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**How sand grains stop a high speed intruder**[1]

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When a speeding intruder impacts on a granular material, it comes rapidly to rest after penetrating only a modest distance. Empirical dynamical models, dating to the 19th century (if not earlier), describe the drag on the intruder in terms of two types of depth-dependent forces: one a static force, which also includes gravity, and the other a collisional force proportional to the square of the instantaneous speed of the intruder. What processes occur in the material to so quickly decelerate the intruder? We address this question through experiments and simulations (work of Lou Kondic and collaborators). We first probe the granular response using quasi-two-dimensional granular materials consisting of photoelastic discs. When such a particle experiences a force, it appears bright under cross-polarized illumination. High speed video reveals dynamic force transmission into the material along force chains that form in response to the intruder motion. These chains are nearly normal to the intruder surface, implying that collisional rather than frictional forces dominate the momentum transfer from intruder to grains. These observations allow the formation of a collision-based model that correctly captures the collisional drag force for both 2D and 3D intruders of a variety of shapes. This talk will develop a collisional picture of impact, and also explore the change in the system response as the impact speed increases. Experimental collaborators include Abe Clark, Cacey Stevens Bester, and Alec Petersen.

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