Acoustic probing and triggering of shear instability in granular media

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Laboratory studies of granular friction have emerged as a powerful tool for investigating dynamics of seismic faults[1], including dynamic triggering of earthquakes at remote distance[2]. However, the physical origin of dynamic triggering still remains a challenging issue due to small strain amplitude of impinging seismic waves[3]. Advances in granular physics and acoustics have paved the way for better understanding of how seismic waves may trigger fault slips. Unlike ordinary solids and liquids, static and dynamic properties of dense granular media are determined by the inhomogeneous contact force network exhibiting multiple metastable configurations; they may undergo a transition from jammed solid to flowing liquid states when the external driving such as shearing or shaking is beyond a certain threshold[4]. The emerging view is that dynamic perturbation of sheared gouge materials causes a material failure and fault slip that can be characterized as unjamming transition induced by the acoustic fluidization[5,6].

Here we investigate the granular shear instability (earthquake nucleation) in granular media by acoustic *probing*. Decrease of the shear wave velocity decreases and development of the fabric anisotropy are observed prior to failure. We find that the correlation function of the multiply scattered Coda waves is very sensitive to the stick-slip like rearrangement of granular network during shear banding[7]. Next, we study the causal effect of impinging elastic waves on their nucleation by nonlinear acoustic *pumping*. In the irreversible regime of the sound-matter interaction, the wave velocity and correspondingly elastic modulus remains weakened after the wave transient and the force network is strongly modified without visible grain motion[5] or accompanied by the plastic deformation[8]. Finally, we show that the onset of sliding triggered far below the static threshold by nonlinear sound waves is due to the acoustic lubrication of the stuck contact area, which reduces the apparent coefficient of friction[6]. This scenario is confirmed by the triggering of granular avalanches in which the acoustic fluidization of *small vibration amplitude* affect basically the friction between solid particles rather than that arising from the dilatancy[1].

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