



AES and the Moon

Jason Crusan

Director | Advanced Exploration Systems

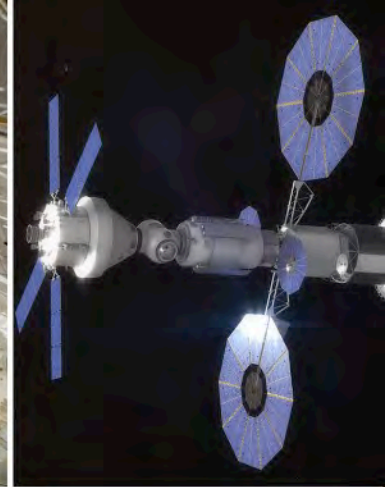
Human Exploration and Operations Mission Directorate

NASA Headquarters





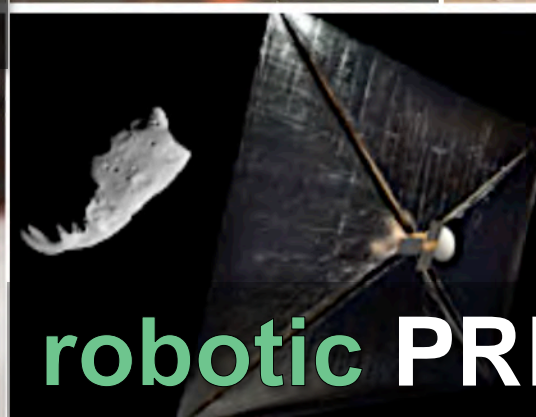
DEEP SPACE habitation



CREW mobility



VEHICLE Systems



robotic **PRECURSORS**

Advanced Exploration Systems



Rapid development and testing of prototype systems and validation of operational concepts to reduce risk and cost of future exploration missions:

- **Crew Mobility Systems**
 - Systems to enable the crew to conduct “hands-on” surface exploration and in-space operations, including advanced space suits, portable life support systems, and EVA tools.
- **Habitation Systems**
 - Systems to enable the crew to live and work safely in deep space, including beyond earth orbit habitats, reliable life support systems, radiation protection, fire safety, and logistics reduction.
- **Vehicle Systems**
 - Systems to enable human and robotic exploration vehicles, including advanced in-space propulsion, extensible lander technology, and modular power systems.
- **Foundational Systems**
 - Systems to enable more efficient mission and ground operations and those that allow for more earth independence, including autonomous mission operations, avionics and software, communications technologies, and synthetic biology applications.
- **Robotic Precursor Activities**
 - Robotic missions and payloads to acquire strategic knowledge on potential destinations for human exploration to inform systems development, including prospecting for lunar ice, demonstrating oxygen production from the Mars atmosphere, secondary payloads and instruments, and research and analysis.
- **Strategic Operations, Integration and Studies**
 - Responsible for the management oversight of the HEO architecture and strategic planning, including mission and systems analysis and international coordination. Conduct studies and analyses to translate strategy into developmental (technology and capability) priorities and operational efficiencies.

FY 16 AES Content



Crew Mobility Systems

- Advanced Space Suit (JSC)

Habitation Systems

- BEAM (JSC)
- Life Support Systems (MSFC)
- Logistics Reduction (JSC)
- Radiation Sensors (JSC)
- Spacecraft Fire Safety (GRC)
- In-Space Manufacturing (MSFC)
- NextSTEP Habitation & Life Support (JSC, MSFC, LaRC)

Vehicle Systems

- Ascent Abort-2 Flight Test (JSC)
- Modular Power Systems (GRC)
- Lander Technologies (MSFC)
- NextSTEP High-Power Electric Propulsion (GRC, JSC)

Foundational Systems

- Autonomous Systems & Operations (ARC)
- Automated Propellant Loading (KSC)
- Avionics & Software (JSC)
- Disruption Tolerant Networking (JSC)
- Ka-Band Objects Observation & Monitoring (KSC)
- Synthetic Biology Applications (ARC)

Robotic Precursor Activities

- Resource Prospector (ARC)
- MOXIE (JPL)
- MEDA (JPL)
- MEDLI-2 (LaRC)
- BioSentinel (ARC)
- Lunar Flashlight (JPL)
- NEA Scout (MSFC)
- Lunar IceCube (HQ/Morehead St)
- Skyfire (HQ/Lockheed Martin)

Strategic Operations, Integration and Study Activities

GER 3 development (ISECG) (JSC, LaRC)

Evolvable Mars Campaign / Human Architecture Team and Innovative studies (JSC, LaRC)

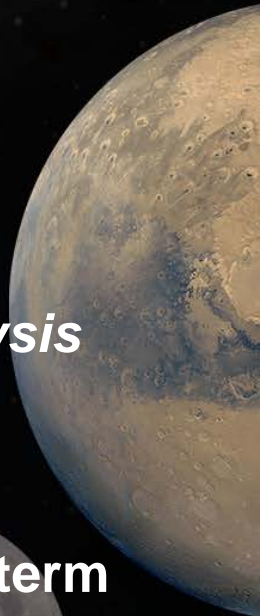
System Maturation Teams (LaRC, JSC)

Strategic Knowledge Gaps



Unknown or incomplete data sets that contribute risk or cost to future human missions to the moon, Mars or near-Earth objects

- **SKG development is ongoing and is jointly sponsored by HEOMD and SMD, who enlist the expertise of international partners and three analysis groups: the *Lunar Exploration Analysis Group (LEAG)*, the *Mars Exploration Program Analysis Group (MEPAG)*, and the *Small Bodies Assessment Group (SBAG)*.**
- **SKGs inform mission/system planning and design and near-term agency investments**
- **Common themes across all destinations:**
 - Human health and performance, radiation, regolith, reliability; geotechnical properties, volatiles, propulsion-induced ejecta, in-situ resource utilization (ISRU) and prospecting, operations/operability (all destinations, including transit), plasma environment



Evidence for Lunar Volatiles



- The Moon has been a popular destination in the last decade, being visited by an impressive armada of international spacecraft.
- ISRO: Chandrayaan-1
- CNSA” Chang’e 1, 2, & 3
- JAXA: Kaguya
- NASA: LRO, LCROSS, GRAIL, LADEE
- Many of these carried instruments that have provided new insights into the Moon’s volatile story.

LEAG Volatiles Special Action Team (VSAT)

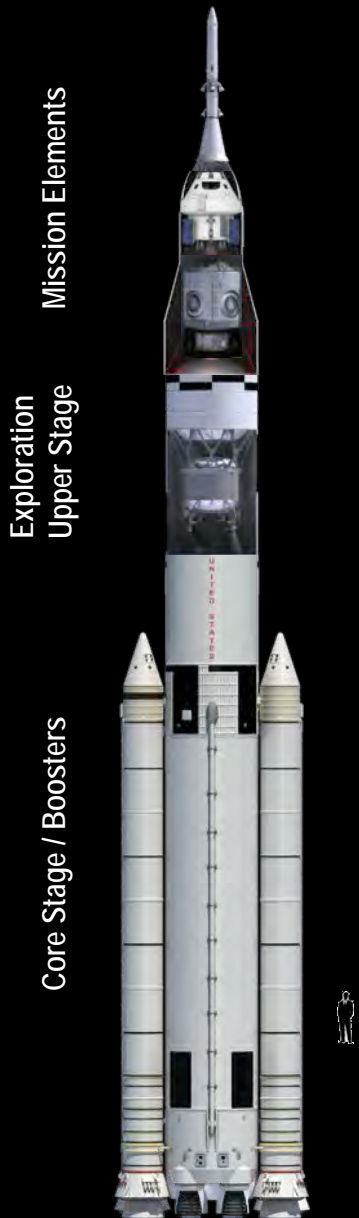
Identify regions where NASA and international / commercial partners could operate on the lunar surface in a cooperative manner to further understand the size, distribution, form, and resource potential of deposits of water ice and other volatiles.

- **3 Regions of Interest** – two south pole, one north pole – identified as having hydrogen and other attributes making them candidates for detailed mission studies
- **7 Orbital Measurement Findings** that support continued orbital missions to further characterize and validate lunar volatiles in the three regions
- **8 Landed Measurement Findings** that identify elements of success for robotic lander missions in support of understanding volatiles for human exploration

South Pole



SLS EM-1 CubeSat Opportunity



- EM-1 offers multiple CubeSat opportunities
- AES is studying the following missions
 - **Lunar Flashlight**
 - Biosentinel
 - NEAScout
 - **SkyFire**
 - **Lunar IceCube**
- Future SLS launches will offer additional opportunities
- Studies such as the LEAG VSAT helps us determine what instruments to fly in future opportunities

Lunar Flashlight Overview

Looking for surface ice deposits and identifying favorable locations for in-situ utilization in lunar south pole cold traps

Measurement Approach:

- Lasers in 4 different near-IR bands illuminate the lunar surface with a 3° beam (1 km spot).
- Light reflected off the lunar surface enters the spectrometer to distinguish water ices from regolith.

Orbit:

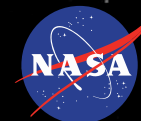
- Elliptical: 20-9,000 km
- Orbit Period: 12 hrs
- Sci Pass: ~10min

Teaming:

- JPL-MSFC
- S/C (6U - 14 kg): JPL
- Mission Design & Nav: JPL
- Propulsion: Green Prop (MSFC)
- Payload: 1-2 micron Spectrometer
- I&T: JPL

Phases

- Launch: SLS EM1
- Schedule: Launch July, 2018
- LOI: Launch +6 months
- Design Review: July, 2016
- Phase E: >1 year



Jet Propulsion Laboratory
California Institute of Technology

NextSTEP BAA Overview



- **Solicited three critical areas for technology maturation:**
 - Advanced Propulsion Systems
 - Habitation Systems (Including Life Support)
 - Small Satellite Missions (EM-1 secondary payloads)
- **Facilitates development of deep space human exploration capabilities in the cis-lunar proving ground and beyond**
- **Continues successful public-private partnership model and spurs commercial endeavors in space**
- **Selected 12 proposals and will proceed to enter into *Fixed Price Contracts* with technical/payment milestones with private-sector partners**
 - Emphasis for eligibility and execution placed on contribution of private corporate resources to the private-public partnership to achieve goals and objectives
 - Selected partners with the technical capability to mature key technologies and demonstrate commitment toward potential commercial application





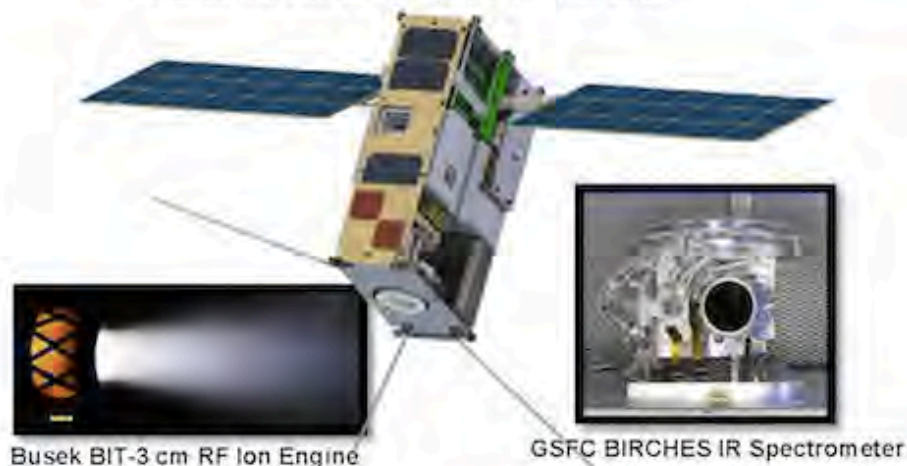
Lunar IceCube



Objectives & Technical Approach:

- A 6U CubeSat mission to prospect for water in ice, liquid, and vapor forms and other lunar volatiles from a low-perigee, inclined lunar orbit using a compact IR spectrometer. Lunar IceCube 6U will:
 - be deployed during lunar trajectory by the SLS on EM-1
 - use an innovative RF Ion engine to achieve lunar capture and a science orbit of 100 km perilune
 - fully characterize water and other volatiles with high spectral resolution (5 nm) and wavelength range (1 to 4 μm)

Lunar IceCube in Flight Configuration



Team: *University, Aerospace Industry, Government*

- **Morehead State University Space Science Center**
Ben Malphrus (PI), Bob Twiggs, Jeff Kruth, Kevin Brown, Roger McNeil, intrepid graduate and undergraduate STEM students
- **The Busek Company**
Kurth Hohman, Vlad Hruby, Mike Tsay
- **NASA Goddard Spaceflight Center**
Science Team: Pamela Clark, Dennis Reuter, Robert MacDowall, Clifford Brambora, Deepak Patel, Ian Banks
Navigation and Tracking: David Folta
- **NASA Goddard Spaceflight Center and Catholic University of America**
Pamela Clark (Science PI)

Schedule:

- Initiate Program: Q1 2015
- TIMs, Reviews, Milestones
As per Requirement
- Launch/LEOP
SLS Maiden Flight
- Lunar Transit
Launch +6 Months
- Science Orbit/Mission
Arrival +3 Months
- Disposal: Q1 2020

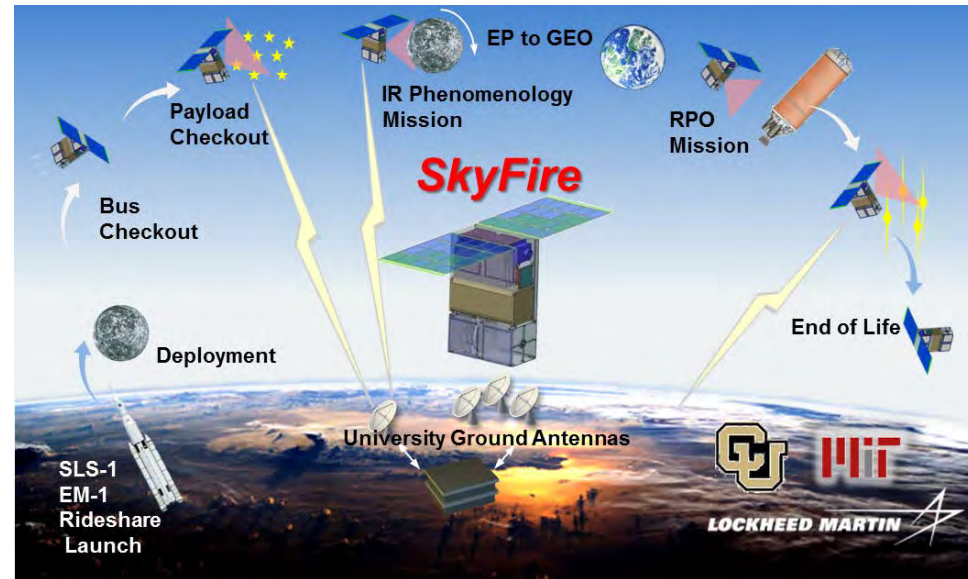


Small Satellite Missions: Lockheed Martin SkyFire



Objectives & Technical Approach:

- Lockheed Martin is building the SkyFire cubesat as a technology development platform that will be co-manifested with additional cubesats on the SLS-1 EM-1 test flight
- Following separation from SLS, SkyFire will fly by the moon taking infrared sensor data in order to enhance our knowledge of the lunar surface
- Using electrospray propulsion, the spacecraft orbit will be lowered to the GEO 'graveyard' orbit for more science and technology mission objectives
- SkyFire will leverage Lockheed Martin's successful additive manufacturing experience for deep space missions



Teammates:

- The Lockheed Martin spacecraft team will consist of the 'Digital Generation' of young spacecraft engineers working with members of the university community
- With SkyFire, LM achieves the multiple benefits of workforce and technology development in partnership with NASA
- Key technology team members:
 - Massachusetts Institute of Technology (MIT)/Accion
 - University of Colorado

Lockheed Martin Contacts:

Program Manager – John Ringelberg
John.c.Ringelberg@lmco.com
Contracts POC - Caitlin Foster
Caitlin.e.Foster@lmco.com

International Partnership

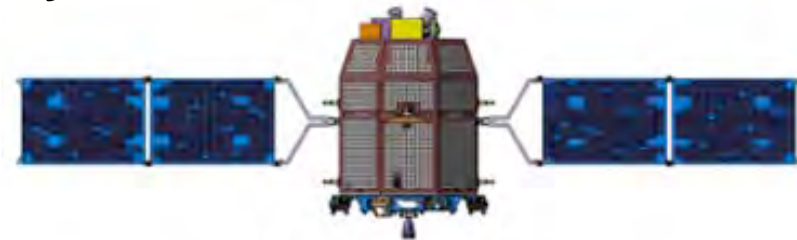
Korea Pathfinder Lunar Orbiter (KPLO)



- Korea is planning a lunar orbiter in the late 2018 timeframe
- NASA (HEOMD) is negotiating payload space for NASA-selected instrument(s) and participation on joint science teams
- What instruments NASA chooses will depend on what KARI chooses to fly
- Details still fluid but a promising potential opportunity for the lunar science community to acquire new lunar data that supports exploration



Launch Configuration

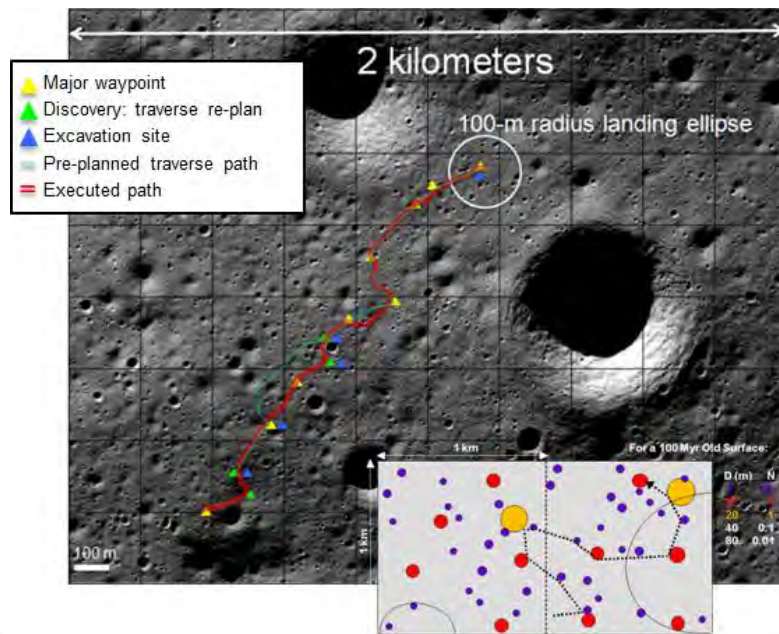


Flight Configuration

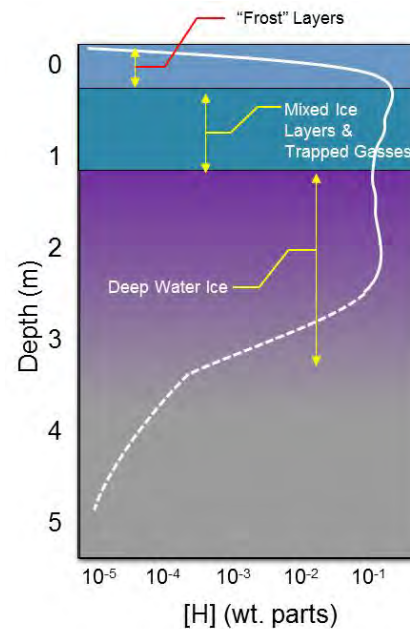
〈Conceptual Design of Korea Pathfinder Lunar Orbiter〉

Need to assess the extent of the resource 'ore body'

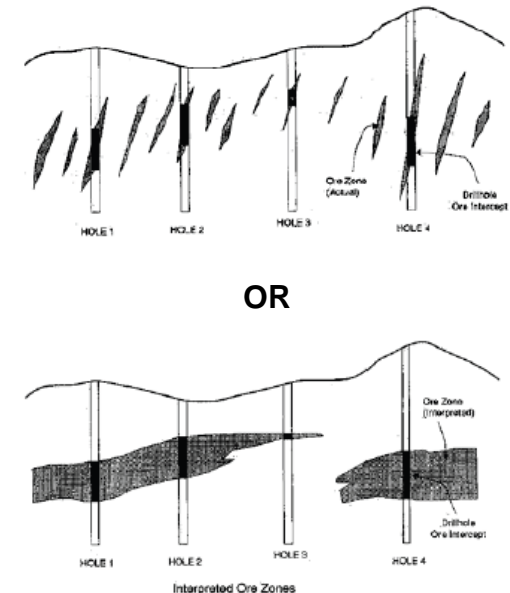
Need to Evaluate Local Region (1 to 3 km)



Need to Determine Vertical Profile



Need to Determine Distribution



An 'Operationally Useful' Resource Depends on What is needed, How much is needed, and How often it is needed

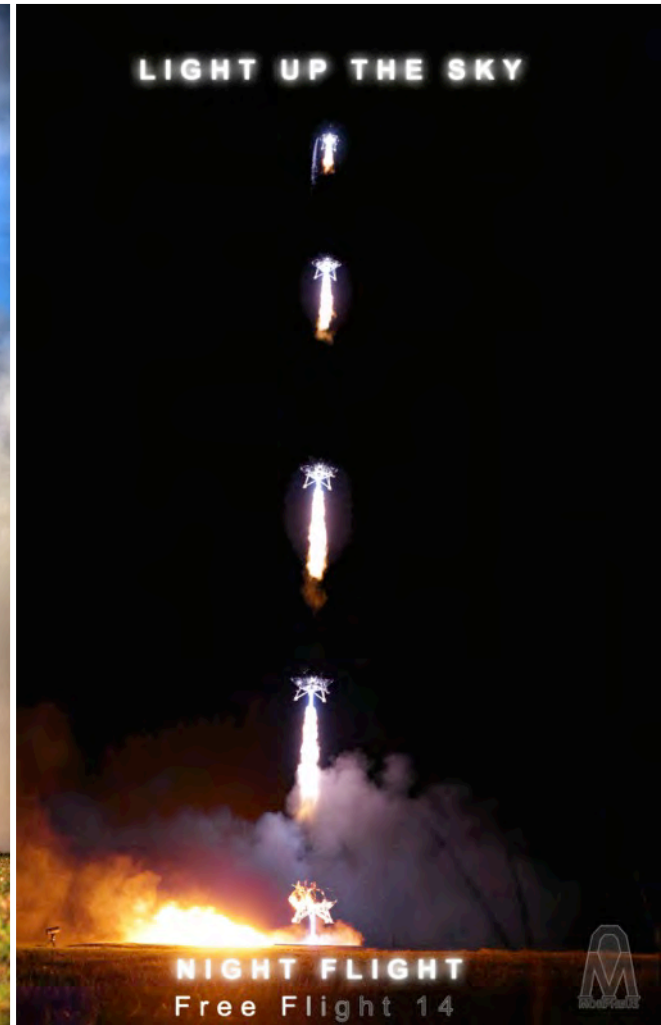
Potential Lunar Resource Needs*

- 1,000 kg oxygen (O₂) per year for life support backup (crew of 4)
- 3,000 kg of O₂ per lunar ascent module launch from surface to L₁/L₂
- 16,000 kg of O₂ per reusable lunar lander ascent/descent vehicle to L₁/L₂ (fuel from Earth)
- 30,000 kg of O₂/Hydrogen (H₂) per reusable lunar lander to L₁/L₂ (no Earth fuel needed)

*Note: ISRU production numbers are only 1st order estimates for 4000 kg payload to/from lunar surface

In house Development of Planetary Lander:

Morpheus — *Rapid Development with Autonomous Landing and Hazard Avoidance*



Lunar CATALYST – Public Private Partnership

<http://www.nasa.gov/lunarcatalyst>



- Lunar Cargo Transportation and Landing by Soft Touchdown (CATALYST)
- Purpose is to encourage and facilitate development of U.S. commercial robotic lunar cargo delivery capabilities
- NASA has accumulated decades of technical experience relevant to lunar cargo transportation (most recently the Mighty Eagle and Morpheus projects)
- NASA has no specific requirements for commercial lunar transportation services, but science and exploration payloads of interest to NASA include:
 - Resource prospecting
 - Sample return
 - Geophysical network deployment missions
 - Technology demonstrations
- NASA issued Request for Information (RFI) on partnerships for industry-led robotic lunar lander development; response indicated significant interest by U.S. private sector (2013)
- NASA issued Lunar CATALYST Announcement for proposals, offering to provide partners with technical expertise, access to facilities, equipment loans, software. Selections were based on both technical and financial evaluation criteria.
- Initiated 3-year no-funds-exchanged Space Act Agreements with 3 companies to develop commercial robotic lunar landers (Sept 2014)
 - Astrobotic Technology
 - Masten Space Systems
 - Moon Express

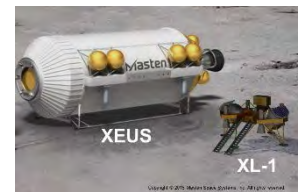


NASA Mighty Eagle and Morpheus Vertical Takeoff / Landing Test Beds



Astrobotic Griffin Lander

Credit: Astrobotic Technology



MSS Landers: XEUS and XL-1

Credit: Masten Space Systems



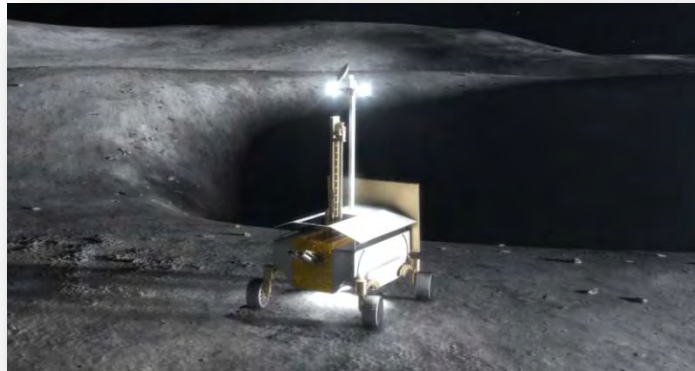
Moon Express MX-1 Lander

Credit: Moon Express

Resource Prospector



Get there...



Find & Excavate Volatiles...



Use the Neutron Spec & Near-IR Spec to look for Hydrogen-rich materials



Go to the areas with highest concentrations of volatiles, Permanently Shadowed Regions (PSRs)



Use the Drill Subsystem to bring material from up to 1 [m] depth to examine with Near-IR Spec

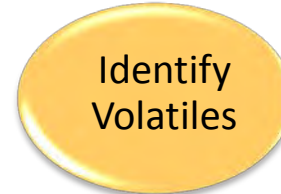
Collect and Process the volatiles...



Use the Drill Subsystem to capture samples from up to 1 [m] depth



Heat samples (150-450 degC) in the OVEN Subsystem



Determine type and quantity of volatiles in the LAVA Subsystem, (H₂, He, CO, CO₂, CH₄, H₂O, N₂, NH₃, H₂S, SO₂)



Image and quantify the water created using the LAVA Subsystem

Paraphrased Requirements

Minimum Success:

- Make measurements from two places separated by at least 100 meters
- Surface or subsurface measurements

Full Success:

- Measurements from two places separated by at least 1000 meters
- Surface and subsurface measurements (drill)
- Measurements in and sample acquired from shadowed area
- Demonstrate ISRU

Stretch Goals:

- Make subsurface measurements (auger) at least eight (8) locations across 1000 m (point-to-point) distance
- Make subsurface measurements (core and process) at least four (4) locations across 1000 m (point-to-point) distance
- Provide geologic context

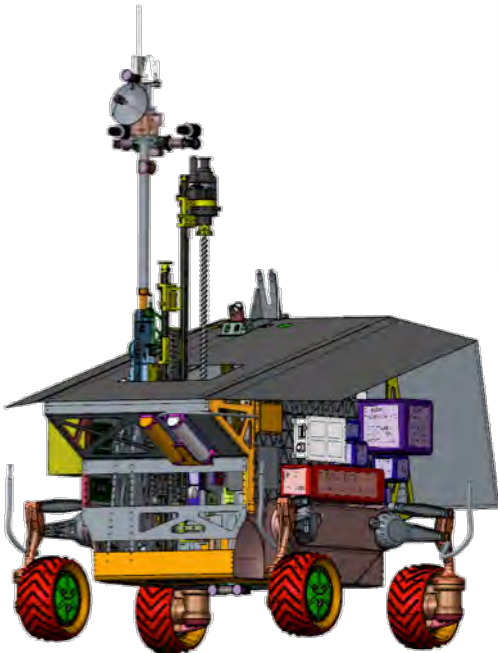
Resource Prospector – The Tool Box



Mobility

Rover

- Mobility system
- Cameras
- Surface interaction



Prospecting

Neutron Spectrometer System (NSS)

- Water-equivalent hydrogen > 0.5 wt% down to 1 meter depth

NIR Volatiles Spectrometer System (NIRVSS)

- Surface H₂O/OH identification
- Near-subsurface sample characterization
- Drill site imaging
- Drill site temperatures

Sampling

Drill

- Subsurface sample acquisition
- Auger for fast subsurface assay
- Sample transfer for detailed subsurface assay

Processing & Analysis

Oxygen & Volatile Extraction Node (OVEN)

- Volatile Content/Oxygen Extraction by warming
- Total sample mass

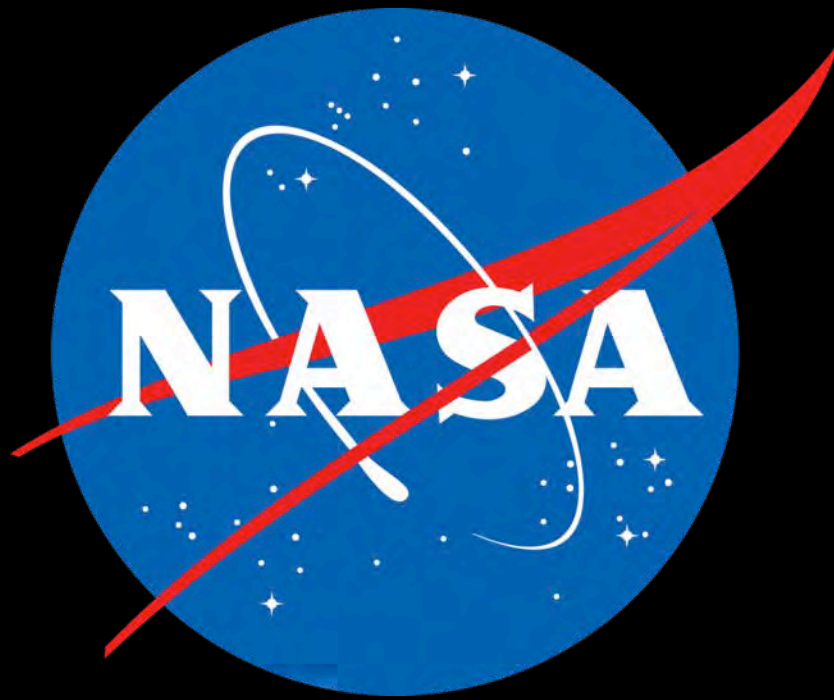
Lunar Advanced Volatile Analysis (LAVA)

- Analytical volatile identification and quantification in delivered sample with GC/MS
- Measure water content of regolith at 0.5% (weight) or greater
- Characterize volatiles of interest below 70 AMU

ISRU Strategy – Phased Implementation



- **ISRU implementation is phased to minimize risk to human exploration plans**
 - **Prospect and Demonstrate** – *Mission Feasibility*
 - Evaluate potential exploration sites: terrain, geology/resources, lighting, etc.
 - Demonstrate critical technologies, functions, and operations
 - Evaluate environmental impacts and long-term operation on hardware: dusty/abrasive/electrostatic regolith, radiation/solar wind, day/night cycles, polar shadowing, etc.
 - **Pilot Scale Operation** – *Mission Enhancement*
 - Perform critical demonstrations at scale and duration to minimize risk of utilization
 - Obtain design and flight experience before finalizing human mission element design
 - Pre-deploy and produce product before crewed missions arrive to enhance mission capability
 - **Utilization Operations** – *Mission Enabling*
 - Produce at scale to enable ISRU-fueled reusable landers and support extended duration human surface operations
 - Commercial involvement or products bought commercially based previous mission results
- **Identify technologies and systems for multiple applications (ISRU, life support, power) and multiple mission (Moon, Mars, NEOs)**
- **Multinational involvement based on expertise and long-term objectives**



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