



Development of the Dust Ejecta Radar Technology (DERT) to Determine Plume-Surface Interaction Ejecta Velocities on Planetary Surfaces

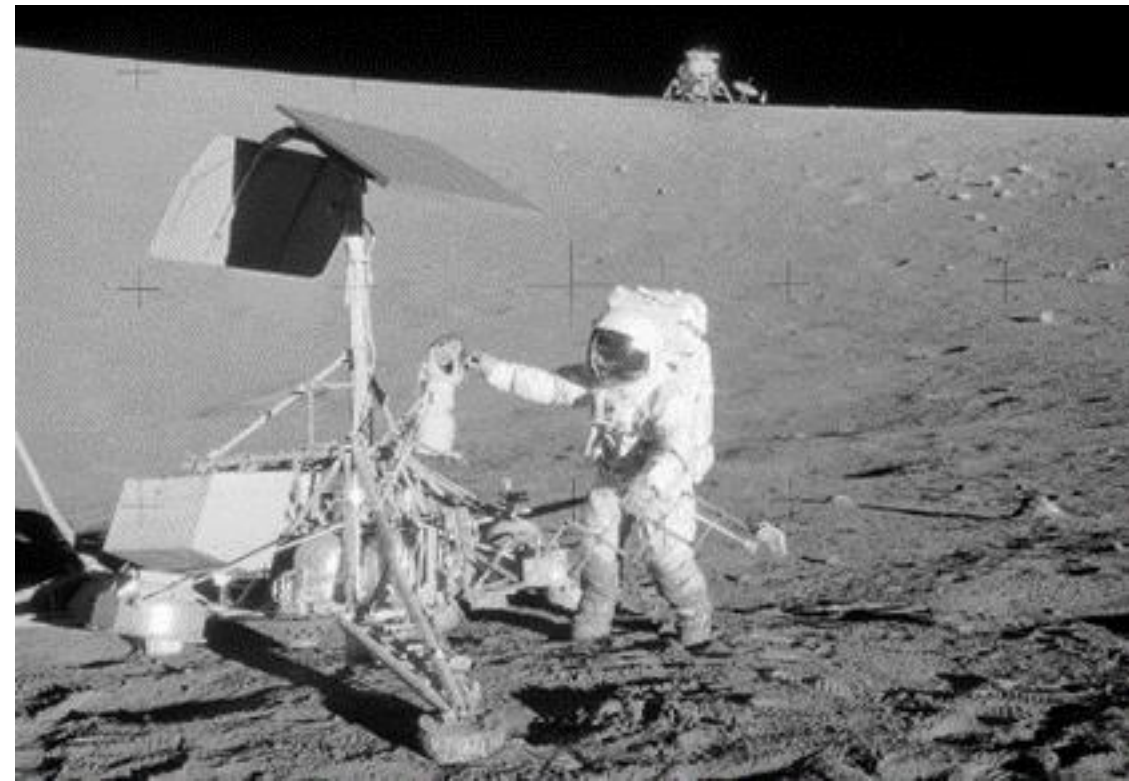


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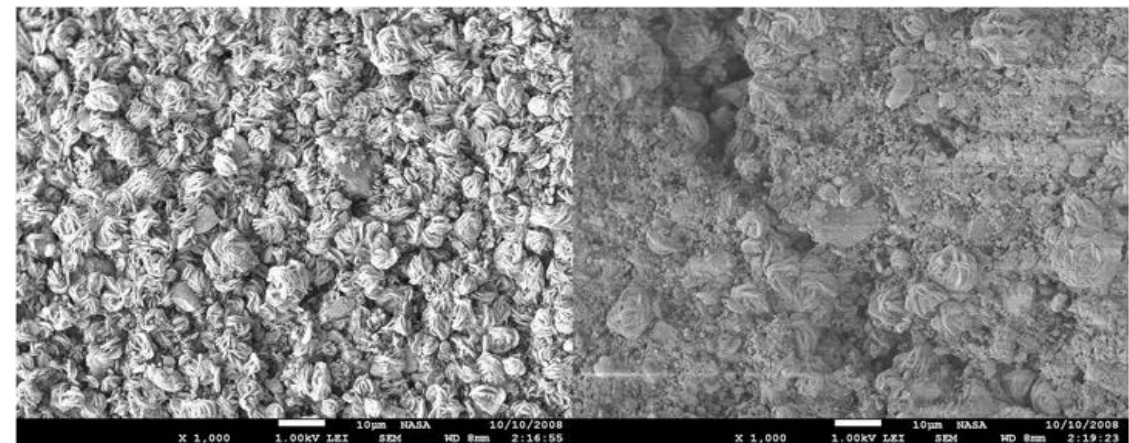
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The Risk of Plume Surface Interactions

- Engine plumes interact with the lunar surface and ejecta regolith.
- High velocity PSI ejecta pose a risk to lunar surface assets.
- The Apollo 12 LM caused damage to Surveyor 3.
- The velocities of PSI ejecta particles must be determined to assess the risk.
- Simulants and indirect observations give a broad range of velocities (>2 km/s).
- *There has been no direct measurement of PSI ejecta velocities.*



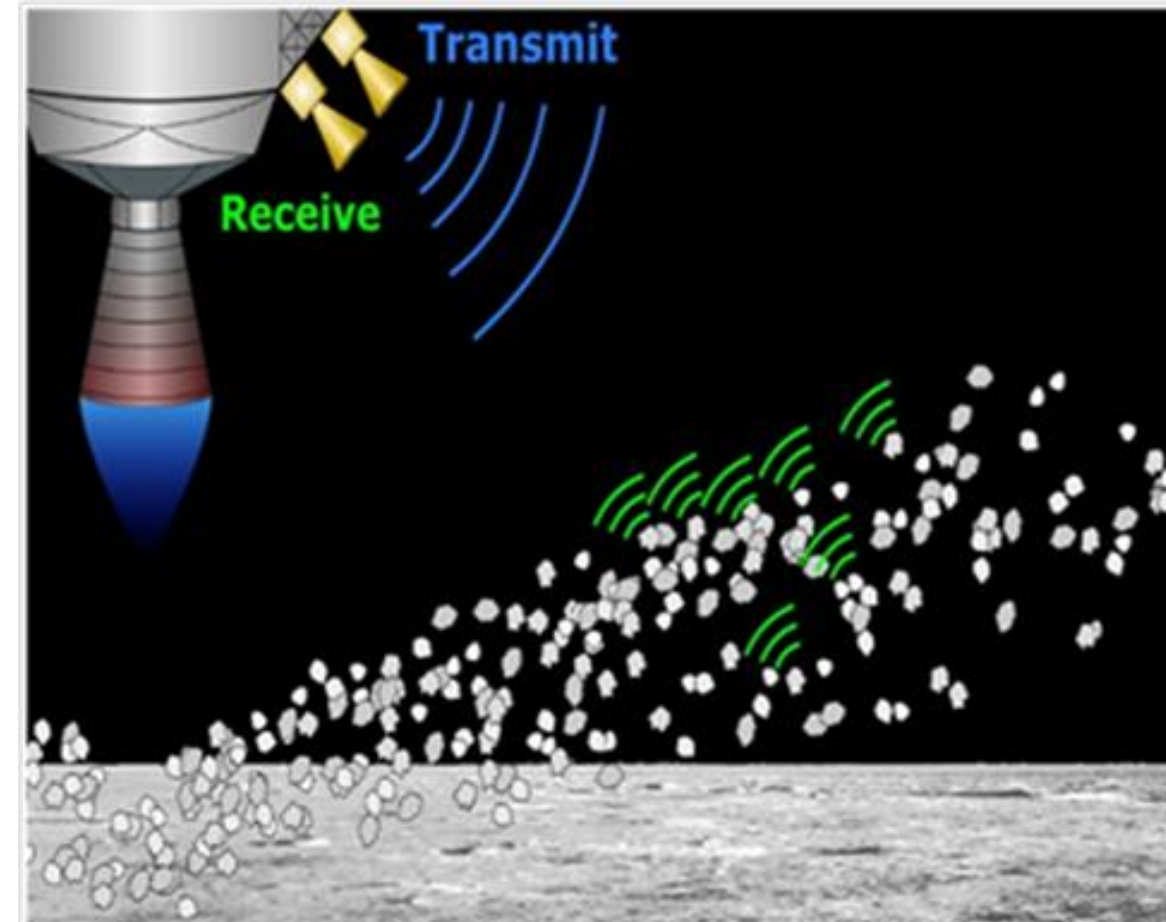
Pete Conrad inspecting Surveyor 3. Apollo 12 behind.



SEM images of S-3. [Left] Undamaged. [Right] PSI damaged.

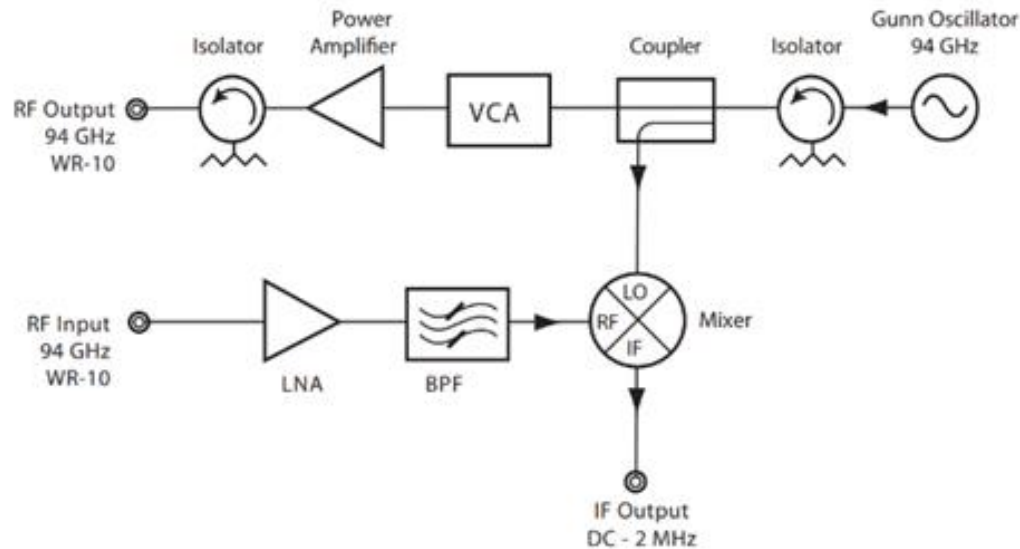
Dust Ejecta Radar Technology

- DERT shall directly measure PSI ejecta velocities.
- DERT uses mm-waves at 94 GHz.
- The Doppler shift of PSI ejecta is recorded.
- DERT shall be appropriately mounted on a suitable lander.
- Here we present test results from a vacuum compatible DERT prototype.
- *This work demonstrates the velocities that have been directly measured by the DERT prototype.*



DERT instrument design concept.

Dust Ejecta Radar Technology



- DERT is a continuous wave radar.
- A voltage-controlled attenuator (VCA) enables transmit power < 24.5 dBm.
- Signal strength depends on ejecta sizes, densities, and index of refraction.
- Analog voltage is sampled from a heterodyne mixer.
- Frequency data is recorded by a real-time spectrum analyzer (Keysight N9020B).
- Frequencies are converted to velocities using the Doppler equation:

$$f_D = f_r - f_0 = \frac{2f_0 v}{c}$$

Dust Ejecta Radar Technology

DERT Prototype Demonstrations



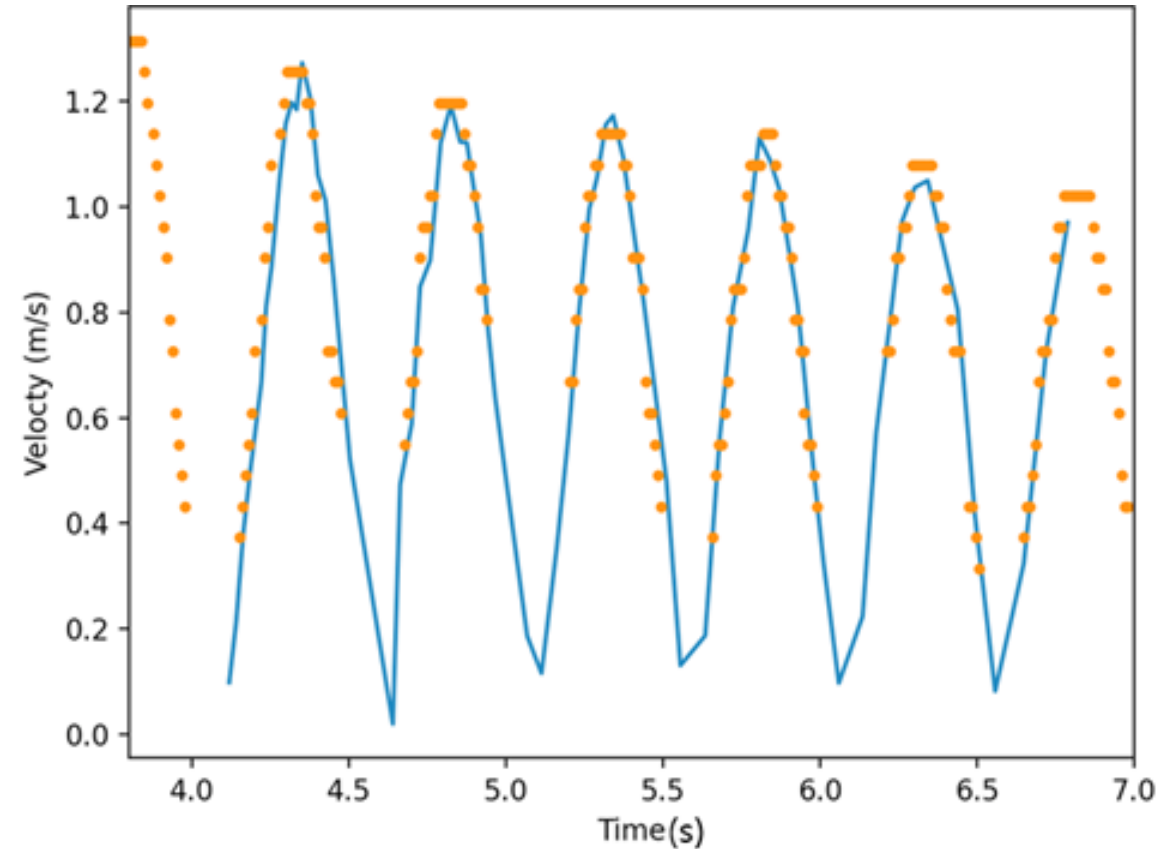
Austin Langton creating a BP-1 ejecta stream at KSC.



- A range of methods were used to demonstrate DERT measured velocities.
- Without regolith simulant:
 - Pendulum
 - DC motor
- With regolith simulant:
 - Compressed air (at KSC and JHU).
 - Shotgun shells.
- BP-1 lunar regolith simulant was used sieved to three sizes (75-212, 212-355, 500-850 μm).
- A high-speed camera was used to independently verify the DERT velocities.

DERT Prototype Demonstrations

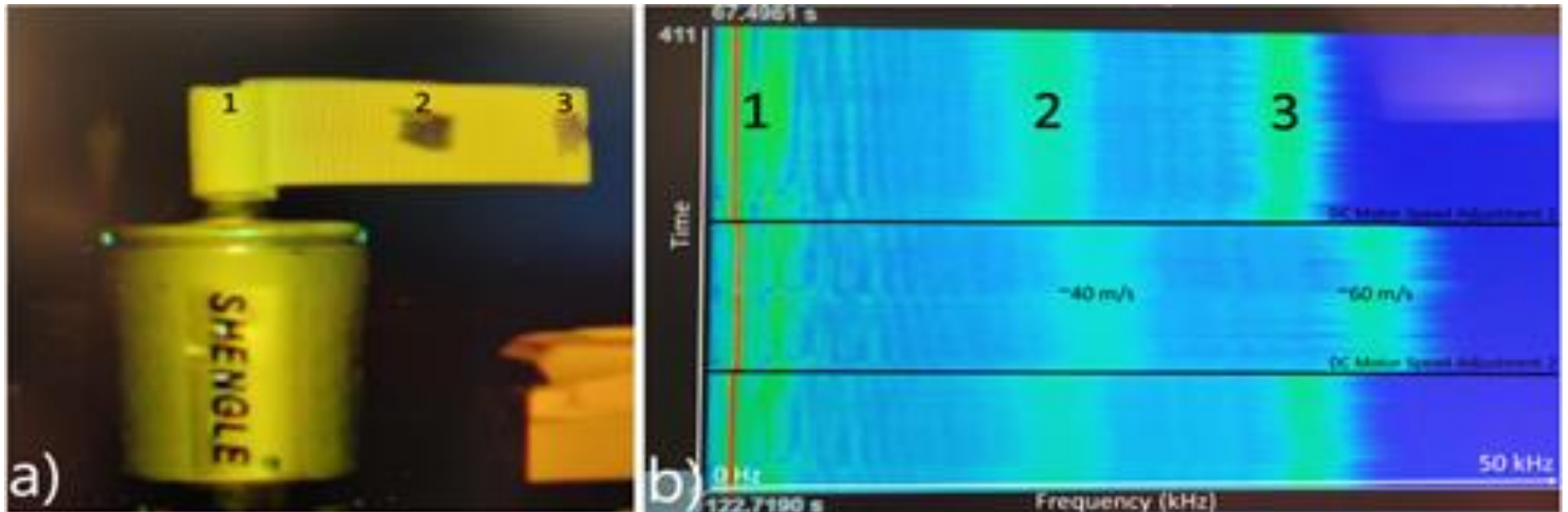
- A simple pendulum was used to demonstrate very low velocities.
- The position of the bob was recorded with the high-speed camera.
- Velocities between 0.3 m/s and 1.3 m/s were measured.
- A DERT accuracy of 0.05 m/s was demonstrated.



Pendulum results. [Orange] DERT measured velocities.
[Blue] High-speed camera measured velocities.

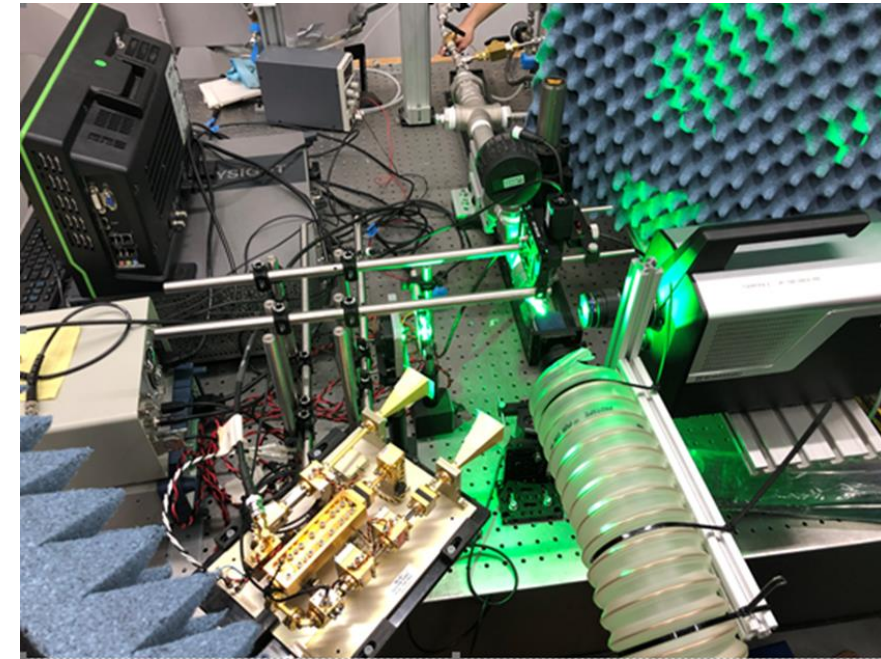
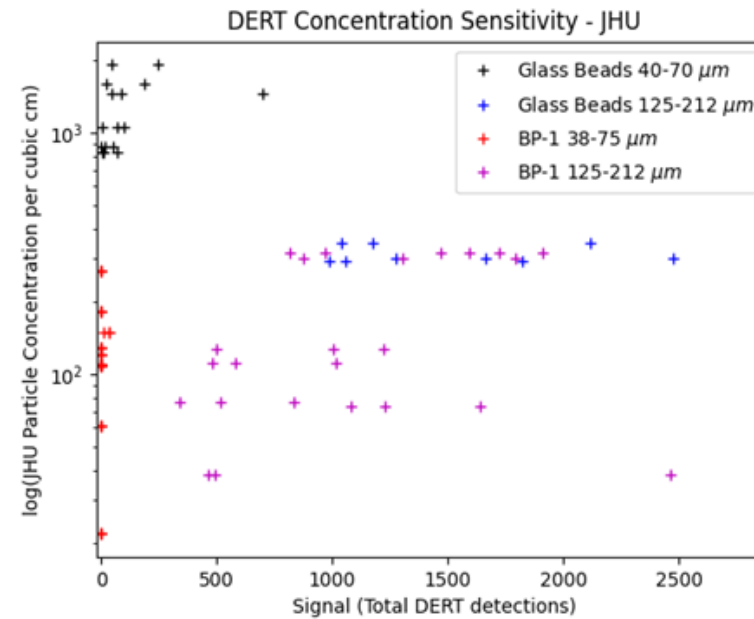
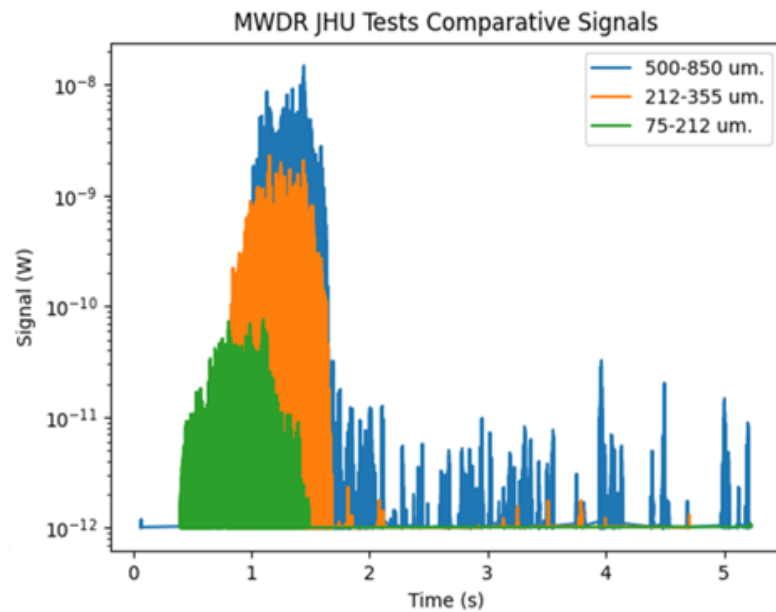
DERT Prototype Demonstrations

- Radar reflective tape was attached to a DC motor at two radii.
- The speed of the motor was varied.
- Accurate velocities up to 60 m/s were measured.



[a] High-speed camera still of the spinning DC motor. [b] Data cube from the spectrum analyzer.

DERT Prototype Demonstrations



- Sensitivity to particle size was tested at JHU's Whiting School of Engineering.
- Particle concentration was measured with a high-speed camera.
- DERT clearly detected particles down to 125 μm .
- DERT partially detected particles below 75 μm .

DERT Prototype Demonstrations

- High-speed tests were carried out at the KSC Weapons Training area.



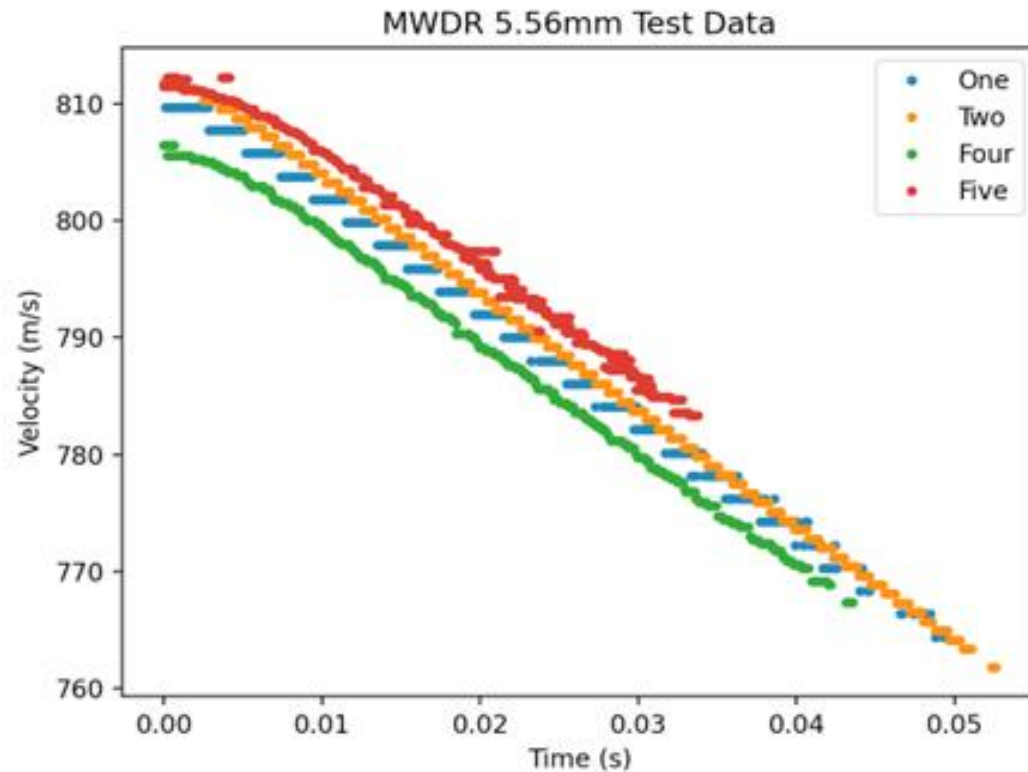
High-speed camera video of a NATO 5.56 mm round (820 m/s).



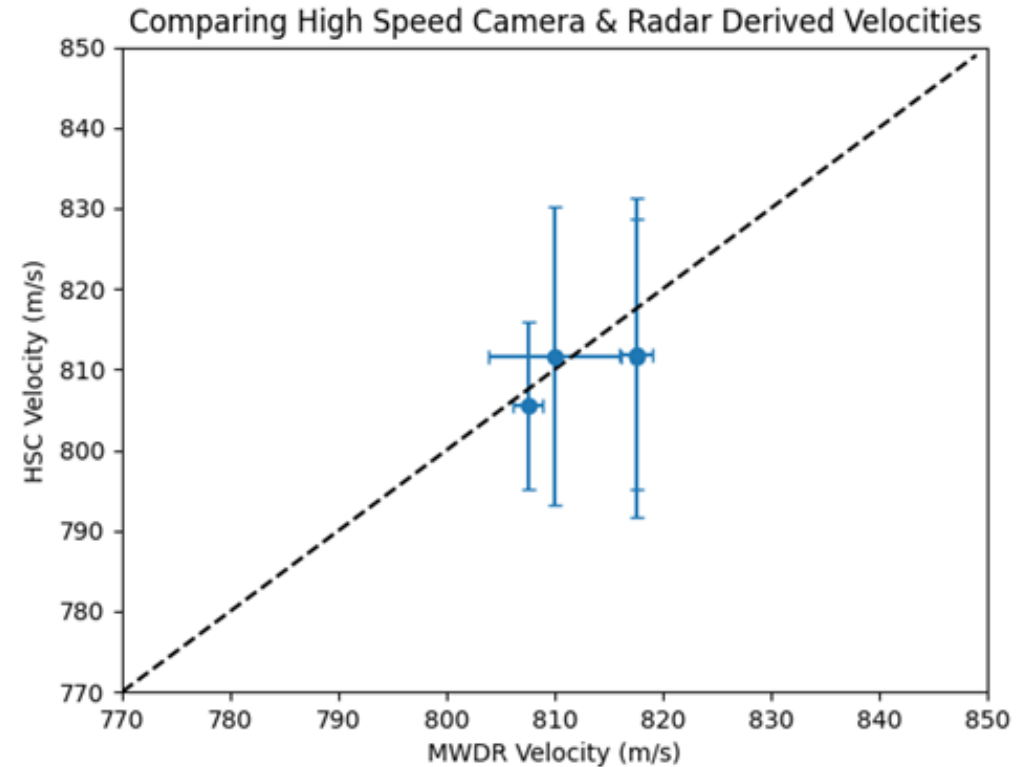
High-speed camera video of BP-1 from a shotgun (250 m/s).



DERT Prototype Demonstrations



DERT measured velocities of four different NATO 5.56 mm rounds. Rapid deceleration from atmospheric drag and rifling can be seen in the data.

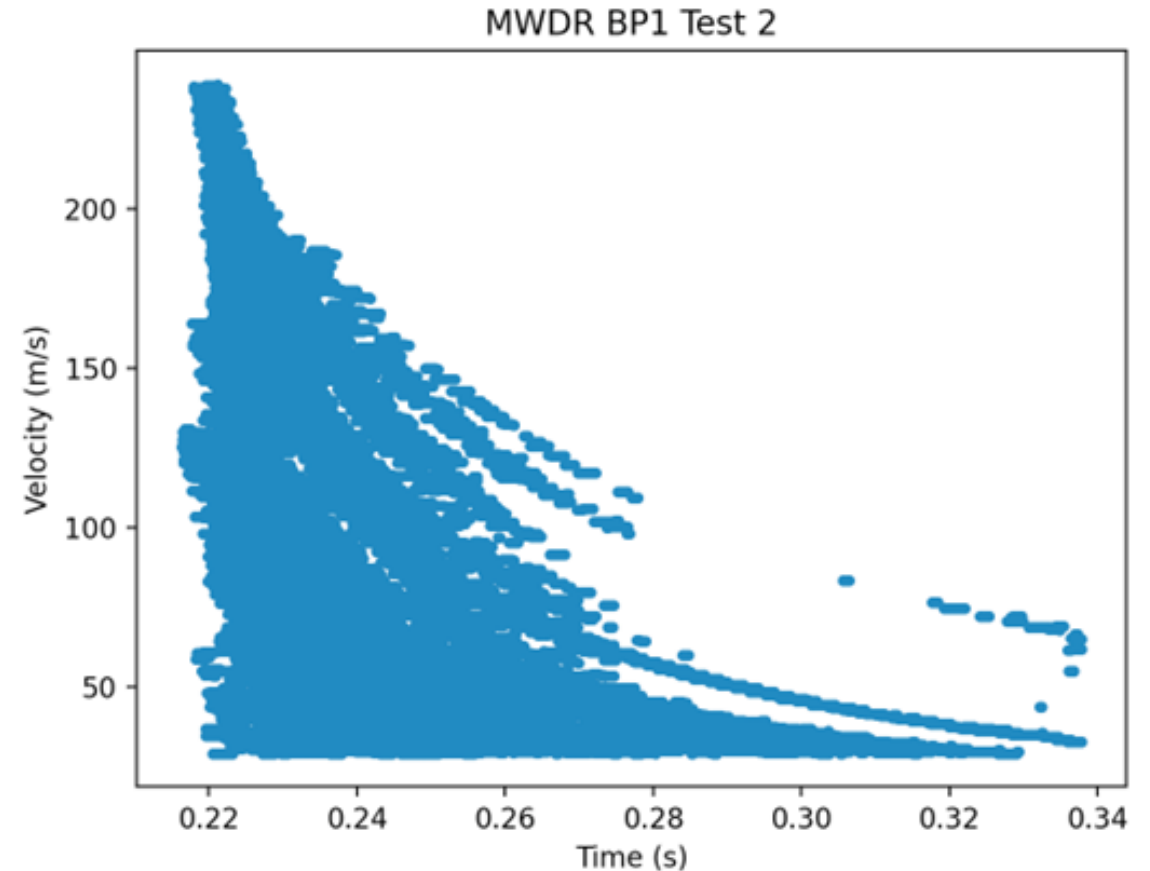


Direct comparison between DERT measure velocities and high-speed camera measured velocities.

- NATO 5.56 mm rounds were measured up to 820 m/s (drag deceleration).
- BP-1 from a shotgun was measured up to 250 m/s (rapid deceleration).

Summary

- The risks to surface assets from PSI ejecta need to be quantified.
- Ejecta velocity must be understood to assess this risk.
- DERT is a 94 GHz Doppler radar that can be mounted on a lunar lander.
- A DERT prototype has been demonstrated to accurately measure velocities from 0.2 – 820 m/s.
- A DERT prototype has detected particles below 75 μm .



Rapid deceleration of BP-1 fired from a shotgun due to atmospheric drag.

Ongoing and Future Work

- Lunar Regolith Ejecta Simulator (LuRES).
 - Belt set up to attached known particles (sizes, concentrations) for repeatable detections and 4 – 6 m/s.
- Vacuum chamber at KSC.
 - Thermal testing
 - Functional testing
- PSI Ground Test, Langley.
 - 60 ft vacuum chamber.
 - 0.75 Torr.
 - Engines fired into large BP-1 test bed.