DARPA-EA-23-02 - 10-Year Lunar Architecture (LunA-10) Capability Study

crescent

ASTROBOTIC

SCOUT

LOCKHEED MARTIN

Source: Artist's Concept

Crescent's Multiservice Modular User Surface Terminal (MUST)

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

Crescent LunA-10 Team Introduction

- **Lockheed Martin is investing to develop a commercial services business model in advance of emerging mission needs** to provide US government agencies flexible and low-cost capabilities to support missions on and around the moon.

- **Crescent Space Services LLC ("Crescent")** is a Lockheed Martin subsidiary that provides **infrastructure-as-a-service for missions in cis-lunar space**, leveraging LM's deep heritage and reliability in space and combining it with the agility of a commercial services platform.

- Crescent is developing **a foundational service for lunar infrastructure, MUST, a lunar user surface terminal for communication, position, navigation and timing, space situational awareness and power** in direct response to government and commercial needs to procure capabilities as-a-service. Future service offerings will include **data storage & processing**.
  - **SCOUT Space:** Throughout the LunA-10 study program, Scout has been analyzing the lunar environment to determine suitability and performance for its line of high-performance gimbaled telescopes designed purposefully for space domain awareness on LEO and GEO platforms.
  - **Astrobotic:** In this LunA-10 effort, Astrobotic has scaled its NITE lunar night survival system to efficiently heat and power MUST terminals during the lunar night and serve as an emergency generator in case of a primary power system failure.
  - **Lockheed Martin Space:** Lockheed Martin provides decades of experience and their expertise in mission design, modeling, and simulation work which has been leveraged for LunA-10.

Crescent LunA-10 Team

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MUST Introduction of Capabilities and Services

Surface & Space Situational Awareness

SCOUT

Capable of providing terrain-based navigation and tracking of health and status of surface and orbiting assets.

Position & Navigation

crescent

Informing assets and systems on the lunar surface of their precise location to keep missions on target.

Nighttime Integrated Thermal and Electricity

ASTROBOTIC

Provides external power and heat throughout lunar night(s).

Source: Artist's Concept

Source: Astrobotic

Earth Communications System

crescent

Provides high bandwidth communications and navigation services via relay services to Earth and Direct to Earth.

SmartSat™

LOCKHEED MARTIN

Software framework which enables reconfigurability and mission flexibility.

Surface Area Network

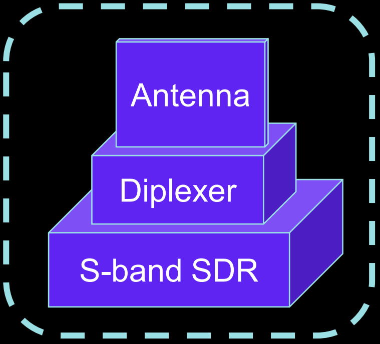
crescent

Scalable service providing communications and navigation services to lunar surface users.

MUST-MVP

- ECS & PNT only
  - Inputs: Power, Position and Timing Data
  - Outputs: Comm/PNT Data
  - Use Cases: Space-based user or dispersed missions operating independently

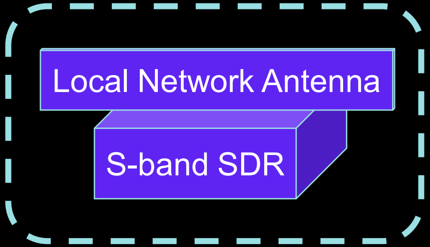
- **< 0.7kg**
- **< 20W (max consumption)**



MUST-SAN

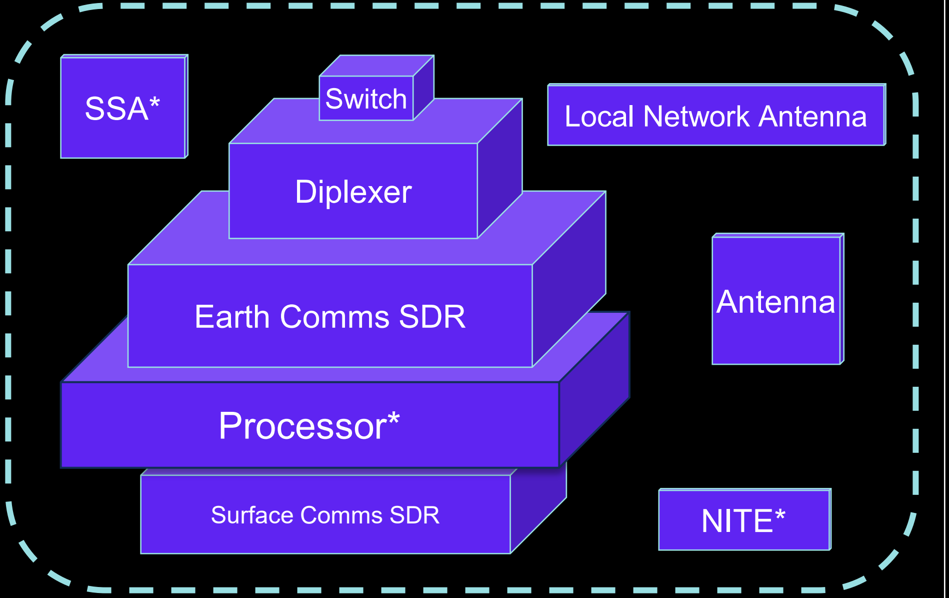
- SAN only
  - Inputs: Power
  - Outputs: Comm Data
  - Use Cases: Creates an independent SAN user (e.g. small rover)

- **< 0.75kg**
- **< 40W (max consumption)**



MUST

- Combination of MUST-MVP & MUST-SAN w/ optional SSA and NITE services
  - Inputs: Power, Position and Timing Data, Raw Pixel Data for Processor*, Payload Thermal Data for NITE*
  - Outputs: Comm/PNT Data, Processed Imagery from Processor*, Raw Pixel Data from SSA*, Heat and Power from NITE*
  - Use Cases: Small landers which enables localized SAN which can communicate with MUST-SAN units or with a dismounted astronaut OR larger rovers (e.g. LTVS)*



Base MUST model
- **< 1.5kg**
- **< 60W (max consumption)**

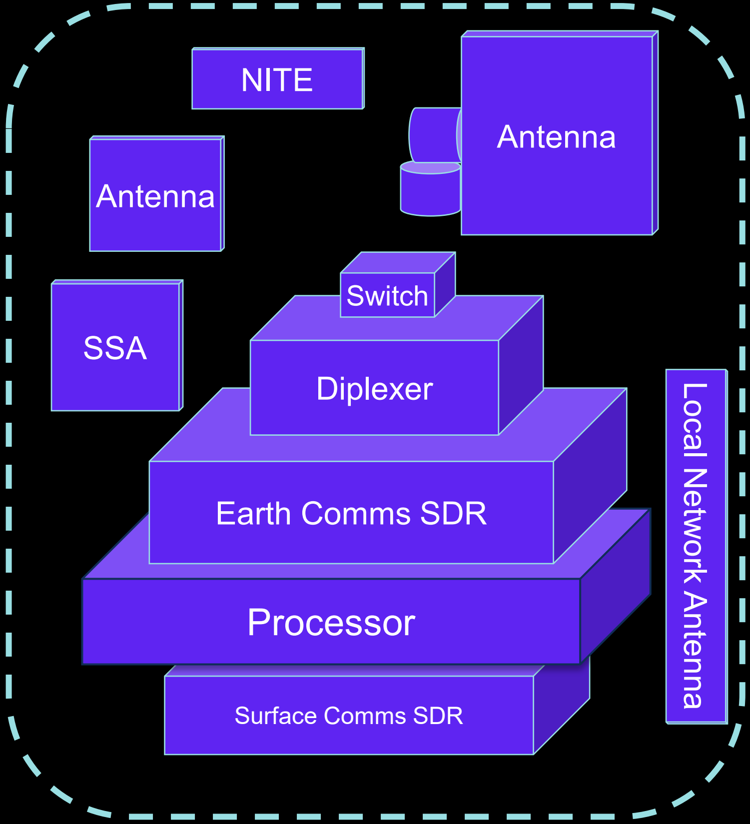
Optional Add-ons
- **< 12kg additional**
- **< 40W additional**

*optional add-ons/services

MUST-HEAVY

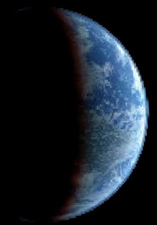
- MUST w/ the additional capability to survive and communicate throughout the lunar night
  - Inputs: Power, Position and Timing Data, Raw Pixel Data, Payload Thermal Data
  - Outputs: Comm/PNT Data, Processed Imagery, Heat and Power
  - Use Cases: Human Landing Systems; multi-node infrastructure now supported by SAN creating a mesh network

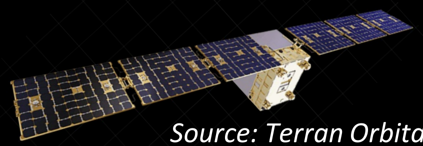
- **< 20kg**
- **< 125W (max consumption)**



Source: Artist's Concept

Earth Communications System (ECS) Service





Source: Terran Orbital

Source: Artist's Concept

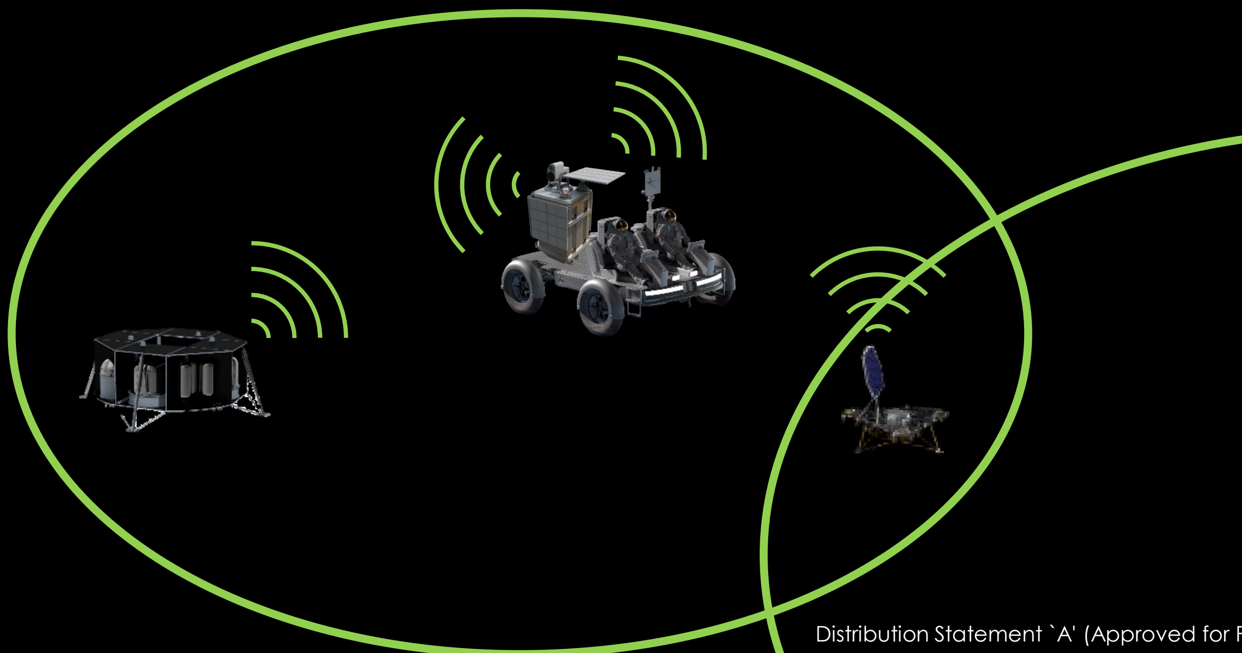
- Hardware
  - Software Defined Radio
  - Radio Frequency Diplexer
  - Mission Specific Antenna Solution
    - Low Rates – S-band passive patch array
    - High Rate – Ka-band Electronically Steerable Array or Deployable reflector

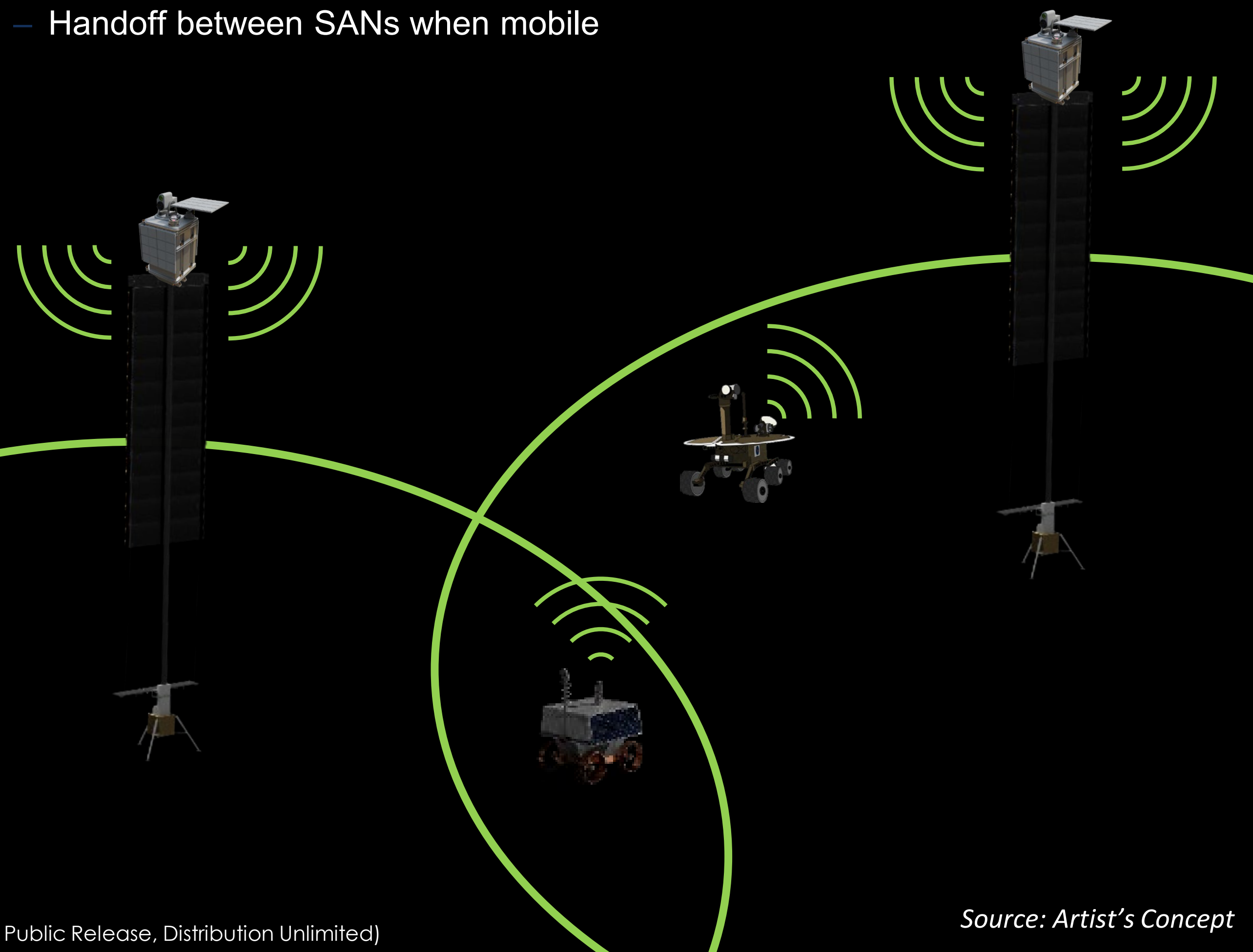
- Utility of ECS
  - Direct-To-Earth
    - Scalable backhaul rates to commercial ground stations and/or Deep Space Network
  - Relay
    - LunaNet compliant signal for backhaul through Lunar Orbital Relay systems
  - Mesh
    - Surface Area Network supports local users
    - Extends coverage area with additional MUST terminals or MUST out of line of sight via orbital relay service.
  - Position, Navigation, Timing
    - Use of heritage Deep Space radiometric signals
    - Combined with imagery and local terrain knowledge for accuracy and reduced solution time

Surface Area Network (SAN) Service

- Surface Area Network is formed with a network terminal (radio, processor, antenna) within MUST.
  - Ex: 5G network
- The SAN system uses a millimeter-wave SDR and antenna to create a local communications network to enable routing, prioritization, processing, aggregation, and transfer of data between lunar surface missions using standardized/interoperable protocols and interfaces defined during LunA-10.
- Potential collaboration area with other LunA-10 contributors – creating the network, hardware/software, and/or management

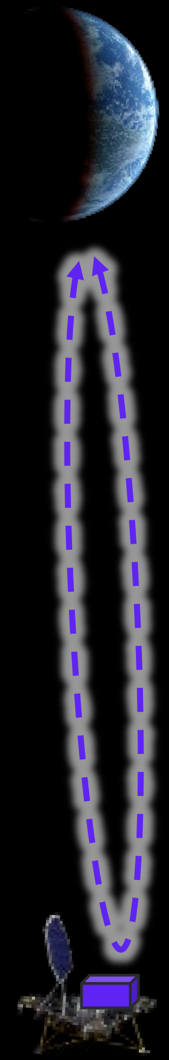
- Utility of SANs:
  - Communication and PNT out to visible horizon
  - Simplifies user comm system which allows for lower SWaP on individual missions
  - Data aggregation to central hub
  - Surface Localization, rapid time-to-fix
  - Handoff between SANs when mobile





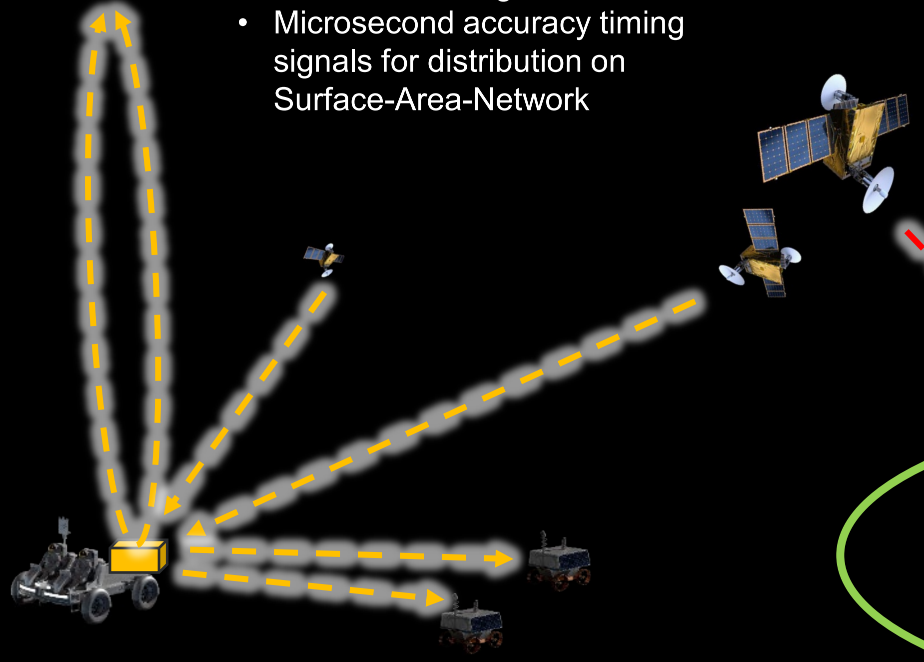
Source: Artist's Concept

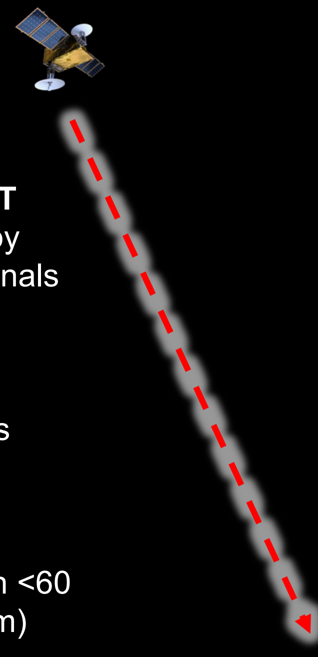
Position, Navigation, and Timing (PNT) Service



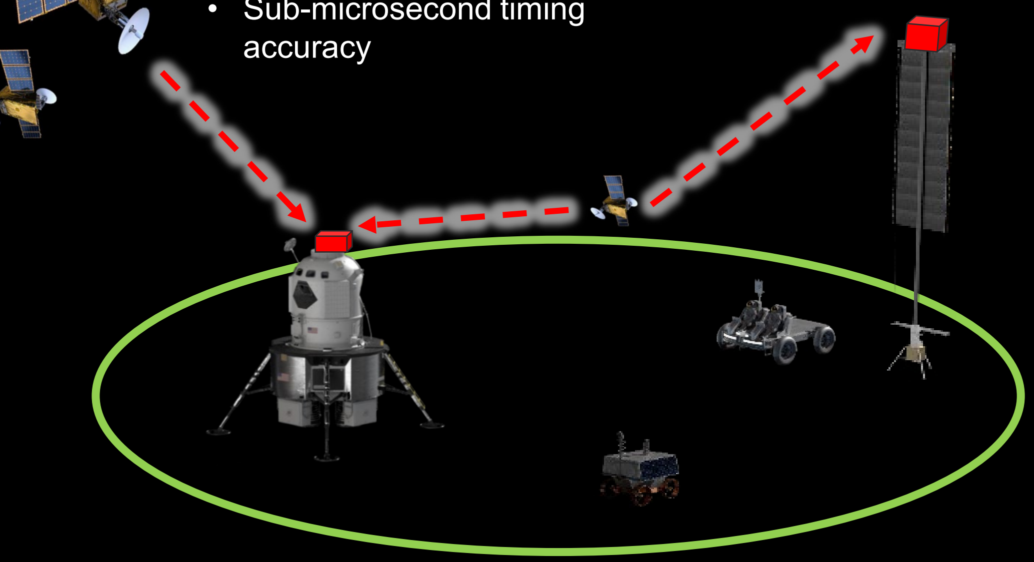
Two-Way Ranging Solutions
- Terrestrially based PNT solutions
- MUST ECS turns-around terrestrially generated ranging and Doppler signals
- Up to 5m accuracy
- Longer duration (hours/days) integration period for solutions

Hybrid PNT Solution
- PNT solutions generated by MUST based on timing signals from Lunar orbiters
- Solutions augmented with traditional two-way ranging and doppler signals
- Compatible with NASA's LunaNet AFS signal structure
- Microsecond accuracy timing signals for distribution on Surface-Area-Network





3GPP Powered Surface PNT
- PNT solutions generated by MUST based on timing signals from Lunar orbiters
- PNT solutions from local infrastructure elements distributed to surface users
- 3GPP radio-metrics incorporated for increased accuracy and reduced
- Single meter accuracy with <60 second time to 1st fix (warm)
- Sub-microsecond timing accuracy

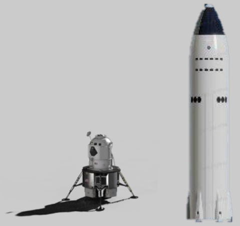


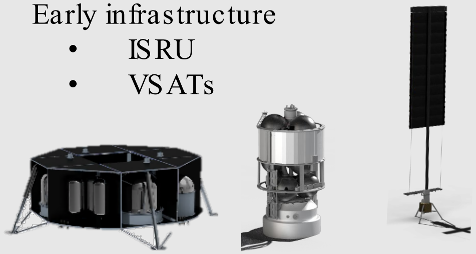
2026 | 2030 | 2035

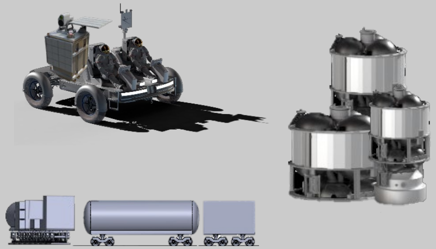
Source: Artist's Concept

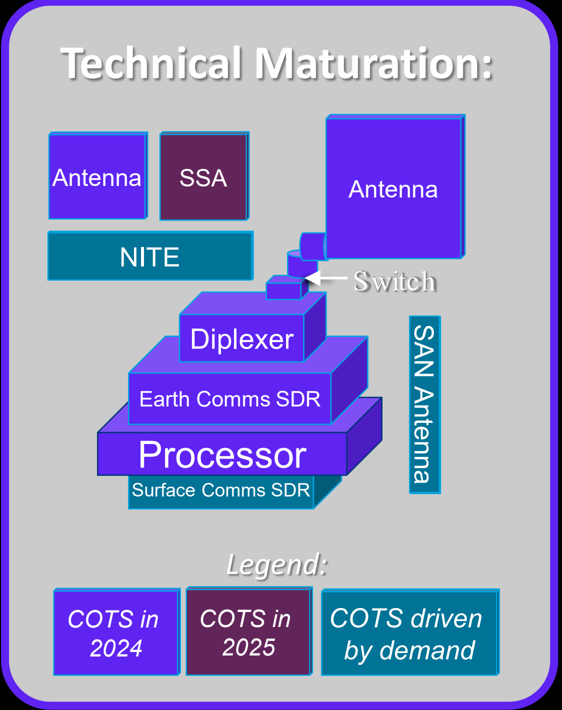
Scaling Capability and Demand

	Development	Demand

2026 MUST-MVP demonstration	• MUST-MVP hardware is TRL-9
	• Work to go is integration and productization
	    • Developing commercial interfaces
	    • Developing ICDs and User Guide
		• Focus on science landers, rovers, and limited Artemis missions
		

2026-2030 deployment of more capable MUST units (MUST-HEAVY)	• Nearly all MUST-HEAVY hardware on track to be available COTS in 2025
	• Definition of specific SAN requirements needed for minor modifications to existing COTS h/w
	• Additional integration work required
	    • Gimbal control
	    • S/W applications
		• Expanded human and scientific exploration missions
		• Early infrastructure
		    • ISRU
		    • VSATs
		

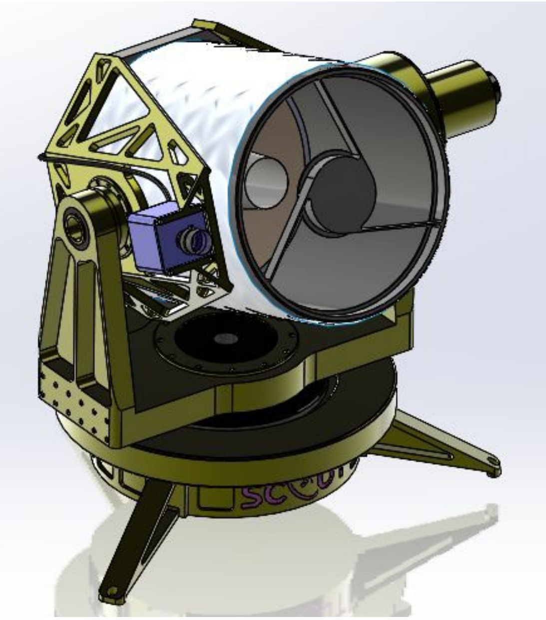
2030+ extend MUST network and implement 3GPP	• Modifications needed to MUST units for 3GPP
	    • Waveform modifications to SDRs
	    • Potentially modifications to SAN Antenna
	    • Network orchestration development
	• Opportunity to continue updating and optimizing processing options and hosted s/w
		• Permanent human presence
		• Large scale infrastructure roll out
		

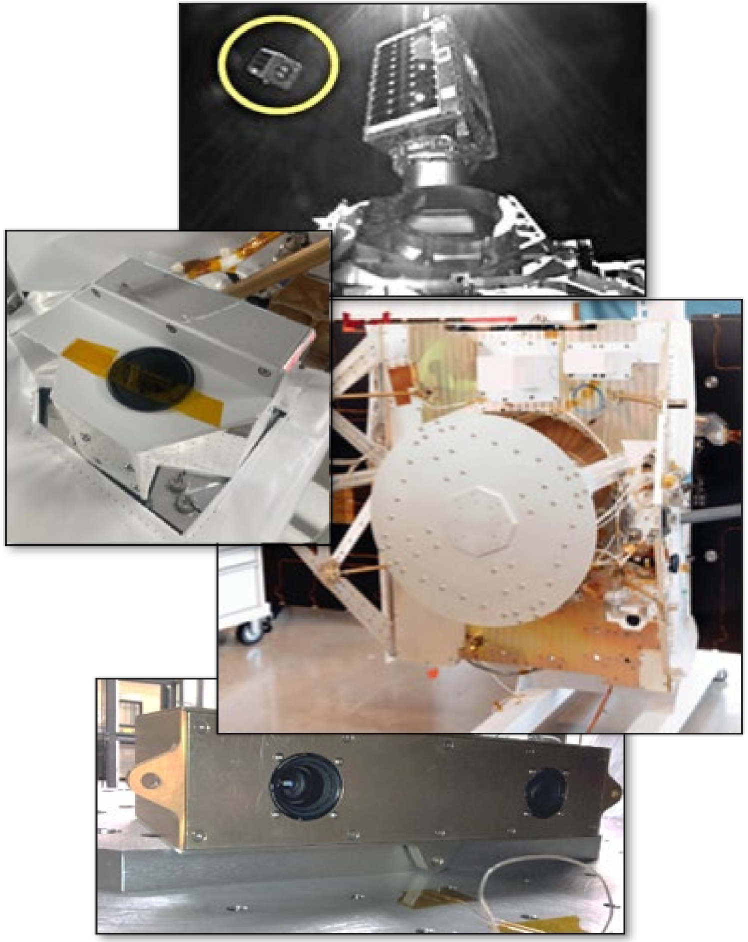


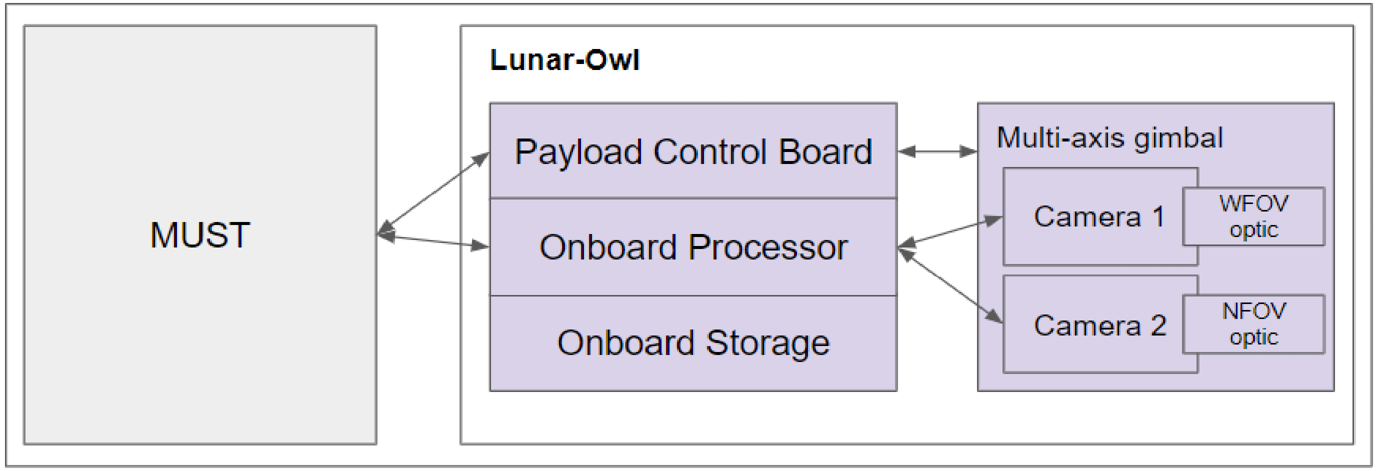
Source: Artist's Concept

Lunar-OWL Service Overview

- **Overview:** Owl is a high-performance, low-SWaP gimbaled optical system designed for long-range space domain awareness (SDA) missions. Lunar-Owl provides an SSA data-as-a-service via both taskable and opportunistic data collection methods, ensuring comprehensive coverage and real-time intelligence in the lunar environment.
- SWaP: <15-35kg, <55-75W
- Capabilities: Long-range lunar SSA, magnitude < 16-18



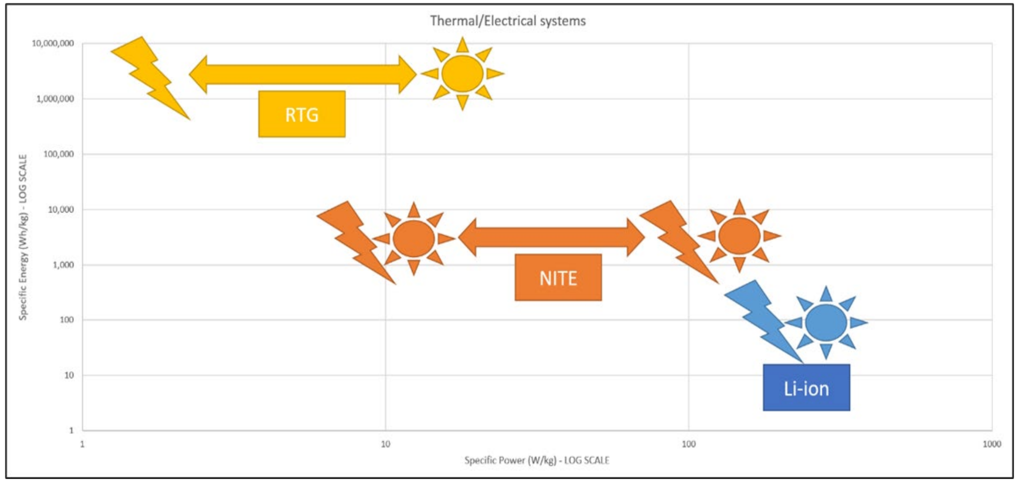




Source: SCOUT Space, Inc.

NITE Service Overview

- Astrobotic's Nighttime Integrated Thermal and Electricity (NITE™) system produces both heat and power in a non-nuclear system to allow MUST's continuous operations of critical systems during the cold lunar night
- Additional Applications:
  - Support access to other low temperature areas of interest such as PSRs
  - Deliver early-stage heat & power to enable standup of longer-term permanent operations
  - Provide backup heat and power
- Fills the gap between traditional heating/electric solutions
  - Specific energy goal of 1300 Wh/kg (combined heat and electricity); An order of magnitude higher than batteries
  - Specific Power (W/kg); Between low RTG levels and Li-ion battery levels; Depends on thermal/electrical ratio
- NITE is also throttleable
  - RTG's run continuously once activated and can produce excess heat that must be managed
  - NITE can be turned on and off or slowed down
- NITE also has regulatory advantages over RTG's, which require additional time & funding to address launch of nuclear materials

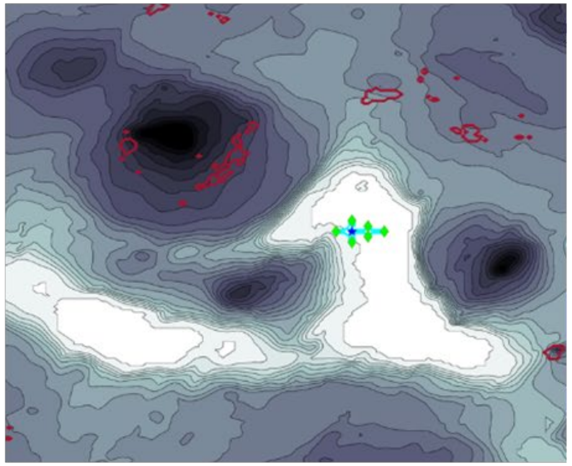


Specific Energy vs. Specific Power for Various Heating/Electric Solutions

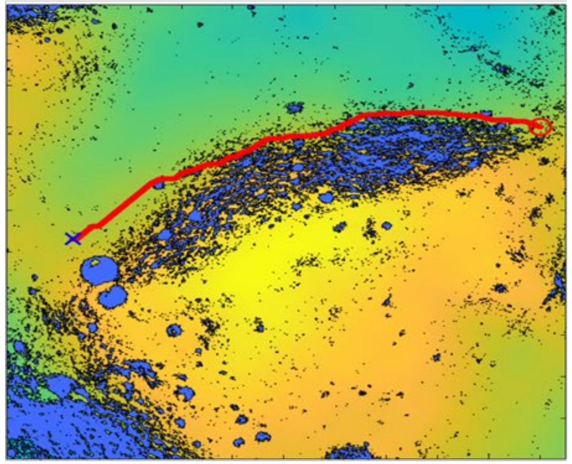
Source: Astrobotic

Lunar Economy Analysis Platform (LEAP) Overview

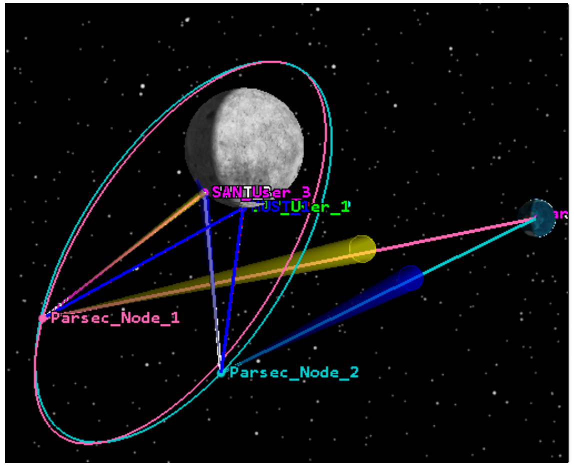
Optimize Power Grid Architecture



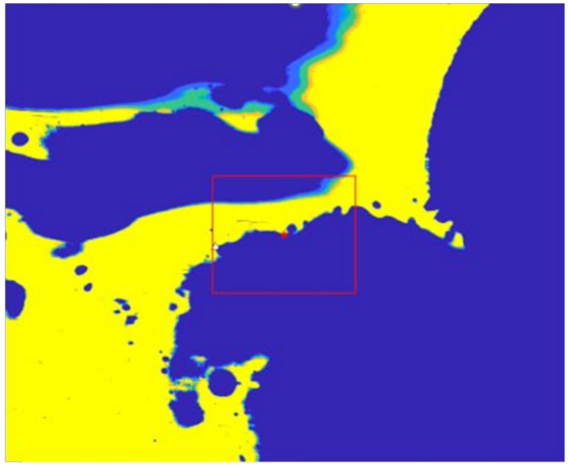
Multivariate Lunar Path Planning



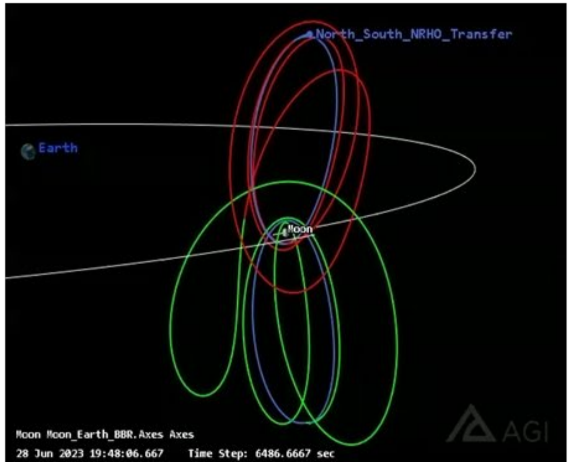
Model Lunar Comms Networks



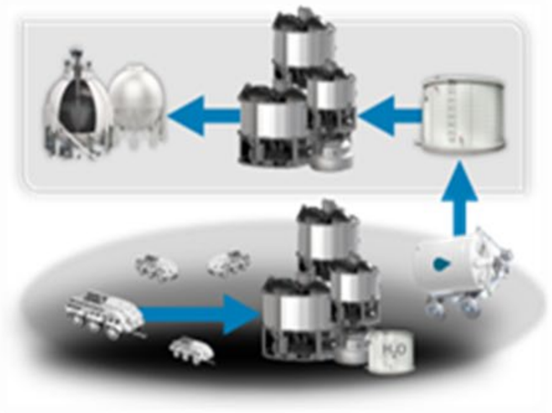
Analyze Illumination vs Height, Time



Model Propellant Demand and Refueling



Calculate ISRU Infrastructure Needs



Integrated lunar infrastructure system-of-systems analyses

Modular tools in a common environment

Object-oriented modeling

Common data structure

Design Features

Source: Lockheed Martin

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QUESTIONS