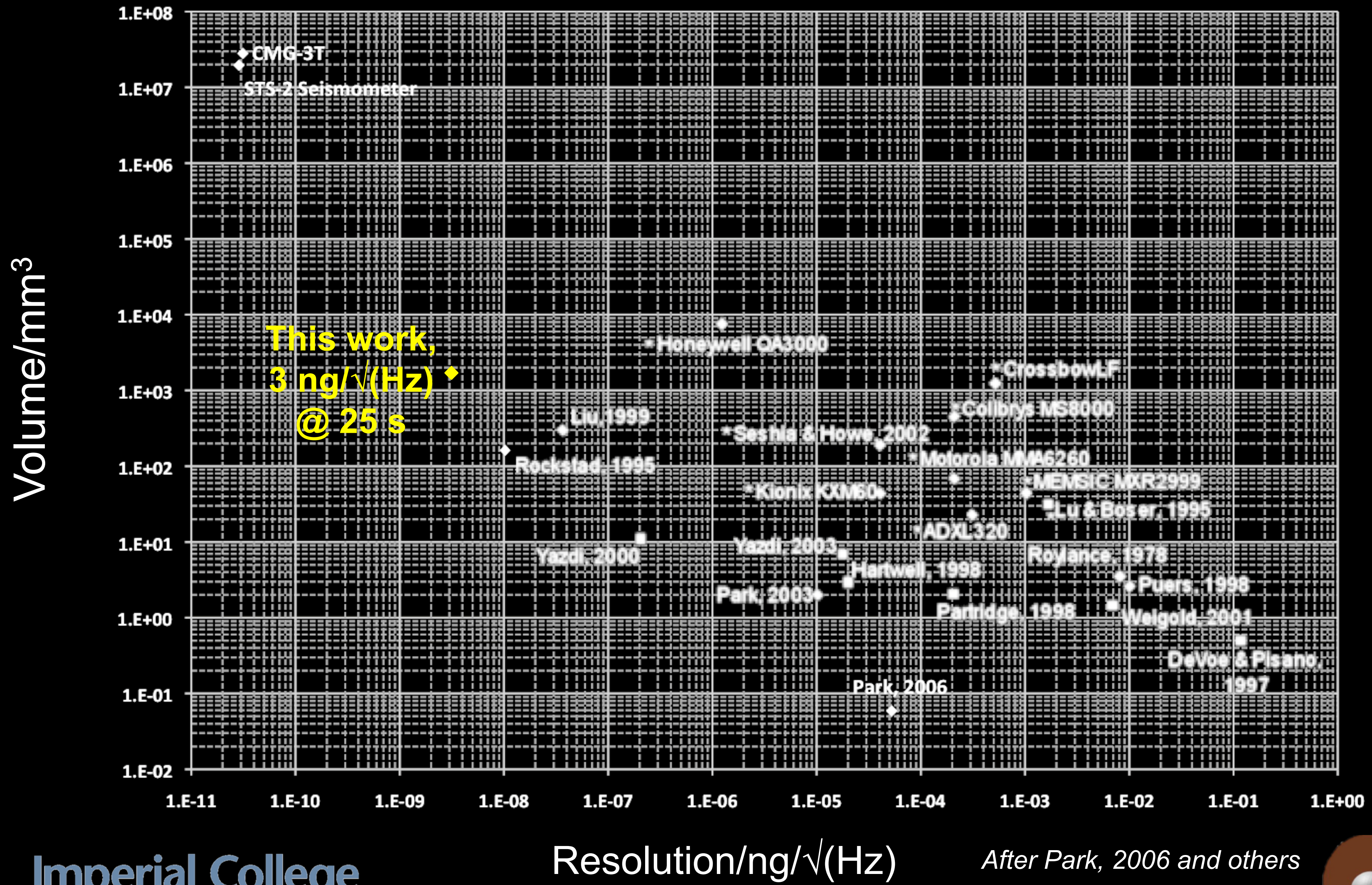
Accelerometer performance vs volume



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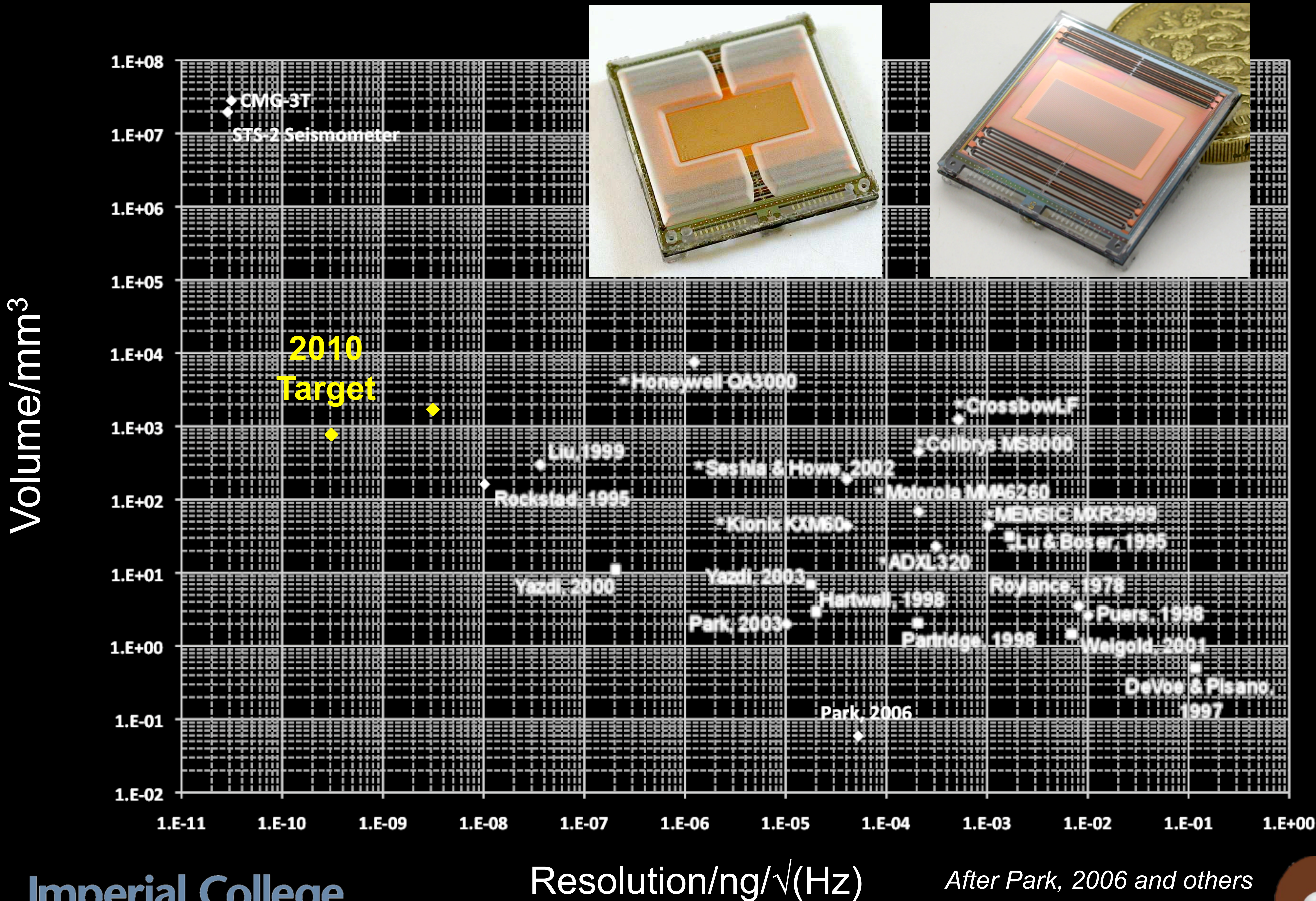
Future work



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Packaging for Shock

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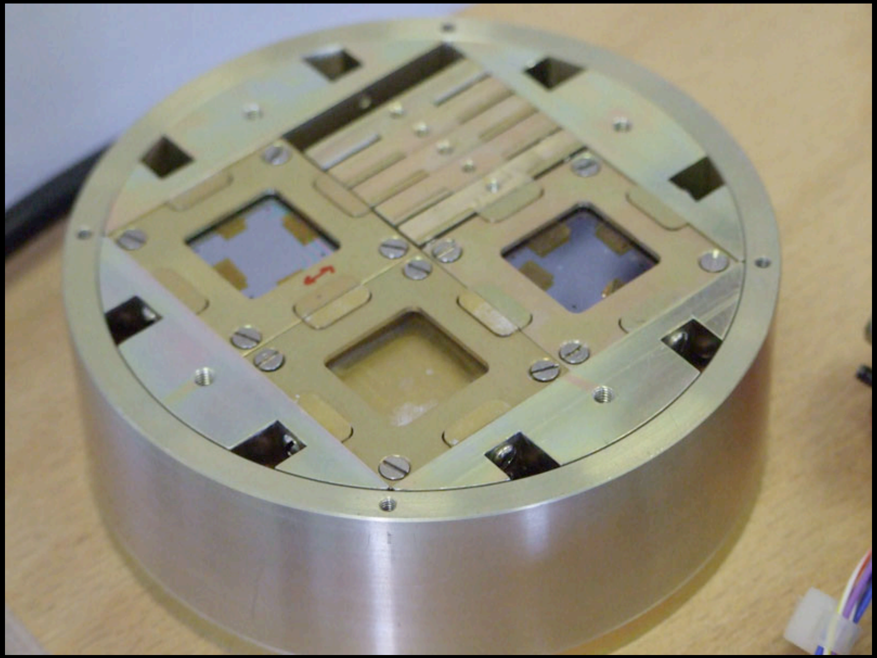
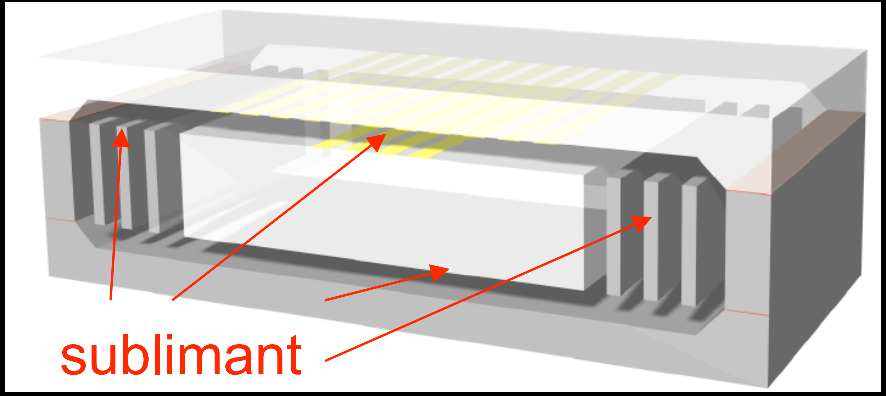
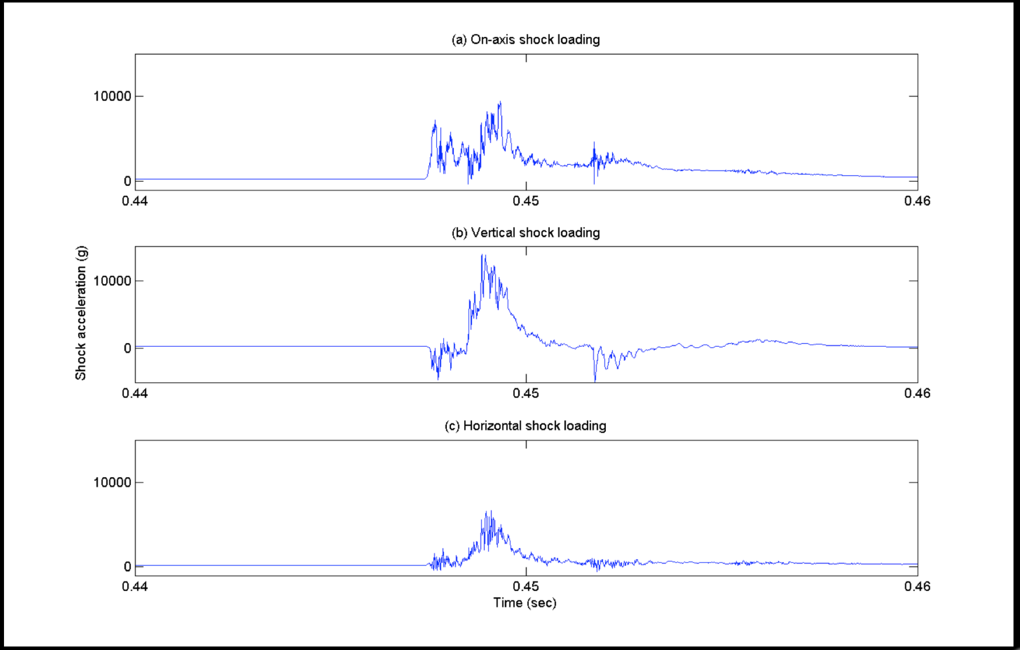
Pendine test







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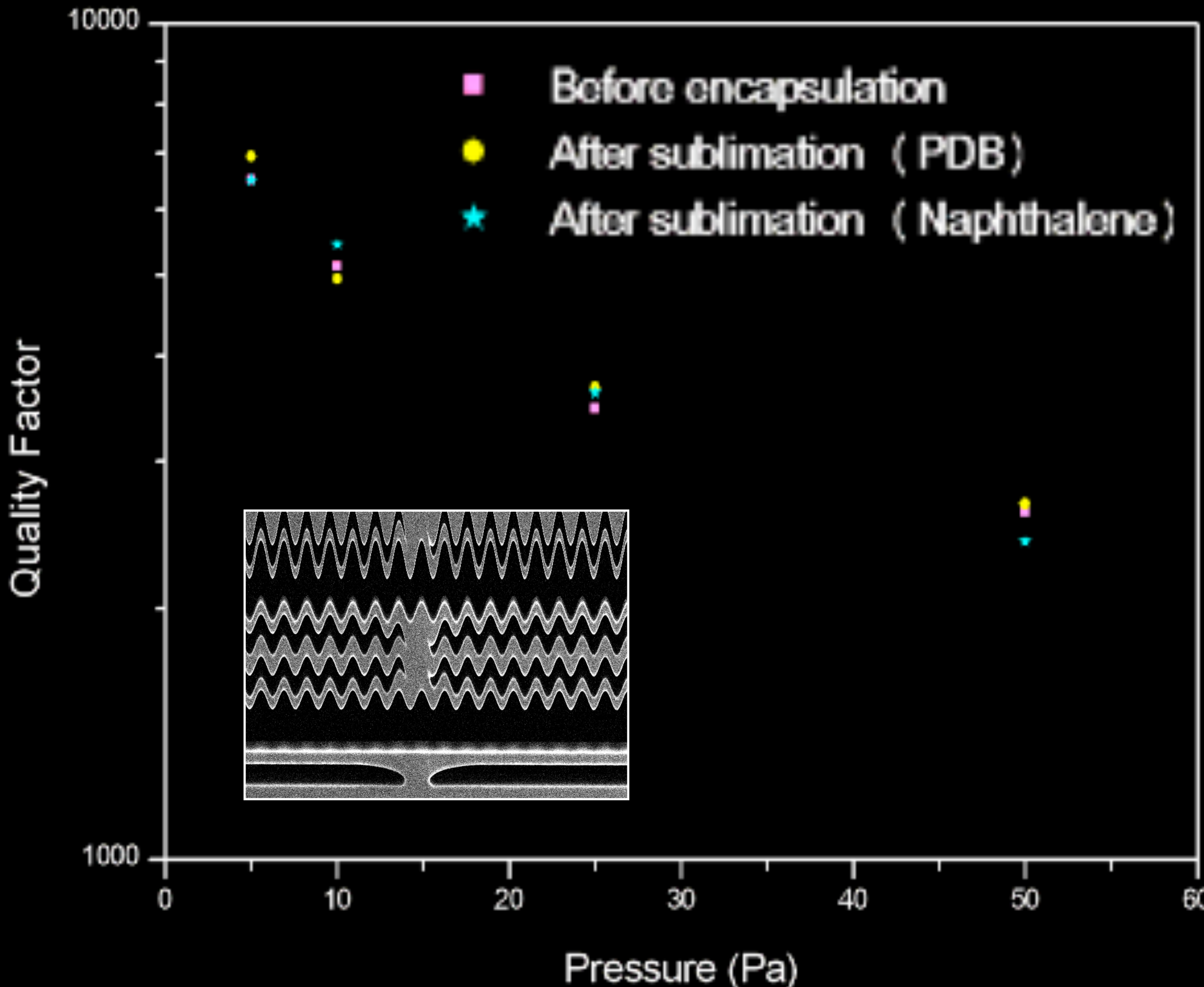
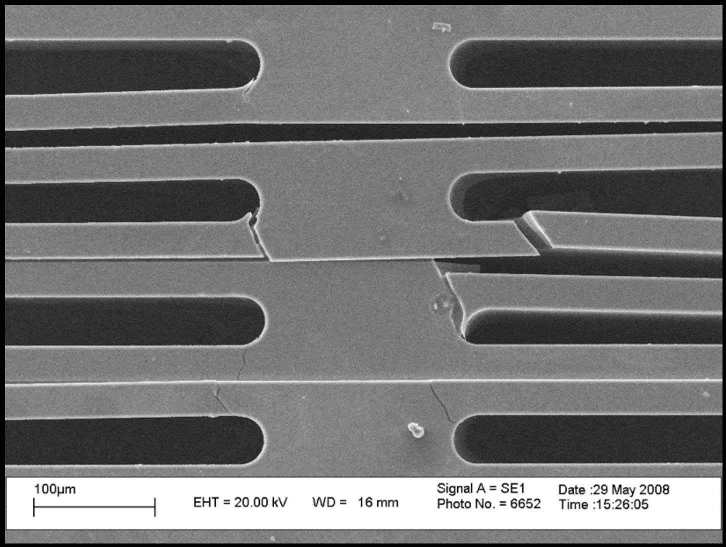
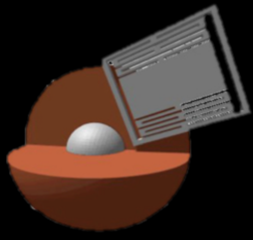
Shock Mitigation Results

- Evacuation released the suspensions from sublimant encapsulation
- **quality factor, Q, returned to pretest levels**
- Demonstrated potential survivability of silicon suspensions at very high shock levels

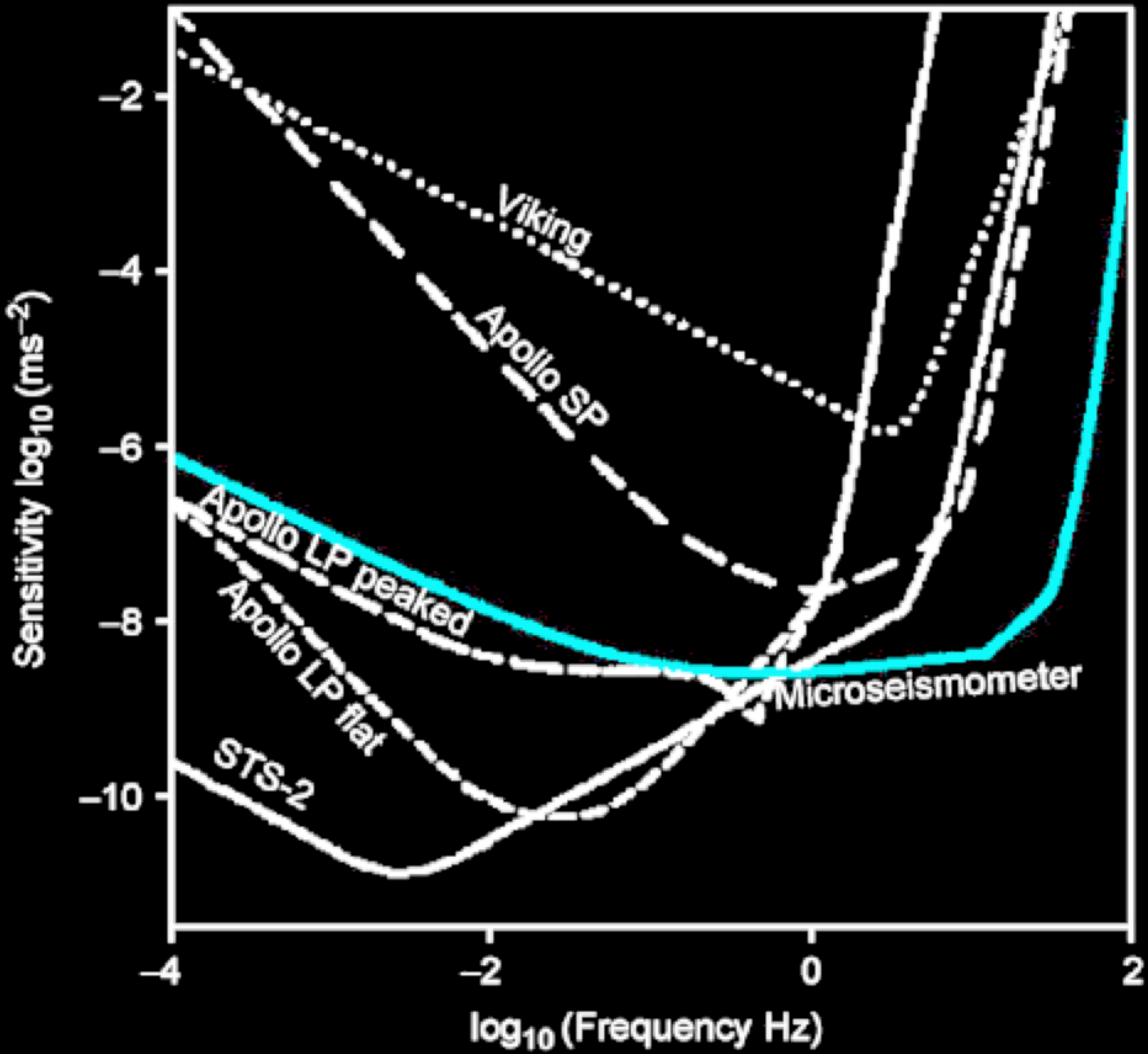


Unpackaged





Comparison with existing seismometers



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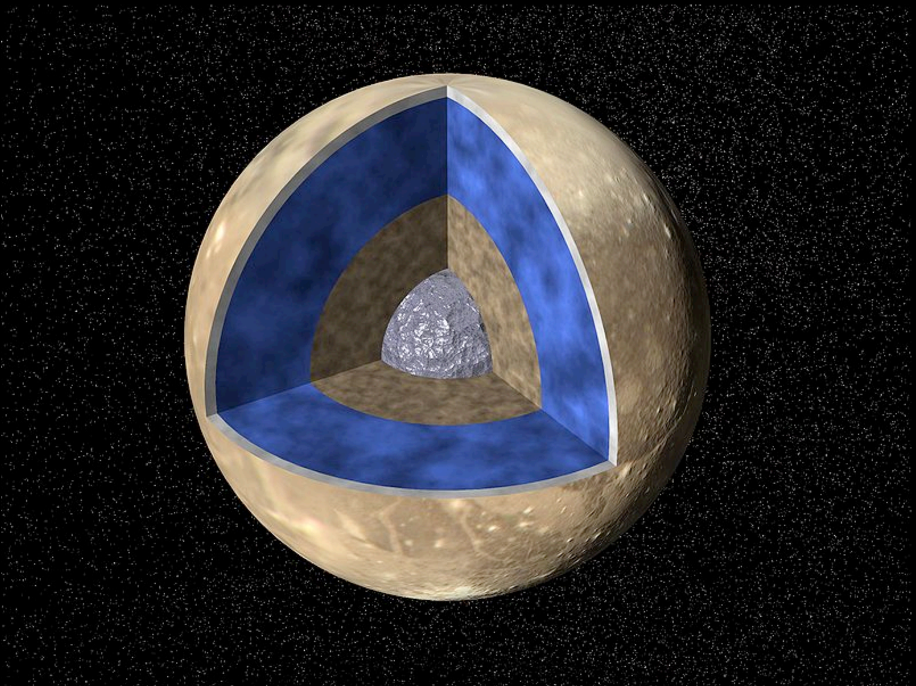
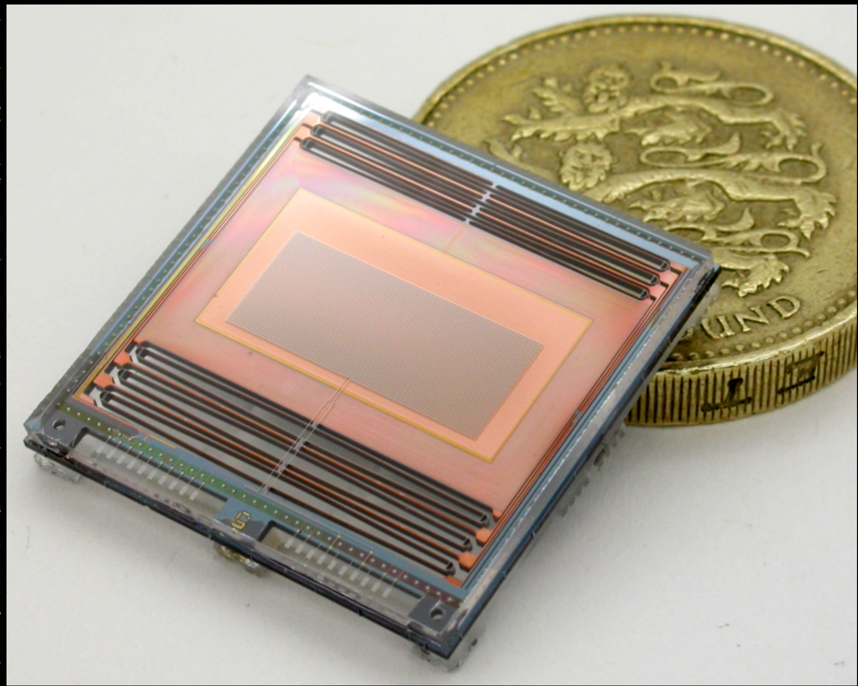
Summary

• A penetrator-deployed seismometer would produce unique, critical and complimentary information on the internal structure of Europa and Ganymede

• A microseismometer is under development under a UK TDA to meet both the science and engineering requirements of this demanding application reaching TRL 5 by 2012





Thanks to Kinemetrics Inc. and the UK Science and Technology Facilities Council for funding

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