Interplanetary CubeSat Gravity & Bi-Static Radar Experiments: Revealing the subsurface features of Phobos

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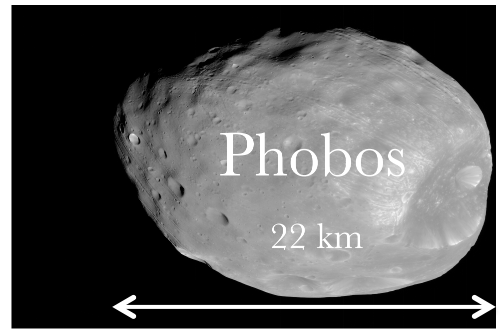
Science Objectives

1. Identify stratified layering of impact ejecta from changes in the dielectric properties of the regolith. This can help to determine if a layer of regolith on Phobos is from Martian ejecta or another planetary body.

2. Characterize the subsurface composition to determine if Phobos is an icy moon or loosely bound material. This will shed light on the question of whether Phobos is a captured object from the outer solar system or if it formed in Mars orbit.

Phobos

- Orbital Period: 7 hours 39 minutes
- Altitude: 5989 km
- Eccentricity: 0.015
- Inclination: 1.1°
- Size: 27 km × 22 km × 18 km
- Composition: low density, low albedo, dust on surface



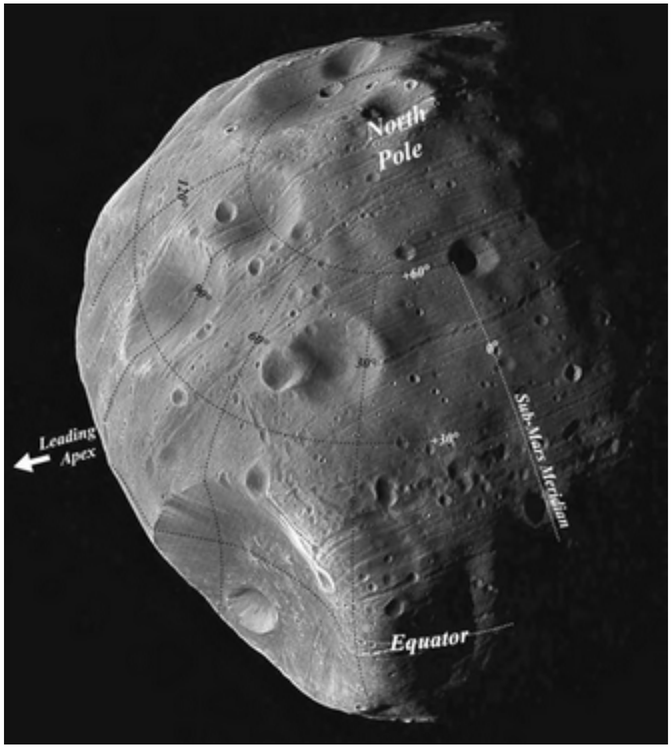
6792 km

Mars

Phobos Origin & Evolution

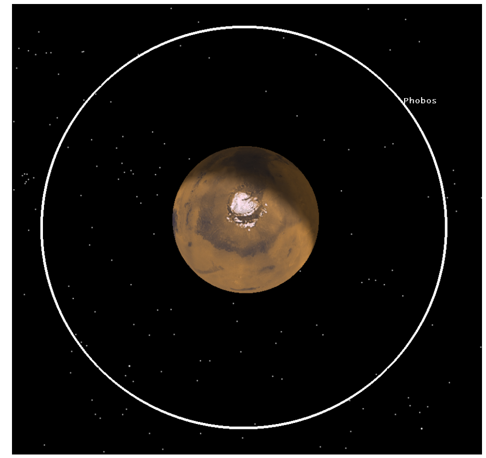
- Dielectric properties of the shallow subsurface provide information on the regolith materials. This will shed light on the composition and origin.

- Measurement will provide information on the lateral and vertical variation of the dielectric properties (e.g. regolith layering).



Phobos Surface

- Phobos-Grunt mission launching in 2020, would return Mars samples from the surface of Phobos.
- Recent studies have shown that Phobos surface contains rocks and soil ejected from the Martian surface by large impacts.
- ~250 ppm of the top regolith on Phobos is thought to be of Martian origin (Ramsley and Head, 2013).
- The Martian material is thought to be evenly distributed across the surface.

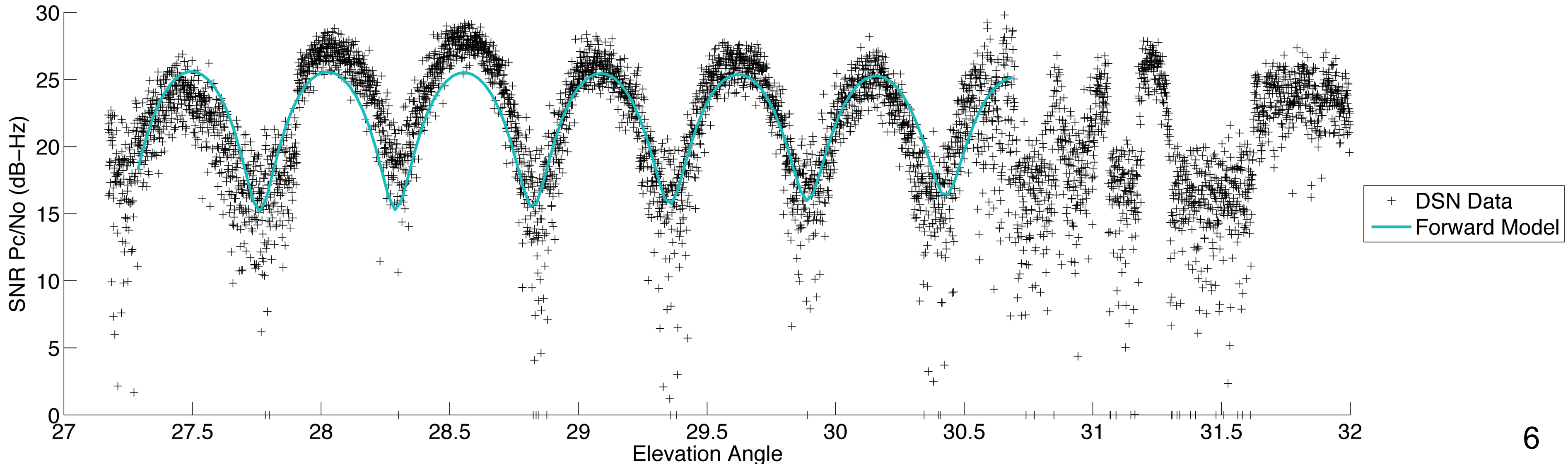


Investigation Technique

1. The feasibility of using the rover X-band system with the interference pattern technique to probe Mars was accomplished with data collected during and after Opportunity's landing.
2. Radio signals traveling directly to the DSN from the rover had a shorter path than signals reflected from the surface and subsurface before traveling to the DSN.
3. These signals may arrive in phase (constructive interference, stronger signal) or out of phase (destructive interference, weaker signal). As the Earth set on Mars and the relative path lengths of these signals changed, the amplitude and period of the interference varied with time.
4. This allowed for geophysical properties of the surface and subsurface to be retrieved since the antenna position was known.

Opportunity Data and Model Fit

Multipath data recorded in open loop by the Deep Space Network immediately after the landing of the Opportunity Rover (MER-B) show good agreement with a simple two layer soil model of ~25cm sand covering a lower layer of basaltic bedrock.



Experiment Implementation

1. During Opportunity's landing, the signal was transmitted by the rover X-band system and received by the DSN on Earth.
2. The use of telecommunications systems for scientific measurements has been a key feature of most solar system exploration missions for decades, including landed vehicles on Mars.
3. Active bi-static radar using the spacecraft as the active transmitting element and DSN ground antennas as the receiving element has often produced scientific results of high value.

Experiment Implementation

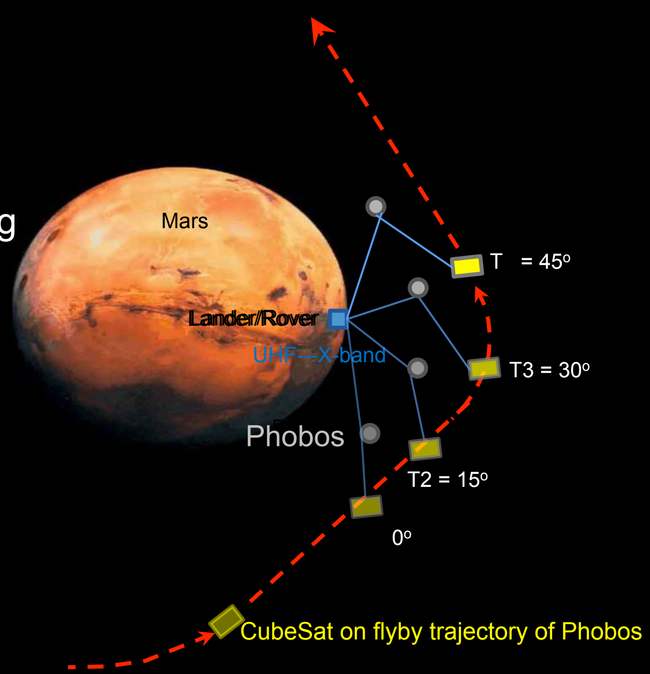
Building on the same dual-use of telecommunications instruments, we present two cases for performing Bi-Static Radar experiments on Phobos:

1. A Mars surface asset (rover or lander) transmitting the signal and an Interplanetary CubeSat receiving the signal
2. Two Interplanetary CubeSats flying in tandem, the first CubeSat transmitting the signal and the second CubeSat receiving.

The period and amplitude of the interference pattern contain information on the dielectric properties of the subsurface along with their lateral and vertical variations, including discontinuities.

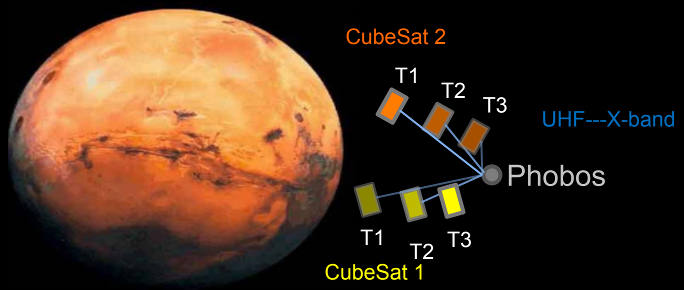
Case I: Lander/Rover to CubeSat

- Use landed spacecraft such as Opportunity, Curiosity, or Insight as transmitter
- Rovers can provide dual bands (UHF & X-band)
- CubeSat can receive both UHF & X-band in open-loop and is equipped with a stable timing reference
- Science data is stored onboard CubeSat for later transmission to Earth
- CubeSat can support 250 bps data rate



Case II: CubeSat to CubeSat

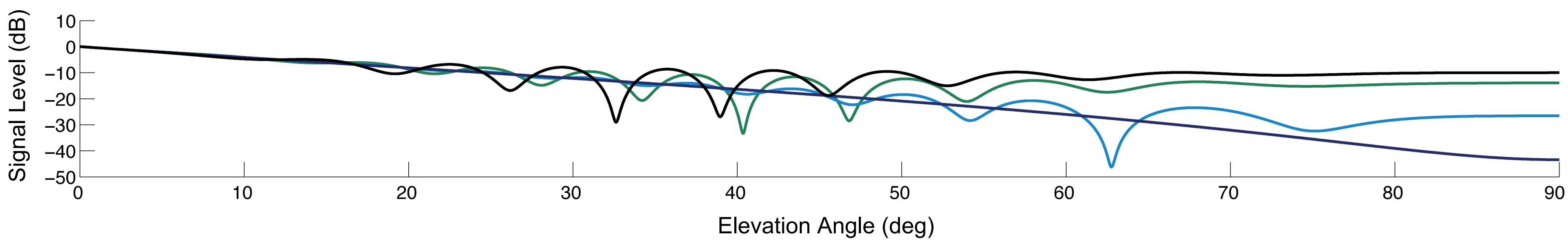
- Two CubeSats equipped to transmit/receive both UHF & X-band in open loop with a stable timing reference
- CubeSat 1 transmits signal toward Phobos
- This signal is reflected from Phobos and received by CubeSat 2
- Science data is stored onboard CubeSat 2 for later transmission to Earth
- CubeSats can support 250 bps data rate



Reflected Signal Magnitude

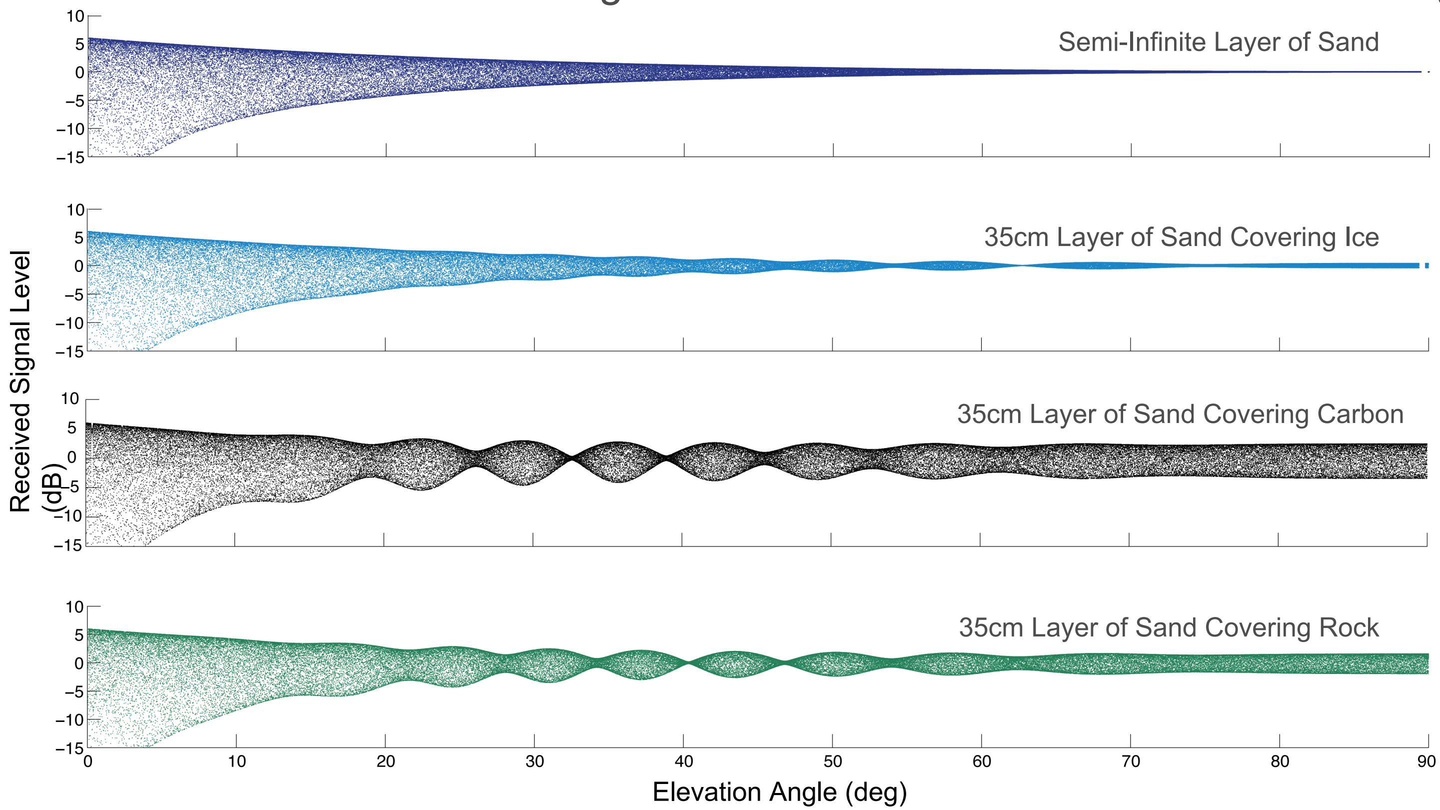
For a CubeSat orbiting 400km above Phobos, a reflected signal in the X-band will show interference lobes like the following for:

- Semi-infinite layer of sand (dark blue)
- 35 cm layer of sand covering ice (light blue)
- 35 cm layer of sand covering carbon (black)
- 35 cm layer of sand covering basaltic bedrock (green)



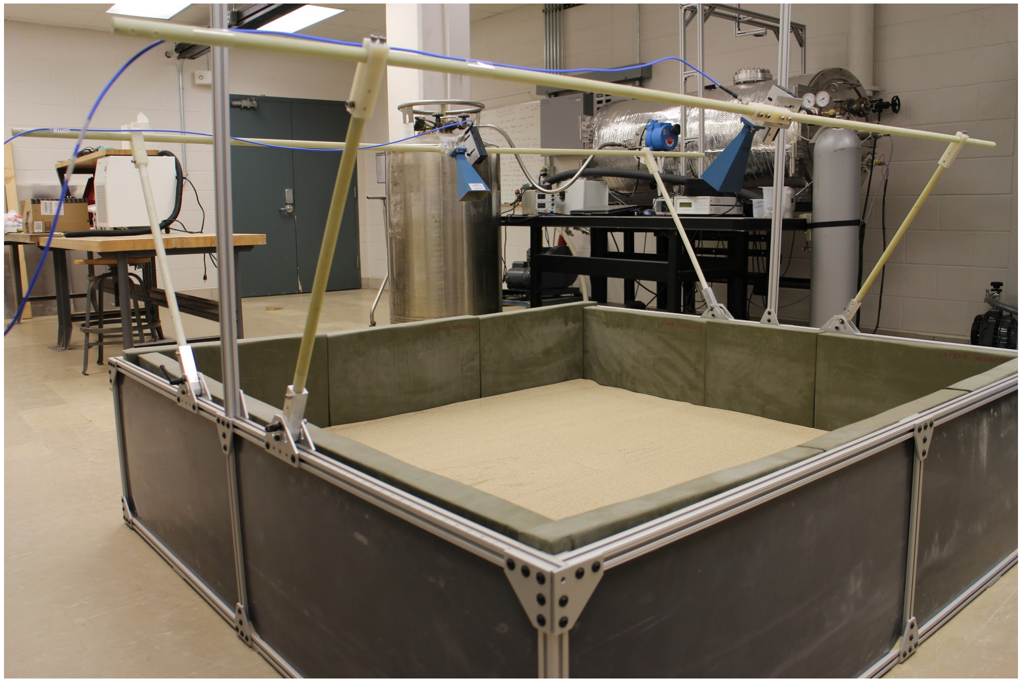
Resulting Interference Pattern

Combination of direct and reflected signals as a function of incidence/elevation angle

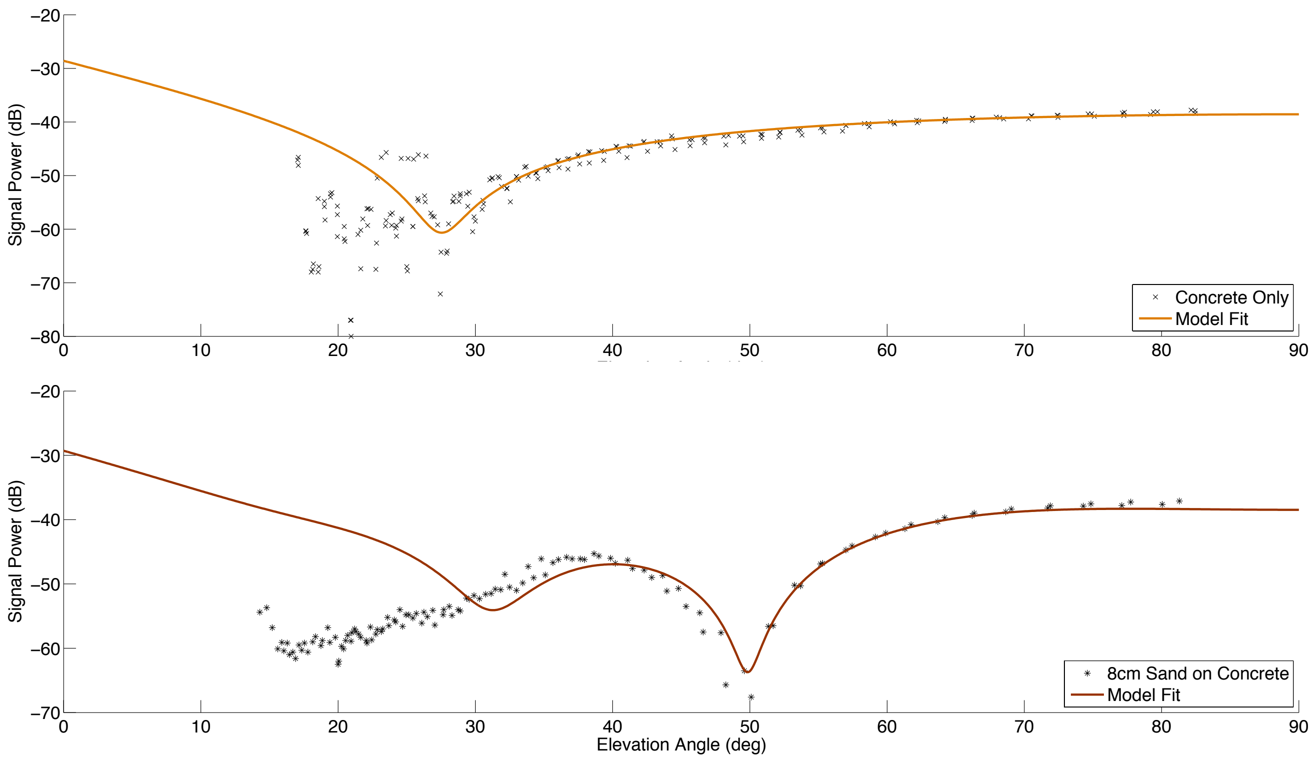


Model Verification

- The University of Michigan has developed a numerical model and laboratory experiments to predict the interference patterns.
- Laboratory experiments are used to validate models and to study the effects of realistic soils on the interference patterns.
- The experimental setup features two antennas to measure the reflected signal and interference pattern with changes in incidence angle.



Model Verification



Note: Edge effects in the experiments at low elevation angles

Conclusions

1. Bi-static radar measurements of Phobos can be done using interplanetary CubeSats to detect the interference patterns generated by the combination of the direct signals and the signals reflected from the surface and subsurface.

2. The Interference Pattern Technique (IPT) provides a methodology for:
   i. Identifying stratified layering of impact ejecta from changes in the dielectric properties of the regolith with depth.
   ii. Characterizing the subsurface composition to test the various hypotheses about the origin of Phobos.