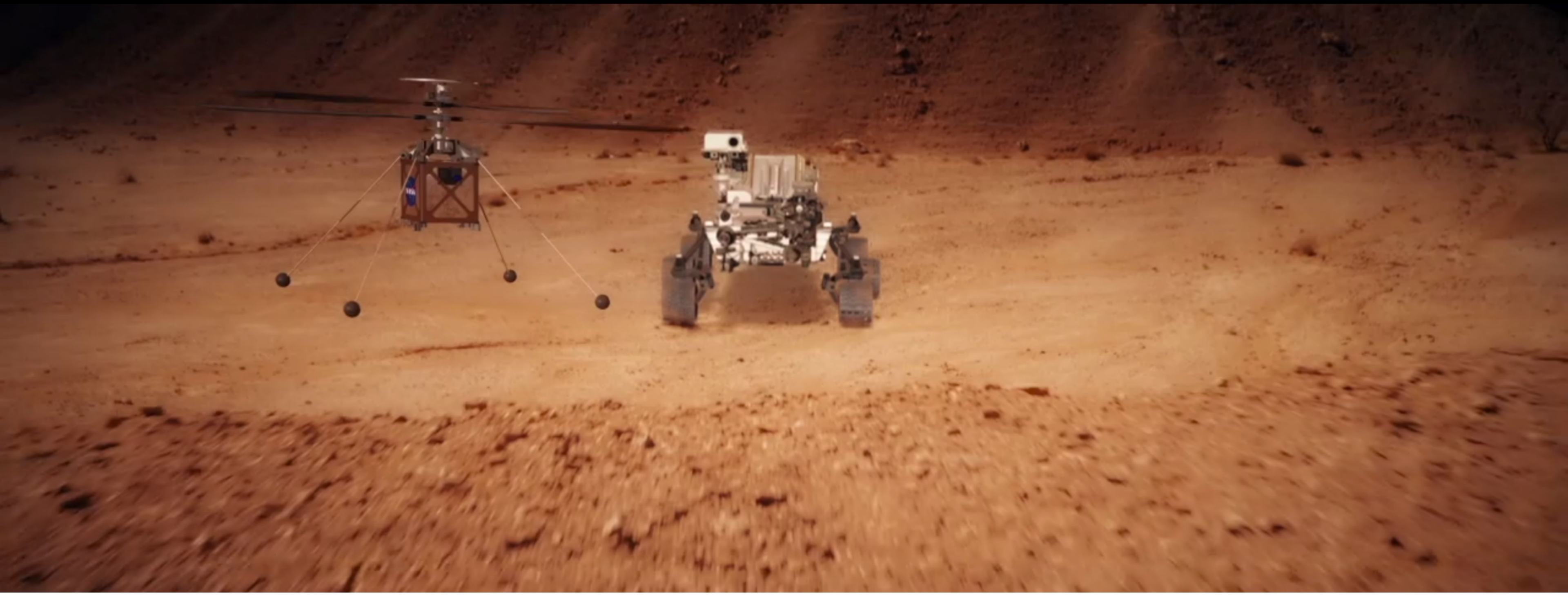


Opportunistic Bistatic Radar with Telecommunications Systems on Planetary Helicopters

Mars Recurring Slope Linea and Beyond

David Bell, Abigail Fraeman, Daniel Nunes, Joseph Lazio, Julie Castillo-Rogez

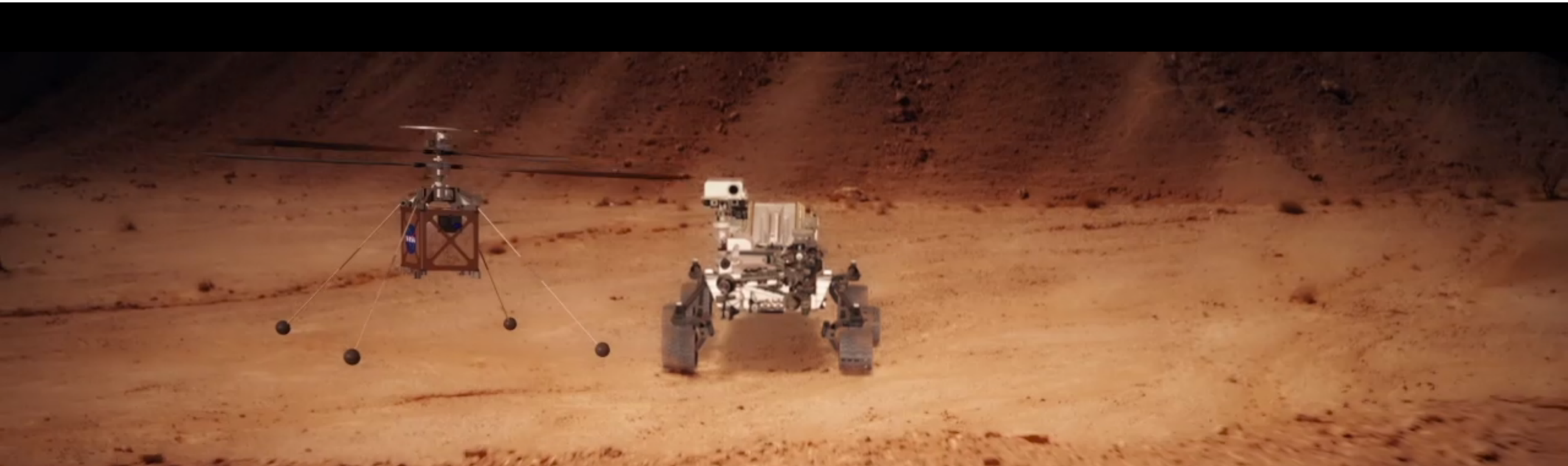
Jet Propulsion Laboratory
California Institute of Technology

42nd Committee on Space Research Scientific Assembly

Opportunistic Bistatic Radar with Telecommunications Systems on Planetary Helicopters

Martian shallow subsurface is largely unexplored but could be important water reservoir

Helicopters capable of flying in Martian atmosphere opens new technology to study shallow subsurface using "opportunistic" bistatic radar, taking advantage of communication systems already on helicopter and paired rover/lander



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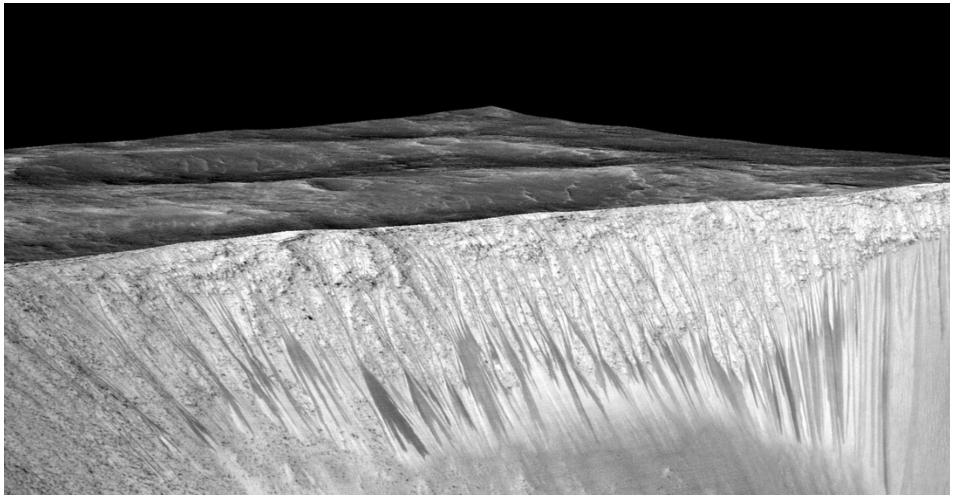
Science of the Shallow Subsurface

Recurring Slope Lineae

- **Downslope movement seen on steep Martian slopes during summer months**
- **Dry debris flows? Caused by thin films of salty water?**
  - **If so, what is source of the water – atmospheric adsorption or subsurface aquifer?**

RSLs on the wall of Newton Crater growing over time. Image credit: NASA/JPL-Caltech/Univ. of Arizona



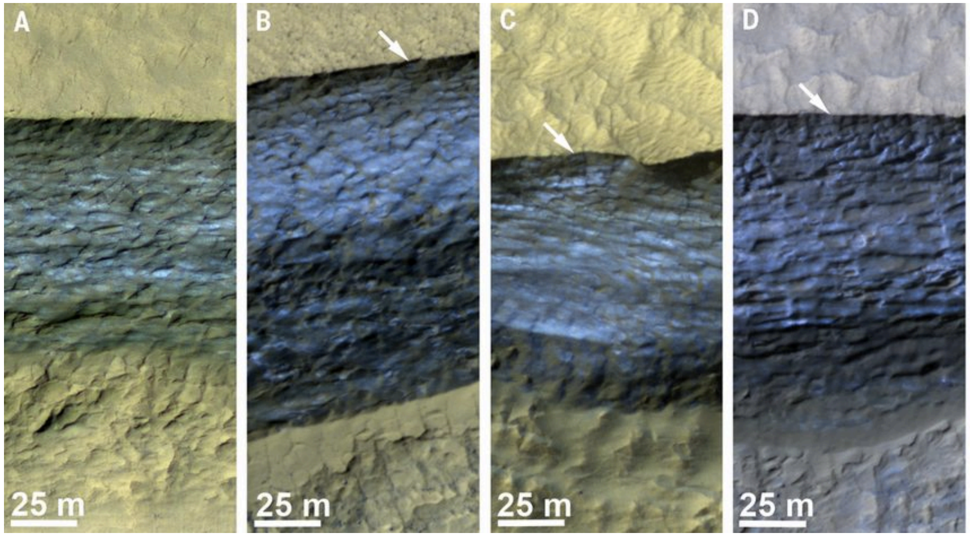
3D perspective view of RSLs on wall of Garni Crater highlighting challenging terrain in which features occur - 1.5x vertical exaggeration. Image credit: NASA/JPL-Caltech/Univ. of Arizona

Science of the Shallow Subsurface

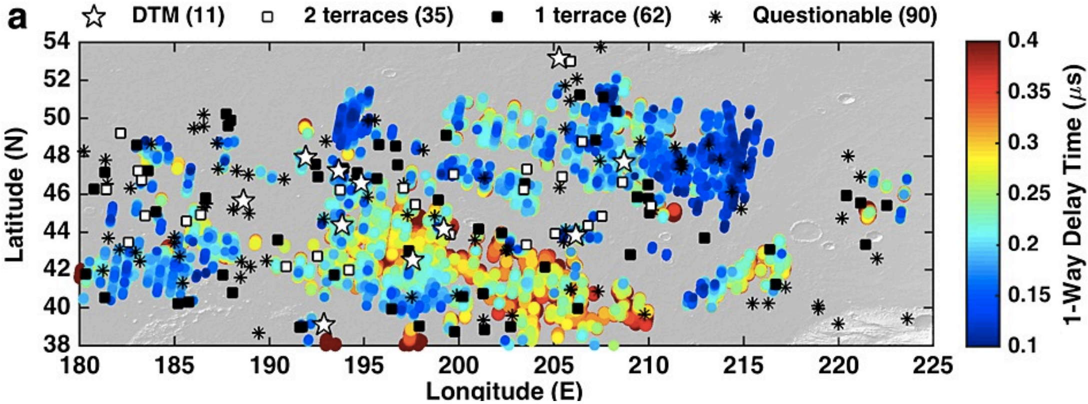
Near-surface ice explorer

Orbital data show near-surface water ice is present in Martian mid-latitudes

- **Implications for past Martian climate**
- **Potential *in situ* resource for future human exploration**



Cliffs exposing near surface water ice at Martian mid-latitudes (Dundas et al. 2018, *Science*)



Geomorphic and orbital radar mapping showing exposure of ice as low at 38˚ latitude (Bramson et al. 2015, GRL)

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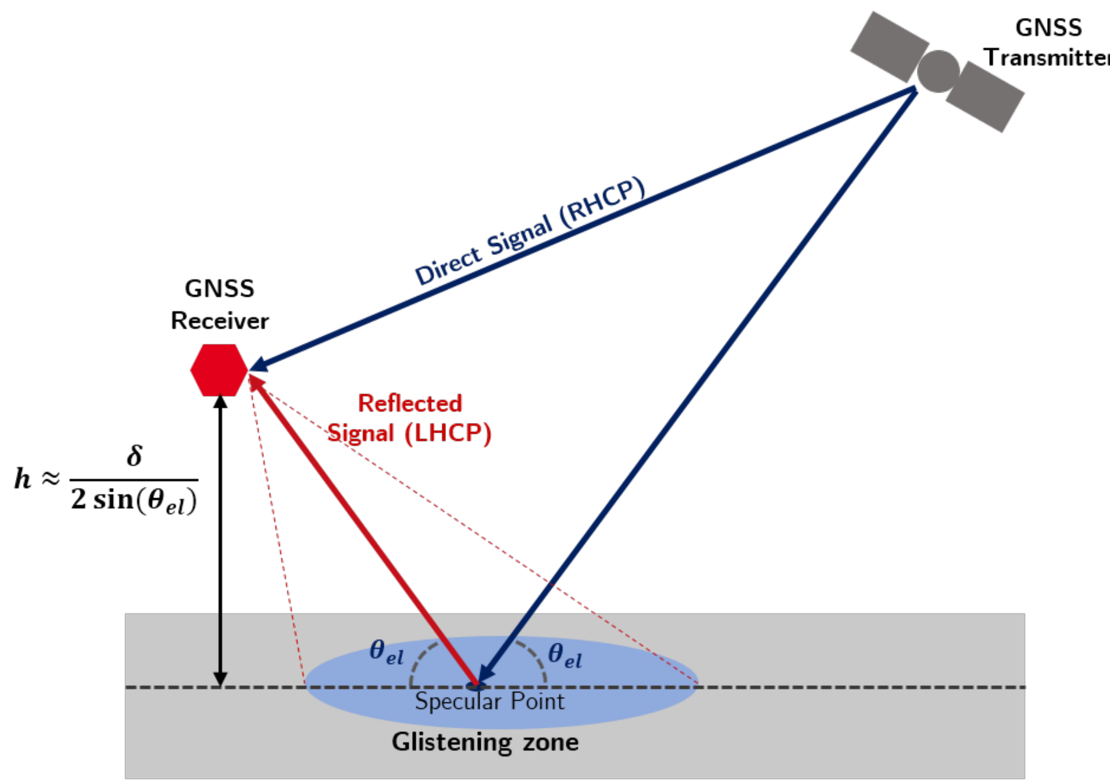
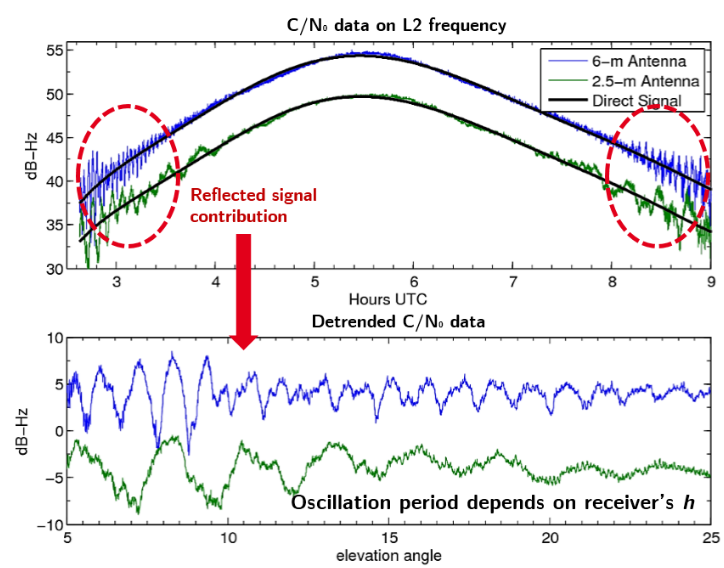
Bistatic Radar Signatures I

- Multipath signal results from constructive and destructive interference between direct and reflected rays
- ☹ Bad for telecommunications
- ☺ Good for science
- Used commonly on Earth, e.g., GPS reflectometry for soil moisture measurements



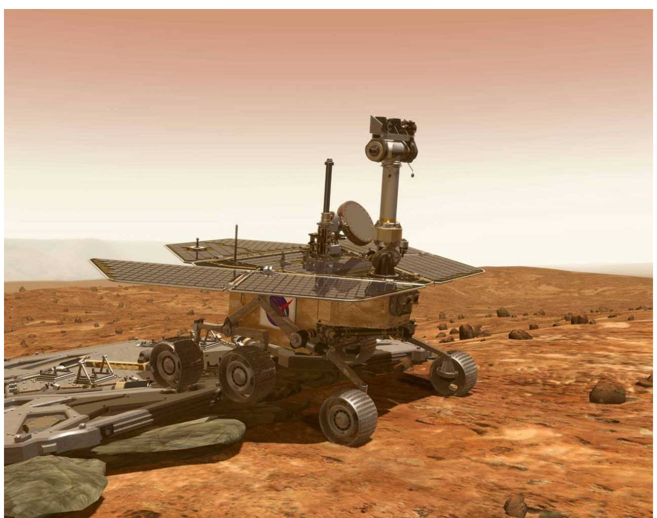


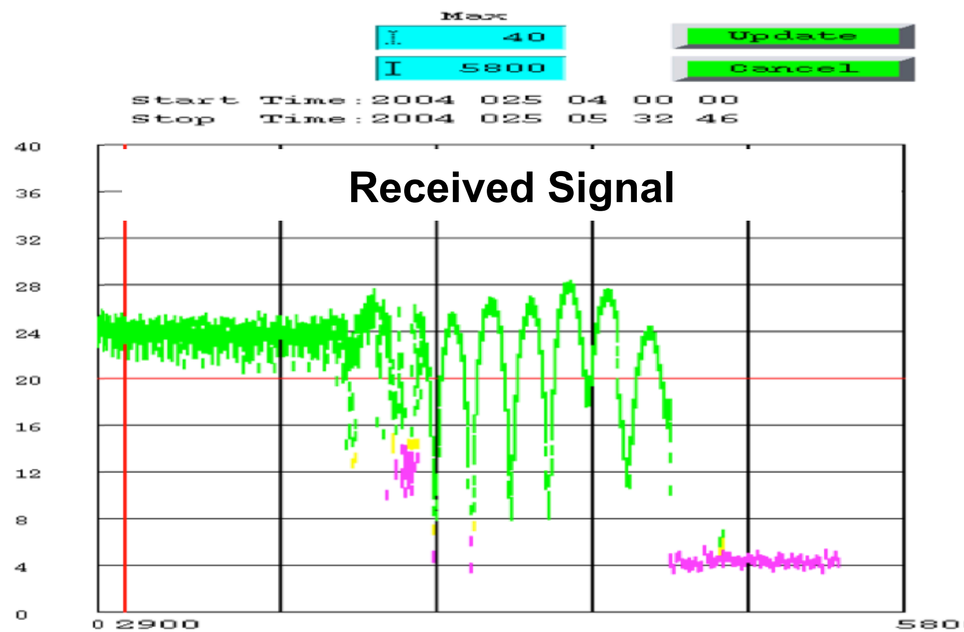
Botteron et al.

Bistatic Radar Signatures II

- **Signal level variation as seen on the X-band link, just after landing, from transmitter turn-on time to loss of signal, as Earth was setting on local Mars horizon**
- **Return link X-band showed 20 dB signal variations at Earth set**

  Using best estimate of (complex) dielectric parameters of Martian soil at landing site predicted 20 dB signal variations near Earth set
- **Reversing, could use measured signals to estimate or bound dielectric properties of Martian soil**





Uplink is DSS-14 (70m), 500 kW @ 8650 MHz

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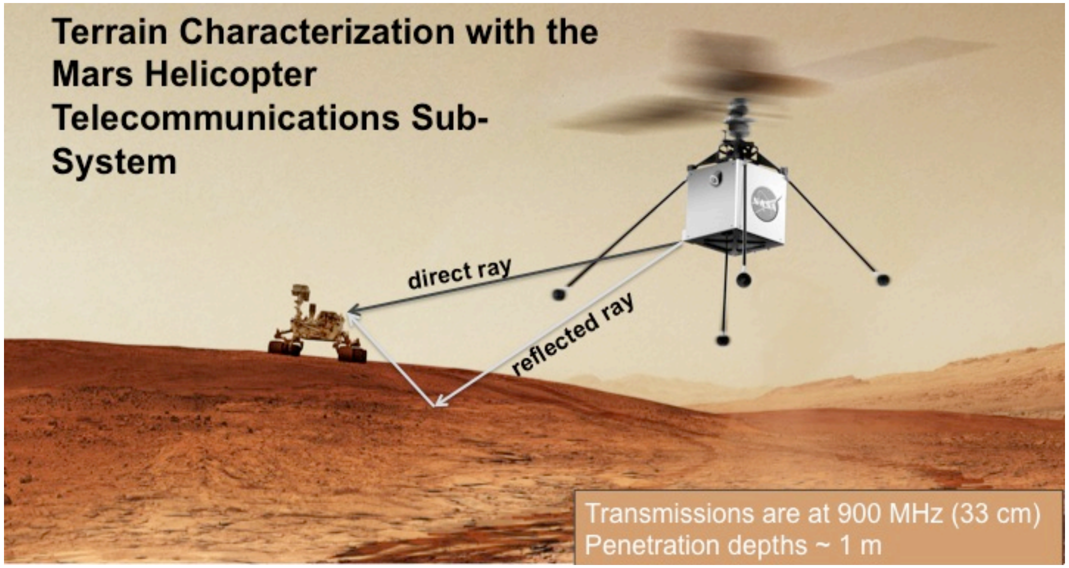
Helicopter Bistatic Radar I

Science

- Detection of near-surface water, e.g., recurring slope linea
- General layering information to provide morphological science data and to identify sites near rover that warrant further investigation

Hazard Avoidance: Tracking changes in Mars Helicopter-to-Rover received signal to assess sand depth along planned rover traverse

Proposed Mars Helicopter employs a 900 MHz telecom link with the rover



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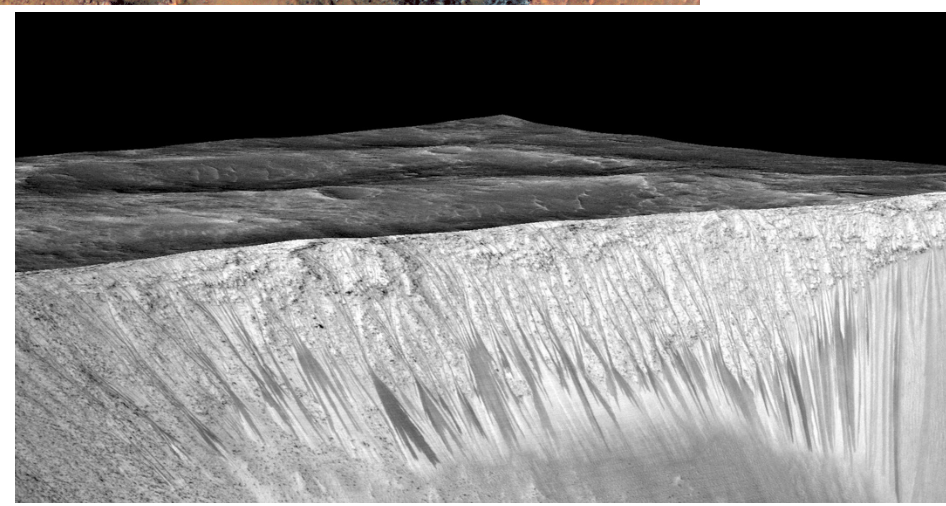
Science of the Shallow Subsurface

Recurring Slope Lineae

- Downslope movement seen on steep Martian slopes during summer months
- Dry debris flows? Caused by thin films of salty water?
  - If so, what is source of the water – atmospheric adsorption or subsurface aquifer?

➢ **Helicopter bistatic radar could be used to distinguish wet/dry origin of RSLs and search for aquifers**

RSLs on the wall of Newton Crater growing over time. Image credit: NASA/JPL-Caltech/Univ. of Arizona



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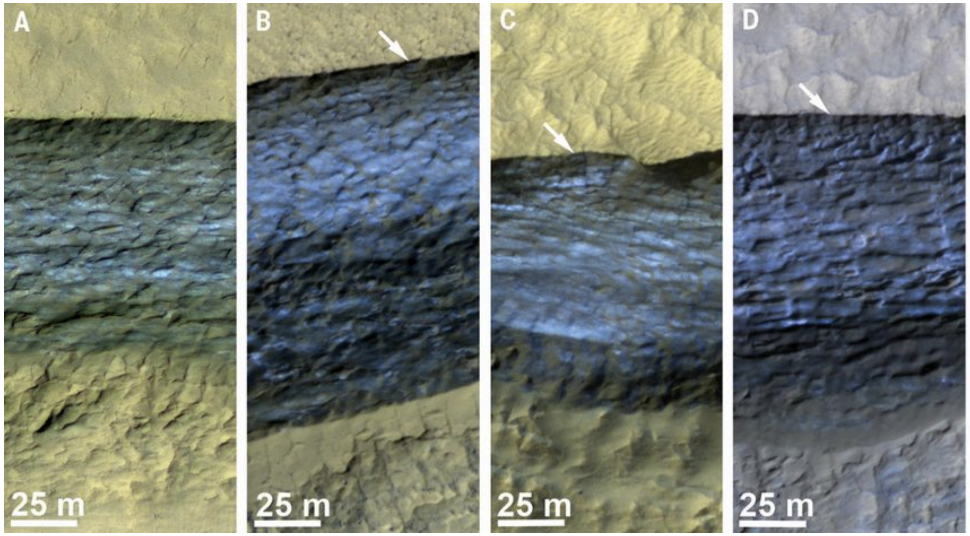
Near-surface ice explorer

- Orbital data show near-surface water ice is present in Martian mid-latitudes
  - Implications for past Martian climate
  - Potential *in situ* resource for future human exploration

➢ **Helicopter bistatic radar could be used to map distribution and depth of near-surface ice across wide areas**



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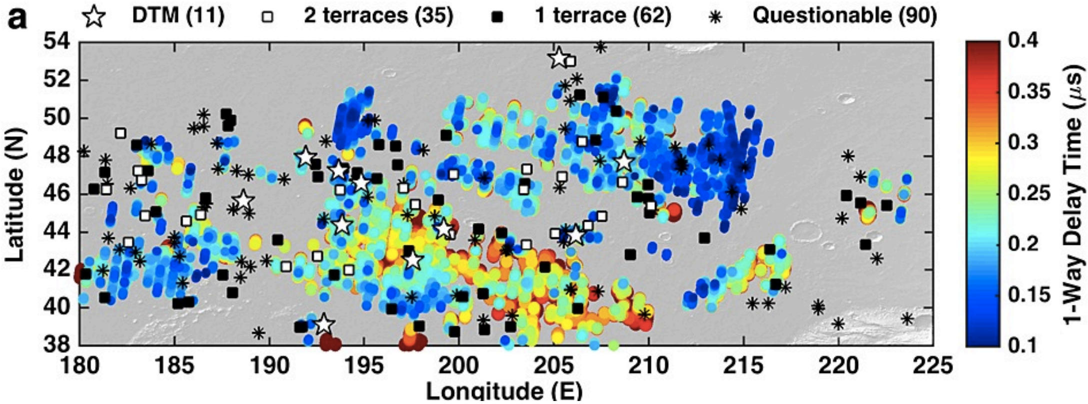

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Helicopter Bistatic Radar II

Mars 2020/RIMFAX is ground penetrating radar

- RIMFAX Band is 150 MHz to 1200 MHz
- RIMFAX is capable of passive, listen-only modes

Coordination between Helicopter and Rover science operations may yield information on both reflected and refracted waves to allow measurement of propagation speed and attenuation in general vicinity

- Map spatial variations of density and mineralogy of shallow subsurface
- Map temporal variations due to potential thermal or water adsorption effects

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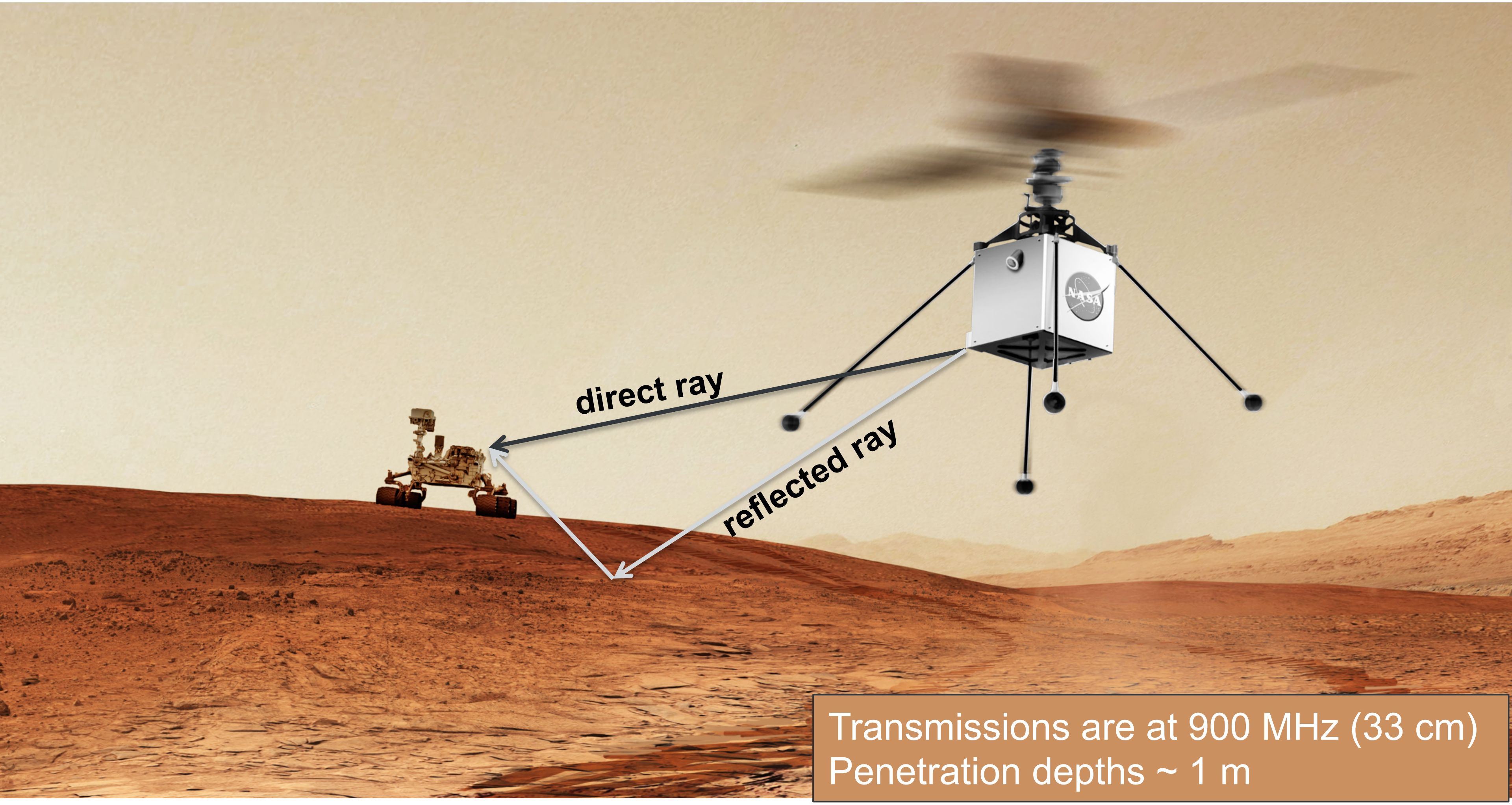
Opportunistic Bistatic Radar on Mars Helicopter



Transmissions are at 900 MHz (33 cm)
Penetration depths ~ 1 m

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Opportunistic Bistatic Radar on Mars Helicopter

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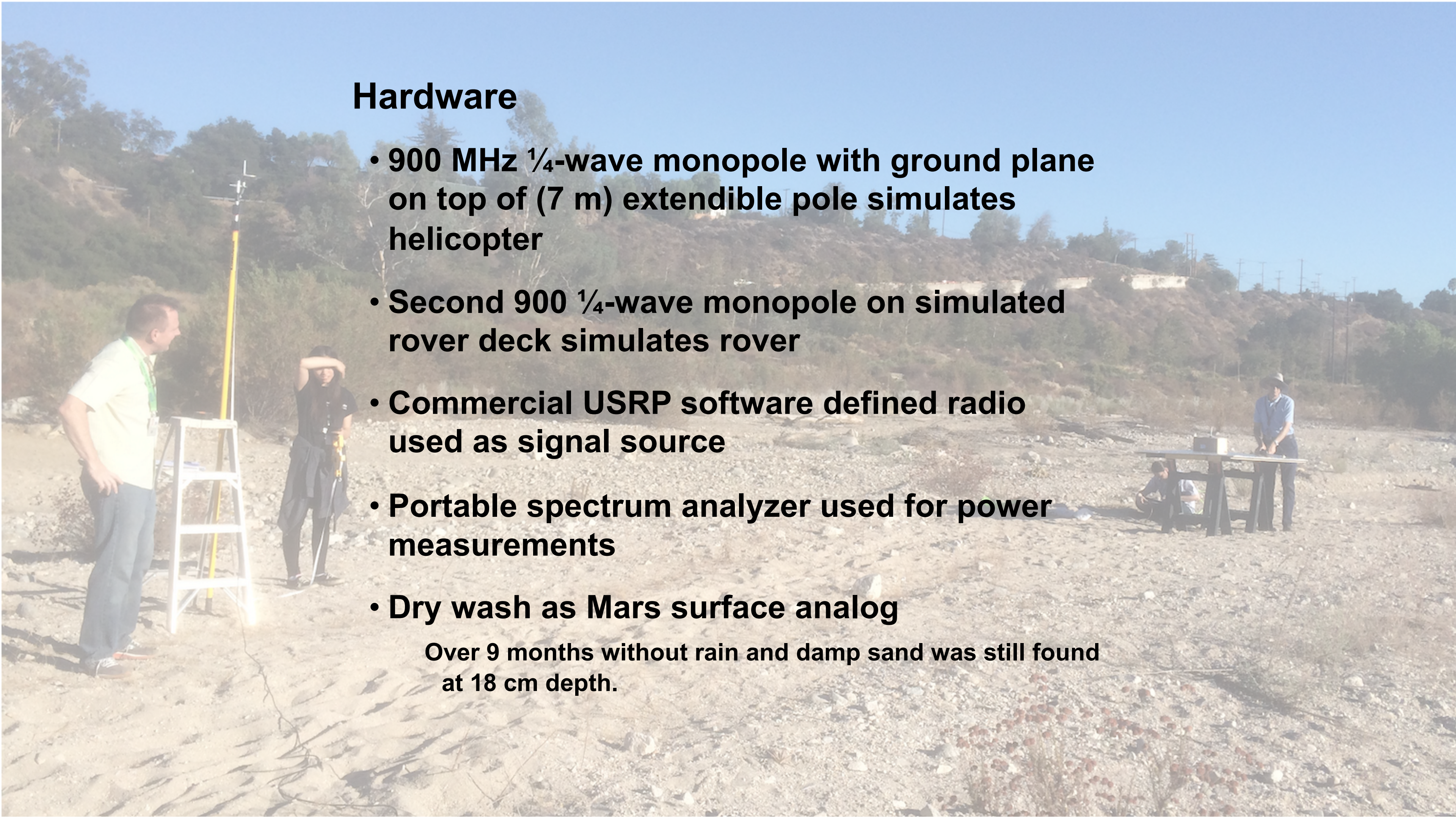
Hardware for Helicopter Analog



Hardware

- 900 MHz ¼-wave monopole with ground plane on top of (7 m) extendible pole simulates helicopter
- Second 900 ¼-wave monopole on simulated rover deck simulates rover
- Commercial USRP software defined radio used as signal source
- Portable spectrum analyzer used for power measurements
- Dry wash as Mars surface analog

  Over 9 months without rain and damp sand was still found at 18 cm depth.

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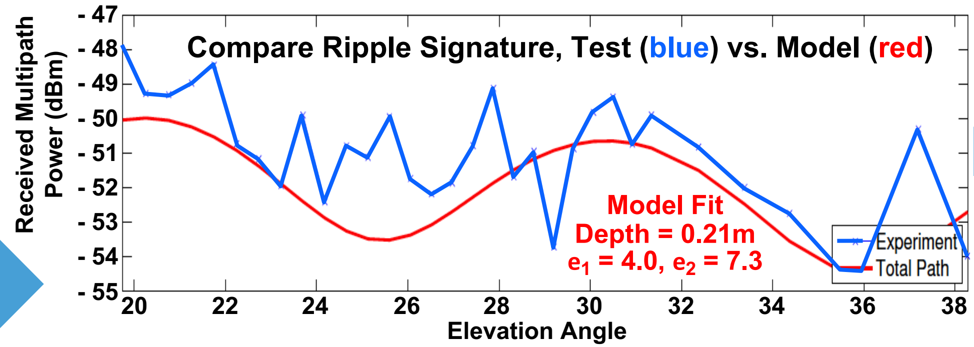
Modeling and Estimation Details

- Received power vs. elevation angle produces multipath interference ripple signature
- Gradient search of model space produces best fit solutions to layer dielectric properties and layer depths

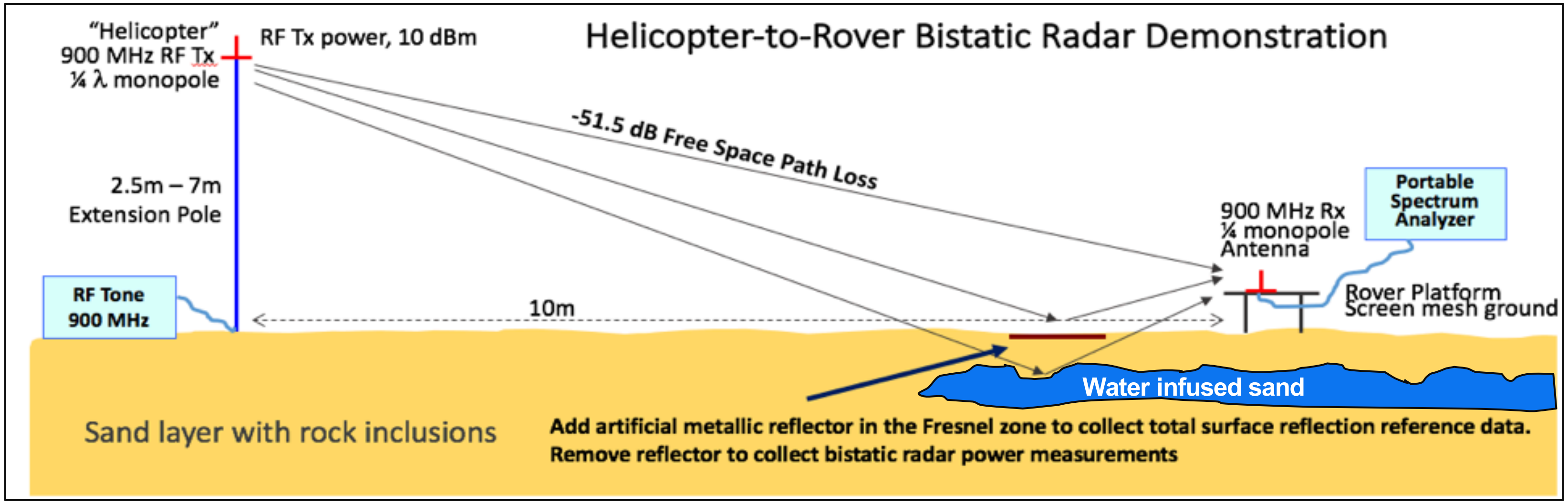
Iterate over model space parameters:
- **Layer Depth**
- **Layer Dielectrics**
- **Surface Roughness**
- **Geometry Uncertainties**

***a priori* Knowledge and Probabilities**

RF Propagation Model



Bayesian Selection of Best Fit Solutions



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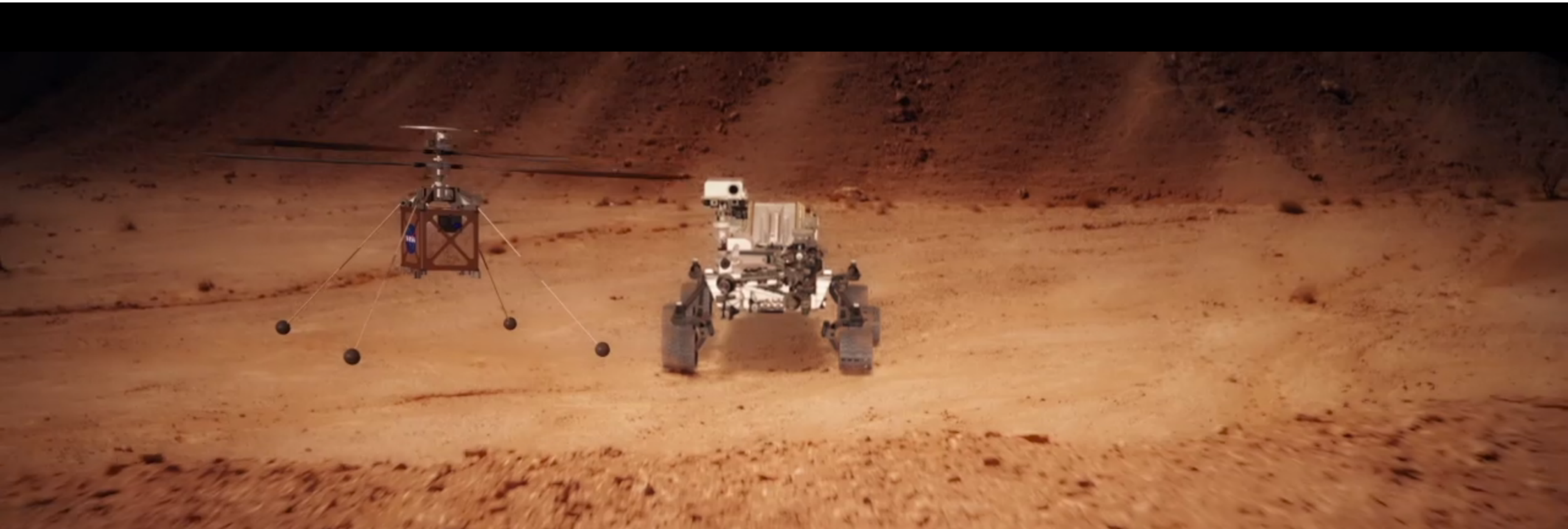
Summary

Multipath propagation essentially inevitable

- ✓ **Can exploit for science**
  - **Already demonstrated for Earth science**
  - **Proof of concept for MER/Opportunity**
- ✓ **Beneficial for hazard avoidance**

Initial tests promising -> Additional analog testing planned



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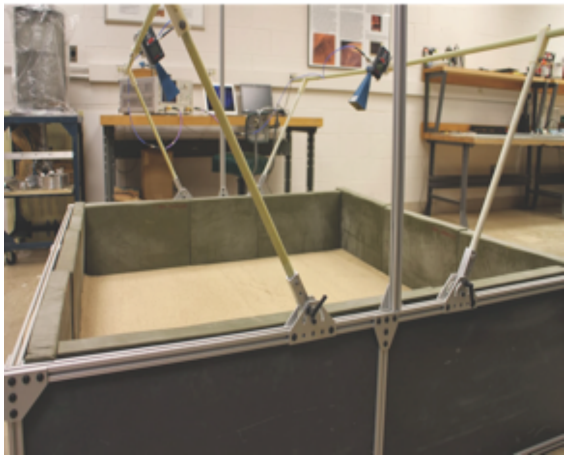
UMich: Higher Frequency, Wider Bandwidth



Top Layer Sand Depth = 20cm
Bottom Layer is highly reflective
Top: $\varepsilon_1 = 2.76 - j\,0.11$
Bottom: $\varepsilon_2 = 54.5 - j\,36.8$
Null Spacing = 451 MHz

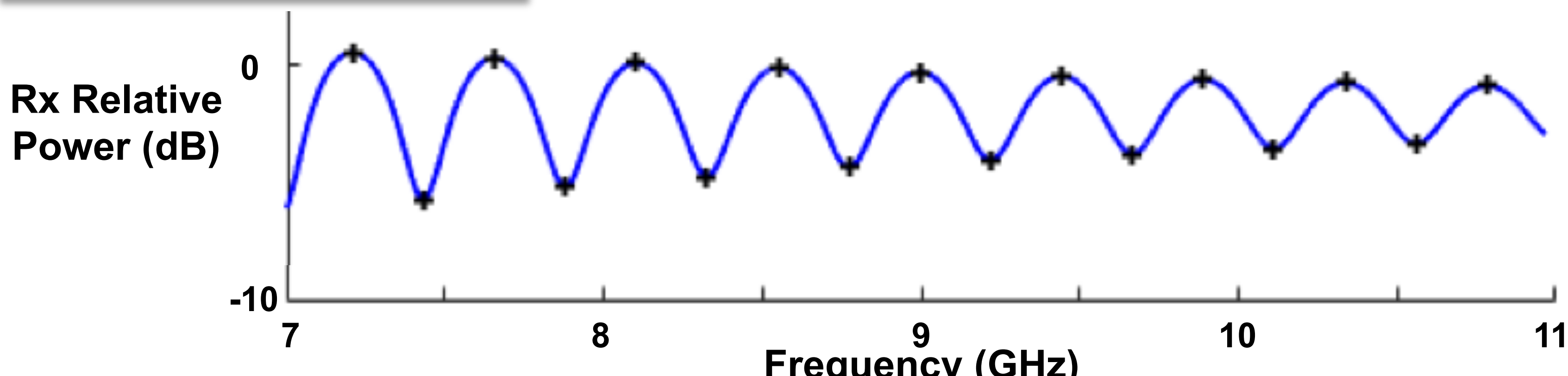
University of Michigan

- Use of higher frequencies enables detection of thin dielectric layers
- Use of wider bandwidth and frequency sweep allows detection of the deilectric layers with fixed signal geometry.
- Variables include: First layer sand depth, second layer dielectric type (e.g. concrete or metallic layer), surface roughness.

Results

- Sand depth resolution of 0.25cm between 6.75 cm and 20.0 cm
- Fixed Angle: 0 deg. incidence angle, (90 deg. elevation)
- **Result: new metric: Null Spacing (GHz) vs. top layer sand depth**
- Largely independent of incident angle

Not Requested but show Thin layer detection using Higher Freq. X-band



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Hardware and Modeling for Helicopter Link

Hardware

- 900 MHz ¼-wave monopole with ground plane on top of 2m - 7m extendible pole simulates the helicopter end of the link.
- Second 900 ¼-wave monopole on simulated rover deck simulates the rover end of the link
- Commercial USRP software defined radio used as signal source
- Portable spectrum analyzer used for power measurements
- Dry wash as Mars surface analog. Over 9 months without rain and damp sand was still found at 18 cm depth.

Modeling

- High fidelity total EM response of two ideal monopole antennas and ground effects using finite element method of moments to predict antenna pattern as used in the field.
- Lower dimensionality parametric EM model, that agrees with high fidelity model, is used with field data to perform gradient search for best fit estimates of sand layer depth for layer 1 and dielectric values of layer 1 and layer 2.

Results

- 900 MHz, 33cm wavelength, can detect thick layers of damp sand or other change in dielectric.
- Cannot detect liquid water layer that is thin relative to the RF wavelength
- Cannot detect water ice with dielectric value that is too close to sand.
- Suggests using higher frequencies to detect thinner liquid layers at shallow depth