Acoustic monitoring of lab-simulated earthquakes with LDV

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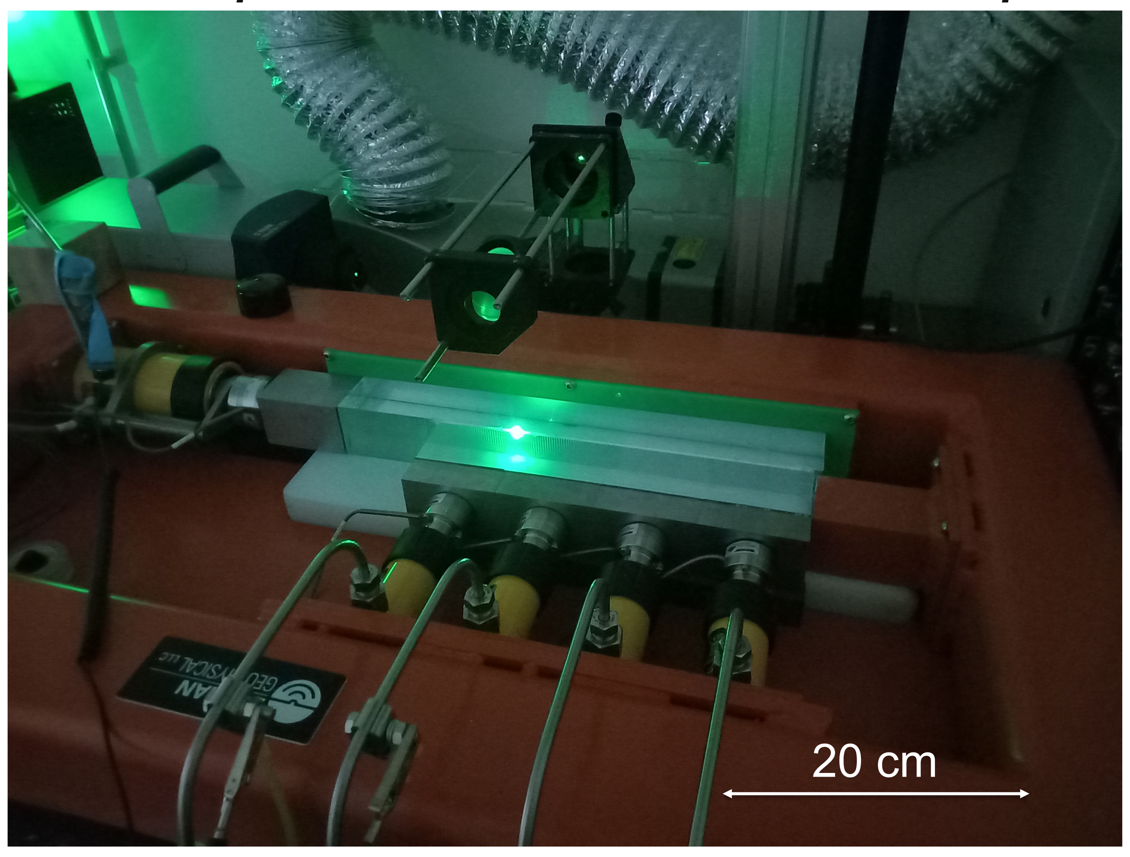
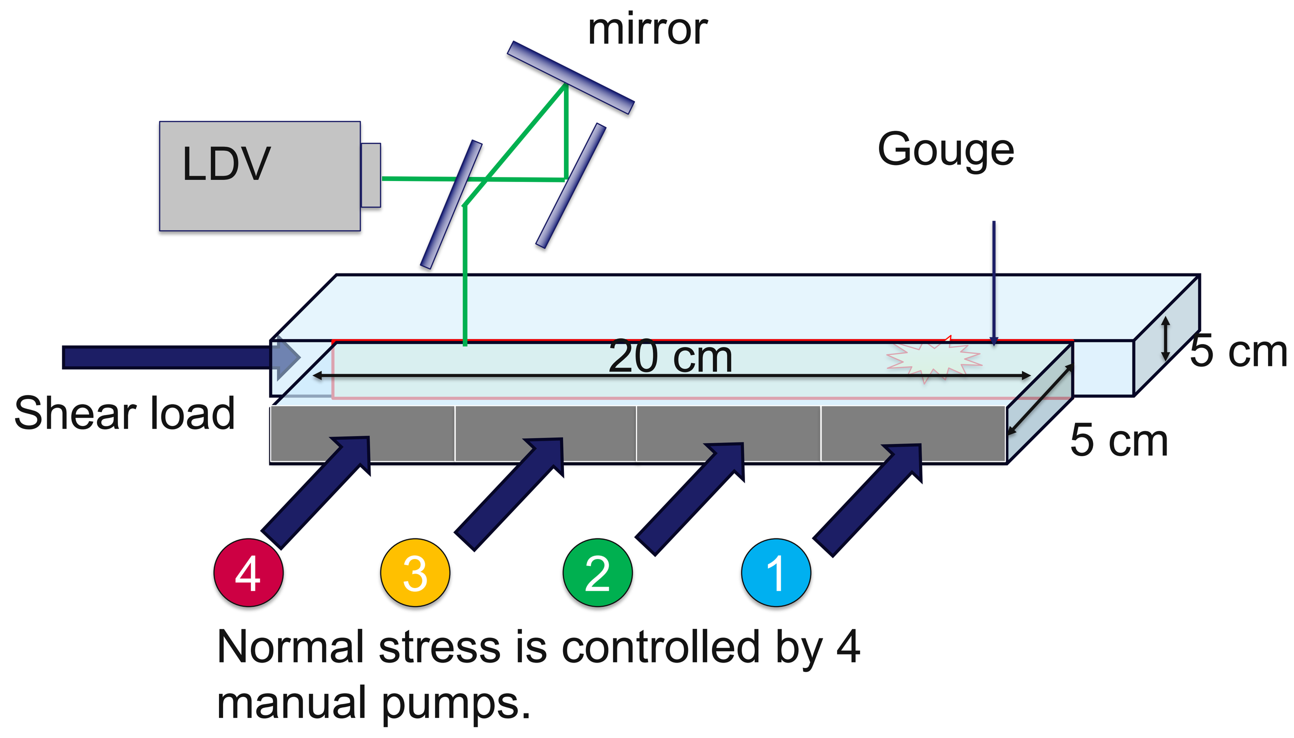
Introduction

Just as natural earthquakes generate seismic waves, laboratory friction experiments are sometimes accompanied by acoustic emissions (AE), a crucial indicator of friction stability. In general, fault gouge material is much weaker than the surrounding rock, creating a large impedance contrast that prevents weak AE from propagating outward to the host block. Conventional experiments typically use piezoelectric sensors attached to the host rock, which may not fully capture the dynamics within the fault material. A Laser Doppler Vibrometer (LDV) enables contactless vibration measurements not only on the host block but also directly on the fault gouge, allowing AE to be measured closer to its source. Here, we evaluate the advantages and limitations of on-fault AE measurement using LDV.

Experimental earthquake simulation machine and its simplified sketch

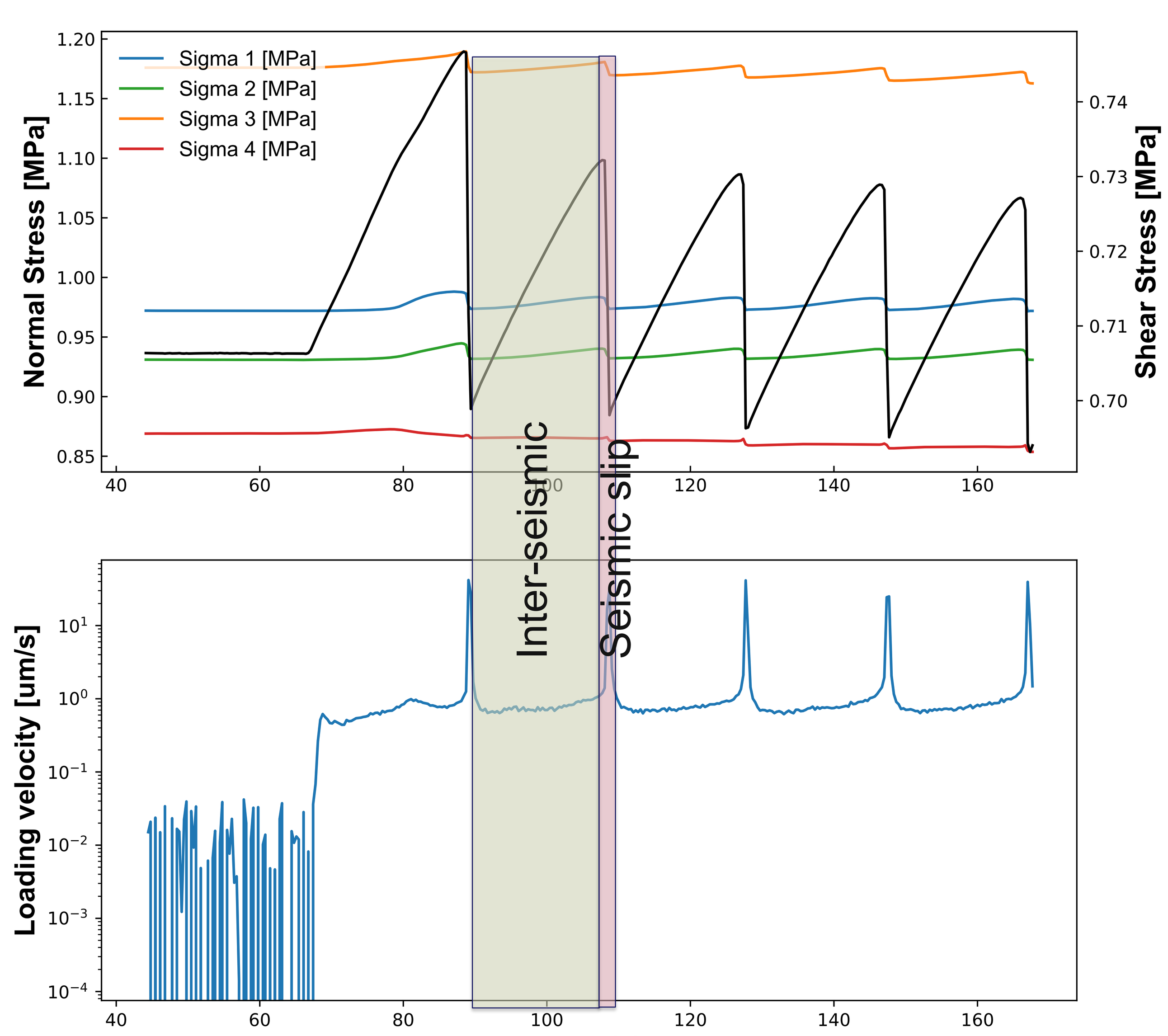




We use four manual pumps to apply the normal loading and one servo pump to drive the shear load. During the experiment, the shear load is applied at a constant pumping rate at 1 ml/min, while the normal load pumps remain locked. The fault surface is filled with a thin layer (~3 mm) of **powdered quartz** with grain sizes in the tens of micrometers. Stick-slip behavior along the fault surface is considered an analog to the natural earthquake cycle.

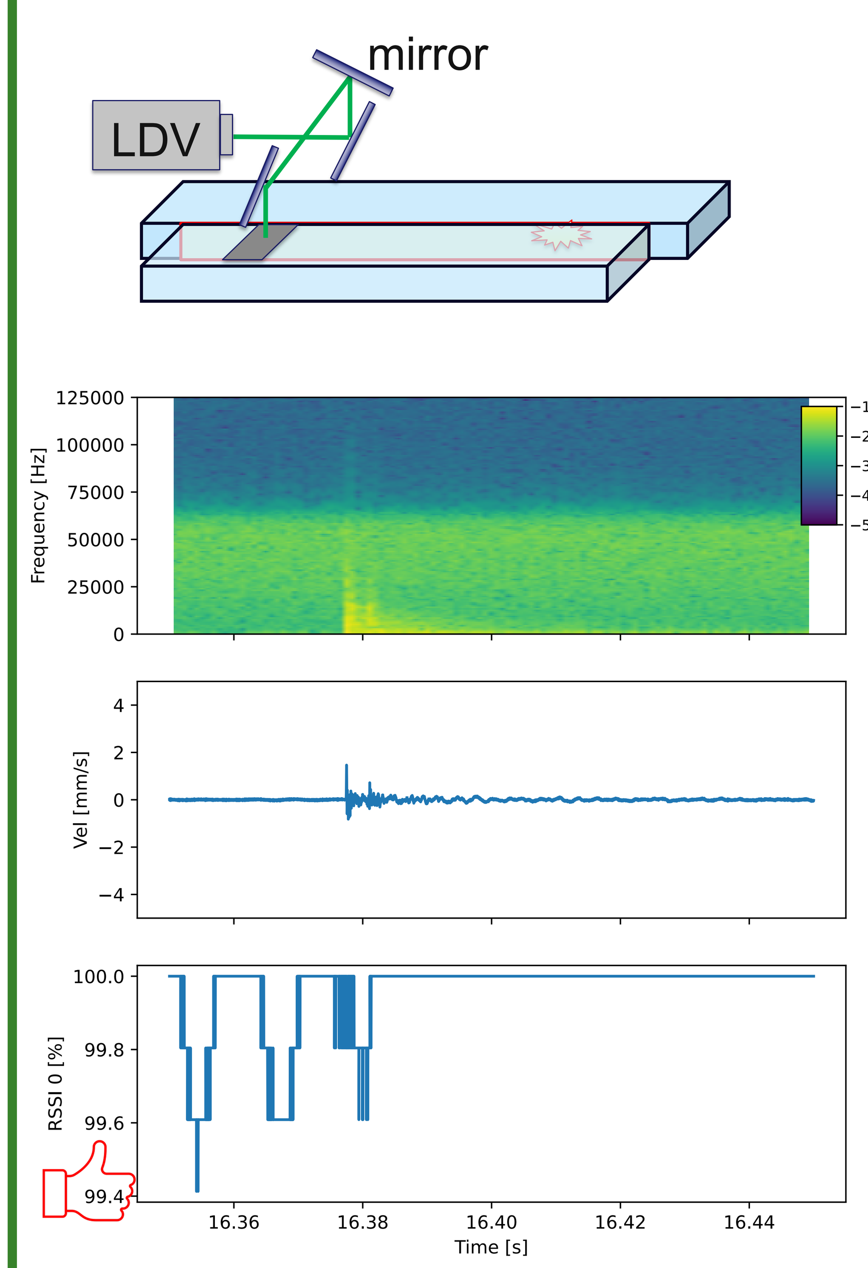
Simulated earthquakes

Stick-slip cycles are observed in our experiment. During inter-seismic periods, shear stress initially increases nearly linearly before gradually yielding, accompanied by a steady rise in loading velocity. This continues until rapid seismic slip occurs, causing a shear stress drop of approximately 0.04 MPa (~5%). The increase in normal stress during the inter-seismic period suggests fault dilatation, which varies along the fault.

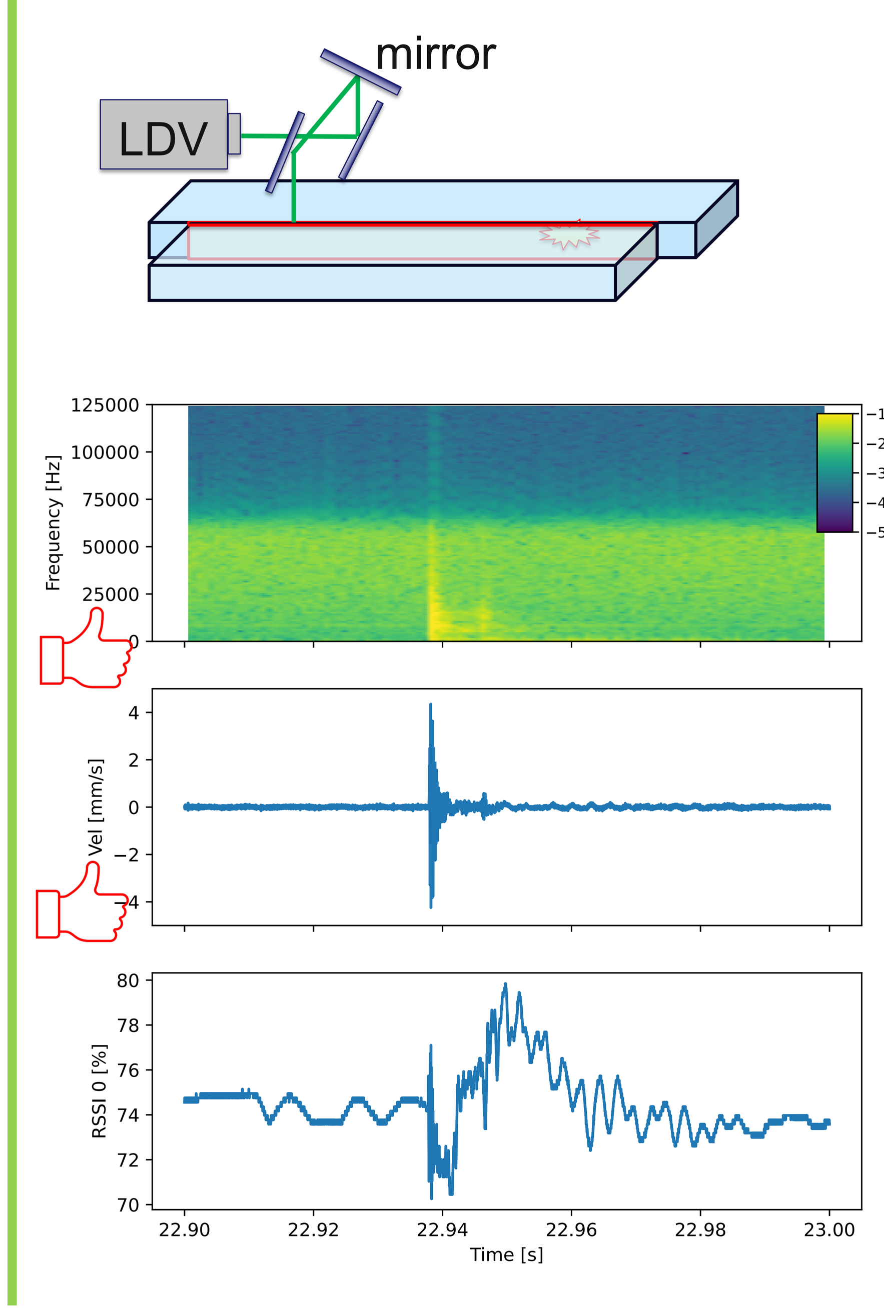


Acoustic emissions

LDV pointed at the hosting block with reflecting tape



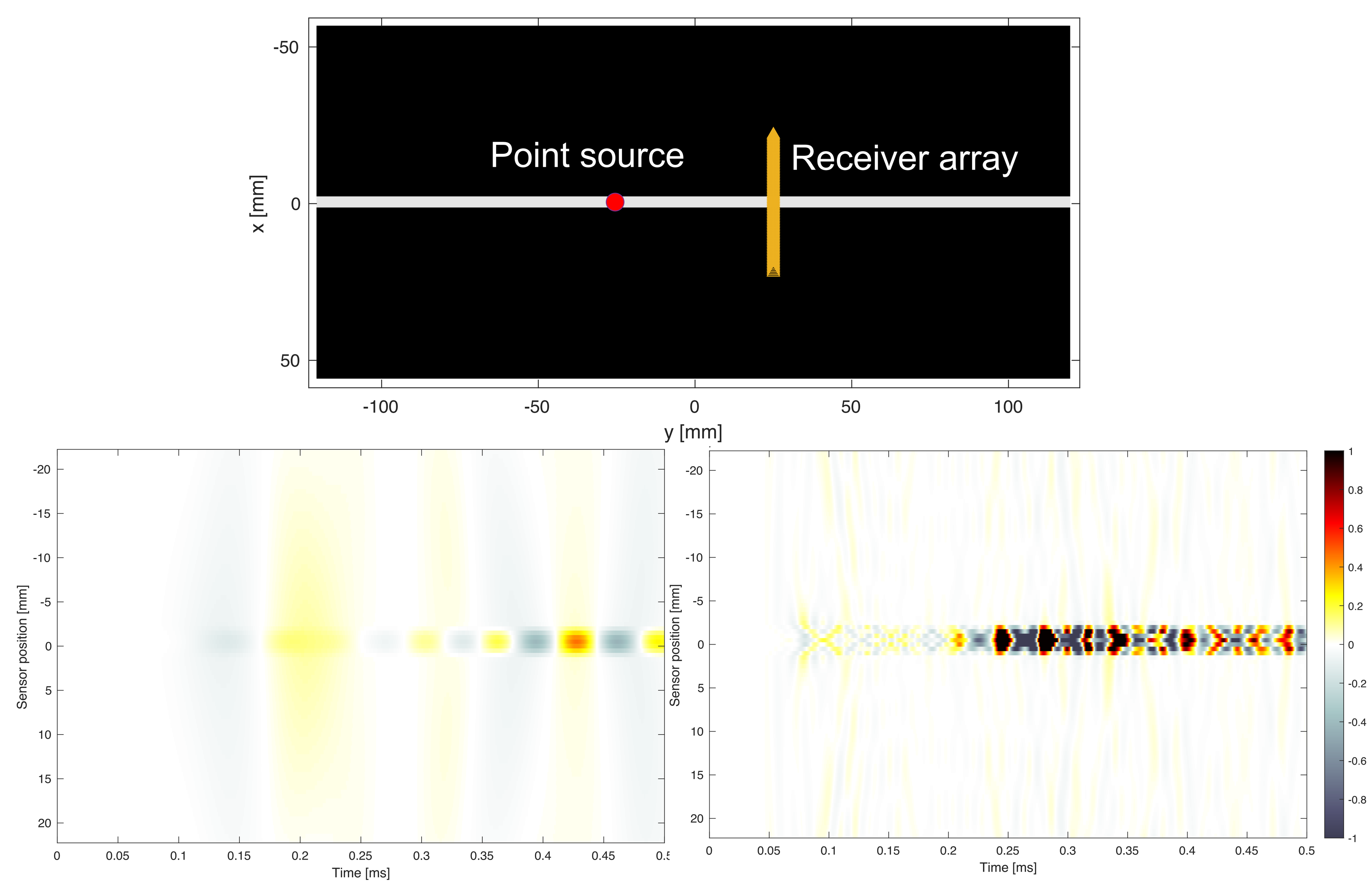
LDV pointed at the fault gouge



AE data were acquired using 50 kHz bandwidth and a 10 mm/s velocity range. Two AE signals are presented here for comparison. RSSI, an indicator of light intensity, is directly related to acoustic signal noise level. When the LDV is pointed at the fault gouge, the resulting RSSI is low and unstable, leading to a higher noise level; however, it also measures higher AE amplitude and captures more higher frequency contain.

Trapped mode

To validate the above observation, we perform a numerical simulation of elastic wave propagation using the geometry shown below. A 5 mm layer with low density and low elastic modulus represents the weak fault gouge, enclosed by stronger host blocks. The result confirms that the gouge layer traps acoustic waves, especially the higher-frequency part.



Dominant 5 kHz source **Dominant 30 kHz source**

Conclusions

We conduct shear experiment on analog fault gouge and continuously measure the acoustic emissions (AE) with an LDV aimed at either the host block or the fault gouge. Our measurements reveal that while on-fault measurements suffer from increased noise level, they capture stronger AE signals, especially at higher frequency. Numerical simulations confirm that the high impedance contrast between the fault gouge and host block traps more higher frequency signal.