Development of a Doppler Radar System to Determine Plume-Surface Interaction Ejecta Velocities

National Aeronautics and Space Administration

NASA Exploration Systems Development Mission Directorate

Austin.G.Langton@NASA.gov

Plume-Surface Interaction (PSI) Project | Space Resources Round Table | Golden, Colorado, June 6-9, 2023

Dust Ejecta RADAR Technology - DERT

Team Members

KSC ESDMD PSI Project Team:

- Dr. Jim Mantovani
- Austin Langton
- Dr. Beverly Kemmerer
- Austin Atkins
- Dr. Dan Batcheldor
- Matt Wittal
- Dr. Gary Bastin
- Julia Worrell

Special thanks to NASA ESDMD for continuing to support the PSI project

Importance of Ejecta Energy Flux

Morpheus Free Flight7 (FF7) at the Kennedy Space Center (KSC) Shuttle Landing Facility (SLF) on Monday, February 10, 2014.

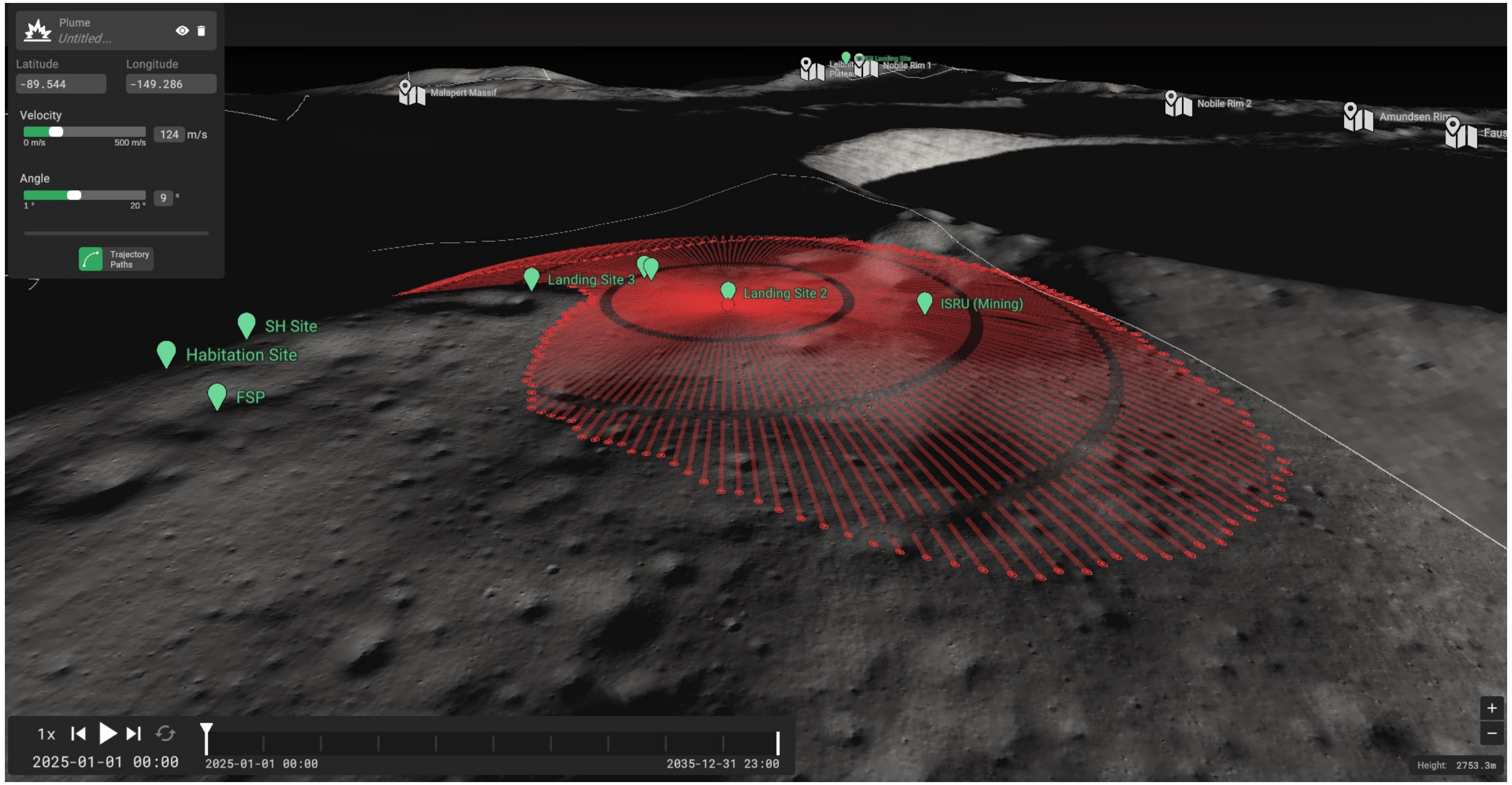
Importance of Ejecta Energy Flux

- High-speed PSI ejecta pose a significant risk to lunar surface assets and infrastructure due to impact energy/flux and abrasive blasting effects. Ejecta can also pose a serious risk to orbital assets.
- Proper risk assessment of frequent landings to The Moon requires knowledge of PSI ejecta particle size, velocity, and density.
- DERT will provide a unique dataset based on direct measurements of ejecta particle velocities and particle concentrations during plume impingement, which will help inform risk assessments associated with impacts by high-speed PSI ejecta particles (energy flux).

Debris stretches along the perimeter of Launch Pad 39A at NASA's Kennedy Space Center. It is residue from the damage that occurred during the May 31, 2008 launch of space shuttle Discovery.

Importance of Ejecta Energy Flux

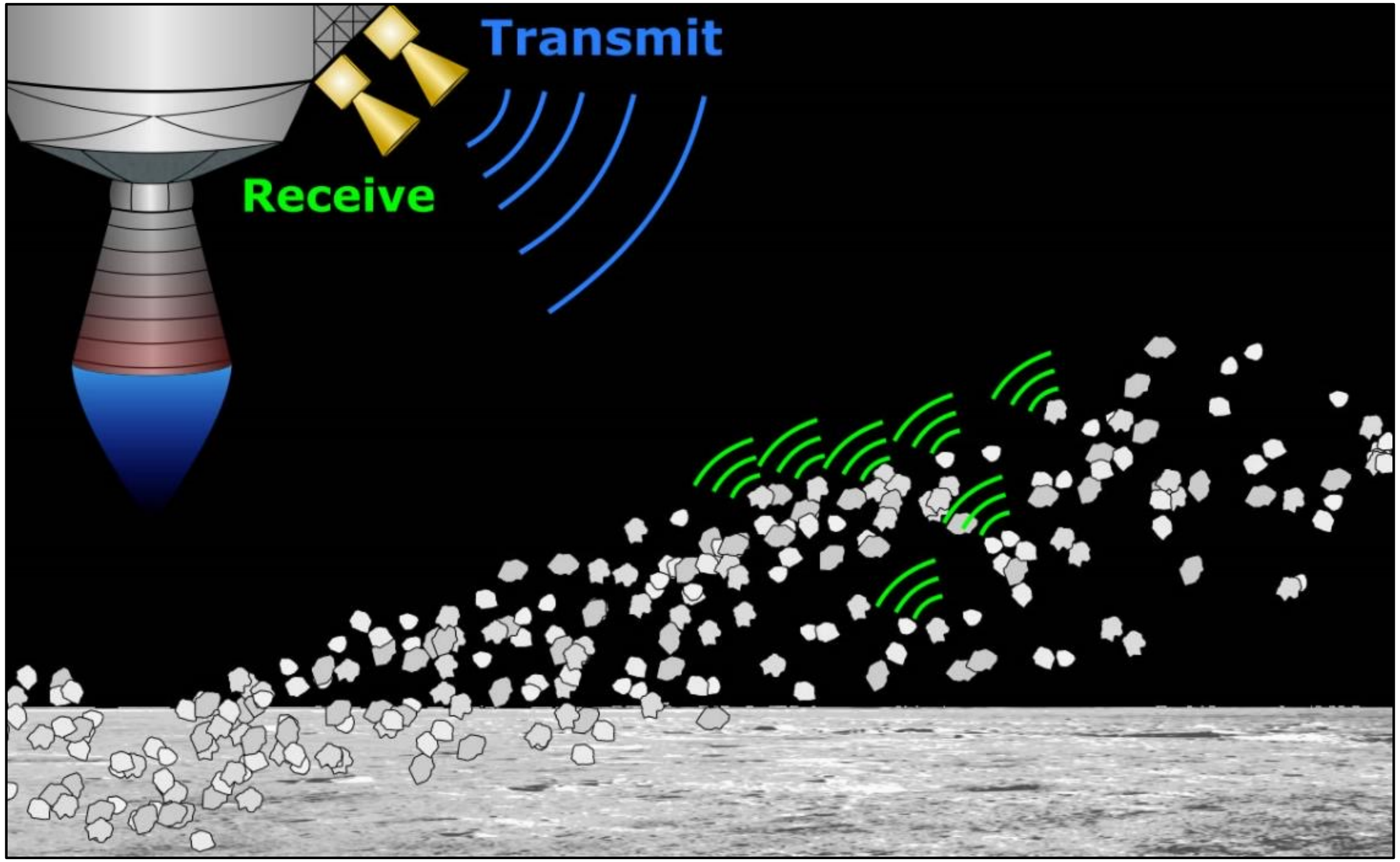
- Models demonstrate Lunar PSI ejecta can travel significant distances from the landing site.
- Direct velocity data of ejecta will determine the lunar locations at risk.
- Local topography reduces risk at certain azimuths from the landing site.



Example of LUNEX software developed at KSC to support the PSI project. The red arcs demonstrate the trajectories of ejecta particles of a given velocity and elevation from a chosen landing site.

Millimeter Wave Doppler Radar – 94 GHz

- Transmitted RF waves scatter off particles ejected in the plume resulting in a Doppler shifted returned signal which provides velocity information.
- Smaller particles (<300 μm) expected to have velocities from .1 – 2.5 km/s and are in Rayleigh Scattering regime (D<.1λ)
- **Signal strength** received depends upon particle diameter, index of refraction, radar look angle, particle count in sight of radar (mass flow rate from plume) and radar physical parameters (transmit power, horn antenna gain, atmospheric attenuation etc.)

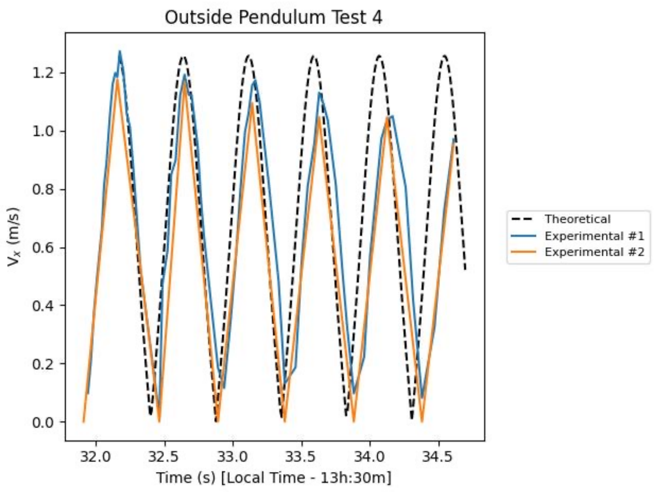


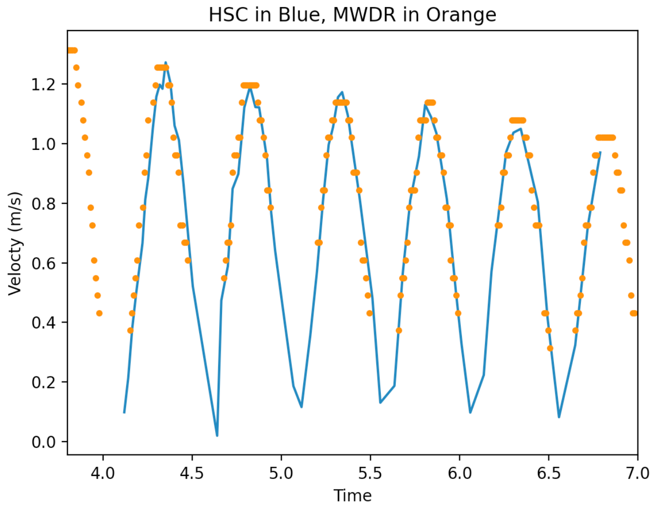
Flight Instrument design concept. Photo Credit: Austin Atkins

Dust Ejecta RADAR Technology - DERT

Pendulum Tests

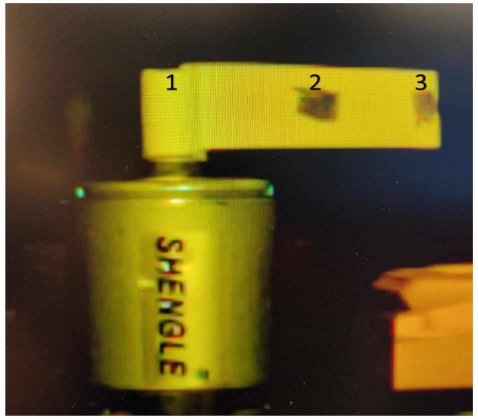
- An experiment was conducted with a pendulum to compare results using particle tracking software from a High Speed Camera and velocity measurements from the Millimeter Wave Doppler RADAR
- Fig. a represents pendulum theoretical motion vs actual Fig. b shows excellent agreement between the High Speed Camera data and the data from the Millimeter Wave Doppler RADAR.



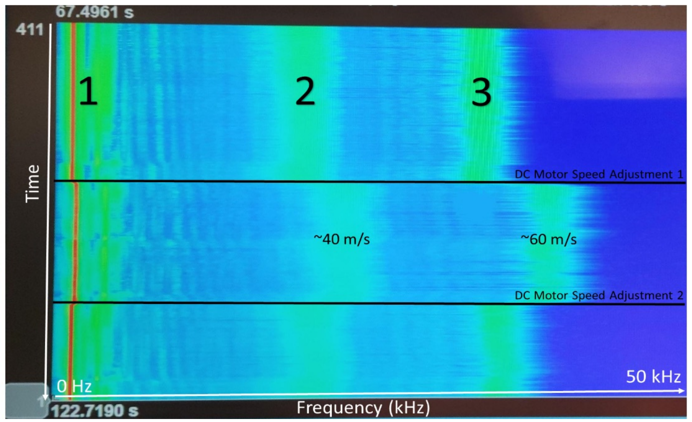


DC Motor Tests

- An experiment was conducted with a DC Motor with two highly reflective targets taped to a RF transparent flag. Velocity was ascertained from the a High Speed Camera based on the period of rotation.
- The Spectrum Analyzer Waterfall Image shows excellent signal return from the center spindle and the two reflective pieces. During the capture time the speed of the DC Motor was adjusted twice.



High Speed Camera still frame (fps = 20,000)

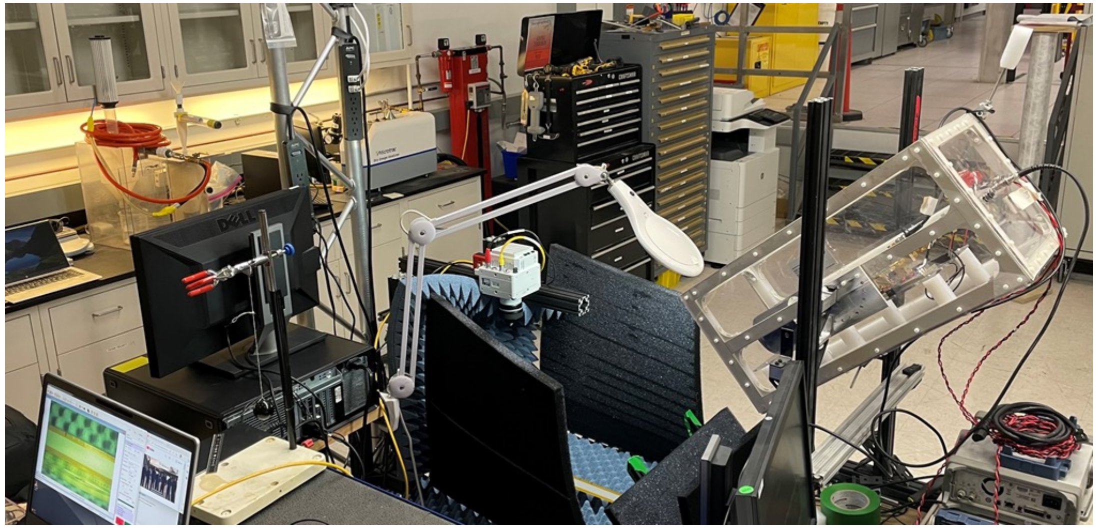


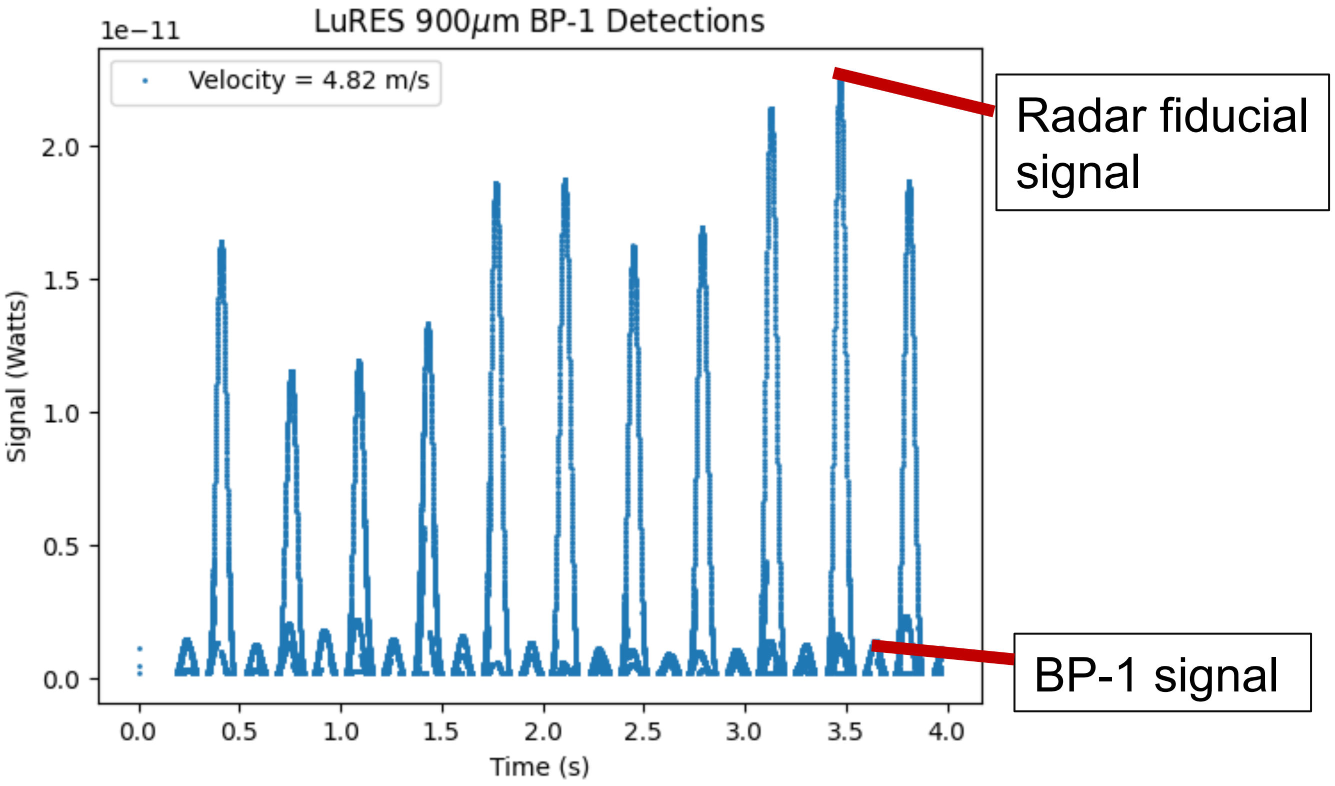
Real Time Spectrum Analyzer Waterfall Intensity vs Time

Dust Ejecta RADAR Technology - DERT

LuRES Testing

- **Lu**nar **R**egolith **E**jecta **S**imulator.
- Belt based instrument that produces known periodic signals from discrete radar targets, i.e., individual regolith simulant particles.
- Established sensitivity limits, range limits, and demonstrates correct geometric adjustment due to ejecta elevations and radar look angles.

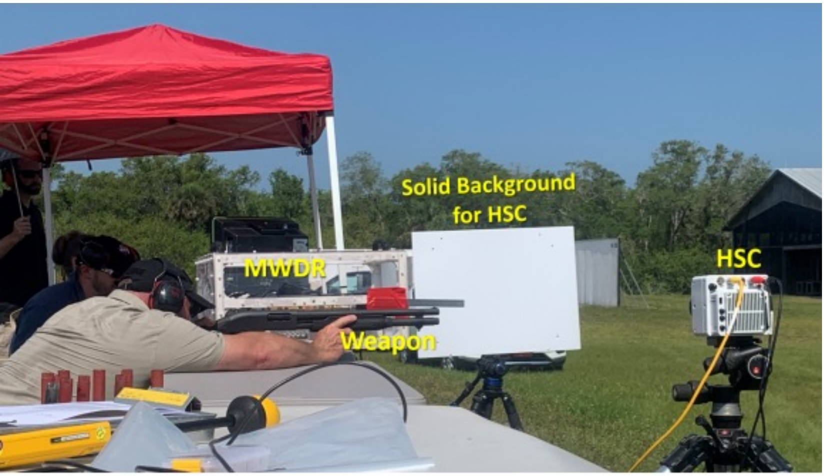


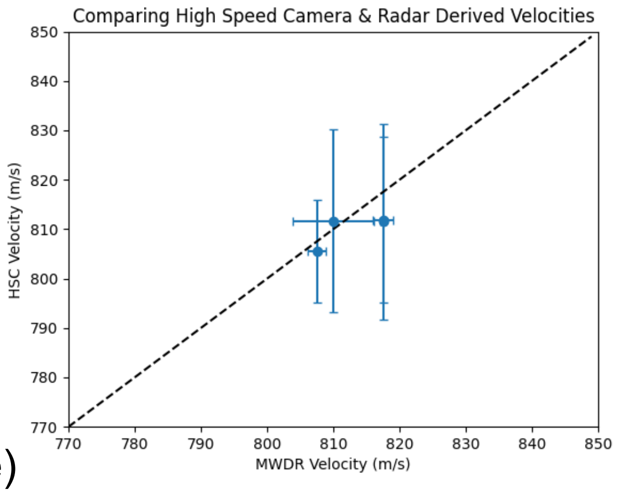


Dust Ejecta RADAR Technology - DERT

KSC Weapons Training Area Tests

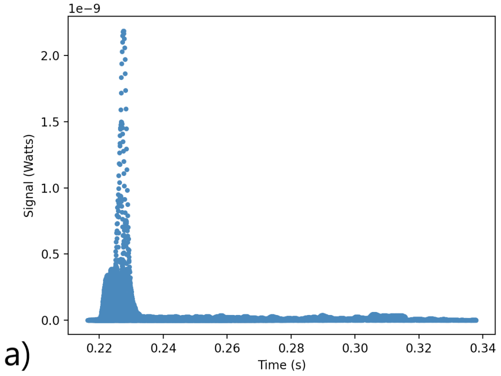
- Small arms projectile velocities were measured using a HSC and the MWDR.
- Various projectiles were used, including a 1 oz. rifled shotgun slug, 5.56mm NATO rounds, 00 Buck Shot, Winchester # 8 Bird Shot, shell-loaded BP-1 and shell-loaded sieved BP-1 (212-355µm).
- Fig. e) represents HSC and Radar derived velocities for the 5.56mm NATO Round.



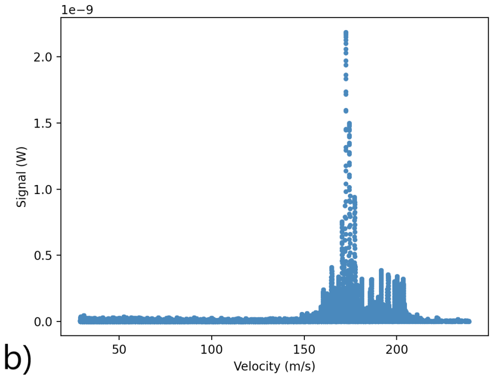


e)

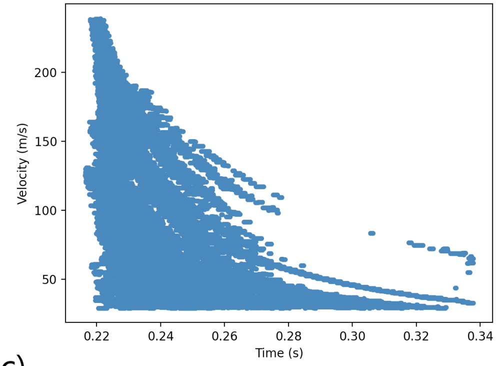
- Figs. a-d represent compiled results from the shell-loaded BP-1 shotgun test:
  a) Signal vs Time
  b) Signal vs. Velocity
  c) Velocity vs. Time
  d) Signal Width vs. Time



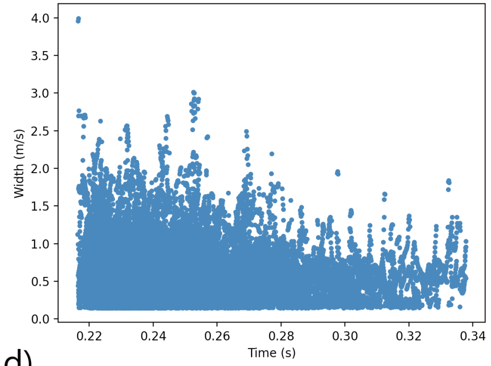
a)



b)



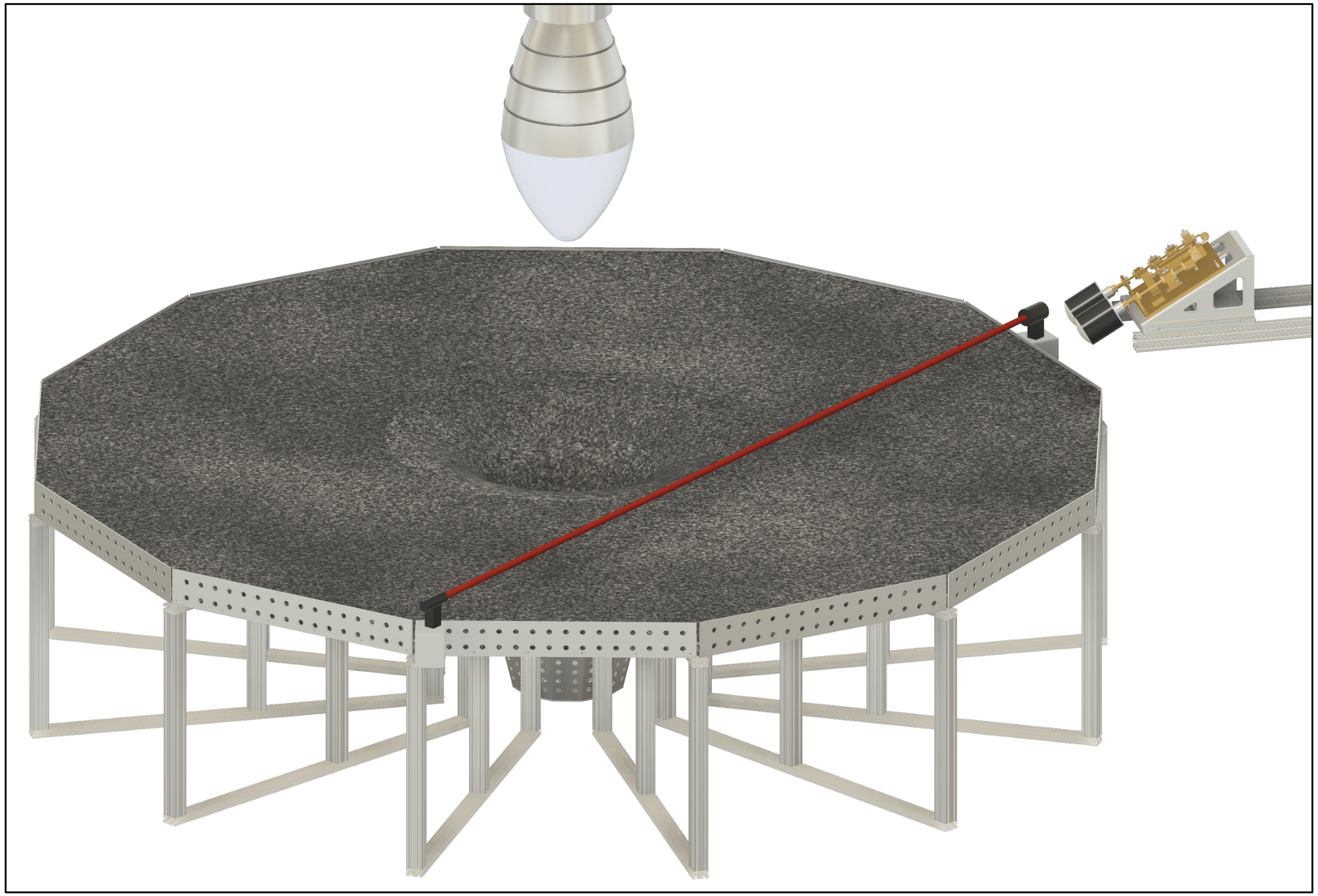
c)

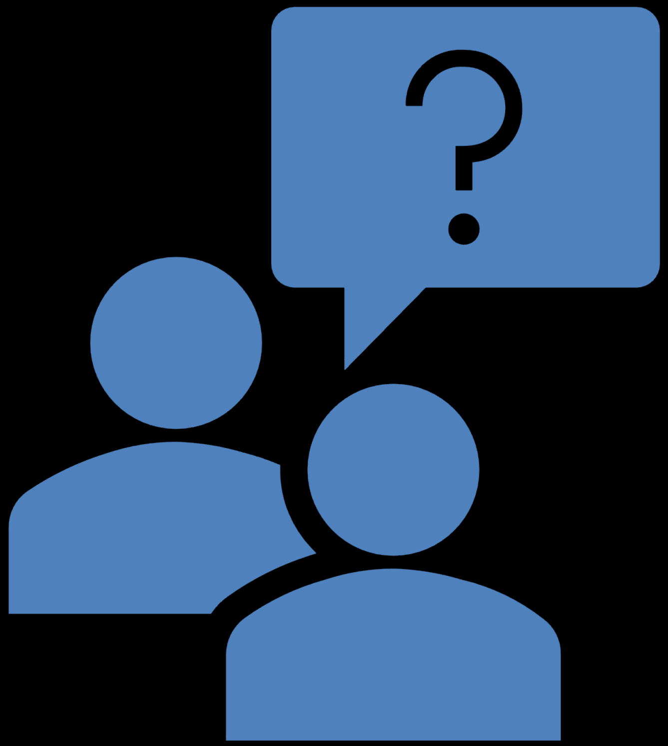


d)

Dust Ejecta RADAR Technology – DERT Next Steps

- KSC is providing BP-1 and soil bin concept for ESDMD PSI Project
- KSC will integrate DERT into PSI Project Full Scale Ground Test campaign at LaRC to advance to TRL 5
- Working on new partnerships





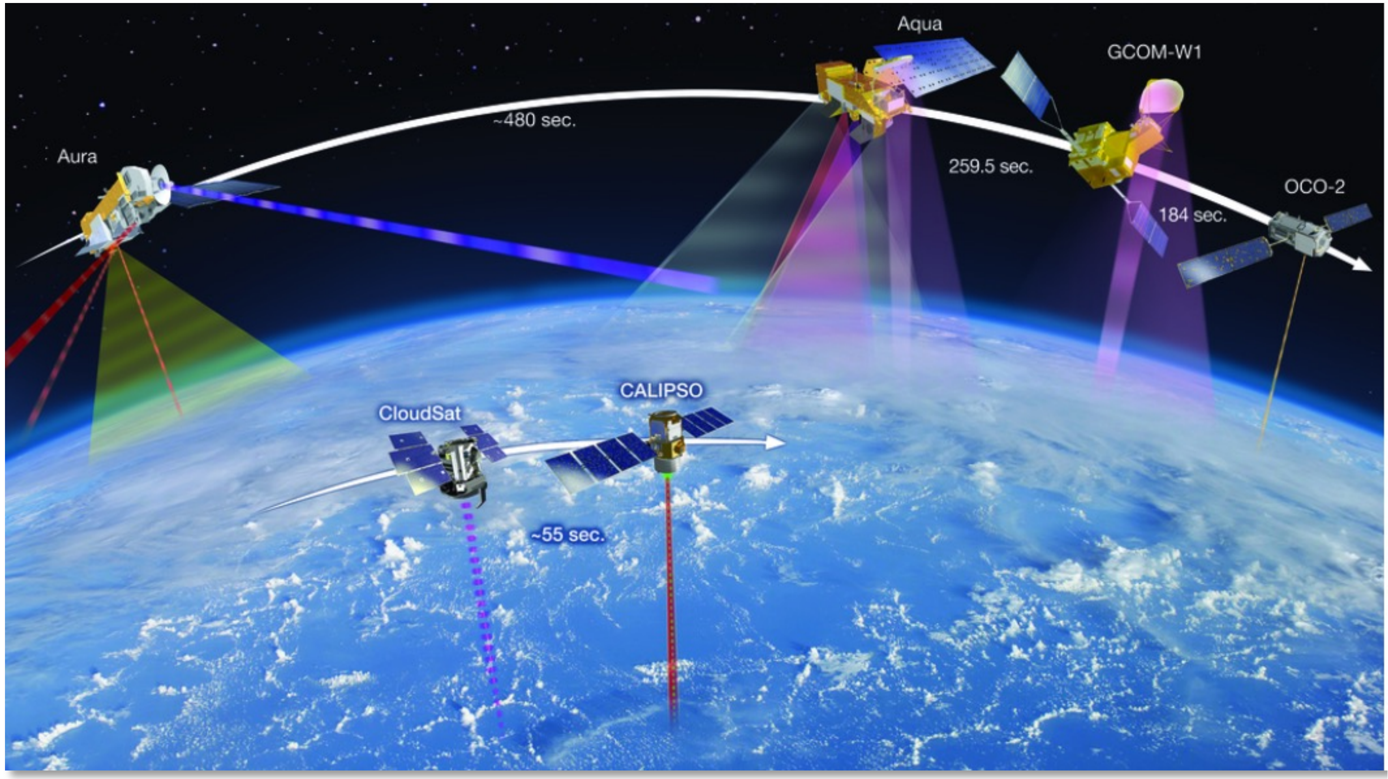
Q & A

Backup Slides

Millimeter Wave Doppler Radar: History

- The Feasibility of Using Millimeter Wave Doppler Radar (MWDR) to Measure the Velocity and Particle Mass Flow of Rocket Plumes on Mars and the Moon was first proposed by Dr. Bob Youngquist and Stan Starr at NASA KSC.
- Millimeter Wave Radar applications: Landing RADAR, imaging, radio astronomy, remote sensing, automotive radars, military and space applications, airport security screening, telecommunications, and to study Sand/Duststorms and Doppler Radar Observations of Dust Devils in Texas

CloudSat - Overview: Home (colostate.edu)



Credit: NASA Goddard Space Flight Center

Key Performance Parameters: PSI Instruments

Performance Parameter		SOA	Threshold Value	Project Goal
KPP				
Lunar Environment	Prediction of ejecta energy flux (W/m^2)	N/A	Predict within +/- 50%	Predict within +/- 10%
Mars Environment	Prediction of ejecta energy flux (W/m^2)	TBD	Predict within +/- 25%	Predict within +/- 10%

Notes:

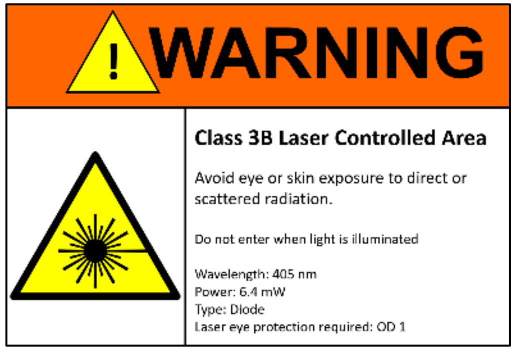
a) Predictions developed through (1) computational approaches and (2) ground test and flight data-driven scaling correlations

b) Approach for evaluating the predictions specified in the above the KPPs will be outlined in the Project Plan and detailed in an attachment to the Project Plan.

Safety

The Laser and RF Hazard:

- Electromagnetic energy interacts with the human body through oscillating electric and magnetic fields that can vary in both amplitude and frequency.
- In addition, the intensity of the radiation (energy per unit area) is the primary value measured for hazard and risk mitigation.
- There are many mechanisms by which the electromagnetic energy can affect various tissues / organs etc. and the dominating factor is determined by the frequency.
- For microwaves the primary hazards are tissue heating and whole-body heating where the penetration depth is limited to the outer layers of skin.
- For lasers, the primary hazards are injury to the eyes (burned retina) and burned skin.



The Silica Hazard:

- Workers who inhale these very small crystalline silica particles are at increased risk of developing serious silica-related diseases, including:
  - ❖ Silicosis, an incurable lung disease that can lead to disability and death;
  - ❖ Lung cancer;
  - ❖ Chronic obstructive pulmonary disease (COPD); and
  - ❖ Kidney disease.
- Handling Lunar Simulants such as BP-1 is an Authorized Lab Capability by users in the GMRO

Graphic courtesy of OSHA

Further Capabilities of MWDR

KSC New Technology Report

Kinetic Energy Density Measurement with MWDR (Submitted by Dr. Bob Youngquist and team):
Kinetic Energy Density Measurement of a Particle Cloud Using Heterodyne Millimeter Wave Doppler Radar

Outside Work

Millimeter Wave Radar Phased Array Antenna Electronic Beam Steering:
IBM Builds MM-Wave Transceiver To Improve Mobile Communications, Radar Imaging - Millimeter Wave Products | Waveguide Products | MM Wave Components (miwv.com)

Reflectivity, Rain Rate, and Kinetic Energy Flux Relationships Based on Raindrop Spectra
Reflectivity, Rain Rate, and Kinetic Energy Flux Relationships Based on Raindrop Spectra in: Journal of Applied Meteorology and Climatology Volume 39 Issue 11 (2000) (ametsoc.org)

60 Ghz, 600 ps pulsed Millimeter Wave Radar used for Hand Gesture detection:
Pulsed Millimeter Wave Radar for Hand Gesture Sensing and Classification | IEEE Journals & Magazine | IEEE Xplore/