LUNAR Science

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&
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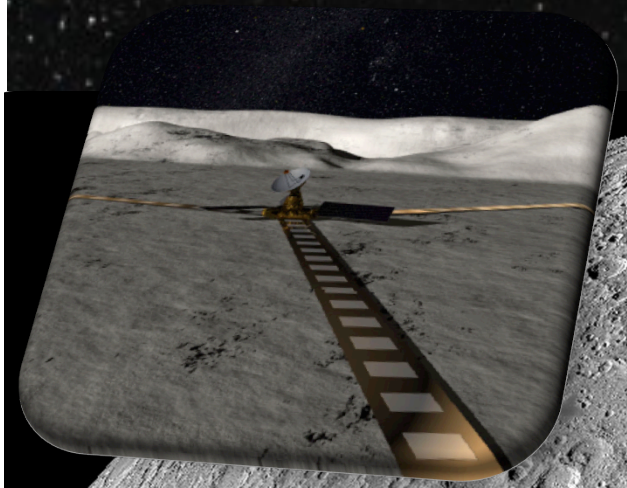
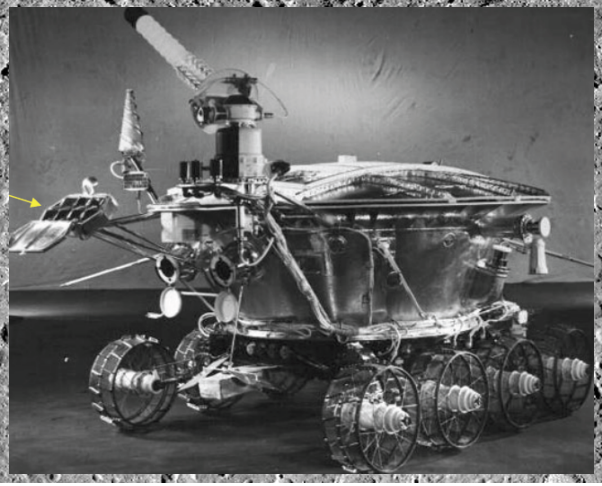
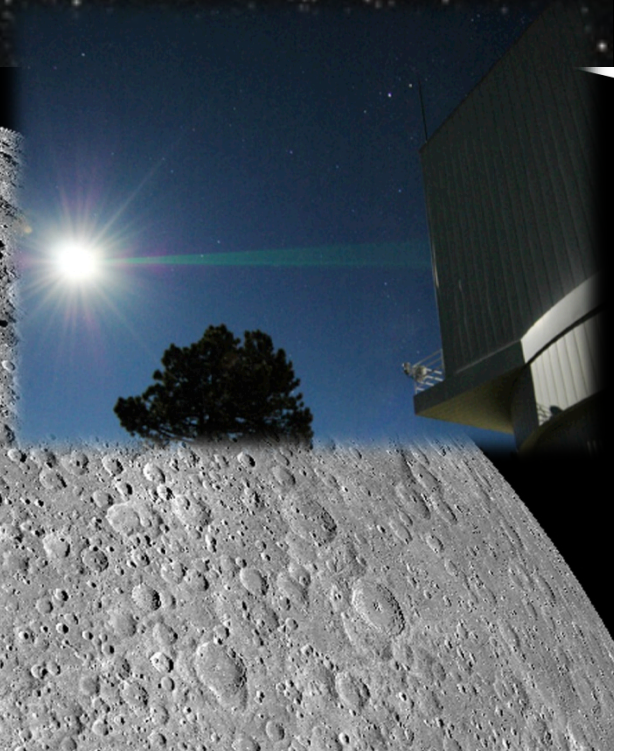






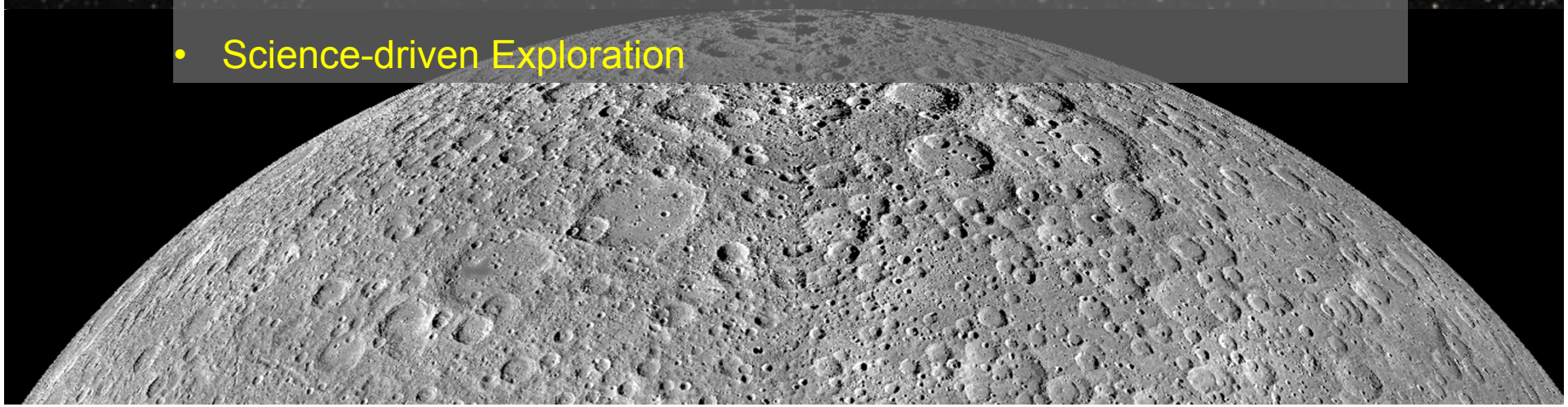
Lunar Science and LUNAR
Lunar University Network for Astrophysics Research

- Determine size of core, from which constraints on initial composition and planetary differentiation can be obtained (science of the Moon)
  Lunar laser ranging

- Monitor lunar atmosphere density and processes affecting it (science of the Moon)
  Relative ionospheric opacity measurements (riometry)

- Characteristics of newly discovered population of nanometer-sized dust particles “nanodust” (science on the Moon)
  Electrical pulses from dust impacts on radio antennas

- Science-driven Exploration

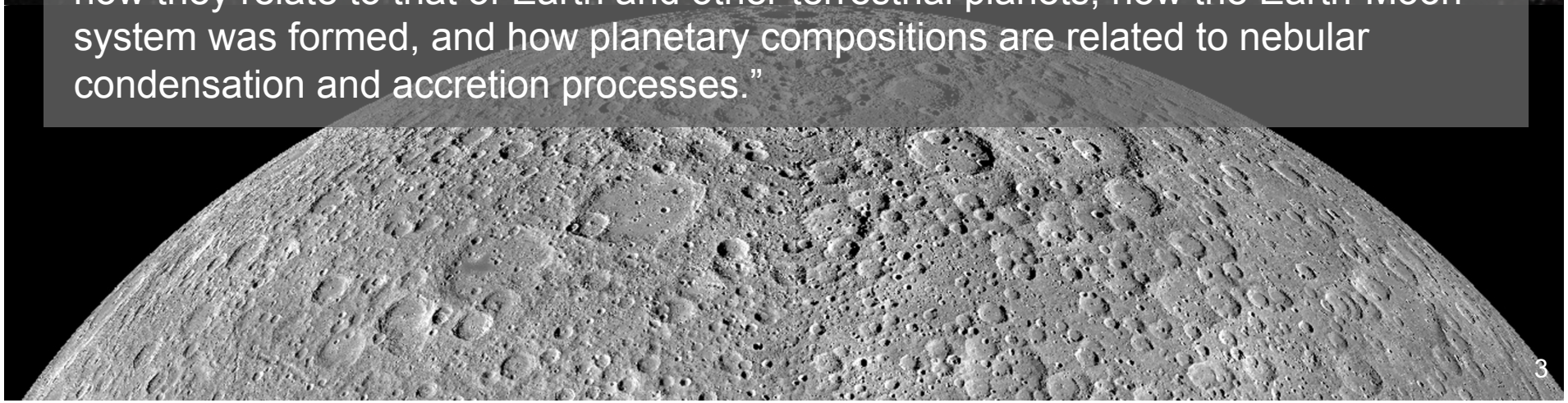


Lunar Geophysical Network

Vision and Voyages for Planetary Science in the Decade 2013-2022

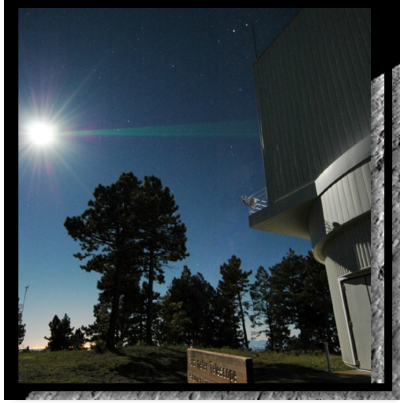
- "Deploying a global, long-lived network of geophysical instruments on the surface of the Moon to understand the nature and evolution of the lunar interior from the crust to the core will allow the examination of planetary differentiation that was essentially frozen in time at some 3-to-3.5 billion years ago. ***Such data (e.g., seismic, heat flow, laser ranging, and magnetic field/electromagnetic sounding) are critical to determining the initial composition of the Moon and the Earth-Moon system."***

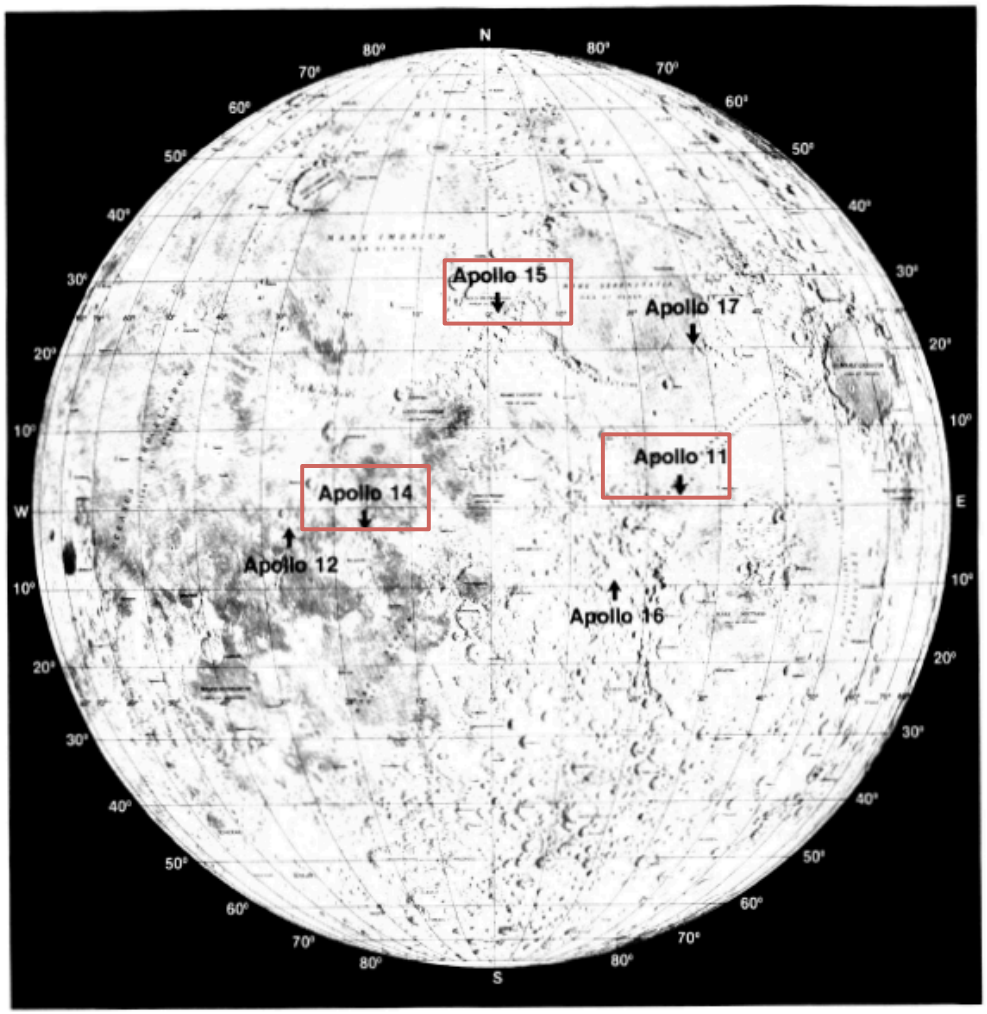
- Important scientific objectives include: "Determine the size of structural components (e.g., crust, mantle, and core) making up the interior of the Moon, including their composition and compositional variations to estimate bulk lunar composition and how they relate to that of Earth and other terrestrial planets, how the Earth-Moon system was formed, and how planetary compositions are related to nebular condensation and accretion processes."



Lunar Laser Ranging

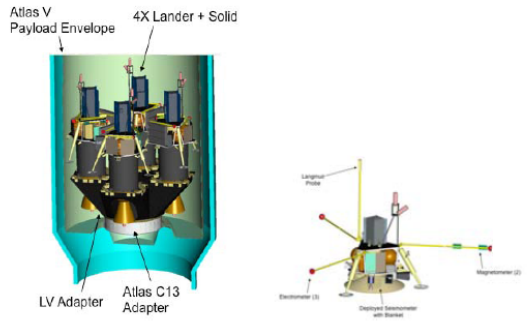
- Shoot laser beam at Moon
- Measure time-of-flight of laser pulse
- Observed − Predicted arrival time at observatory used to improve model
- Requires long duration program and latitude & longitude diversity of reflectors on Moon





Lunar Geophysical Network

Lunar Lander Network—Four Landers



SOURCE: NASA Mission Study (transmitted from George J. Tahu, NASA Planetary Science Division)

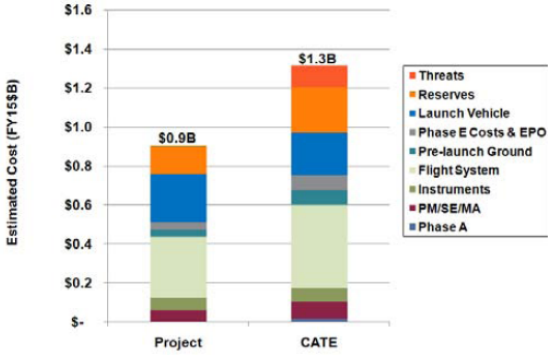
Key Challenges

- **DACS Propulsion**
  - *Development needed for MON-25/MMH combustion stability*
- **Mass**
  - *Low dry mass contingency for this development phase*
  - *Propulsion requirements multiply impact to overall mass growth*
- **Reliability**
  - *Single-string network reliability*
- **Mission Operations**
  - *High tempo operations for multi-lander cruise and landing phase*

Scientific Objectives

- **Enhance knowledge of lunar interior**
- **Key science themes:**
  - *Determine lateral variations in the structure and composition of the lunar crust, upper mantle, lower mantle, and lunar core*
  - *Determine distribution and origin of lunar seismic activity*
  - *Determine the lunar global heat flow budget to better constrain knowledge of lunar thermal evolution*
  - *Determine bulk lunar composition of radioactive heat-producing elements*
  - *Determine nature and origin of lunar crustal magnetic field*

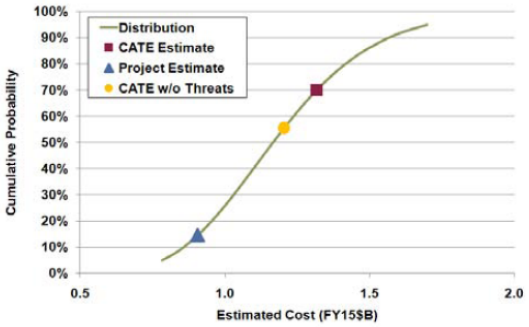
Key Cost Element Comparison



Key Parameters

- **Payload**
  - *Seismometer*
  - *Heat Flow Experiment*
  - *Electromagnetic Sounder*
  - *Lunar Laser Ranging*
  - *Guest Payload*
  - *Education/Public Outreach Pancam*
- **Advanced Stirling Radioisotope Generator Surface Power**
- **Launch Mass: 3572 kg (257 kg individual lander mass)**
- **Launch Date: 2016 (on Atlas V 511)**
- **Direct lunar near-side landing**

Cost Risk Analysis S-Curve

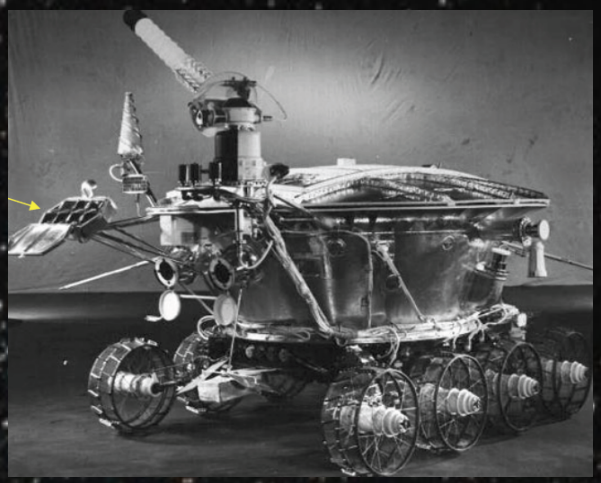


LUNAR Efforts to Advance Lunar Laser Ranging

Recovery of Lunokhod 1 Retroflector with APOLLO

Lead: Thomas Murphy (University of California, San Diego)

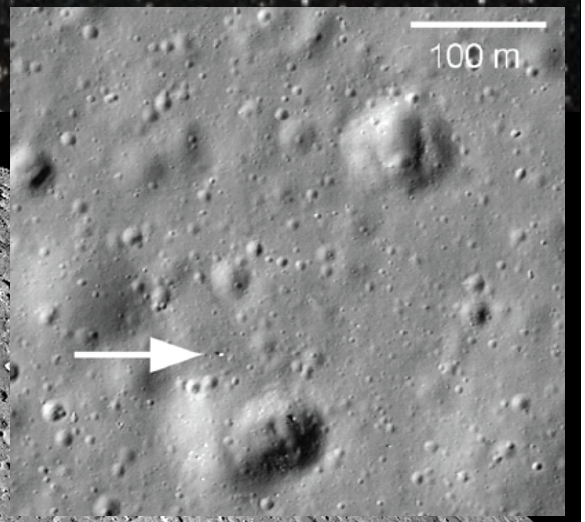
Apache Point Observatory Lunar Laser-ranging Operation (APOLLO)



Lunokhod 1 Lander

- Offset was 40 m (270 ns) in projected range (100 m lateral), putting signal at edge of gate.

- Potential Science: Offers best leverage on libration (slow oscillation motion of the Moon) determination => key for center of mass determination & lunar interior study.
- Exploration: Improvements in lunar cartography



LROC image of Lunokhod 1 site

Lunar Interior Science Results from LLR

- Core data set for lunar interior is the historical record of the librations. Most effectively obtained by observing all 5 retroreflectors in short period of time (which APOLLO can do). This cancels a number of systematic errors.

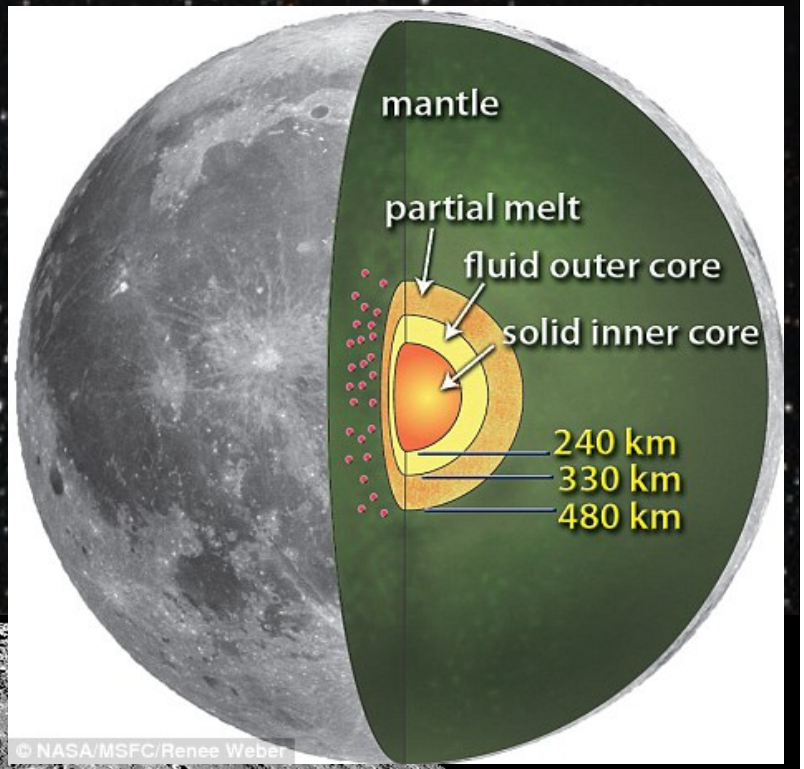
- Liquid Core: Fluid core moment of inertia is latest lunar geophysical parameter to emerge from LLR analysis.
  - For uniform liquid Fe core without an inner core, LLR estimates radius of 390±30 km.
  - For Fe-FeS eutectic, radius would be 415 km.

Librations of the Moon

Lunar Interior Science Results from LLR

- Oblateness of the lunar core: detection of oblateness is independent evidence of fluid core. For 390 km core, difference between major & minor axes is ≈ 80 km.

- Search for a solid inner core: It is reasonable to expect that the Moon would have a solid core interior to the fluid core, but it remains undetected. An inner core might be detected through its influence on physical librations or gravity [...]. This is a goal for next generation LLR with factor of 100 improvement in accuracy ($\sim 10\ \mu m$).

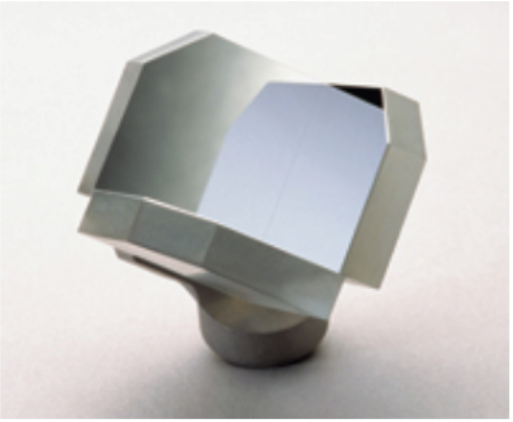


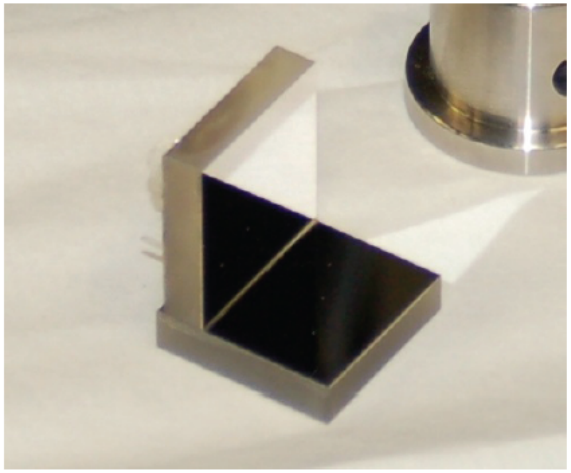
LUNAR Efforts to Advance Laser Ranging

Hydroxide Bonding and Hollow Cubes

Lead: Stephen Merkowitz (NASA/GSFC)

- GSFC has been investigating in-house hollow corner cube development
- Attempting to use Hydroxide-Bonding techniques to bond mirrors
  - Easy: only need a small amount of hydroxide solution (typically KOH or sodium silicate)
  - Strong: >1 MPa in shear
  - Can bond large surface areas
  - Works with a variety of materials
  - Can survive large temperature changes
- Currently understanding how the hydroxide bond cures
  - How much does it change the angles between surfaces?



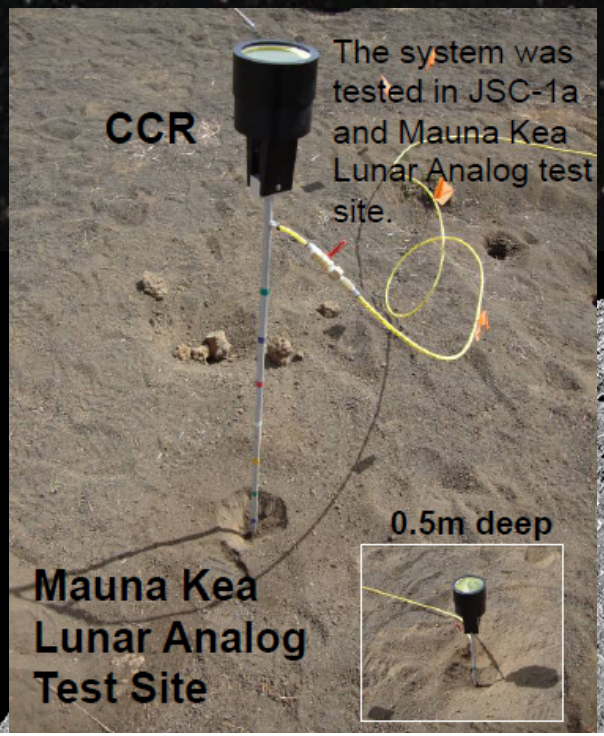


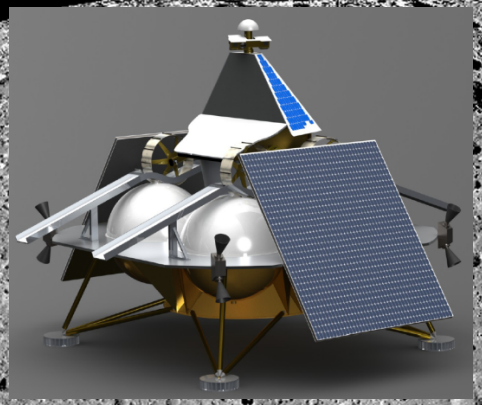
Two 1" mirrors bonded using the hydroxide bonding method

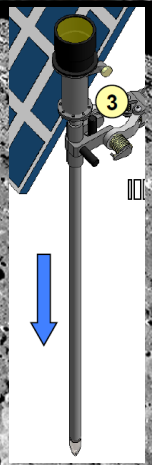
LUNAR Efforts to Advance Laser Ranging

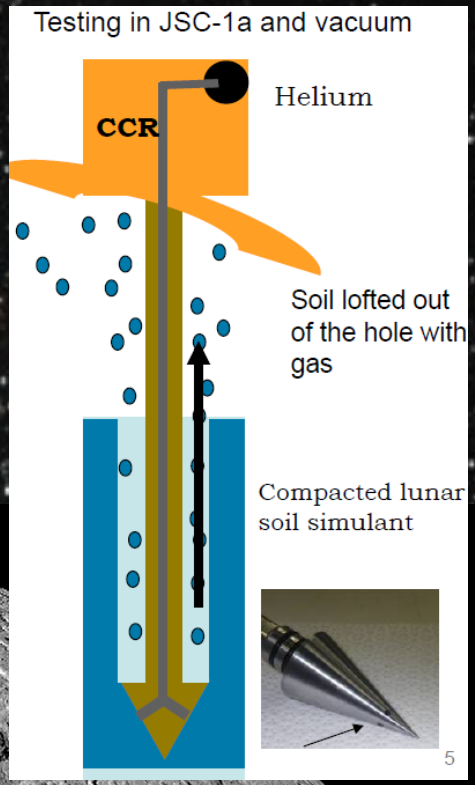
Gas Assisted Drilling

Leads: Kris Zacny (Honeybee Robotics), Douglas Currie (Univ. Maryland)









Probing the Ionized Lunar Atmosphere

Lunar Ionosphere & Riometry

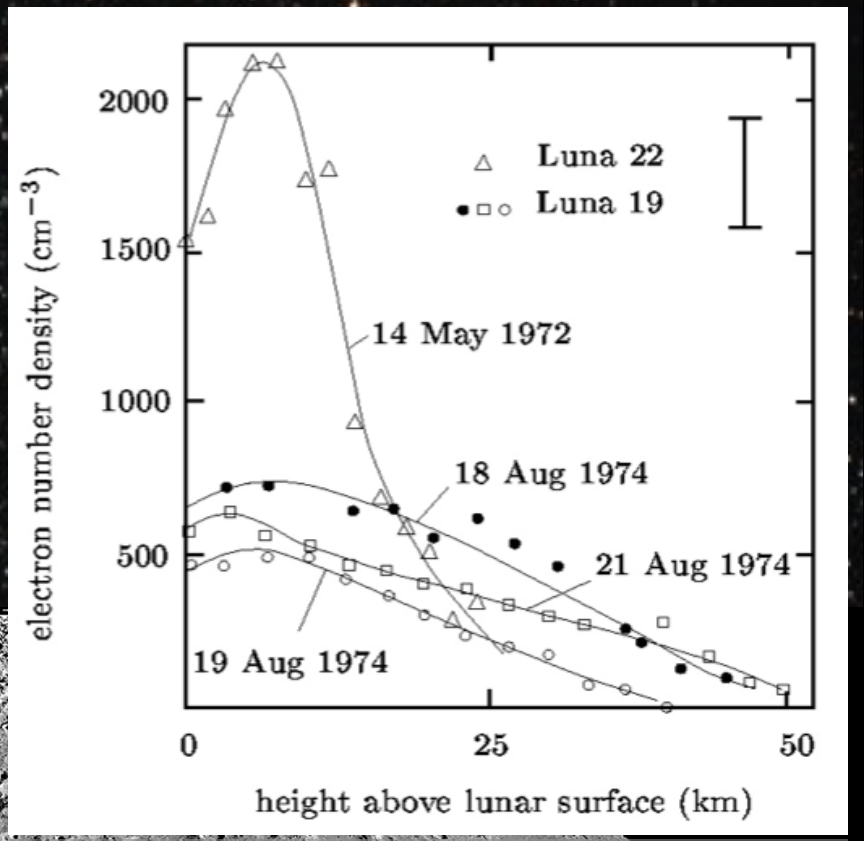
Lead: Joseph Lazio (JPL/CIT)

- "[E]xospheres, those tenuous atmospheres that exist on … the Moon, Mercury, asteroids, and some of the satellites of the giant planets, are poorly understood …. Insight into how they form, evolve, and interact with the space environment would greatly benefit from comparisons of such structures on a diversity of bodies." *Visions and Voyages*

- Determining & tracking the properties of the lunar exosphere both robustly and over time requires a lunar-based methodology so the exosphere can be monitored over multiple day-night cycles from a fixed location(s).

- A *lunar relative ionosphere opacity meter* (*riometer*) exploits characteristic of a plasma to measure the ionospheric density

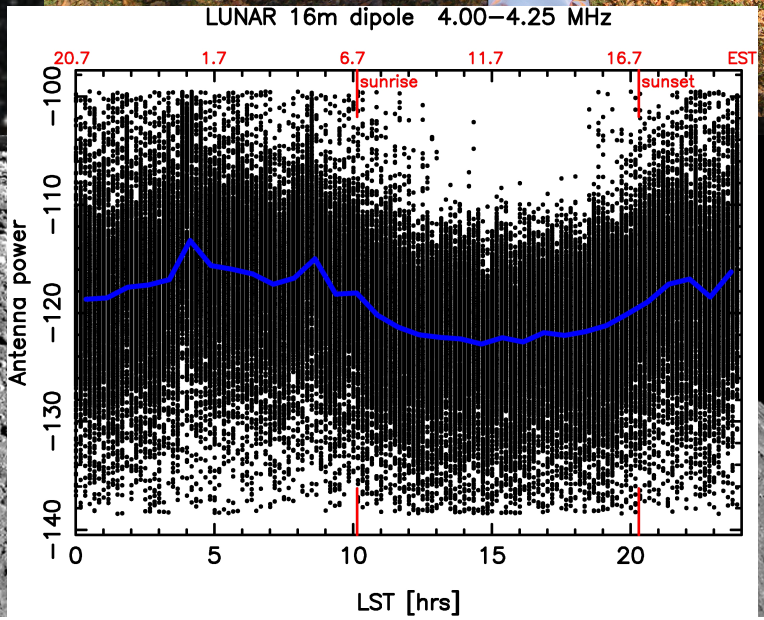
$$f_p = 9 \text{ kHz } (n_e/1 \text{ cm}^{-3})^{1/2}$$

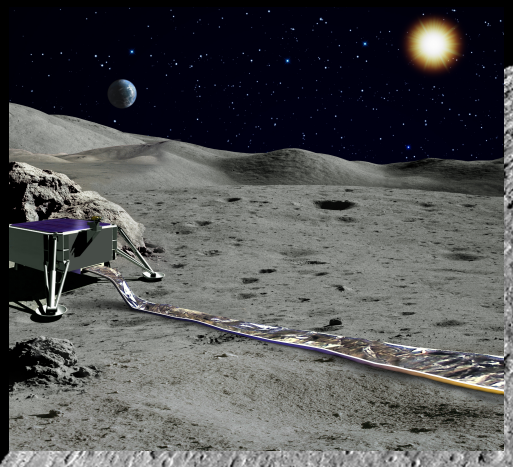


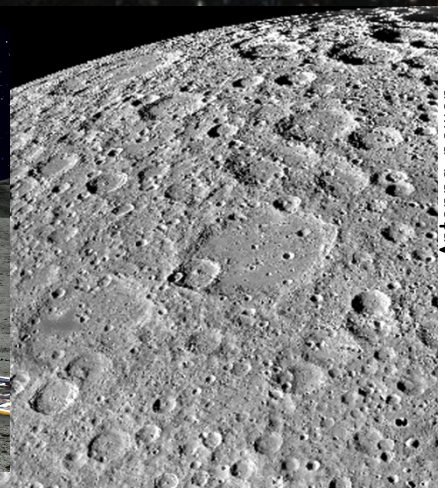
Lunar ionosphere electron densities derived from dual-frequency radio occultation measurements during the Luna 19 and Luna 22 missions .

Riometer Concept

- Polyimide film based dipole(s)
- Radio receiver
- Power
  - < 10 W target
- Mass
  - < 10 kg target
- Siting
  - Anywhere on near side
  - Far side also interesting



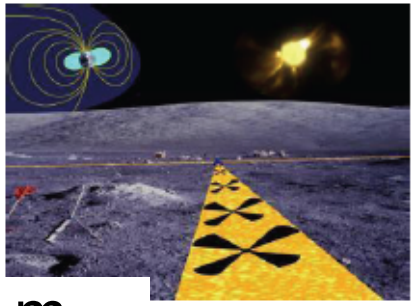




An Interplanetary Dust Detector on the Lunar Surface

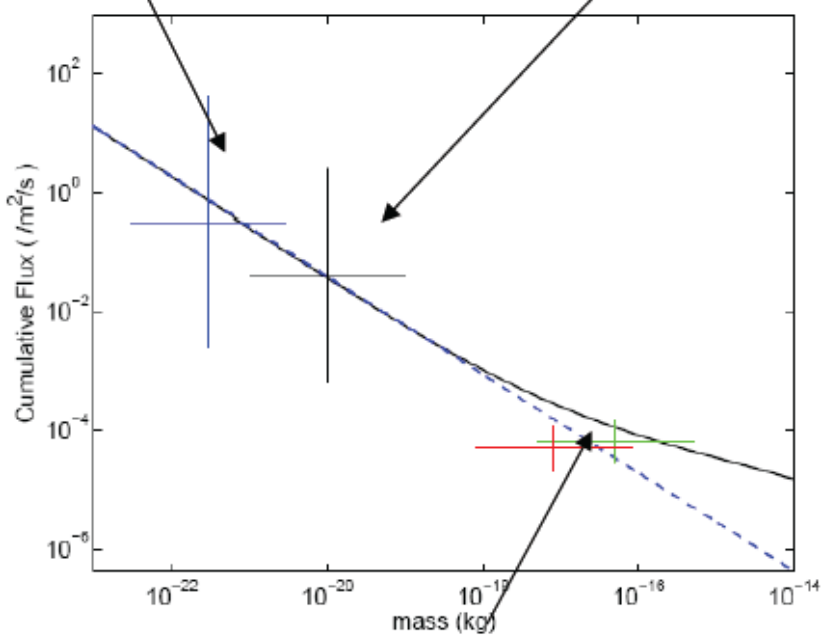
Lead: Justin Kasper (Harvard-Smithsonian CfA)

- STEREO Results for dust fluxes at 1 AU
- Solid line compares with model [Grun et al, 1985]
- Implications for ROLSS
- Three 500 m x 1 m Kapton = 1500 m^2
- Order 10^3 dust impacts per second

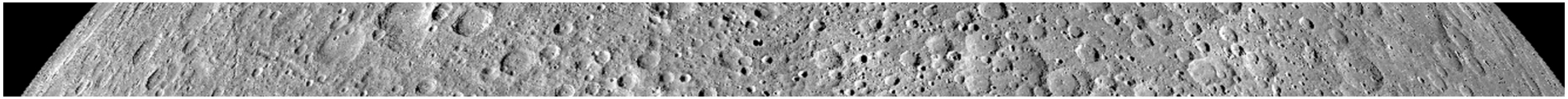


WAVES TDS (1 antenna hit) [Zaslavsky et al, in prep]

WAVES LFR [Meyer-Vernet et al, 2009]



S/WAVES TDS (Beta and ISD) (3 antenna hit) [Zaslavsky et al, in prep.]



Science-driven Exploration

L2-Farside mission

- Telerobotically deploy packages to the far side
- Astronauts would travel 15% farther from Earth than *Apollo* astronauts, and spend almost 3× longer in deep space.
- Demonstrate Orion's life support systems for one-month duration missions
- Demonstrate the high speed reentry capability needed for return from deep space – 40 to 50% faster than reentry from low Earth orbit
- Verify that Orion provides sufficient protection from cosmic rays and solar flares

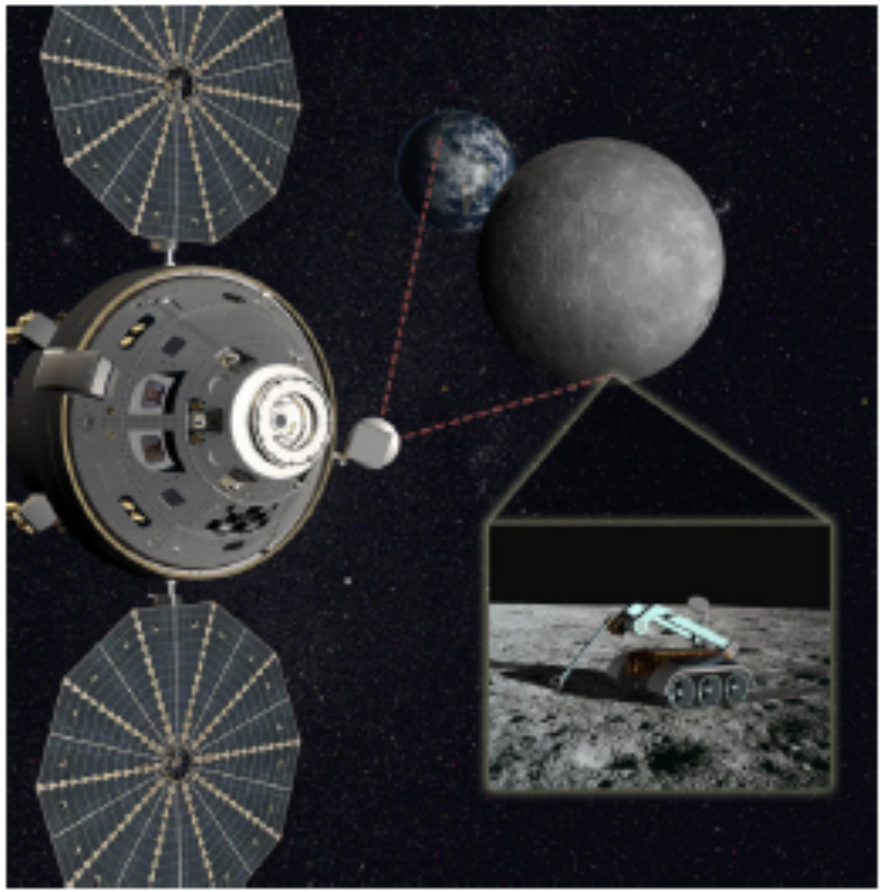
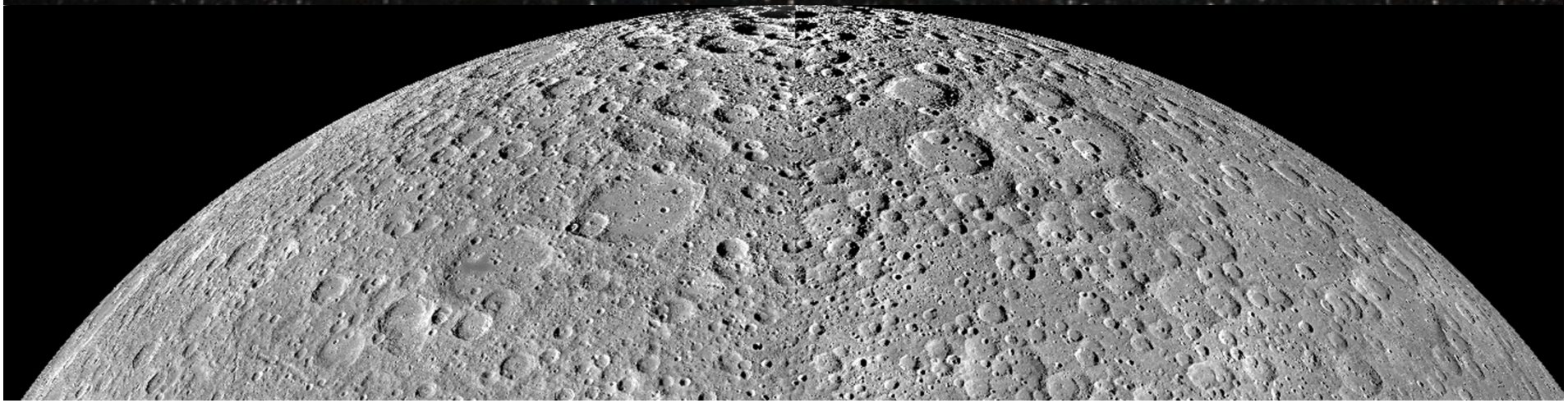
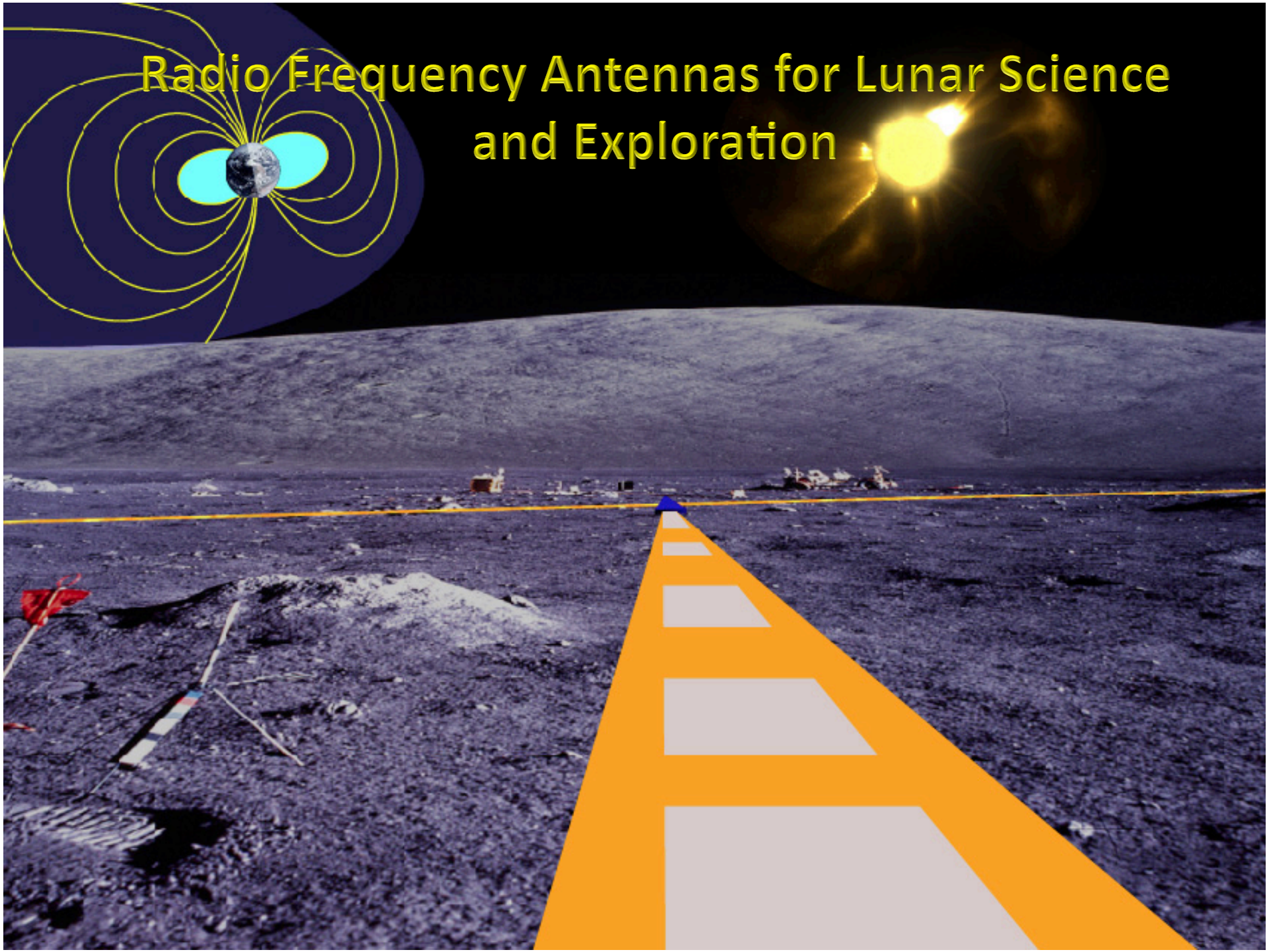


Figure 3. L2-Farside mission using Orion.

Conclusions

- Lunar Laser Ranging will provide critical data to determine the initial composition of the Moon and the Earth-Moon system. Specifically, LLR uniquely measures the properties of the lunar core via librations. LUNAR is advancing LLR:
  - APOLLO recovery of Lunokhod 1, thus dramatically improving measurements of librations.
  - Technology development of next generation retroreflectors.
  - New drilling techniques.

- Dual-use Low Frequency Radio arrays will constrain
  - Lunar ionosphere density via riometry.
  - Nano-size interplanetary dust particles responsible for surface weathering.



Radio Frequency Antennas for Lunar Science and Exploration