

## Dynamics of granular impact cratering

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Solid projectiles were dropped into granular media from various heights, and those deceleration dynamics were measured by an optical method with 100 nanometer and 20 microsecond resolution. Data were obtained for 11 different projectiles (spheres and cylinders) and 4 different granular media. The range of impact speed is from 0 to 4 m/s. The results can all be explained by a stopping force consisting of the sum of two terms: an inertial drag, proportional to velocity squared and independent of depth, and a frictional drag, proportional to depth and independent of speed. The latter scales as the square-root of projectile density and hence is not simply Coulomb friction and hydrostatic pressure. We also demonstrate that this unified stopping force law can explain seemingly-contradictory penetration and dynamics data reported by other researchers [1].

[1] H. Katsuragi & D. J. Durian, Unified force law for granular impact cratering, *Nature Physics* 3, 420, (2007).