Can you hear a landslide coming (before it's too late)?

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The Density of Modes (DoM)

A March 2023 Landslide in San Clemente, CA [1]

We implement a technique (borrowed form thermal systems) to measure the Vibrational Density of Modes (DoM) in granular matter using acoustic excitations.

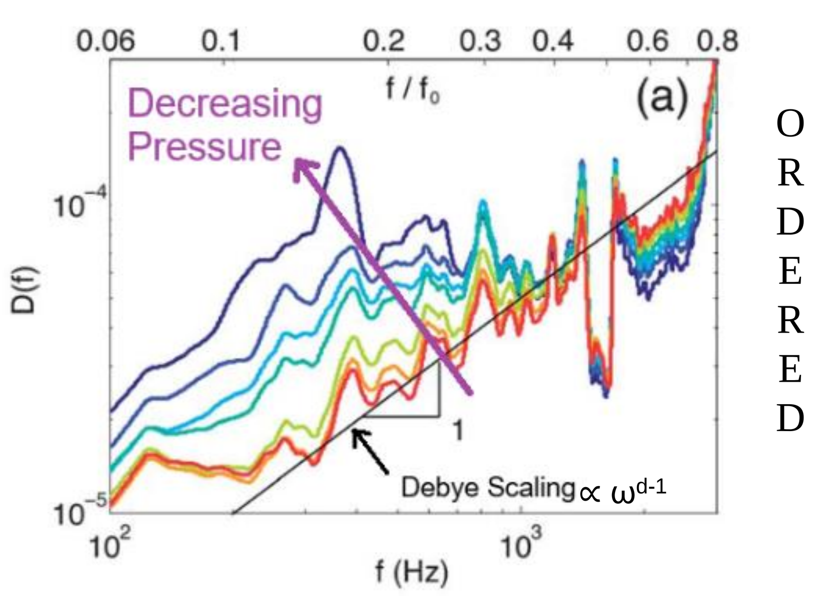
We to use the DoM to identify the state of laboratory granular materials, and eventually forecast failure events in earth materials.

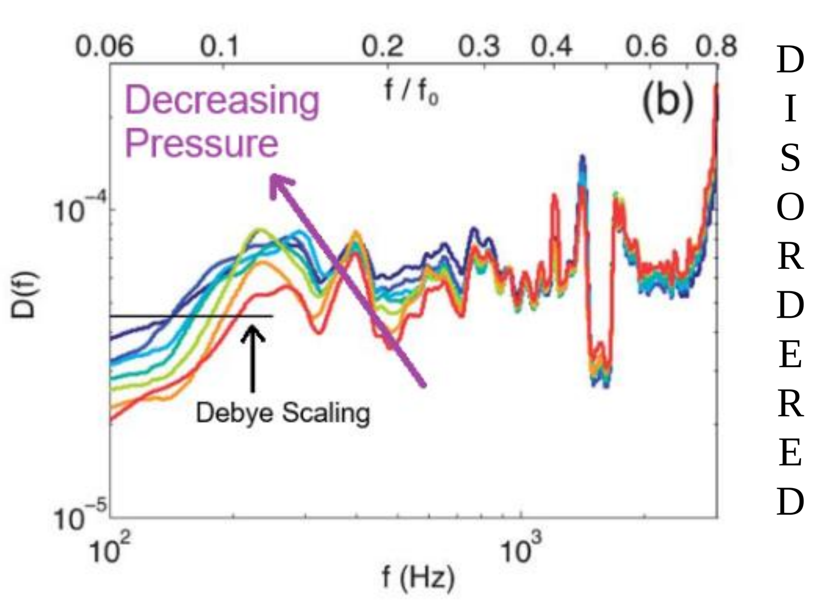
An earthquake causing the ground to liquify [5]

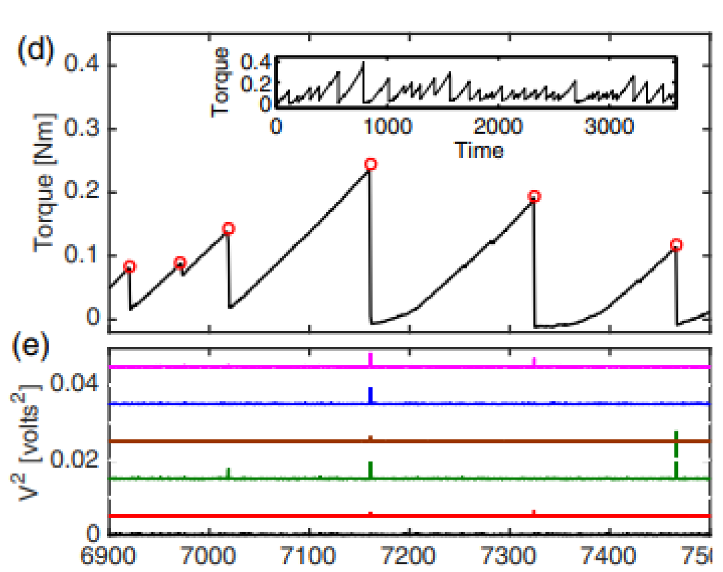
What is the Density of Modes?

The density of modes $D(\omega)$ describes the number of modes per unit frequency ω. It tells us how many possible ways the system can respond at a given frequency.

Jammed disordered system: excess low frequency modes relative to Debye-like scaling below some characteristic frequency ω* [6] .







Piezoelectric sensors detect when a granular material fails (marked as red dots) [4].

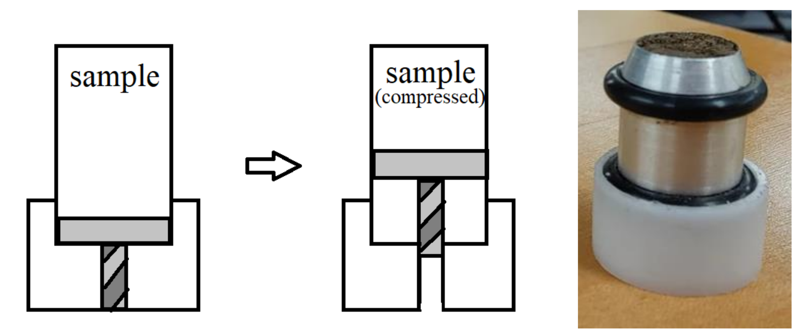
The DoM at 7 pressures for (a) an ordered system (b) a disordered system (Debye scaling is the black line) [2].

Project Goals: Using the DoM to forecast geohazards:

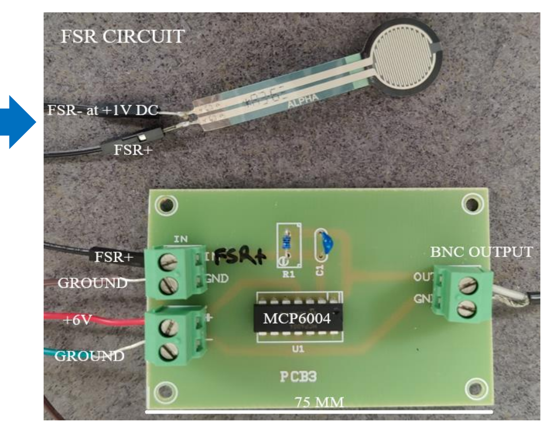
- An excess of low frequency modes in the DoM indicate softer material response.
- Changes in granular structure, applied stress, etc. will change the shape of $D(\omega)$.
- The goal: To quantify the changes in the DoM to understand when failure is likely.

Instrumentation

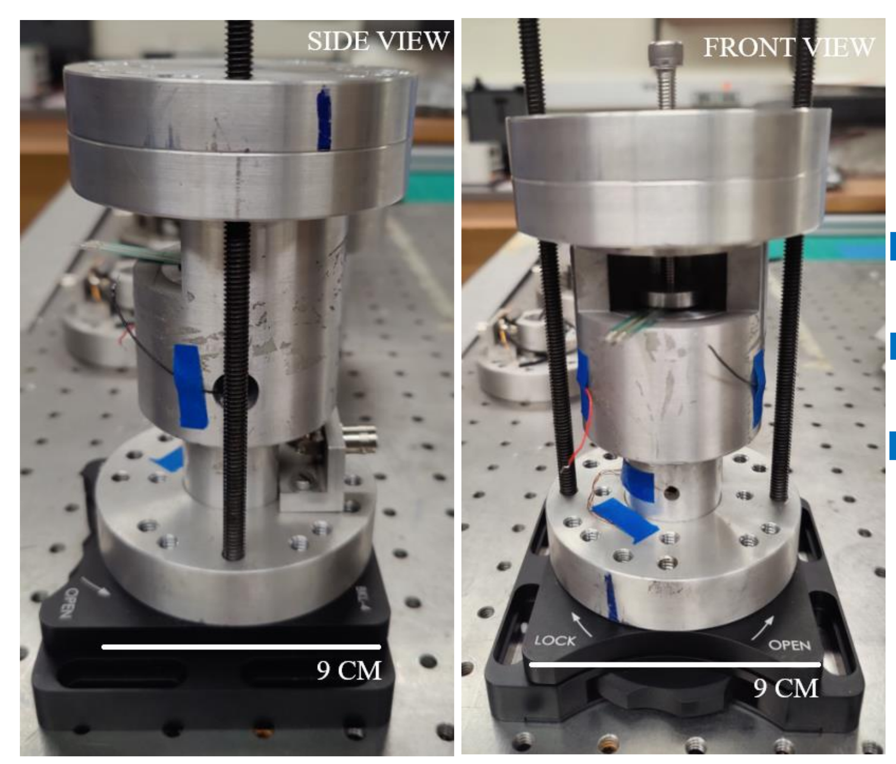
1. Apply constant compressive strain to the sample → with an FSR



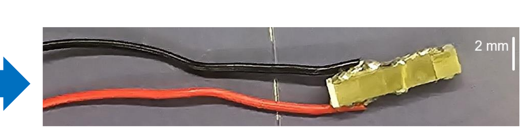
A sample being placed under constant compressive strain using a screw.



The force sensitive resistor



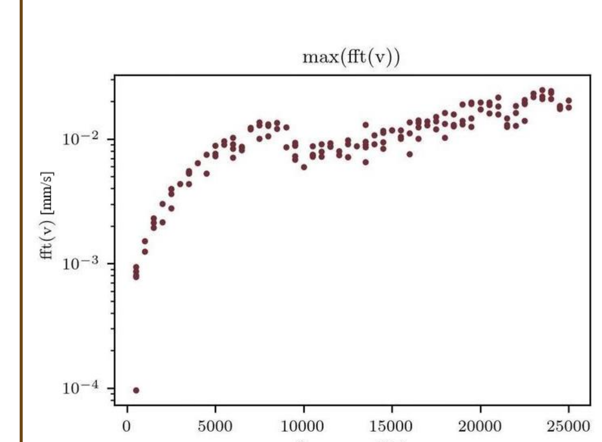
2. Acoustic perturbation → using a piezostack



Piezoelectric stacks apply a constant acoustic perturbation to a sample of grains using a high voltage amplifier.

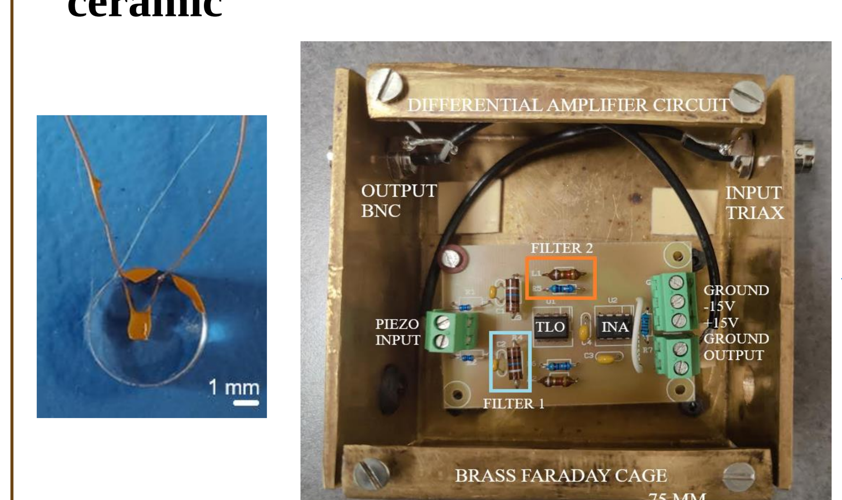
Input wave:

- Gaussian White Noise
- SD: 1.2V
- Mean: 3.95V



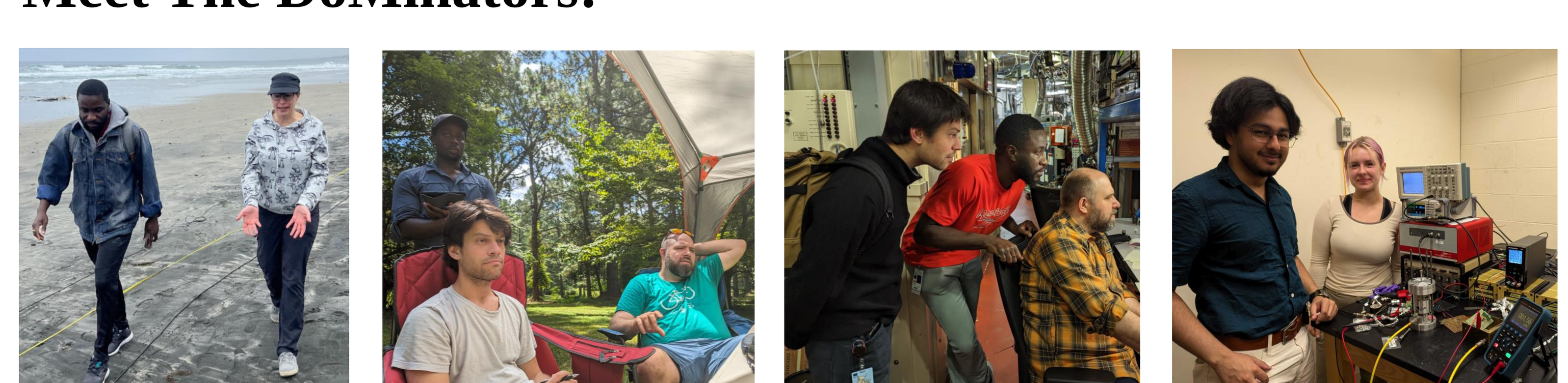
A frequency response curve for the piezostack

3. Measuring DoM → using a piezoelectric ceramic



The piezoelectric sensor and amplification circuit

Meet The DoMinators:



Comparing Field and Lab DoMs

$v(t)$ is obtained by integrating piezoelectric voltage ($\propto$ particle accelerations) over time.

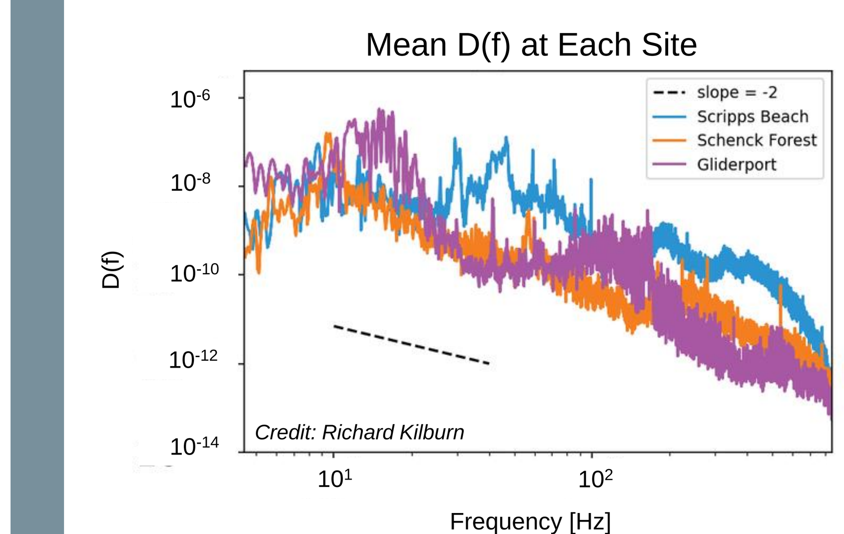
$$C_v(t) \equiv \frac{\sum_i \langle v_i(\tau+t)\cdot v_i(\tau)\rangle_\tau}{\sum_i \langle v_i(\tau)\cdot v_i(\tau)\rangle_\tau}$$

The Velocity Autocorrelation [3,4]

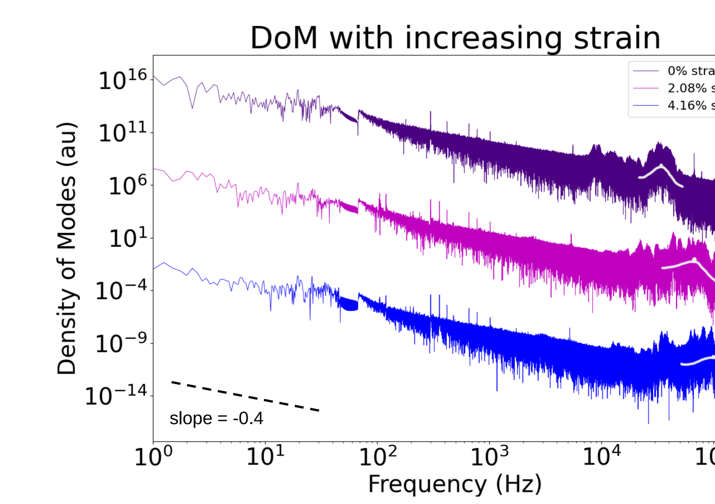
$$D(f) \equiv \int_0^\infty C_v(t)\cos(2\pi f t)\,dt.$$

The DoM [3,4]

Field v/s **Lab**

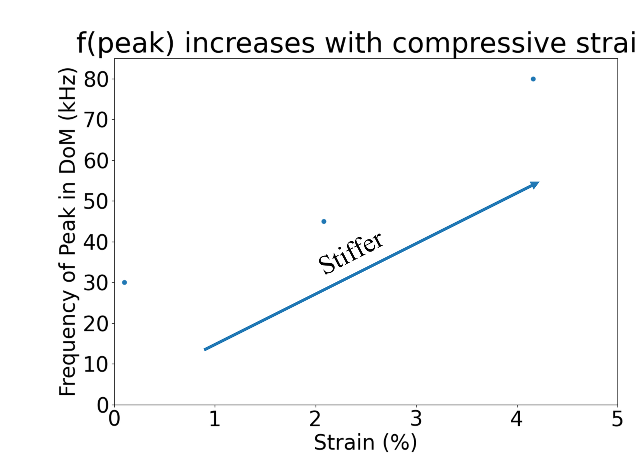


DoM readings from 3 field sites



Effects of low pressure (as a function of strain) on pluviated glass beads (1mm)

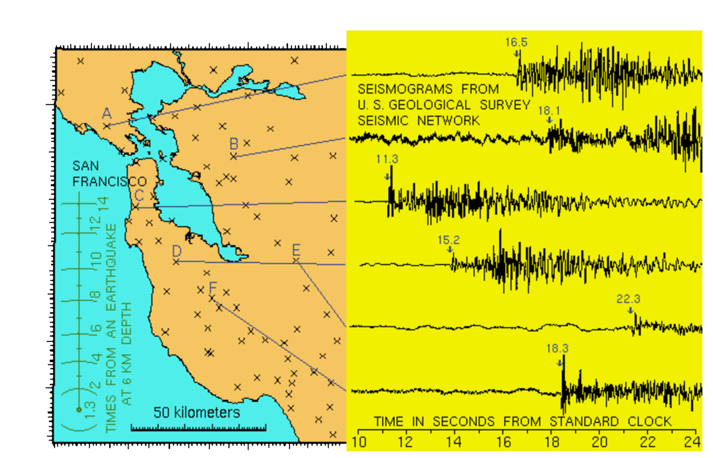
Scripps Beach- sand Schenck Forest- clay Gliderport- soft sediment



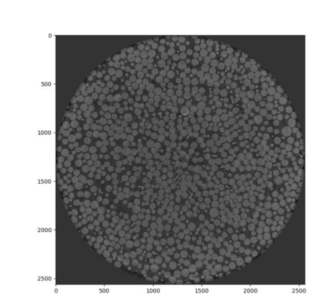
Outlook

Calibrating Geological Monitoring Instrumentation:

Soil structure and packing geometry affects the position of low frequency peaks in the DoM. This could calibrate seismographs to forecast when landscapes might fail.



Calibrating geological instrumentation [7]



An μ-CT of some glass beads.

Using tomography to understand 3D structure:

We can take a micro-tomography scan before and after DoM measurements and reconstruct 3D structure to see how changes in packings are reflected in the DoM.

References

[1] J Smith, Article; San Clemente Times, 032223.
[2] Owens and Daniels, Soft Matter 9, 1214-1219.
[3] Dickey, J. M., and Arthur Paskin. Physical Review 188, 1407.
[4] Theodore A. Brzinski, III, and Karen E. Daniels. Physical Review Letters 188, 1407.
[5] Lincoln, Mark. Christchurch Earthquake, 23-07-24
[6] N. Xu, M. Wyart, A. J. Liu, and S. R. Nagel, Physical Review Letters 98, 175502
[7] US Geological Survey, Maps of Seismic Stations.
[8] S. A. Blue, S. C. Wright, and E. T. Owens, arXiv:2403.10322.