10-Year Lunar Architecture (LunA-10) Capability Study

A Multi-Service Cislunar Commercial Constellation

Presented at LSIC

April 23-25th, 2024

REDWIRE
- Study lead
- RF apertures
- Mission CONOPs

RADAR APPLICATIONS
- SAR/MTI SME

Axta Space Corporation
- Comms SME

CACI EVER VIGILANT
- PNT SME

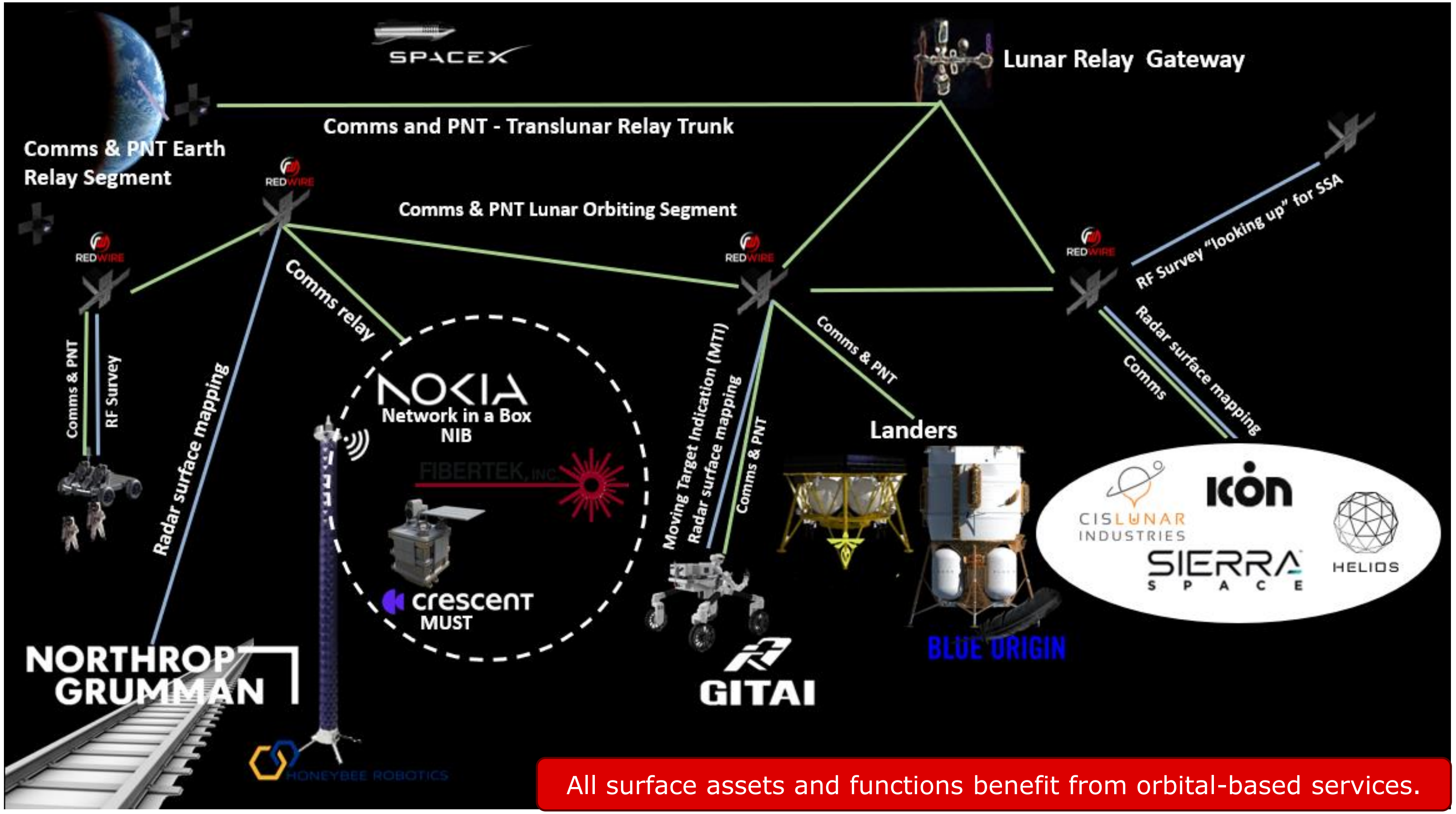
Advanced Space
- Orbital Mechanics SME

This research was developed with funding from the Defense Advanced Research Projects Agency (DARPA).

Redwire LunA-10 Introduction

Redwire proposes a constellation of cislunar orbiters providing multiple RF-based services:

- Communications
- Position, Navigation, and Timing (PNT)
- RF Survey
- SAR/MTI
- Microwave space-based solar power beaming



Source: Redwire

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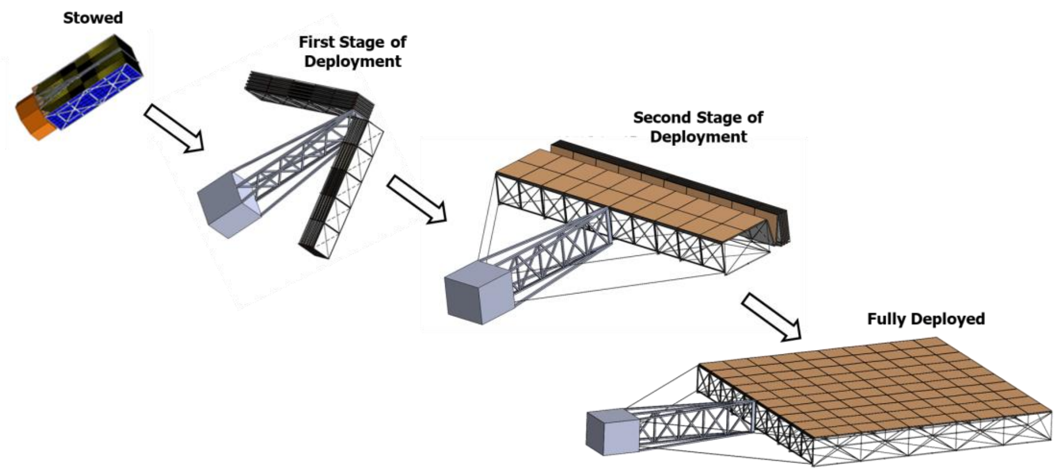
Microwave Power Beaming is Feasible, but not Commercially Viable…

Conclusion: While technically feasible, microwave power beaming from cislunar orbit does not appear to be commercially viable due to aperture size/mass/cost that would be required for meaningful energy delivery

Formation of 12m x 12m aperture



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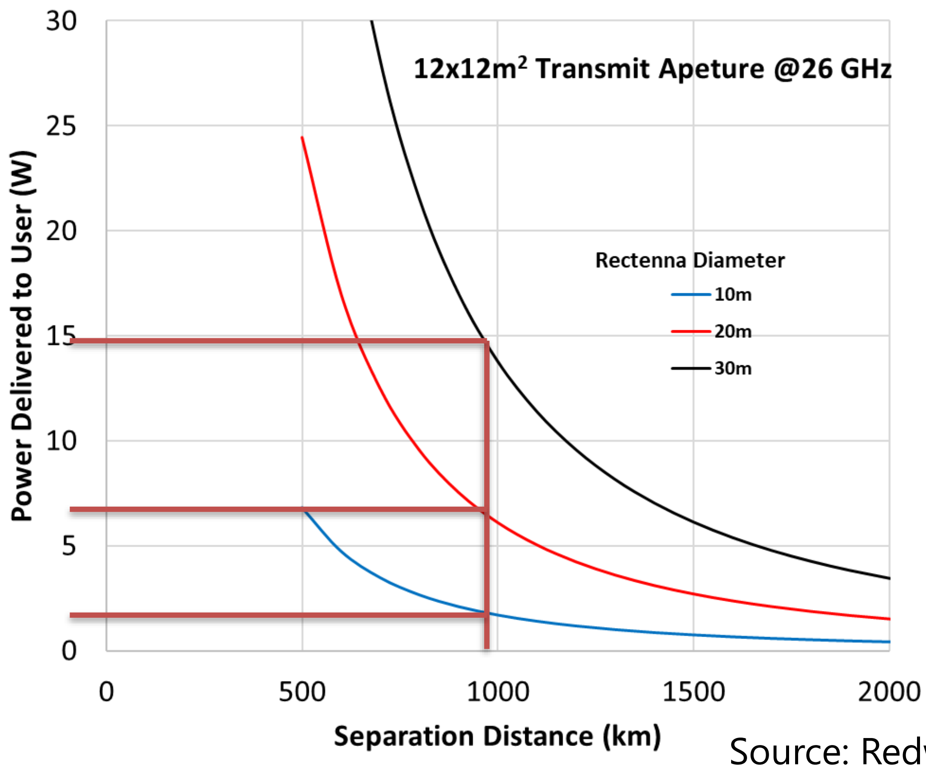

Source: Redwire

Tx antenna >19mx19m could realize a useful amount of power (>500 Whr) with the standard efficiencies @26 GHz and a 30m diameter rectenna

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Full End-to-End Communications and PNT Solution Devised

Summary of Proposed Lunar Comms Architecture

Lunar Surface Segment: **NTE/5G RF last mile**

- Nokia proposed LTE/4G/5G supported solution, 10km, **100mbps**

Lunar Orbiting Segment: **mid/high lunar**

- Constellation 16 sats, ubiquitous coverage, leveraging sustainable frozen lunar orbits, optimized for comms capability, 3000-13000km, **1-10 Gbps**
- PNT hosted on same constellation

Lunar Relay Segment: **NRHO**

- Lunar orbiters to NRHO, 3000-70000km, **1-10Gbps**

Translunar Trunk Segment: **Earth orbiting, high-rate data**

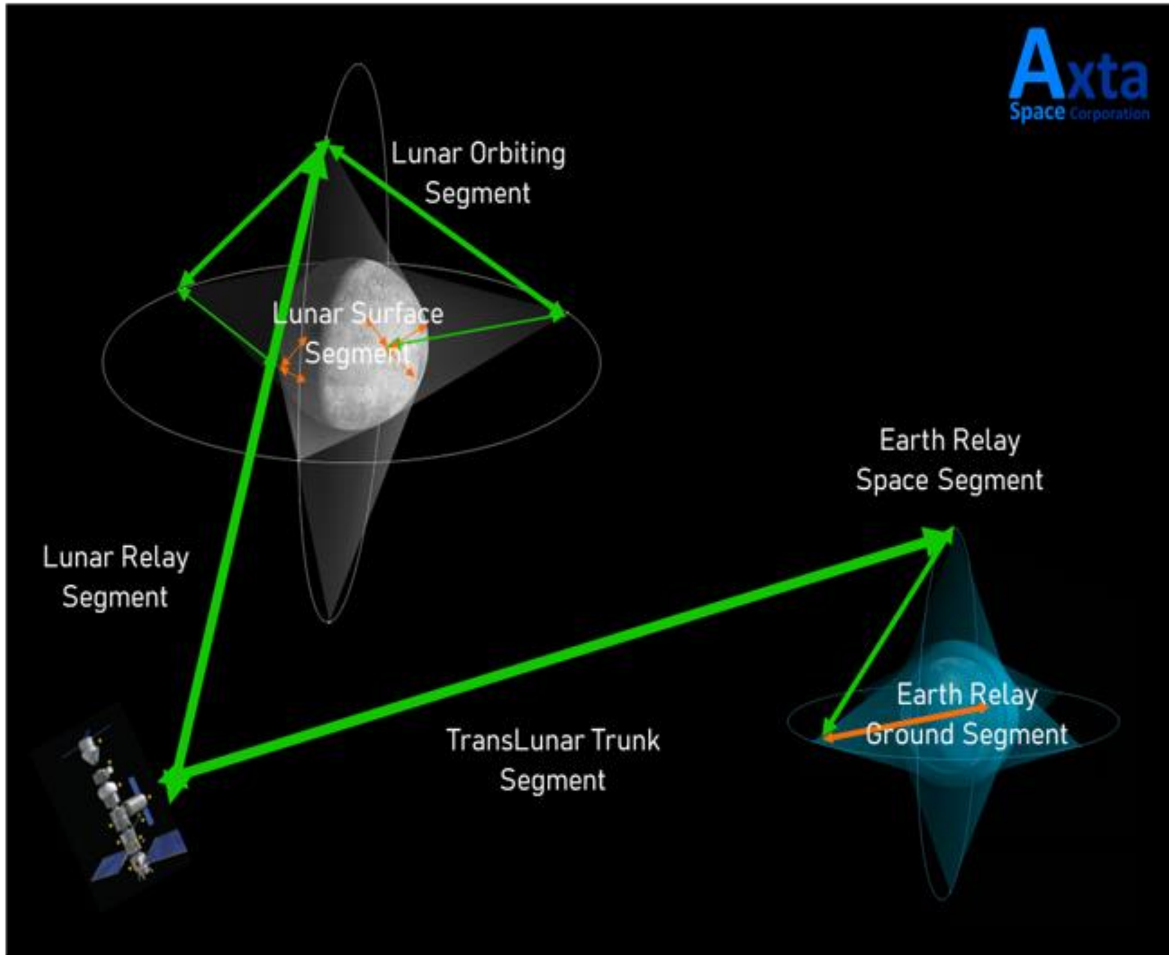
- Long link distance, 390,721km, optical data link, **100Gbps**

Earth Relay Space Segment: **Earth orbiting (prior to atmospherics)**

- Constellation, 3 GEO sats, constant link, 40000km, **100Gbps**

Earth Relay Ground Segment: **Earth-Ground, traditional RF links**

- Gateway into Cloud distribution to any site, optical terrestrial, **1-10Gbps**



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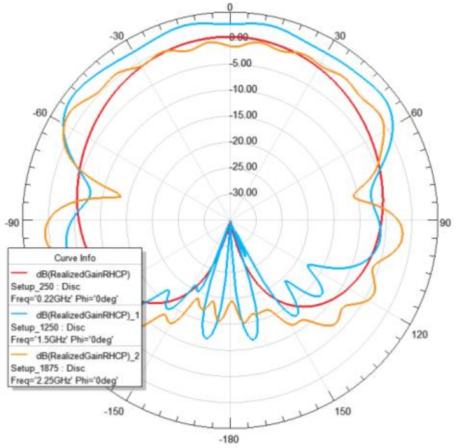
Same Aperture Can Be Used for Both PNT & RF Survey

- An ultra-wideband "Vivaldi" antenna can be used for both PNT and RF survey functions
- For RF Survey mode, system can either "look down" to detect RF sources on the lunar surface, or "look up" at orbiting objects for Space Situational Awareness (SSA)
- Signal strength that can be identified for a given separation distance has been assessed
- System could be used to cue the pointing of a high-gain, narrow beam antenna for signal localization and characterization.

Source: Redwire



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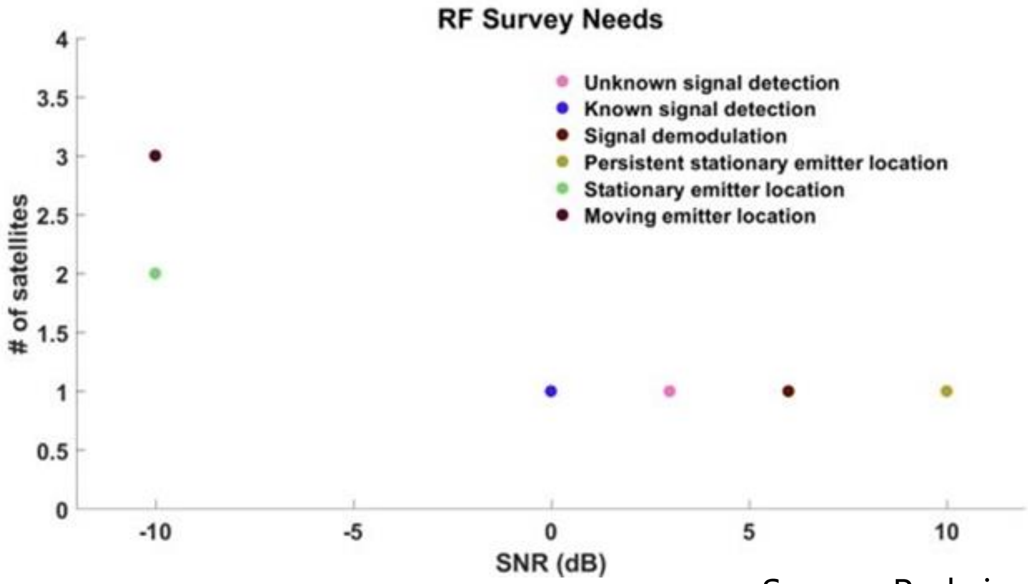

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PNT Performance

Predicted Position and Timing Performance for LPS

Clock Technology	Allan Deviation @65000 sec (Hz/Hz)	σ_{pos} (m)	σ_{time} (ns)
Rb-lamp	5×10^{-14}	20.9	30.2
Cesium beam	1.5×10^{-13}	21.5	31.0
DSAC	2×10^{-15}	20.9	30.1

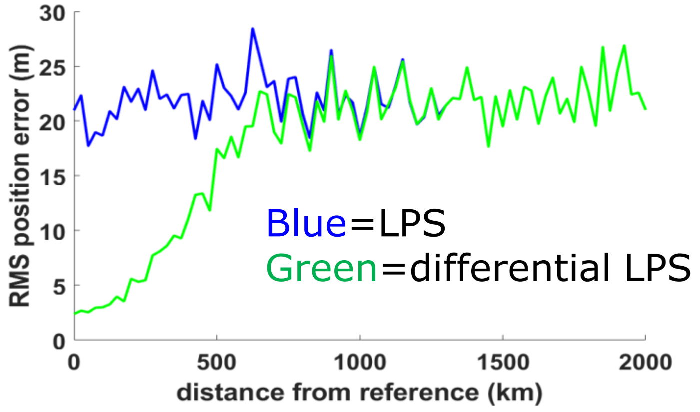
Source: Redwire

Conclusions

- User 3D RMS position errors are expected to be about 21 *meters*
- RMS timing error expected to be about 30 *ns*
- Both position and timing error are limited by ephemeris position error

Navigation performance can be improved by employing a differential LPS system (DLPS)

- This system uses a fixed lunar reference station to compute pseudorange corrections for each satellite
- The corrections are then uplinked to the satellites and broadcast as part of the LPS messages



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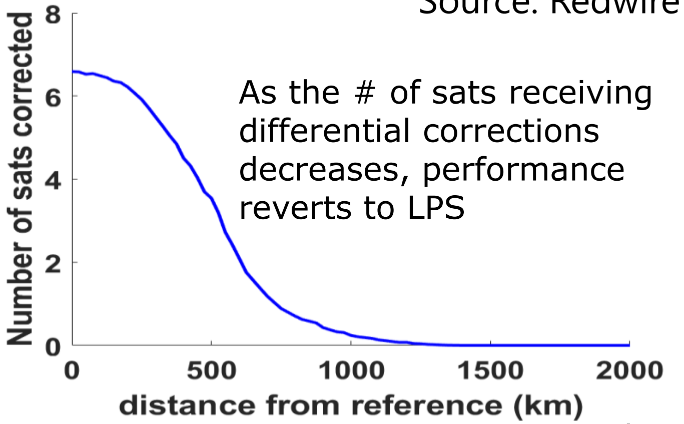

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Conclusions

- User 3D RMS position errors are expected to be about 2.2 *meters* near the reference station
- This best-case error is limited by the random pseudorange error, not the ephemeris error
- Increasing the satellite power to 100W from 1W would decrease the best-case error by a factor of 10 to 0.22 *meters*.

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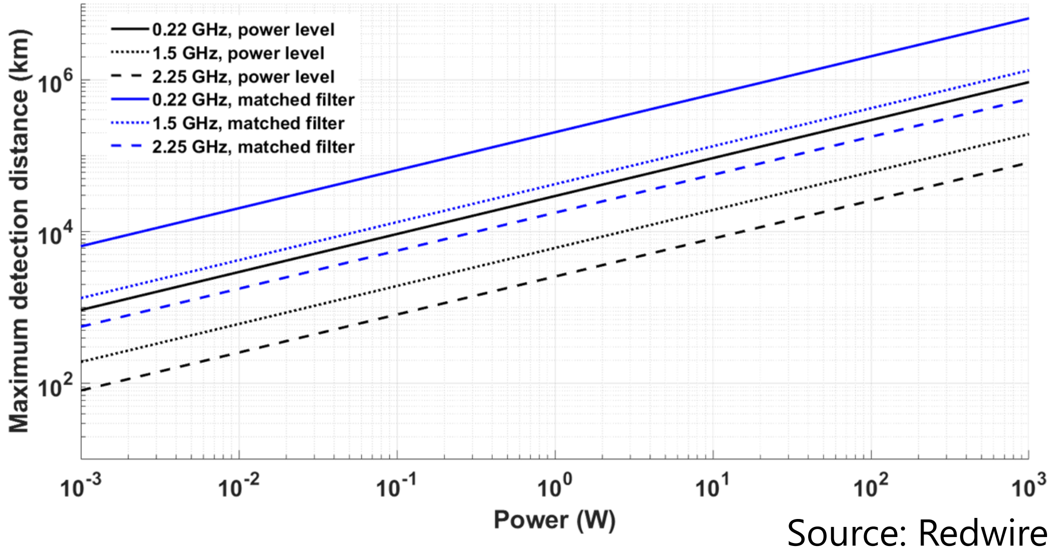
RF Survey Performance

- RF signals can be detected via energy or matched filter methods.
- For three frequencies we computed the expected SNR for a $B = 10kHz$, $P = 1W$ signal versus distance (below).
- The probability of detection for different false alarm probabilities P_{FA} for each method is shown on the right for a 1.0 *sec* duration segment.



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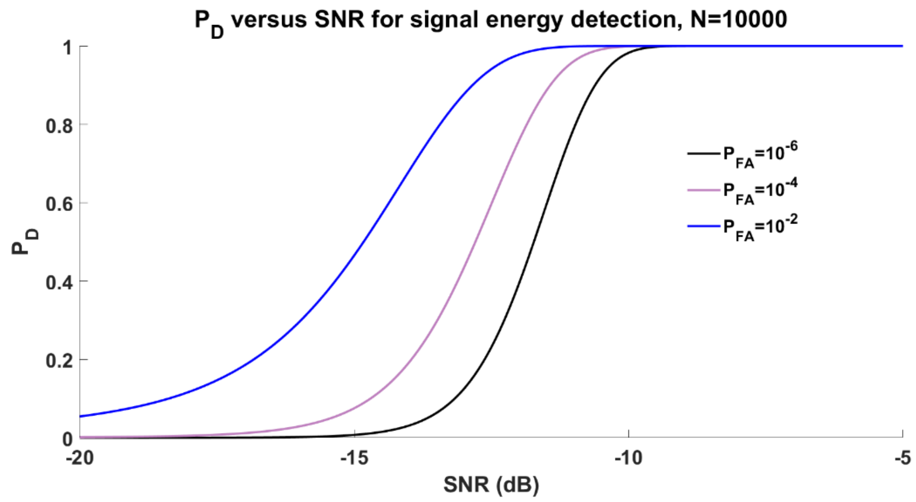

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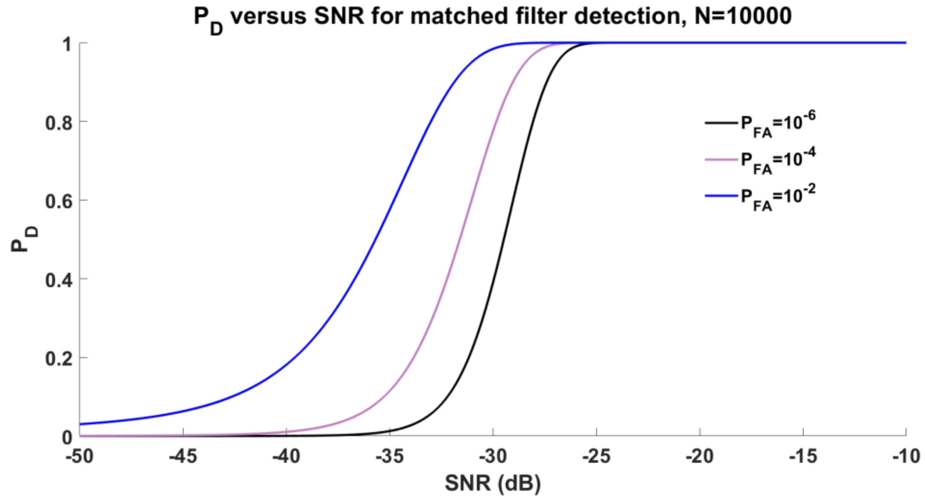

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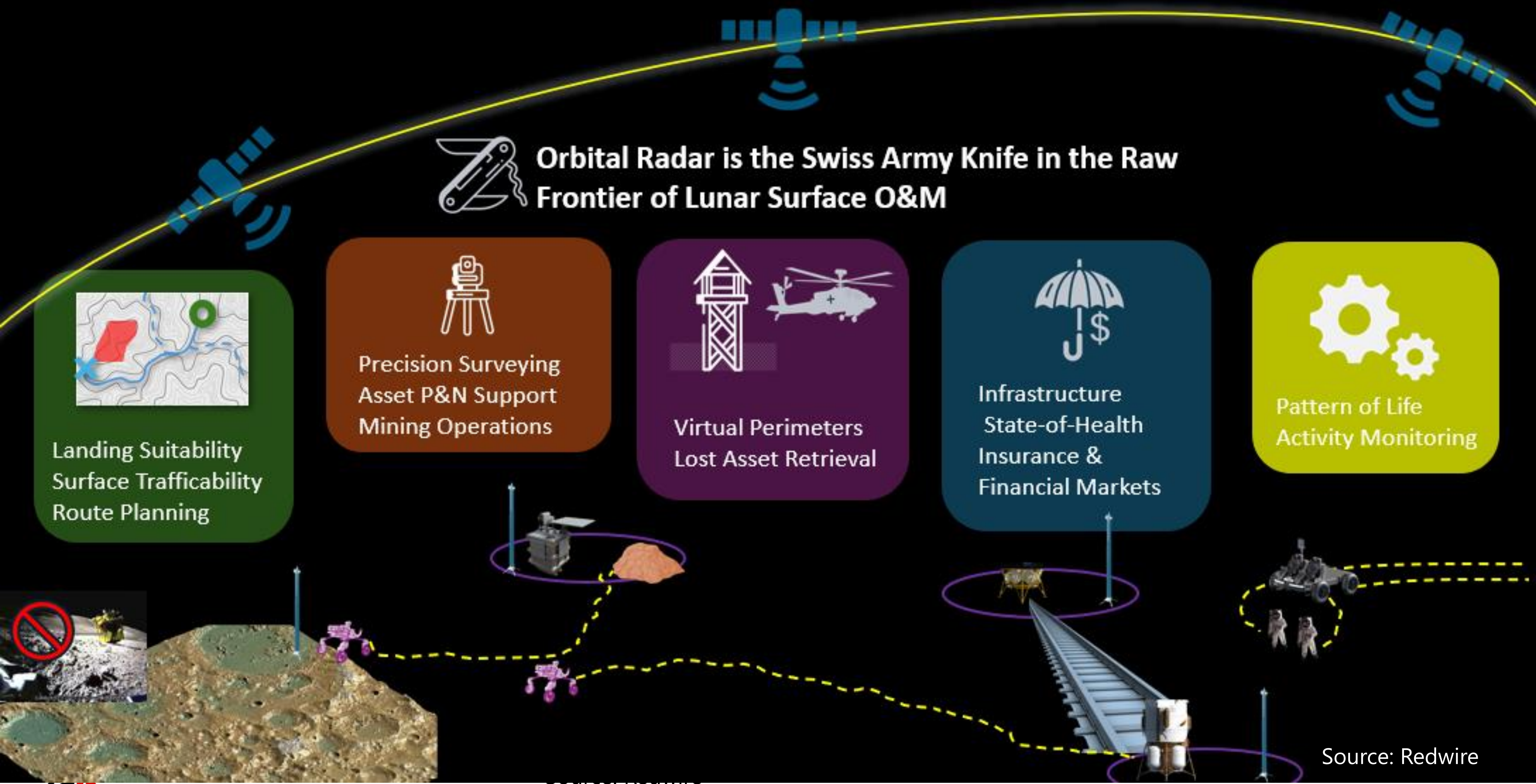

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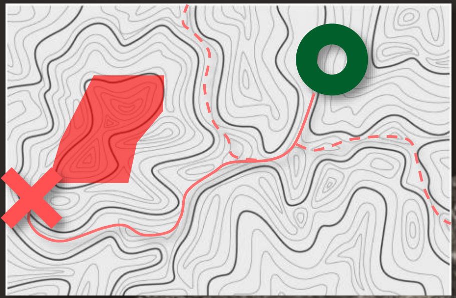
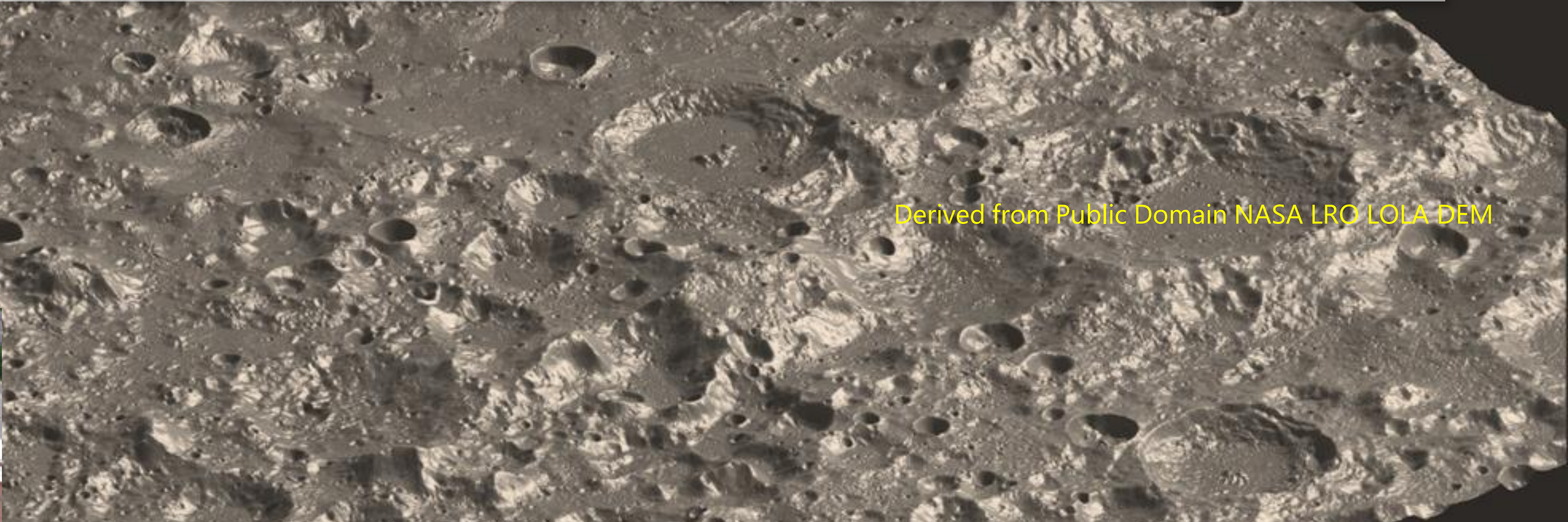


At every scale the lunar surface is very rough, fractal in nature

Precision knowledge at a broad & fine level of detail will be required to enable:

- Near-term landing and site staging (even “small” rocks are problematic!)
- Efficient routing / trafficability for surface rovers (“Google Maps for Moon”)
- Where to emplace pads, route rails, LoS Comms and roadways for longer term economy
- Prospecting and forensics

Orbital Radar imaging can provide lunar terrain detail at the scale of 0.3m or finer



Best available DEM of Lunar South Pole is only 30m post spacing

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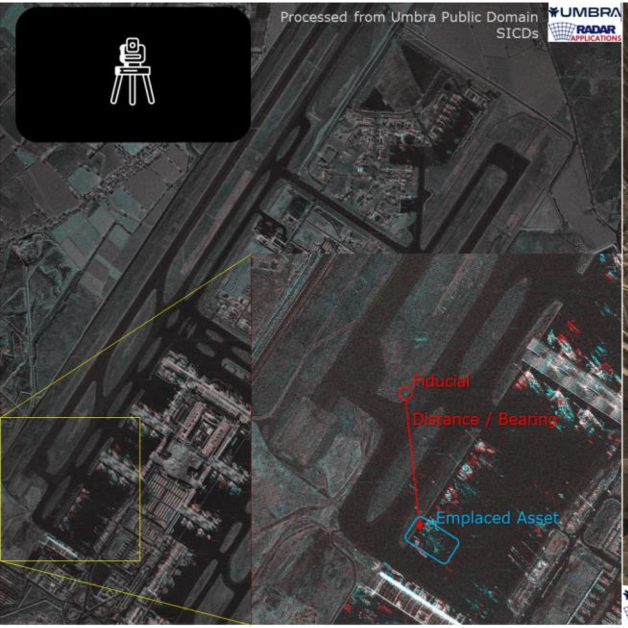
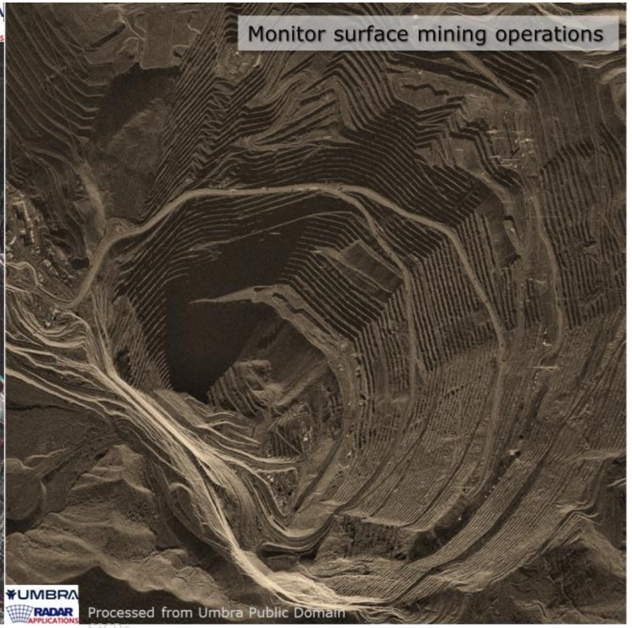
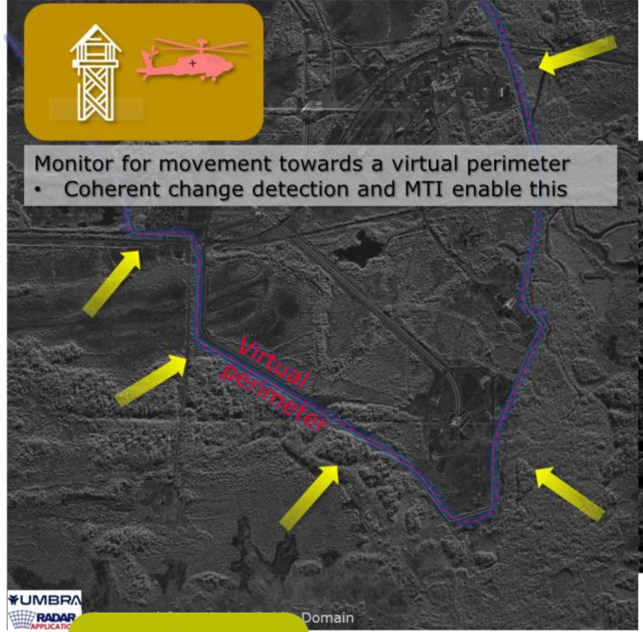
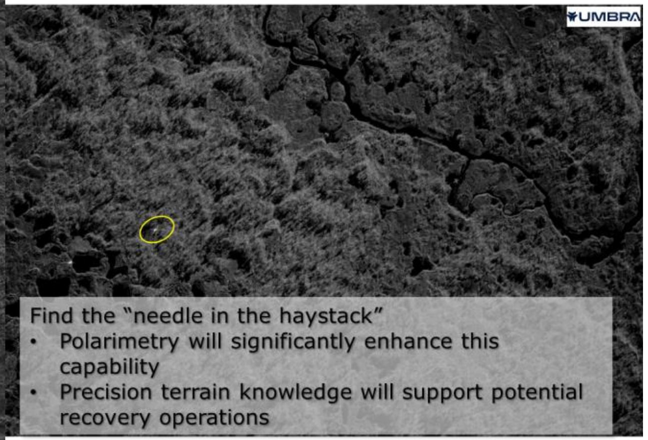
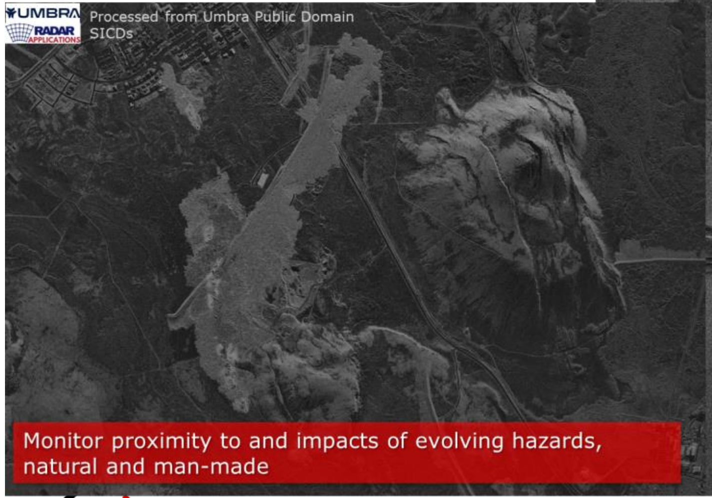


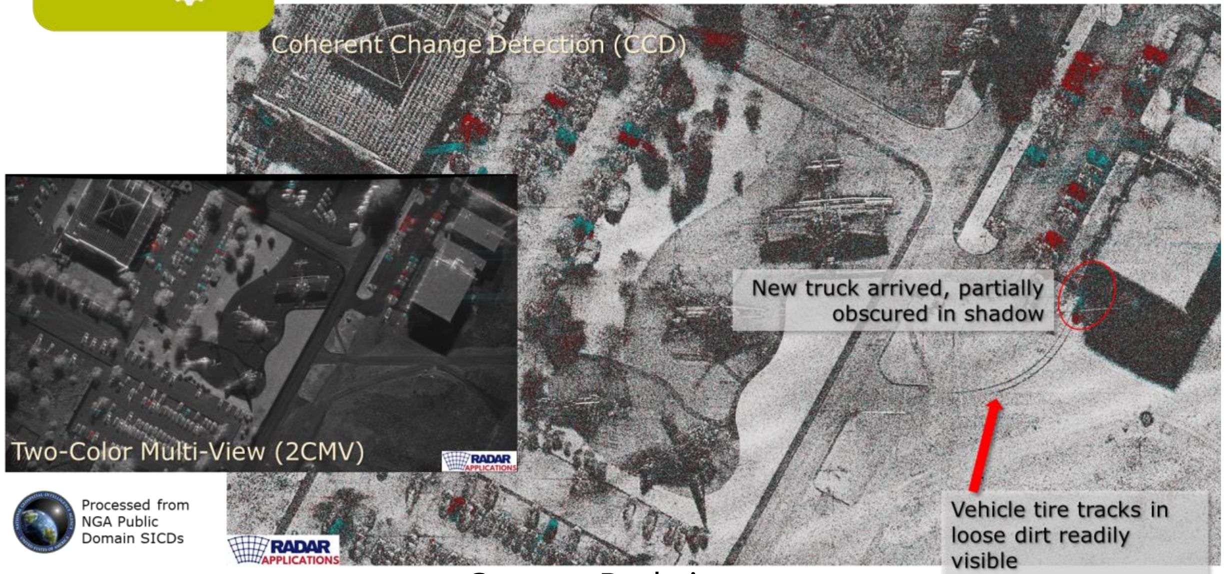








Utilize MTI "dots on map" and SAR CCD to monitor overall patterns-of-life



Processed from NGA Public Domain SICDs

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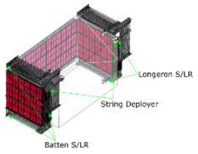
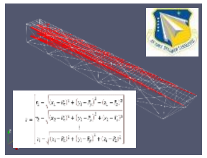
Redwire's Deployable Planar Phased Array Architectures

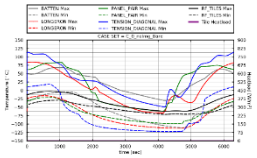
Planar array architectures supporting SAR/MTI have been ground demonstrated.



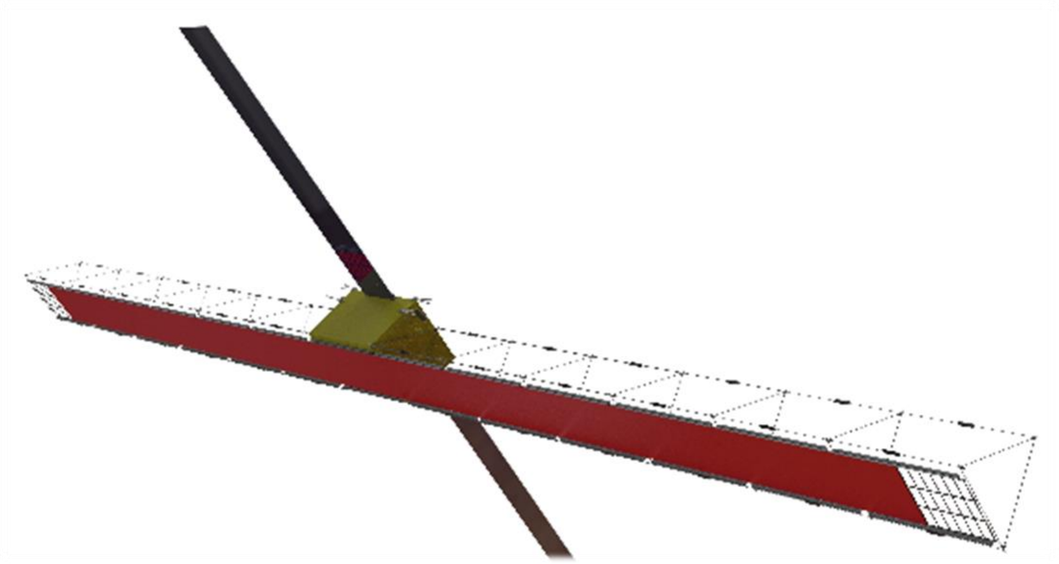
✓ ESPA Compliant for deployment on low-cost platform



✓ Instantaneous metrology enabling active phase correction



✓ On-orbit thermal and structural stability



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Commercialization/Economic Outlook and Mission Timeline

- Deploying a commercially-viable cislunar service presents several economic challenges, primarily driven by the high initial investment required and the need to secure financing where market potential and ROI are uncertain/undemonstrated.
- Pricing is being developed with following assumptions: <5-yr ROI, inclusive of hardware NRE/RE, launch costs, financing and insurance fees, and yearly operational costs.

Service	Considered Independent Service or Infrastructure?	Pricing Strategy
Communications	Infrastructure	yearly subscription
PNT	Infrastructure	yearly subscription
RF Survey	Independent Service	per RF survey
SAR and MTI	Independent Service	per km^2 scanned

Source: Redwire

Year/Task	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Age	Exploration Age			Foundational Age			Industrial Age				Jet Age
Redwire Mission Phasing	TRL 4		Pathfinder Minimum Viable Experiment (MVE)			Minimum Viable Product (MVP) Constellation - South Pole Services			Constellation Expansion		
	Focus is on further analysis, development, detailed design, and demonstration (ground) of hardware and software. This is supported by prototyping of SAR sub arrays (tiles), the full SAR aperture, the PNT/RF Survey aperture, and data processing hardware and algorithms.		A single Pathfinder is designed, produced, and deployed to cislunar orbit to demonstrate SAR/MTI capabilities as well as PNT/RF survey services. With one spacecraft, data will be limited, particularly for PNT. However, data produced will demonstrate full functionality and performance, and ultimately validate models for constellation-based services.			The Pathfinder is augmented with additional assets to form a constellation capable of providing adequate spatial and temporal coverage/resolution for SAR/MTI and PNT/RF survey to South Pole locations. Subscription services will be available to government and commerical customers at South Pole locations.			Assets are added to provide coverage to other Lunar locations (e.g., far side). Subscription services are expanded to include increased coverage.		

Source: Redwire

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THANK YOU!

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