HYPERVELOCITY LABORATORY IMPACTS OF MICRON-SIZED DUST INTO METEORITIC AND FOIL TARGETS

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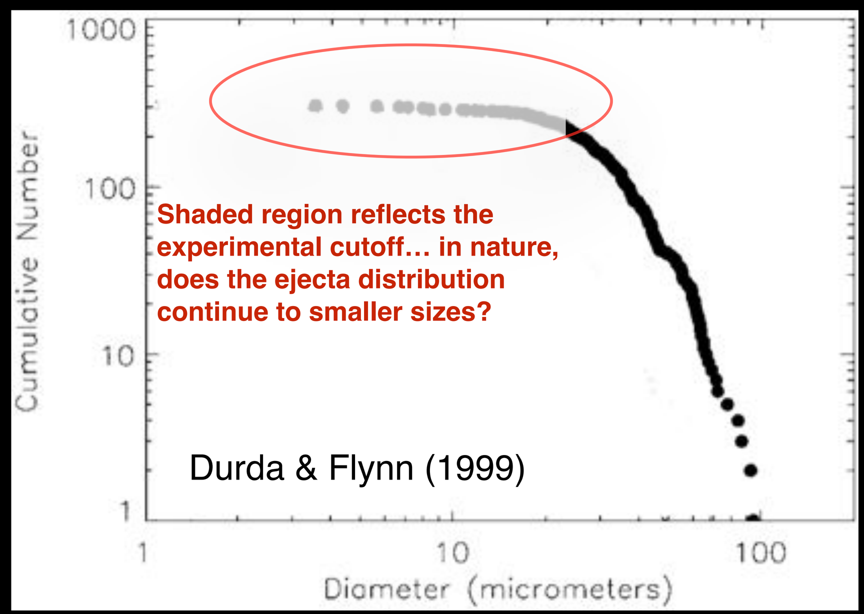
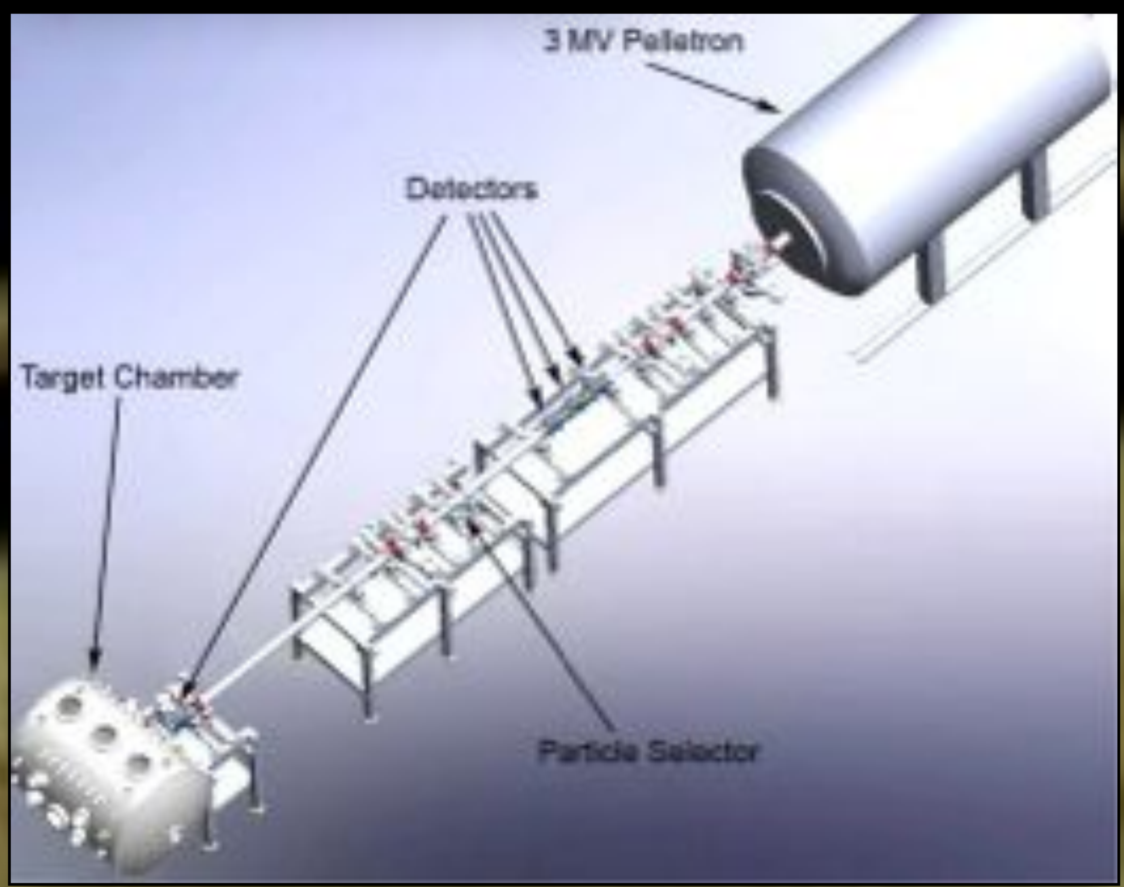
Goal of program: Experimentally determine the size distribution of impact ejecta down to r = 0.1 µm, improving on existing studies by 100x in radius (10^6x in mass).

Overview

Our goal is to study the physics of hypervelocity impacts (5-50 km/sec) by small dust grains into solid targets. These impacts are the source of dusty planetary rings (e.g., Saturn's G and D rings) and the meteoritic (zodiacal) dust [1,2]. Yet virtually no experimental studies have been performed at these size scales. There are few experimental constraints on either the yield or the size distribution of these ejecta.





Experimental Procedure

We are using the new dust accelerator at the University of Colorado's Institute for Modeling Plasmas, Atmospheres, and Cosmic DusT (IMPACT)*, which provides a steady source of hypervelocity grains which can be studied in impact experiments. The beam can produce tens of thousands of impacts/day, compared to 1-3 impacts/day (with larger projectiles) at gas-gun facilities such as the Ames Vertical Gun Range (AVGR) which have been used for most previous impact experiments [3,4].

The IMPACT accelerator [5] works by charging individual Fe grains and passing them through a 3 MV potential. Masses are from 10^{-18}–10^{-10} g (diameters 0.05–3 µm), and velocities are from 1–20 km/sec. The beam control system measures a particle's velocity and mass as it is accelerated, and a particle selector optionally allows individual grains to be removed from the beam. Particles impact the experiment in a vacuum chamber at the end of the 15 meter beamline. Before particle down-selection, the beam produces grains at a rate of ~1/sec, spread over a beam diameter of ~ 1 cm.

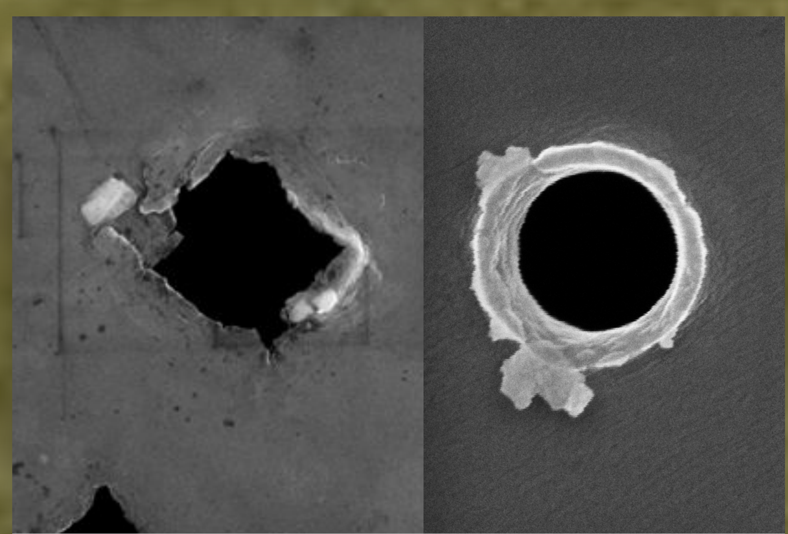
We detect particles by placing ultra-thin gold foils where they can be penetrated by particles. The resulting holes can be used to determine particle size and/or velocity. The foils can be placed in either the main particle beam (for calibration), or adjacent to the impact site (to capture ejecta).

We create the foils by vapor-depositing Au onto thin carbon substrates (6 nm) suspended on a 400-mesh copper grid. After exposure in the particle beam, we remove the foils and image them in a scanning electron microscope (SEM) at magnifications ~ 10,000x (resolution ~ 0.01 µm).

** Formerly Colorado Center for Lunar Dust and Atmospheric Studies*

Target Chamber

Co-I Shu loads our samples into the target chamber at the IMPACT dust accelerator. Micron-sized dust grains come in at approximately 1/second through the port on the right-hand side.

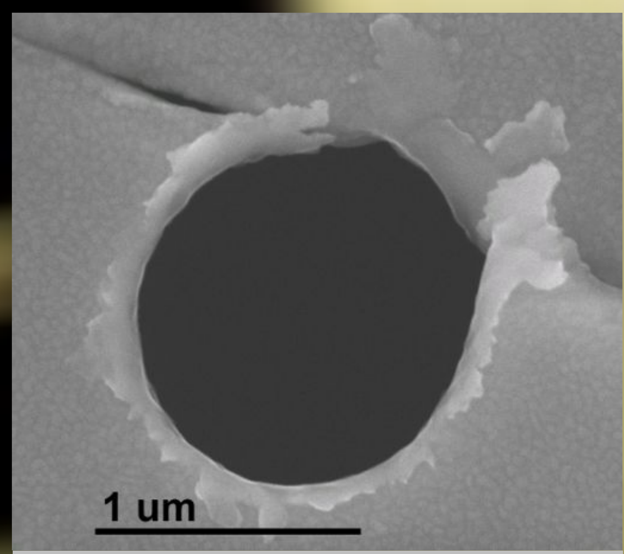


Impact Site or Foil Defect?

In our initial runs (left), we used rolled gold foils of thickness 0.5 µm. Defects in the foils made analysis difficult. In subsequent runs (right), we now make our own vapor-deposited Au foils, which are both more sensitive and virtually defect-free, making it east to identify particle hits unambiguously.

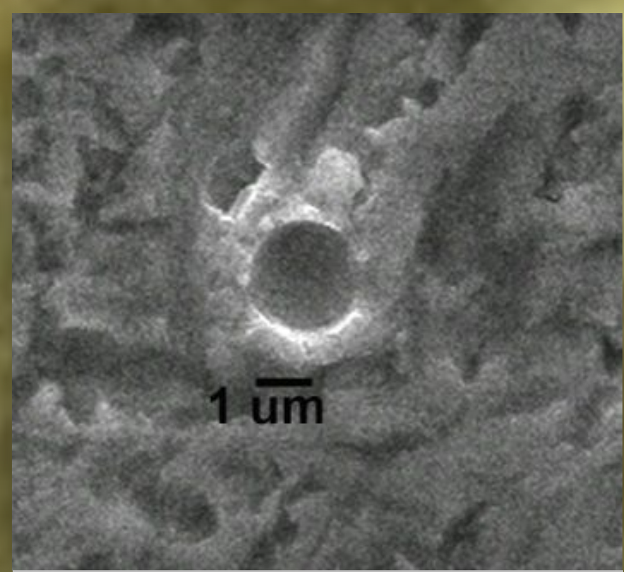
Sample Preparation

Co-I Durda mounts our 3 mm x 3 mm gold foils on the linear stager used to expose them to the particle beam.



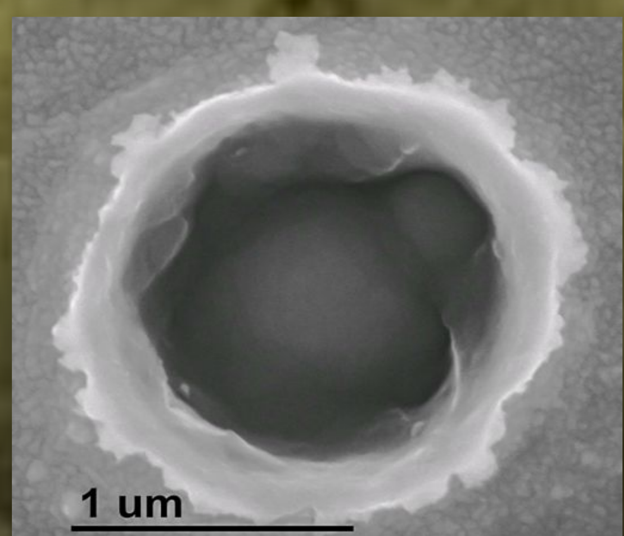
Hole in Foil

Hole punched in 0.1 µm Au foil by an Fe grain at ~3 km/sec. Particle diameter is roughly the hole diameter. Particle direction is out of the page.



Impact into Meteorite

Impact crater from micron-sized Fe grain into polished metal-rich region of meterorite NWA 869. Crater is essentially a depression with raised rim, with volume comparable to impactor, and no ejecta. Impact velocity is ~3 km/sec. SEM image at 1300x.



Impact into Solid Cu

Crater with embedded Fe impactor visible. Target is thick Cu surface. Particle direction is into the page.

Results

We have exposed roughly 20 samples to the particle beam and recorded roughly 10,000 individual impacts at a typical impact velocity of 3 km/sec. We are currently studying the impact sites size distribution and morphology based on SEM imaging. Our preliminary findings are:

- For the Au foil targets, nearly all particles penetrate the 0.1 µm foil (Figure 1). Roughly half of the particles penetrate the 0.5 µm foil. The diameters of the holes punched in the foil are slightly larger than the particle diameters.
- For the 20 µm Cu metal targets, the majority of impactors are embedded in the target completely (Figure 2). Our projectiles were too slow to make ejecta!
- In meteoritic target, the majority of micron-sized impactors at few km/sec speeds are implanted into the target. In the ~20% that are not implanted, small craters are made but with a crater volume that does not exceed the particle volume, and with little to no ejecta (Figure 3). We see similar behavior in both the Si-rich and Ni-rich portions. Again, our particles were too slow to make any significant ejecta

Future work

Phase I (reported here) will continue as we analyze the results of our impacts and understand the relationship between particle size and velocity, target composition, and hole diameter. This calibration work is necessary before direct measurements of ejectra are possible.

In Phase II we will measure the ejecta from hypervelocity impacts. Particles will be shot into the meteoritic targets, and thin foils will be placed adjacent to the beamline to detect the ejecta from the primary target. We will focus on higher velocity particles (10–50 km/sec) which account for the bulk of the interplanetary dust population — the particles shows here are too slow.

Acknowledgements

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