An Ultra-Long-Wavelength Observatory on the Lunar Farside

An ASTRA Mission Concept

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***Mission concept art c/o* Gregg Hallinan**
***The above-lunar sky is a real, low-frequency all-sky image from* OVRO-LWA.**

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Authors

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Compelling Science

Dark Ages Cosmology

- Exotic physics / excess cooling
- Dark matter microphysics
- Inflationary signatures

PhysPAG

Exoplanet Magnetospheres & Space Weather

- Stellar coronal mass ejections
- Exoplanet magnetic fields
- Habitability

ExoPAG

Enabling Science

Galactic Cosmic Rays

- Cosmic ray transport
- ISM magnetic fields
- Baryon feedback from stars

COPAG

Bonus Science

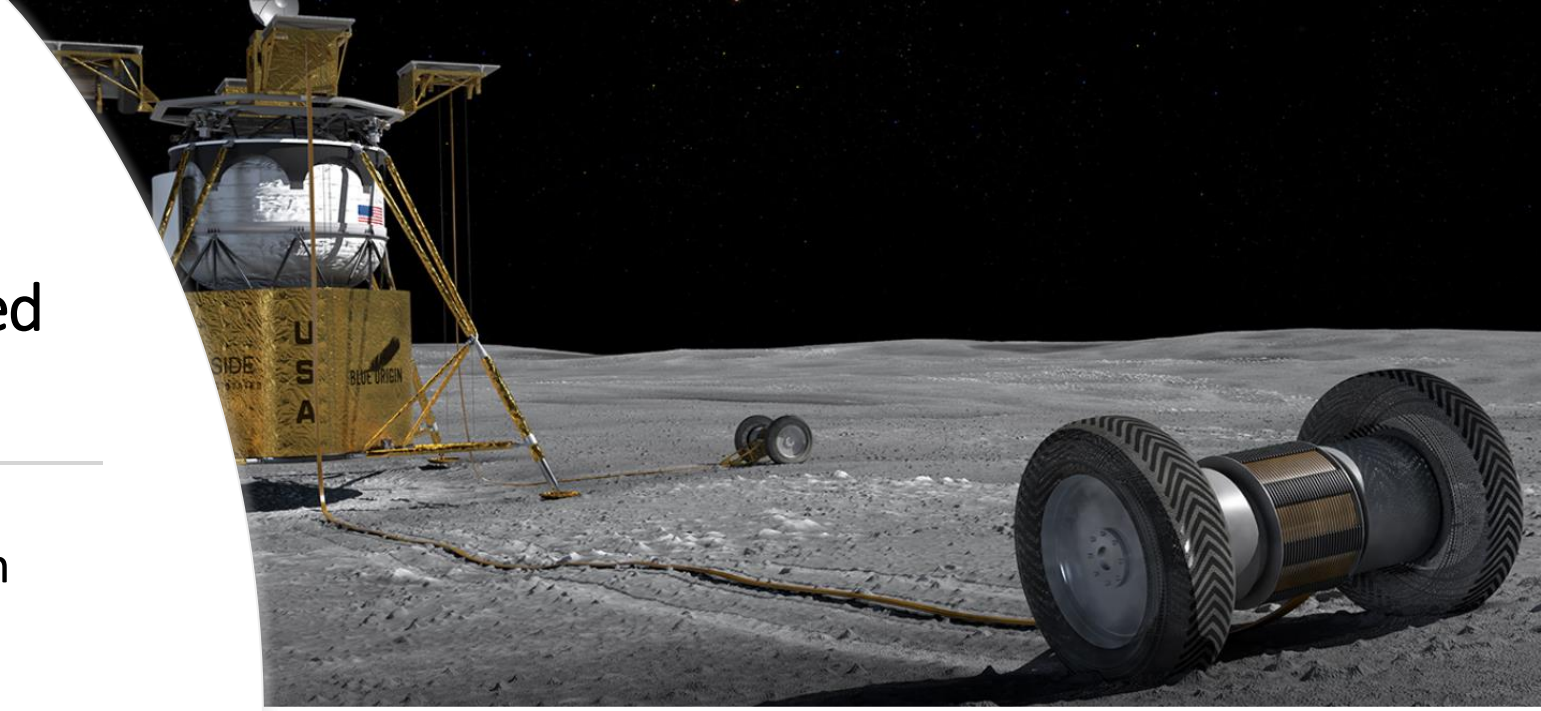
Heliophysics, Lunar Science & Exploration, & Planetary Science

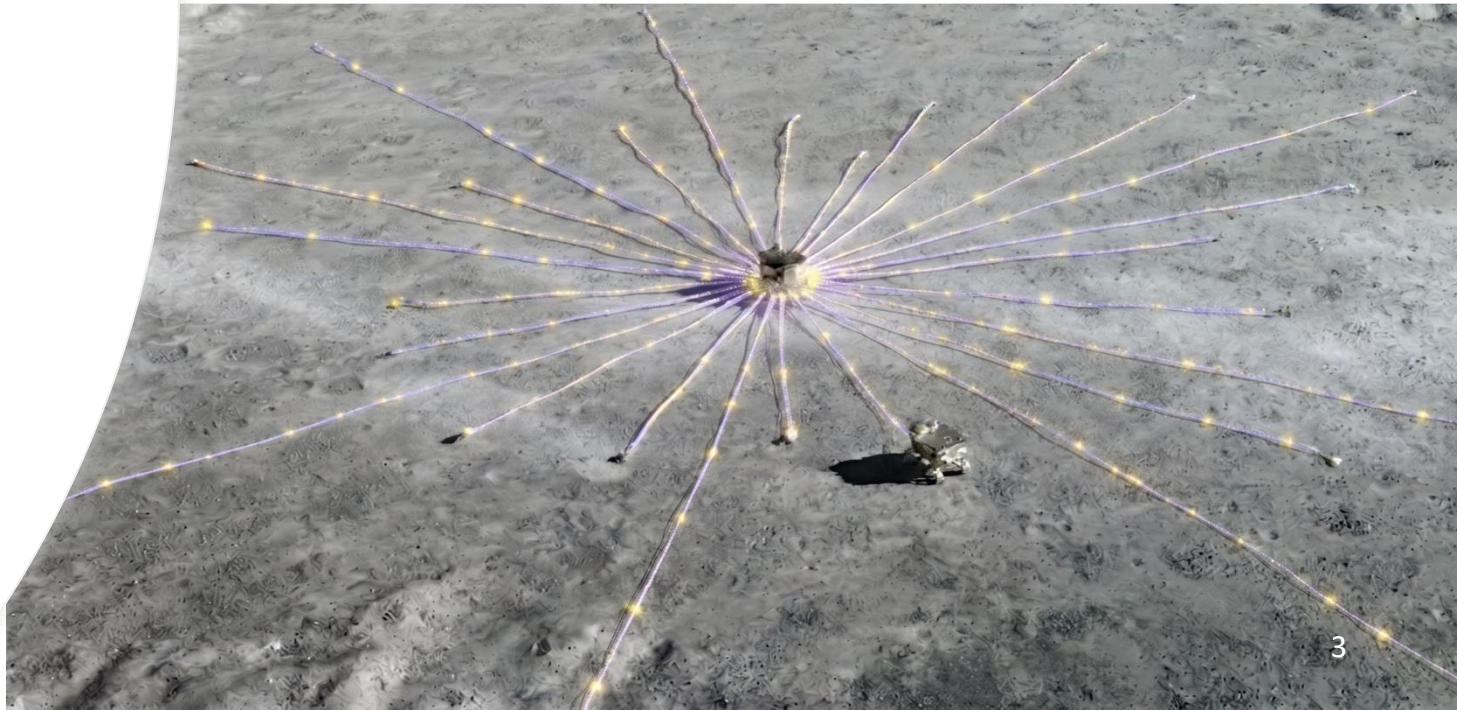
- Solar wind & particle acceleration
- Lunar ionosphere & seismology
- Ice-giant magnetospheres

OPAG & LEAG

The low-frequency radio sky remains one of the last unexplored frontiers in astrophysics.

- Low-frequency interferometric array on the lunar farside
- 128 dual-polarization dipole antennas
- Deployed by rovers across 1-10 km of lunar terrain
- Operating from ~100 kHz to 50 MHz
- Tethered to a central lander for power-and-RF-over-fiber and onboard correlation





Building on more than a decade of technical development for lunar radio astronomy.

Lunar Surface Precursors

In-situ characterization of the lunar radio and plasma environment

- ROLSES
- LuSEE-Night

NASA-funded Concept Studies

Scaling of architecture and TRL-maturation pathways

- FARSIDE
- LCRT
- FarView
- MoonRISE

Flight-qualified Hardware

Inheriting flight-qualified hardware heritage

- SunRISE
- Tethered Power Systems for Lunar Mobility and Power Transmission (TYMPO)

Ground-based Observatories

Utilizing proven operations and data-processing strategies

- OVRO-LWA
  - Full cross-correlation
  - All-sky imaging
  - Calibration pipelines

The most radio-quiet location in the inner Solar System: *the lunar farside*

- Accessing the < 30 MHz sky necessitates moving into space, beyond the Earth's
  - Ionosphere
  - Anthropogenic RFI
  - Auroral Kilometric Radiation (AKR)

- Increased sensitivity within the lunar plasma cavity (during lunar night), reducing the solar wind plasma density and lowing the quasi-thermal noise floor by > 2 orders of magnitude

*Pristine RFI environment of the lunar farside, as measured by Radio Astronomy Explorer 2 in 1973 (**Alexander et al. 1975**).*

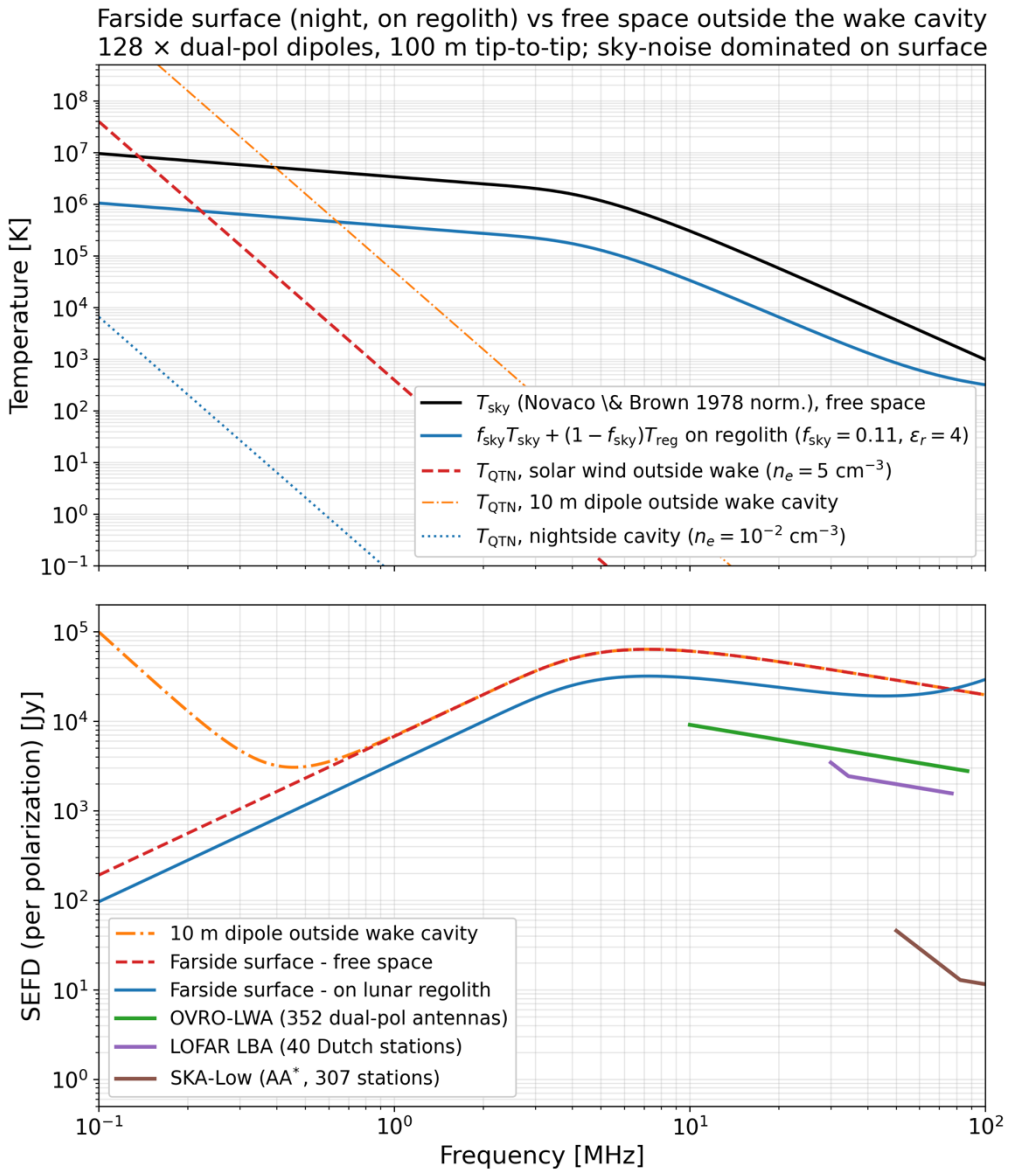


Figure c/o G. Hallinan

Mission Architecture –

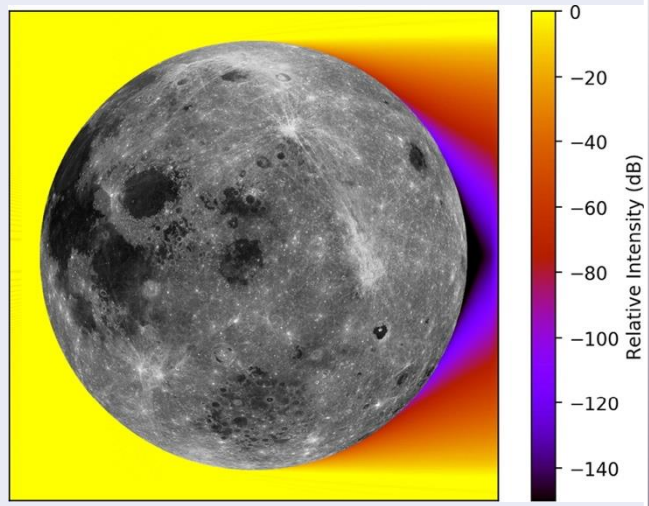
Leveraging existing and high-maturity technology and instruments to achieve next-generation science

Instrument Component	Technology Readiness Level (TRL)
Dipole Antenna: Metallic wire embedded directly in the tether.	**High (Std. Engineering) –** Heritage from the Apollo 17 Surface Electrical Properties (SEP) Experiment and ALSEP tape tethers. Also demonstrated in the field by the MoonRISE CLPS proposal.
Receiver Electronics: Sky-noise-limited low-noise amplifiers (LNAs) and analog-to-digital converters (ADCs)	**High (TRL 6) –** LNAs from the soon-to-be-launched SunRISE spacecraft mission. RF-over-fiber electronics from OVRO-LWA.
Calibration Electronics: Self-calibrating front-end with a Vector Network Analyzer (VNA) to characterize the antenna's electrical properties.	**Low–Med (TRL 4–5) –** Space-adapted EDGES receiver flown on one cubesat; VNAs exist but need space qualification. Regolith/bedrock beam calibration needs development.
Correlator: Centralized FX correlator for interferometric processing of all dipole data.	**High (Std. Engineering) –** Digitizer and rad-hard FPGA host board for interferometric processing, flight-proven over multiple space missions including SunRISE.
Tether-based Power & Data System: Carries power from the central lander to all dipoles and returns data to the lander.	**High (TRL 6) –** TYMPO demonstrated km-scale tether-based power transmission and communication. MoonRISE demonstrated power-over-fiber and RF-over-fiber in the field to reduce RF interference.
Thermal & Mechanical System: Ensures instruments survive the Lunar day–night temperature swings of ~250°C.	**High (TRL 6) –** Farside Seismic Suite CLPS mission's cube-within-a-cube thermal/mechanical architecture survives multiple Lunar day–night cycles.

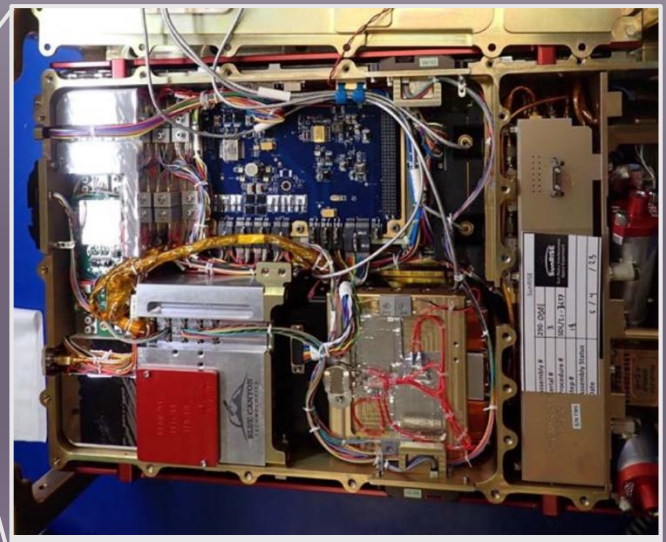
Concept of Operations –

Autonomous deployment and passive operations significantly reduces risk and complexity

Mission Phase	Operational Details
Landing & Positioning	One or more CLPS landers touch down at the selected Lunar farside location, within ~60° of the anti-Earth point for >80 dB attenuation of terrestrial RFI.
Tether Deployment	Single/multiple deployment rovers egress from the landers and deploy tethers in the desired interferometric layout, burying them beneath ~1 cm of Lunar regolith for micrometeorite protection.
Antenna RF & Power	128 dipole antennas embedded in tethers receive power-and-RF-over-optical fiber (preventing coupling between dipoles and tether), creating a static radio interferometer with no moving parts.
Signal Processing	A centralized and EM-shielded correlator located on the lander digitizes, cross-correlates, and time-averages the dipole signals to generate low-data-rate interferometric visibilities for downlink.
Continuous Operation	Operating autonomously without active uplink commanding, the array runs continuously through multiple Lunar day and night cycles for a baseline mission of 2–5 years extendable to a flagship-scale.



Bassett et al. 2020

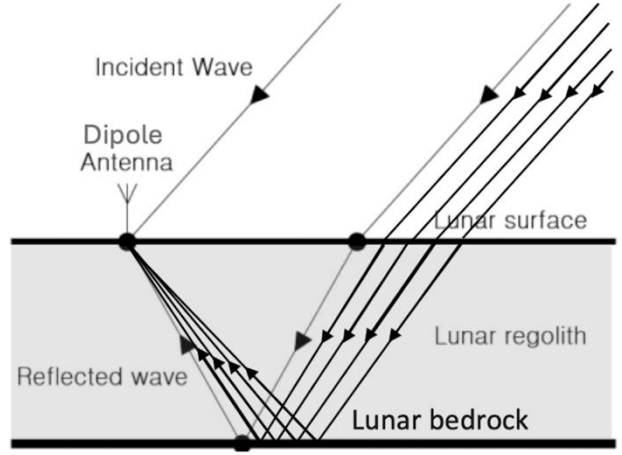


SunRISE smallsat, incl. processing system

Trade Studies –

Open questions – regarding technology, architecture, and implementation – to be explored

Focus Area	Objectives & Options Evaluated
Array Architecture & Layout	Explore single- vs. multi-arm dipole arrays and optimized configurations to determine total dipole count, interferometric layout, and required mission lifetime.
Power Generation & Distribution	Evaluate power generation (RTGs vs. solar arrays with regenerative fuel cells) and distribution (AC-over-copper vs. power-over-fiber) under strict RFI constraints.
Receiver Electronics & Tether Topology	Assess low-power receiver electronics operable through Lunar day-night cycles and optimize tether topology for distribution efficiency versus micrometeorite protection.
Calibration & Regolith Interaction	Evaluate calibration options (GPR, active self-calibration via dipoles, or an orbital beacon satellite) using end-to-end forward-modeling to assess residual systematics against science requirements.
Sky Map Simulation & Science Requirements	Generate physics-based simulated low-frequency sky maps to prioritize target fields for Science Goal 3 and refine spectral imaging requirements.



Zhang et al. 2015

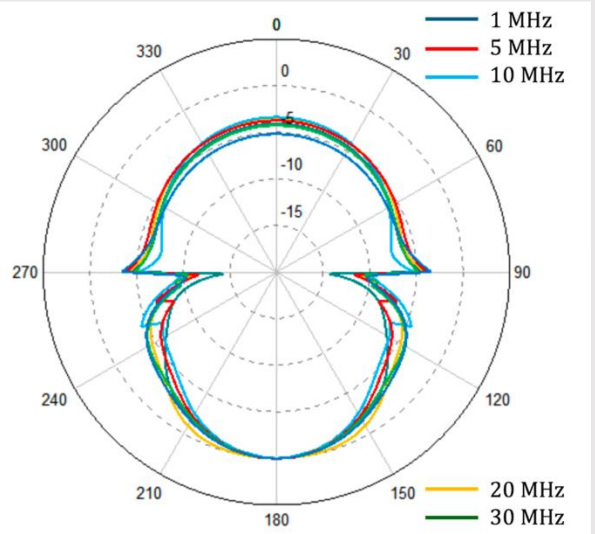


Figure c/o Gaurangi Gupta

Leveraging external capabilities –

Artemis Infrastructure, Commercial Lunar Payload Services (CLPS), and the NASA Moon to Mars (M2M) Strategic Focus and Technology Development

M2M Science & Technology Goals

NASA M2M Objectives

- Physics & Physical Science (PPS): fundamental astrophysics from the lunar farside
- Lunar/Planetary Science (LPS) & Heliophysics Science (HS)
- Science-Enabling (SE) lunar infrastructure:
  including power-and-data transmission architectures

Artemis Science Definition Report

- Surface payload deployment and environmental characterization

Launch & Lunar Landing

Frequent, cost-effective flight opportunities

- Regular CLPS launch cadences
- Possibility for pathfinders *or* incremental / scalable deployment

Targeted delivery to the lunar farside

- Frequent deployments provide technology development / TRL-maturation opportunities

Deployment & Operations

- CLPS rover development and technology demonstration

Cislunar Orbiters

- Utilizing existing network (serving, e.g., Moon Base) for communications and data relay back to Earth
- Orbiting beacons for array calibration (e.g., LuSEE-Night far-field calibration beacon)

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The right mission for the right opportunity!

Team Ad ASTRA talks and posters –

Science Talks

- *Cosmology*
  - Jack Burns, “A Vision for Low Radio Frequency Astrophysics and Cosmology from the Far Side of the Moon: The Cosmic Dark Ages”
- *Exoplanets*
  - Gregg Hallinan, “The Magnetospheres of Terrestrial Exoplanets from the Lunar Farside”
- *Galaxies & Cosmic Rays*
  - Kathryn Plant, “Probing the Galactic ISM Tomographically at Low Frequencies”
  - Martijn Oei & Kathryn Plant, “Galactic Cosmic Ray Physics with the Ultra-long Wavelength Lunar Farside Observatory”

Technology Talks

- Jack Burns, “The FarView Low Frequency Radio Array on the Moon’s Far Side”
- Saptarshi Bandyopadhyay, “Lunar Crater Radio Telescope (LCRT) on the Farside of the Moon”
- Kathryn Plant, “The Digital Signal Processing Trade Space for Space-based Radio Telescopes”
- Nivedita Mahesh, “The Moon as an Astrophysics Platform”

Poster

- Saptarshi Bandyopadhyay, “Moon Radio Interferometer for Science and Exploration (MoonRISE)”