RADAR MAPPING ON THE MOON: ADDING THE THIRD DIMENSION TO LUNAR PROSPECTING.

Sean Gulick[1,2,3], Cyril Grima[1,3], Jack Holt[4,5], Stefano Nerozzi[4], Brandon Jones[3,6,7], Ryan Russell[3,6,7], Medha Prakash[1,2,3], Mercedes Jordan[1,2,3]

[1]Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, sean@ig.utexas.edu

[2]Department of Earth and Planetary Sciences, Jackson School of Geosciences, University of Texas at Austin,

[3]Center for Planetary Systems Habitability, University of Texas at Austin,

[4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ,

[5]Department of Geoscience, University of Arizona, Tucson, AZ,

[6]Center for Space Research, Cockrell School of Engineering, University of Texas at Austin

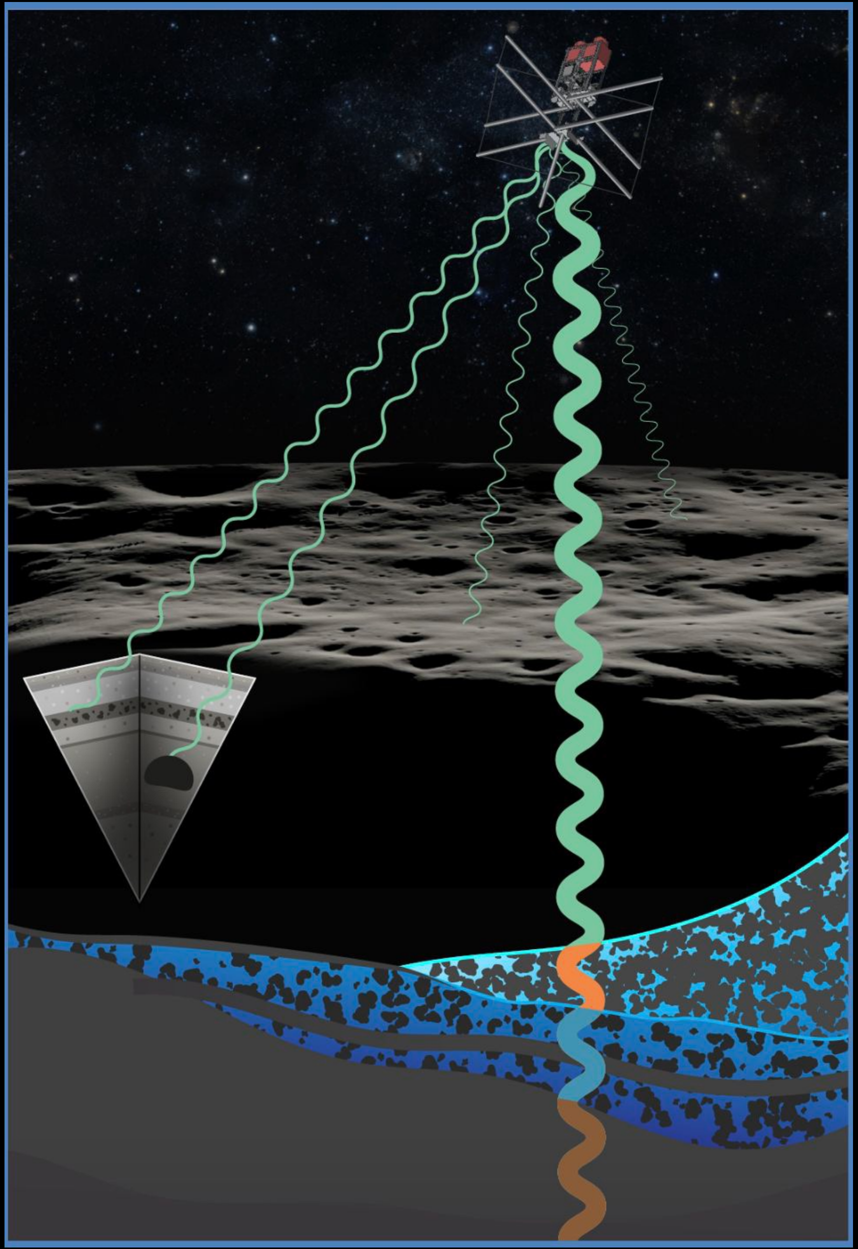
[7]Aerospace Engineering and Engineering Mechanics , Cockrell School of Engineering, University of Texas at Austin

Case for Radar Sounding of the Moon

- Critical to successful operations is adequate site characterization.
- Higher resolution mapping to determine highest priority landing sites that evolve to resource extraction location(s), and selection for moon base(s)
- Subsurface characterization to image regolith homogeneity and depth to base, impact or volcanic units, and opportunities for ISRU.
- Both the Lunar Roadmap and Moon to Mars philosophy are dependent on stable human presence on the Moon which requires resources and in particular water.
- Incredible opportunities to understand the geologic history of the Moon, advance technical capabilities, and solve new engineering challenges.

Nested resolution through paired orbital and rover radar systems

1. Orbital SmallSat mission that overcomes existing challenges in guidance, control, and navigation and includes paired high-frequency radar sounder and neutron spectrometer to characterize the upper meters to 10s of meters of the Lunar subsurface.

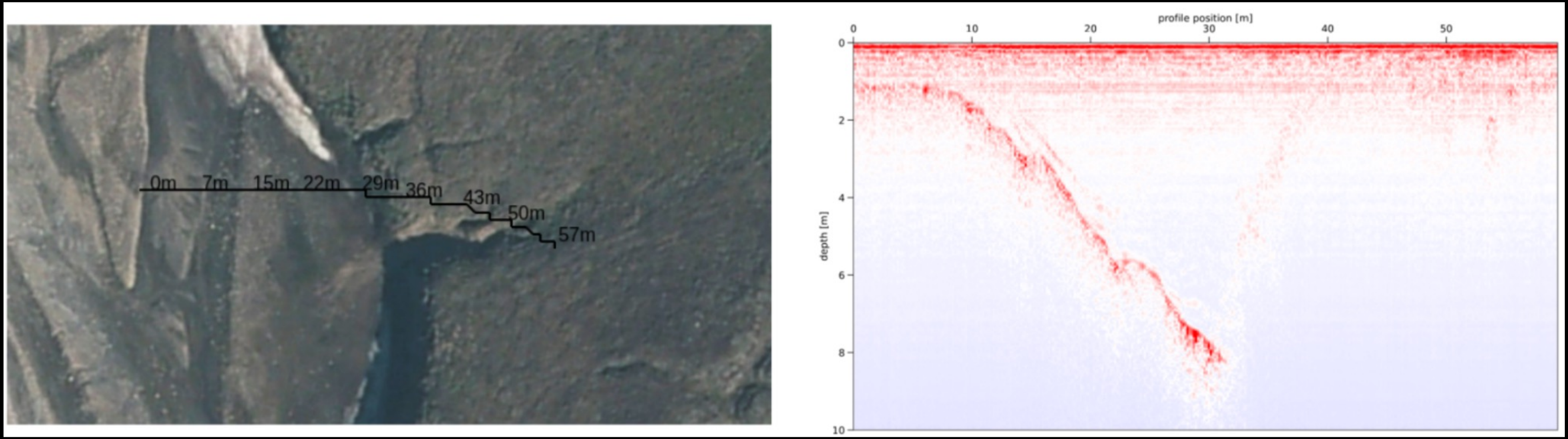


Courtesy of Drs. Jack Holt and Stefano Nerozzi, University of Arizona, showing artist rendition of orbital radar ACORN

Nested resolution through paired orbital and rover radar systems

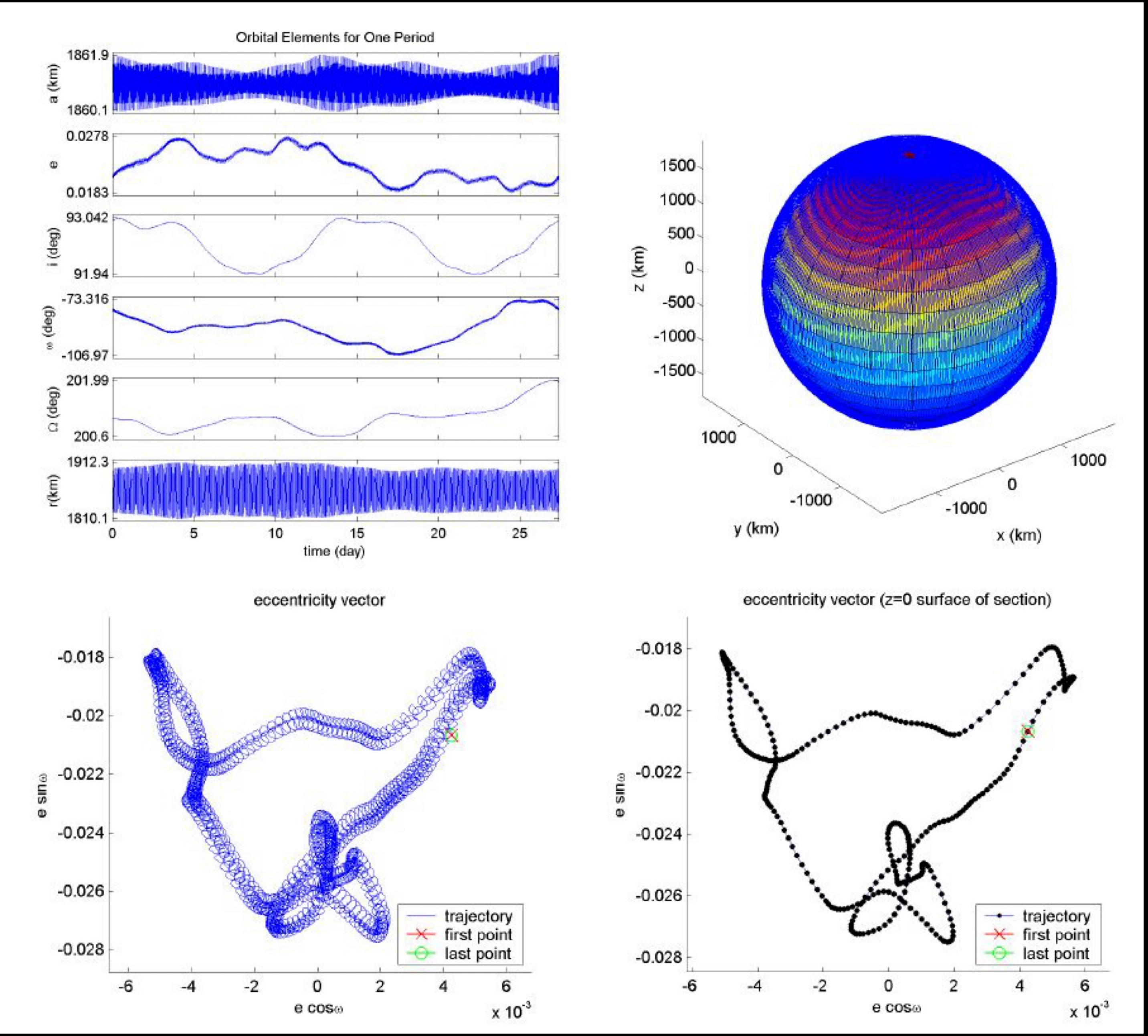
2. Rover-based low size, weight, and power (SWaP) ground penetrating radar (GPR) system for targeted local mapping a higher frequencies and denser line spacing building off orbital reconnaissance

Field Testing of DRS-X GPR from Svalbard: Courtesy of Dr. Dirk Plettemeier, Dresden University of Technology (TUD)



Orbital Technical Challenges:

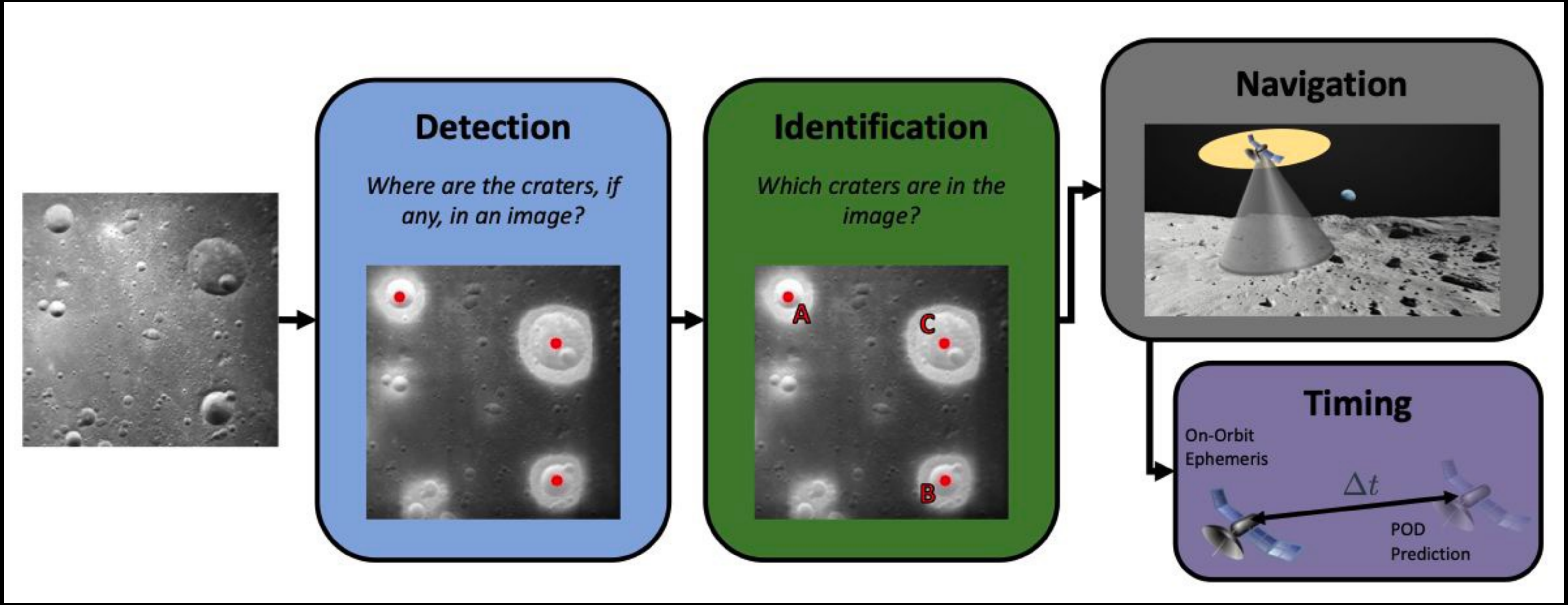
- Lunar global orbit solutions exist (including low lunar orbits) but require:
    - advanced guidance and control algorithms consistent with SWaP limitations.
- Autonomous SmallSat guidance and navigation-
    - computationally efficient
    - long-horizon planning
    - account for mascons
    - handle computation, and communication limitations.



Technical Solutions:

- High Resolution, Fast Gravity Models solutions for autonomous navigation (Russell group)
- Leverage high fidelity topographic data used for crater terrian navigation (Jones group)

CRATER TERRAIN NAVIGATION

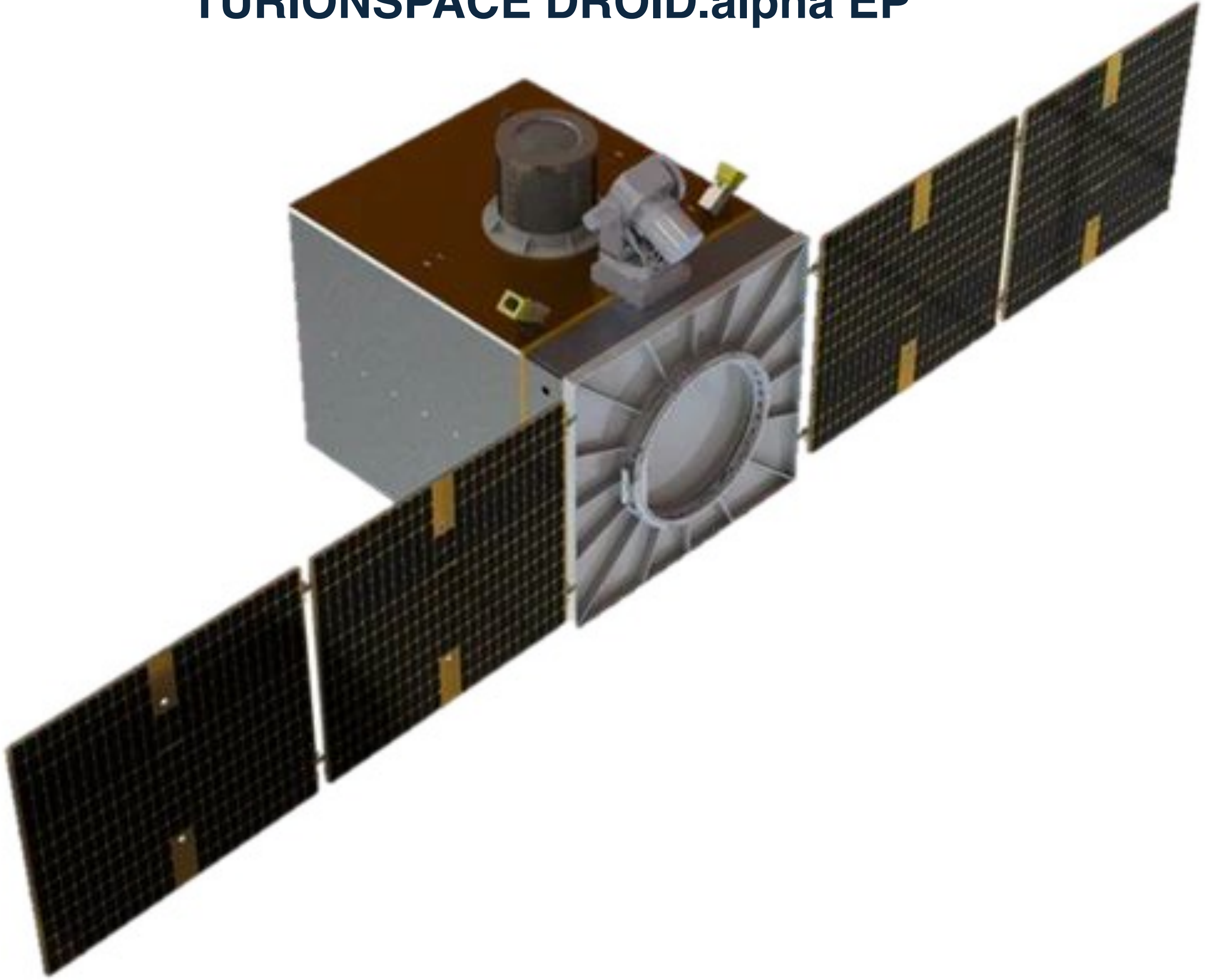


McLaughlin et al., (2022)

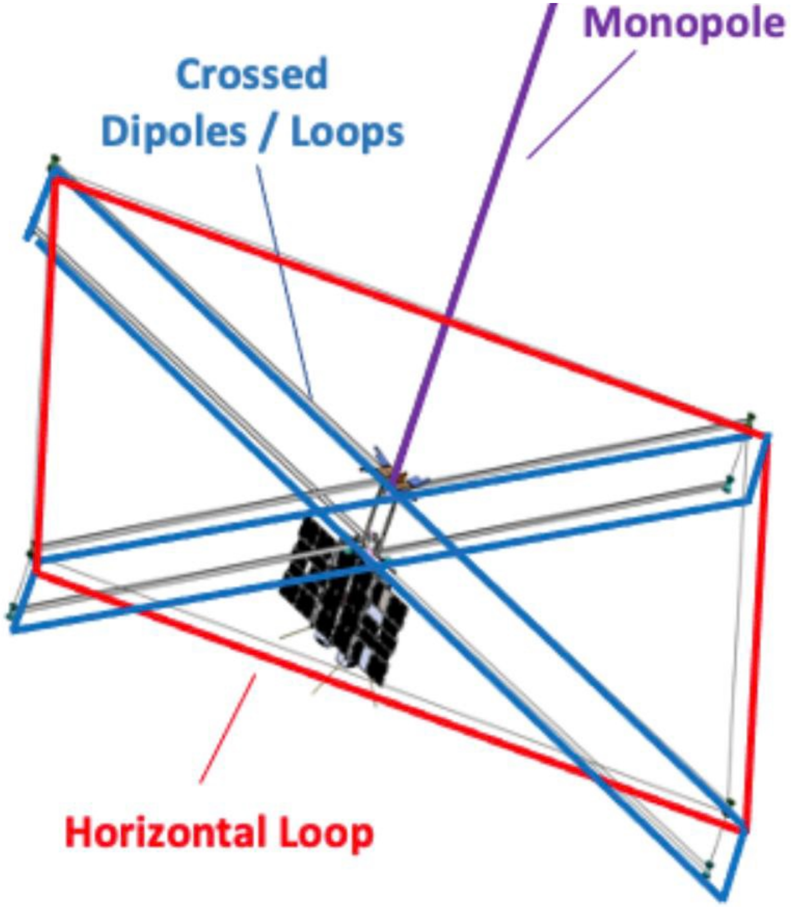
Advanced Compact Orbiting Radar for luNar sounding (ACORN)

40-70 MHz: 3× SHARAD and 15× LRS resolution with global coverage

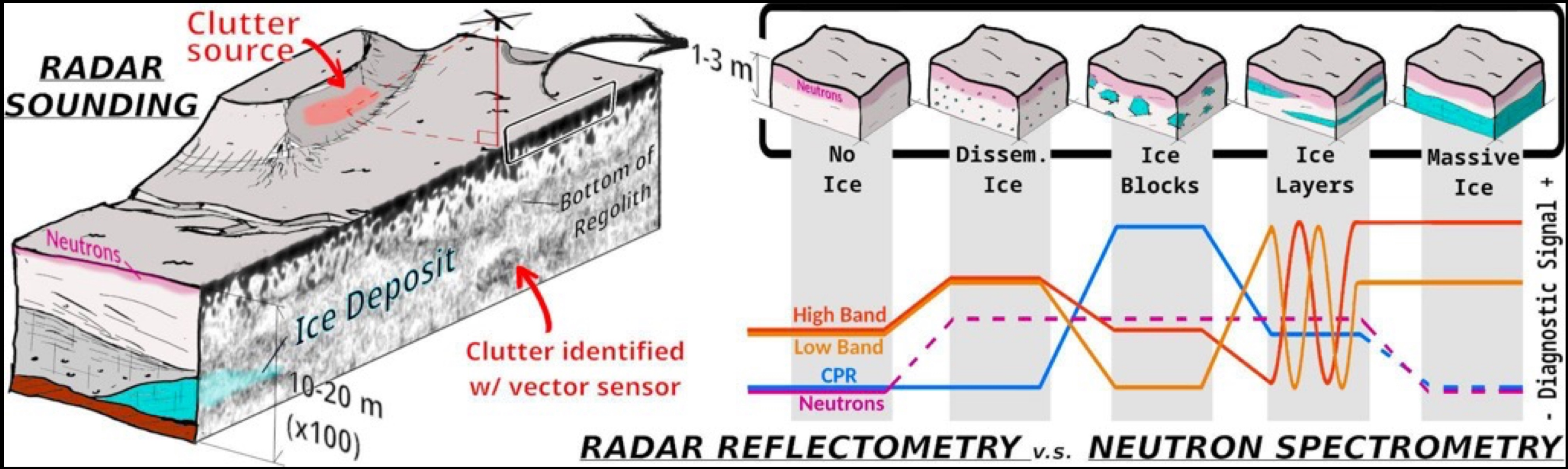
TURIONSPACE DROID.alpha EP



University of Arizona ACORN radar with VSA antenna shown deployed from 6U spacecraft



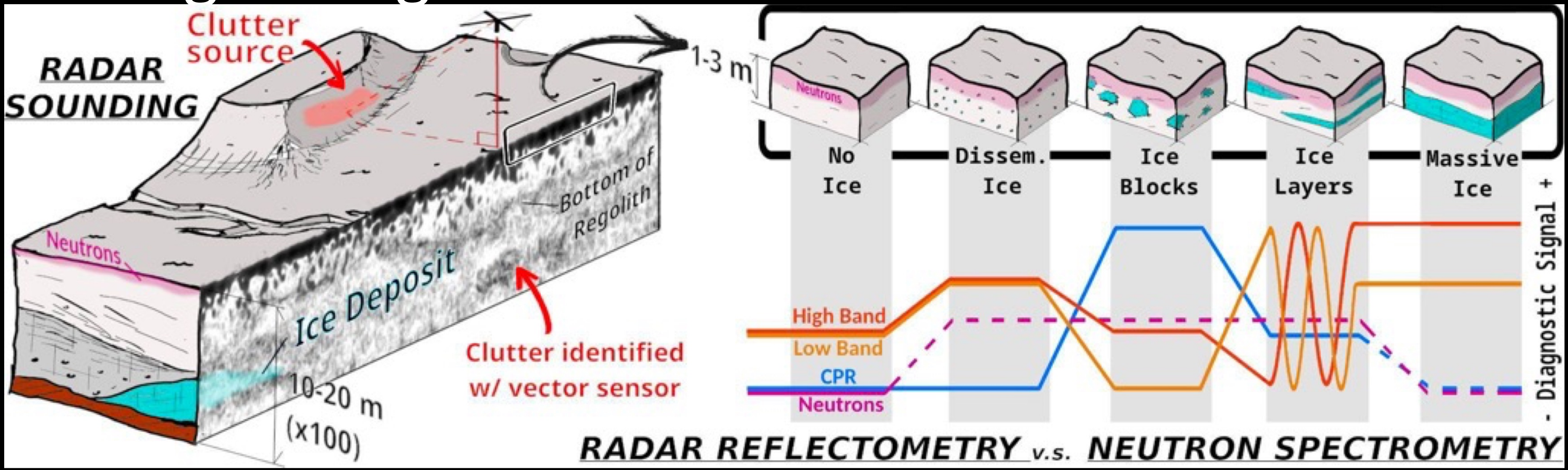
Mapping Ice and Regolith Thickness

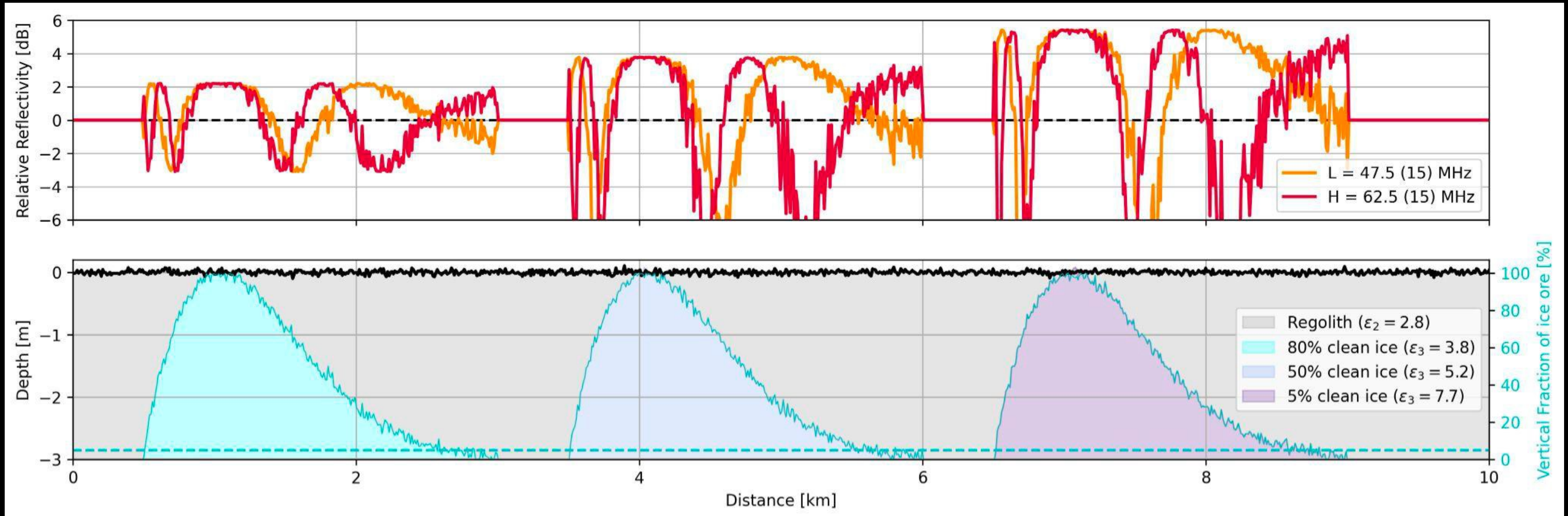


Solution:

1. Neutron spectrometer for ice detection in the top 1 m of regolith
2. High-resolution radar that penetrates tens of meters into the subsurface and resolve physical interfaces in regolith and ice at 1.5-3 m vertical resolution and 0.4-1.2 km horizontal resolution for 10-100 km orbital altitudes

Distinguishing Form of Ice and to Clutter

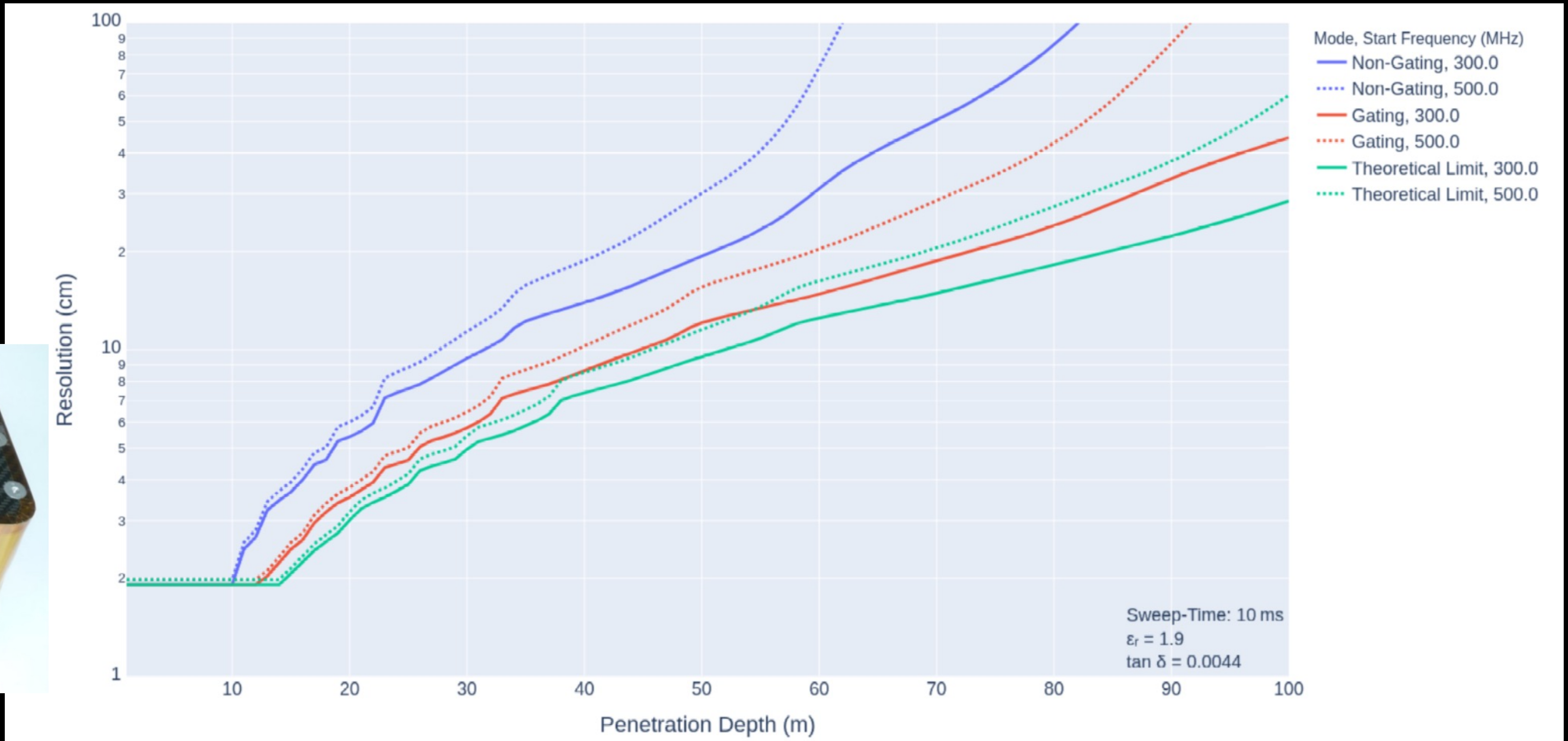




Rover Technical Challenges & Solutions: Deep Regolith Sounder Crosspole DRS-X

- Ensure reduced clutter from radar antenna placement and signal discrimination
- Opportunity for absolute orbital radar calibration through:
  1. a GPR can locally characterize the structure and properties to help calibrate the response of the orbital radar surface return
  2. radiometric reference wherein one can design a radiometric link between the ground and orbital radars to provide a reference signal for absolute calibration.

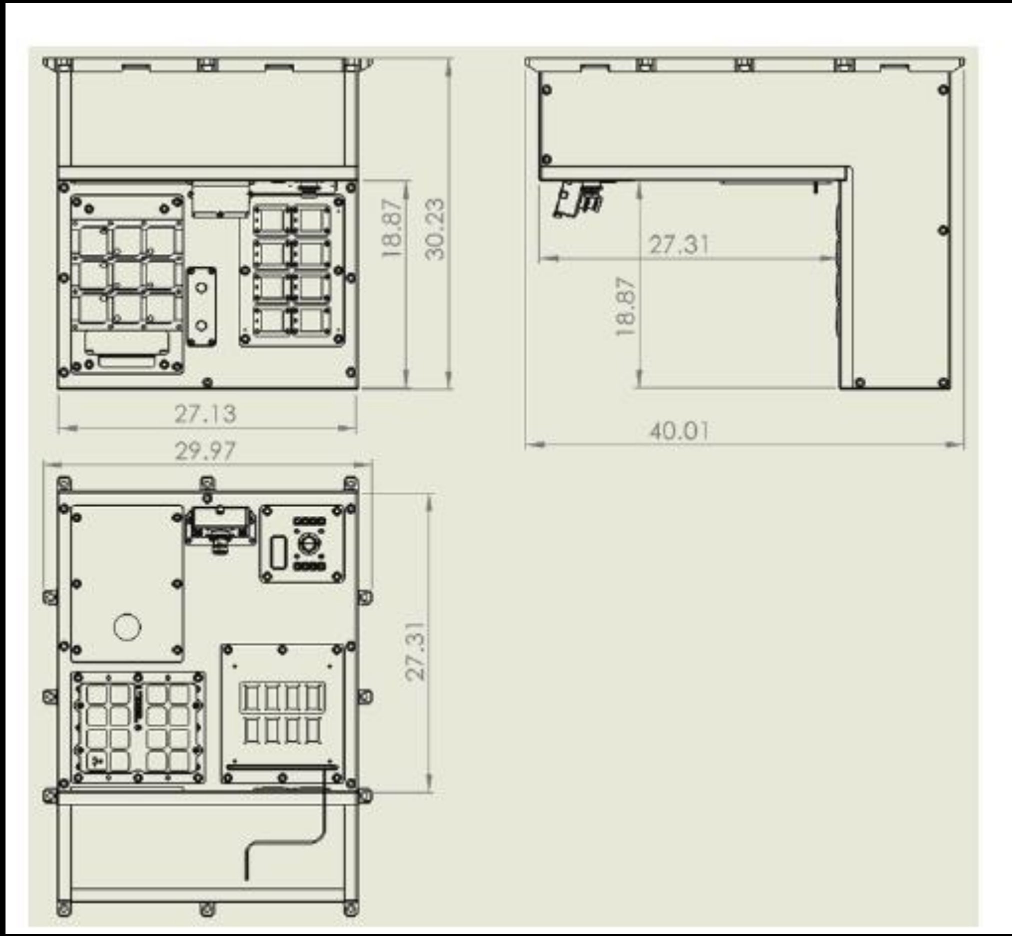
Dresden University of Technology (TUD) designed GPR with Crosspole antenna capable of 0-1.3 GHz



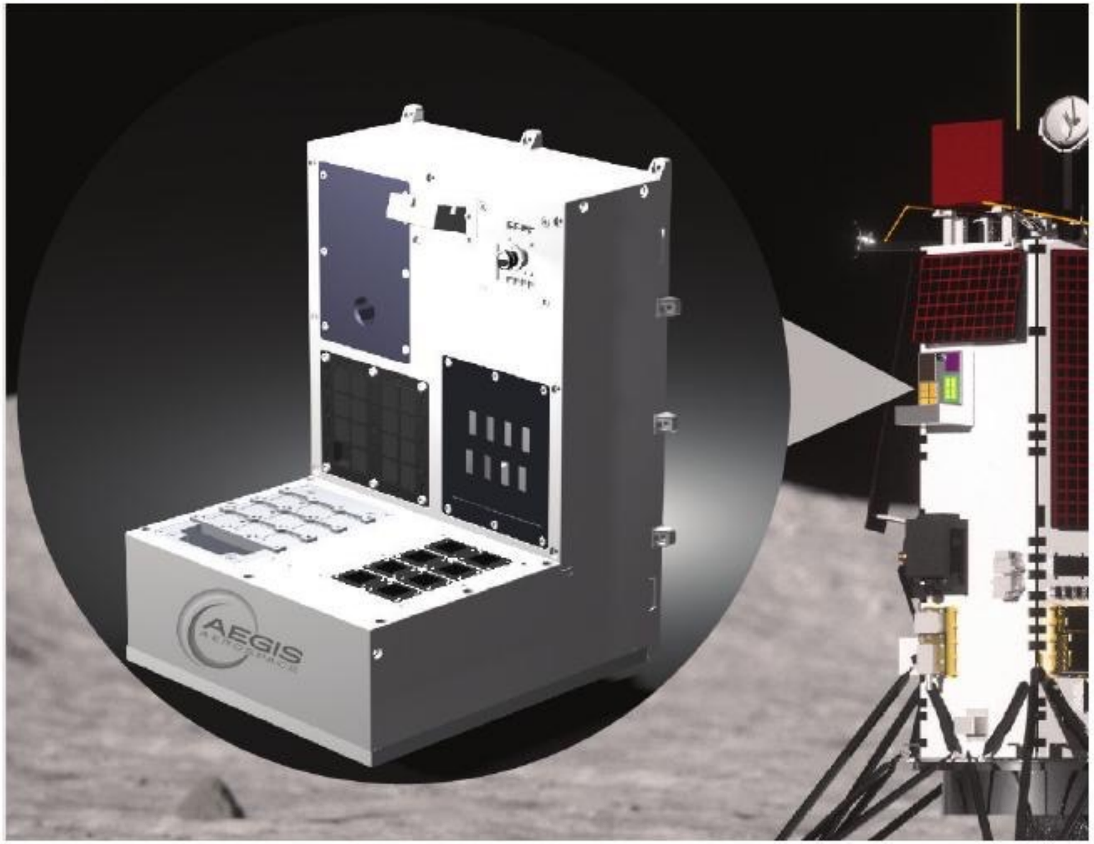
Deep Regolith Sounder Crosspole DRS-X & SSTEFF

Payload up to 6 kg, power up to 40 W

DRS-X: 0.9x.95x.45 m, 0.5 Kg, 1.5-4.4 W



SSTEF on a Lunar Lander



Depiction of Aegis Aerospace's SSTEF lunar test facility on Intuitive Machines' IM-3 lunar lander which has an anticipated mission window through late 2026

Take Home Messages

- The third dimension at depths below 1 m and at a range of resolutions are critical for mapping on the Moon for science, lunar prospecting, and future resource production.
- A prospecting strategy of global coverage from orbit and denser surveying in target locations maximizes opportunity
- Solutions exist for both orbital next generation radar sounder (TRL 4-5) and rover based GPR with customizable frequencies (TRL 7)