Heliophysics Science Committee Report on Science at the Moon

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Heliophysics Subcommittee

What is "Heliophysics"?
(in the context of VSE)

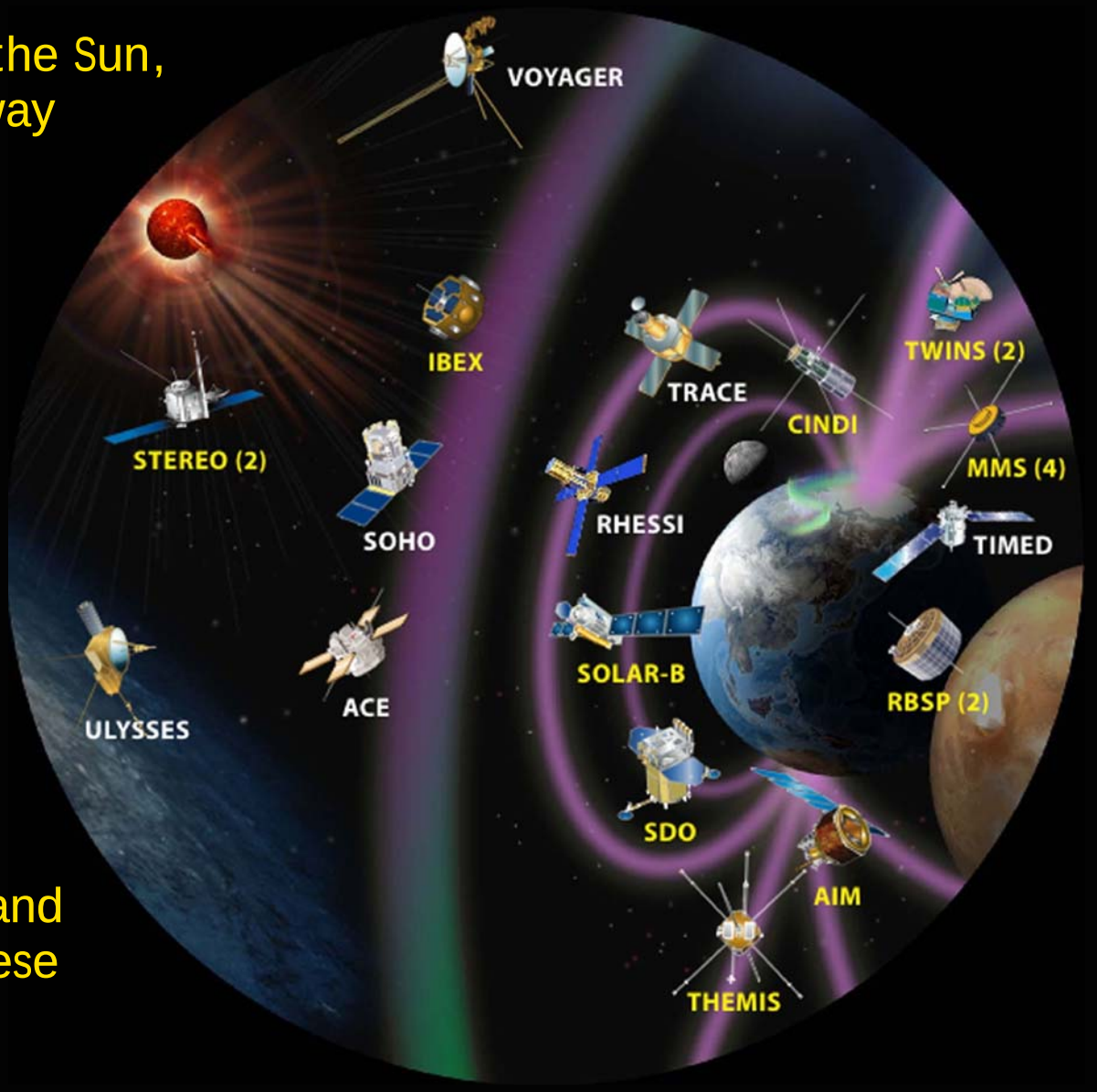
The realm of **heliophysics** is the perilous ocean through which explorers, both robotic and human, must journey to reach the dusty shores of the Moon, then Mars.

Gibson and Spence, 2007

Our Moon is influenced by the Sun, a main-sequence star midway through its stellar life.

Through the eyes of our Heliophysics Great Observatory, we see the Sun, Earth, and Moon as a single, interconnected system moving through interstellar space.

Heliophysics seeks to understand how and why the Sun varies, how the Earth and Moon responds, and how human activities in these environments are affected.



These science activities are considered to be fundamentally useful to the goals of the Vision for Exploration.

Heliophysics Science at the Moon

Science community efforts to explore the range of priority potential Heliophysics science topics have defined four themes:

1) Space Weather, Safeguarding the Journey

2) Heliophysics Science *of* the Moon

3) The Moon as a Historical Record

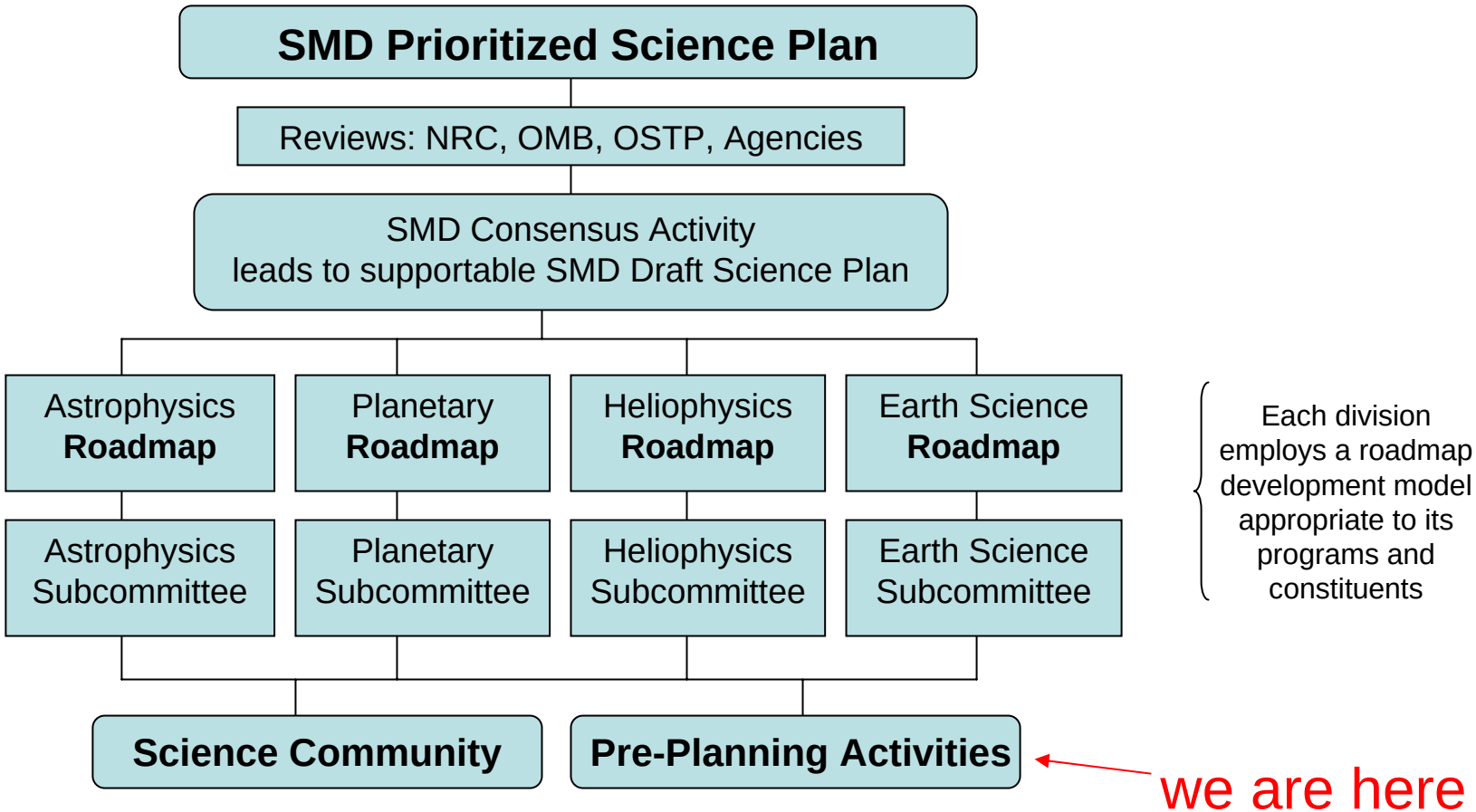
4) The Moon as a Heliophysics Science Platform

Heliophysics Science at the Moon

Subcommittee Workshop Findings:

- Future evaluations must assess cost effectiveness of lunar site versus robotic mission around the Moon or elsewhere.
- Involvement of Scientist Astronaut is critical to full mission success.
- Lunar science assessments formulated at this workshop are valuable input to the next NRC Decadal Survey for Solar and Space Physics and NASA Heliophysics Science Roadmap

Traditional Strategic Planning Process



Heliophysics finding: NASA Science Mission Directorate has a <u>well validated process for establishing science priorities</u> within their resource allocations. Once complete, the lunar science opportunities information should enter into this process in the same manner as other SMD Pre-Planning Activities

Heliophysics Science at the Moon

Subcommittee findings cont'd:

- **Rough** assessment is defined by:
  - High: Science is of high value and achievable within the architecture OR the importance to lunar operations is deemed high
  - Medium: Science is of secondary value and achievable within the architecture OR the objective is deemed important to lunar operations
  - Low: Little or no science return OR the likelihood of achieving the objective within notional architecture is low
- For several objectives, drop-off satellites or early robotic operations are optimal.
- Full assessments and technical details are contained for all concepts in spreadsheet comments and in the Heliophysics Subcommittee report on Heliophysics Science at the Moon.

Report on Heliophysics Science at the Moon

Outline:

Heliophysics Science of the Moon:

- Characterization of Near Lunar Electromagnetic / Plasma Environment
- Determine Crustal Magnetic Fields and their Origins
- Magnetotail Dynamics at Lunar Orbit
- Impact of Plasma Environment on the Moon

Space Weather, Safeguarding the Journey:

- Understand and Predict Space Weather impacts
- Characterize Radiation Bombardment on Lunar Surface
- Understand Interaction of Lunar Dust and Plasma

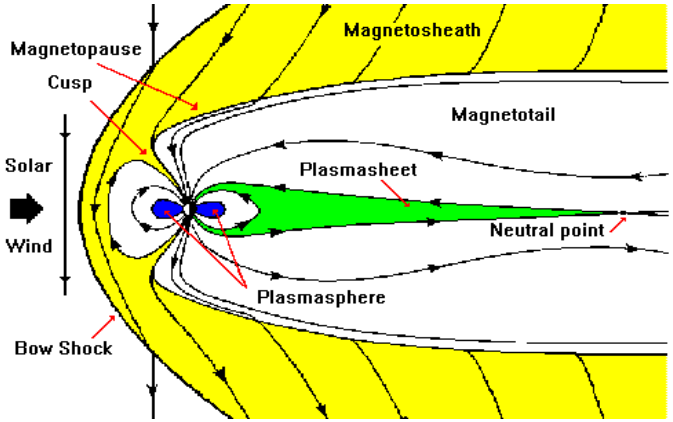
The Moon as a Historical Record:

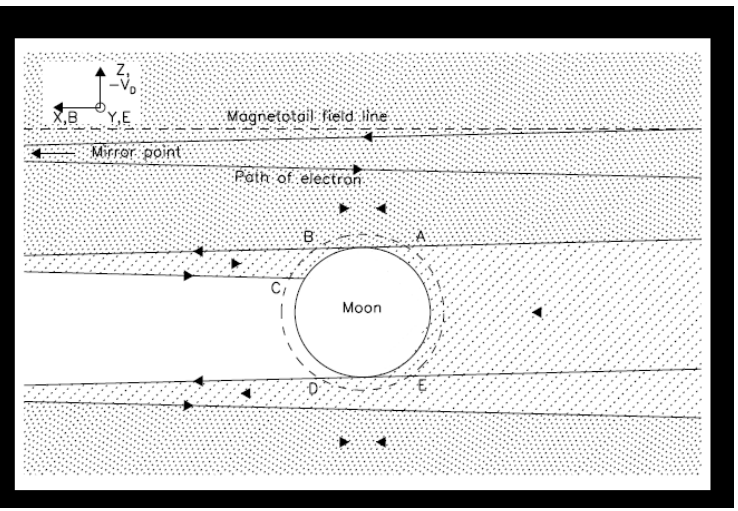
- Composition of the Solar Wind
- History of the Sun
- History of Cosmic Radiation
- History of the Inner Solar System

The Moon as a Heliophysics Science Platform:

- Lunar Wake as a Heliophysics Plasma Laboratory
- Imaging the Heliospheric Boundary
- Radio Observations of the Sun
- Ionospheric/Magnetospheric Imaging
- High-Energy Solar Imaging
- Sun's Role in Climate Change

Heliophysics Science of the Moon





Magnetotail dynamics at lunar orbit

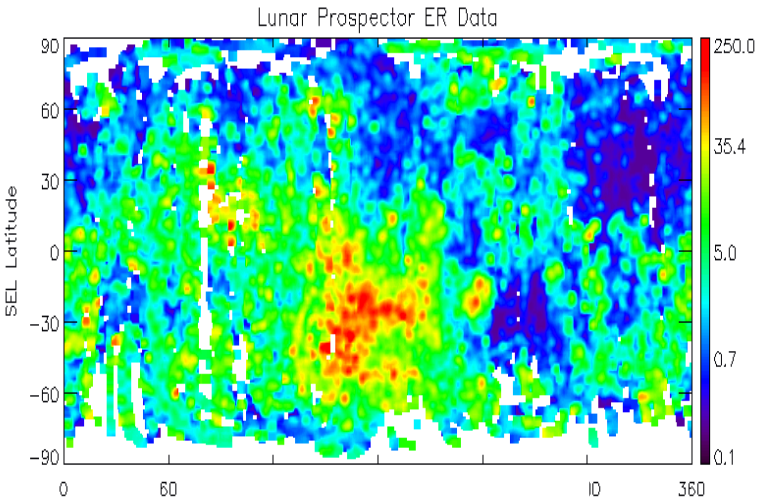
ID# : mHEO3 - Study the dynamics of the magnetotail as it crosses the Moon's orbit to learn about the development and transport of plasmoids.

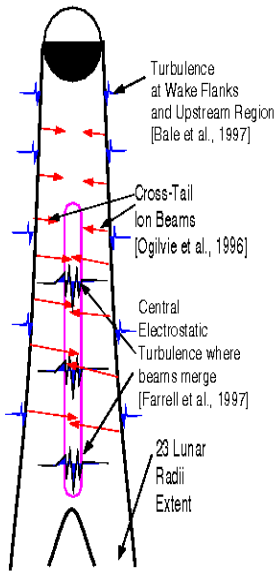
Relative Assessment : High Green

Comments: The dynamical behavior of the distant magnetotail, where a substantial fraction of the total energy coupled into the magnetosphere from the solar wind is stored, is not understood. It is different from the near-Earth, with quasi-continuous, physically different magnetic reconnection. The Moon is an unique location for studying the deep magnetotail, allowing diagnostics of the magnetic field topology and convection velocity by observations of lunar shadowing of ambient electrons

Suitability of Single Site Architecture: Requires an orbital mission, perhaps as a drop-off satellite.

Heliophysics Science of the Moon





Lunar Wake

ID# : mHEO4 - Study the impact of the Moon on the surrounding plasma environment and incident solar wind to better understand the magnetotail. Study fundamental plasma physics at the fluid-kinetic interface.

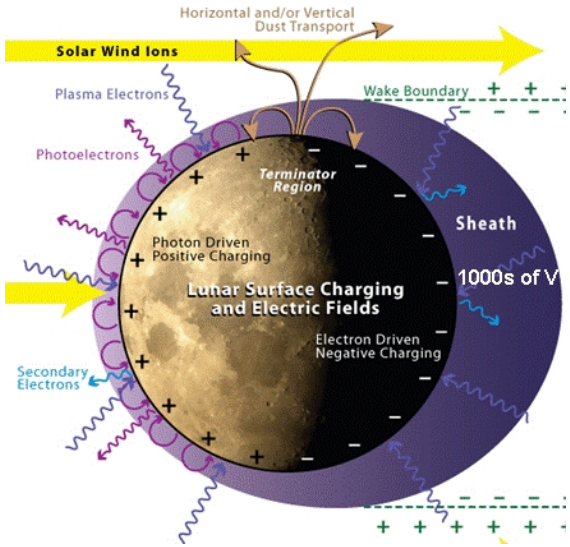
Green

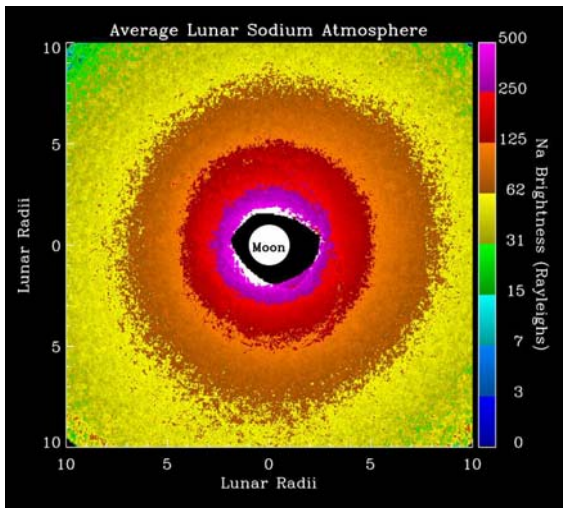
Relative Assessment : High

Comments: The behavior of plasmas in the transition from kinetic (particle) to fluid scales is a problem of critical importance to many fields of study. The size of the lunar disk, and of regions of enhanced magnetism on the lunar surface, span the kinetic and fluid ranges of many particle species. This permits a study of fundamental physics at the kinetic/fluid interface to be made.

Suitability of Single Site Architecture: Requires orbital mission, perhaps as a drop off

Heliophysics Science of the Moon





Characterize natural state of Lunar environment

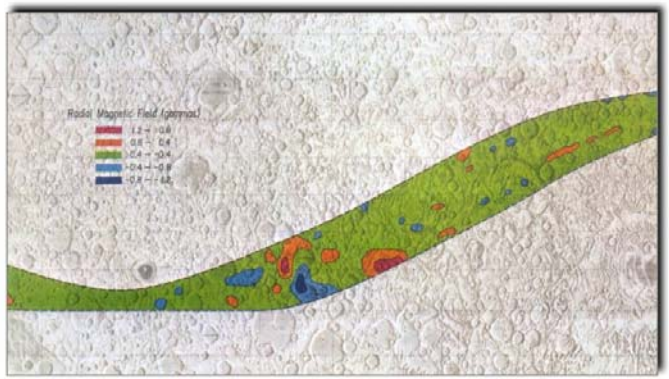
ID# : mENVCH7 - Characterize the lunar atmosphere to understand its natural state. Of major importance, is the electromagnetic and charged dust environment and interaction with the variable space environment.

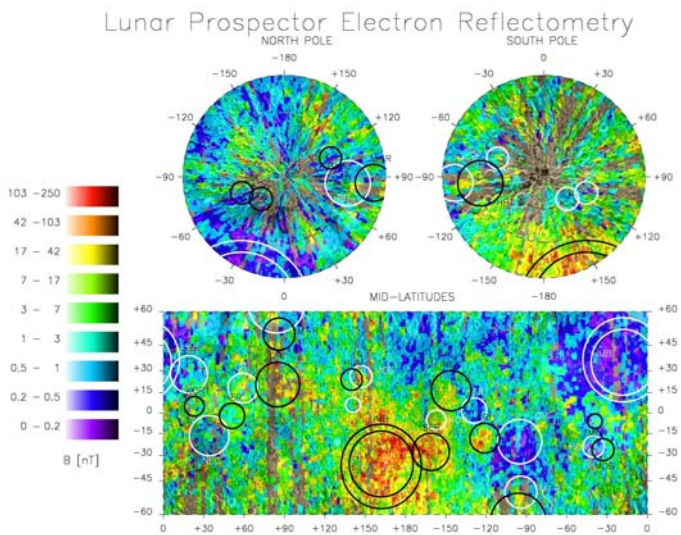
Relative Assessment : High Green

Comments: NRC interim report identifies this objective as high priority. Highly likely that electrostatic charging and dust environment will have direct impact on operational mission. Science applications are specifically targeted to the particular nature of moon environment and the issues of critical systems and human operations. Safety and reliability designs would require investigation before substantial human activity.

Suitability of Single Site Architecture: Requires both orbital mission, perhaps as a drop off, and surface lunar package, before substantial human activity.

Heliophysics Science of the Moon





Lunar crustal magnetic fields and their origins

ID# : mENVCH10 - Map the surface electromagnetic field of the Moon to understand the operational environment of the Moon. Measure the lunar crustal magnetic field and understand its origins and effects.

Relative Assessment : High

Green

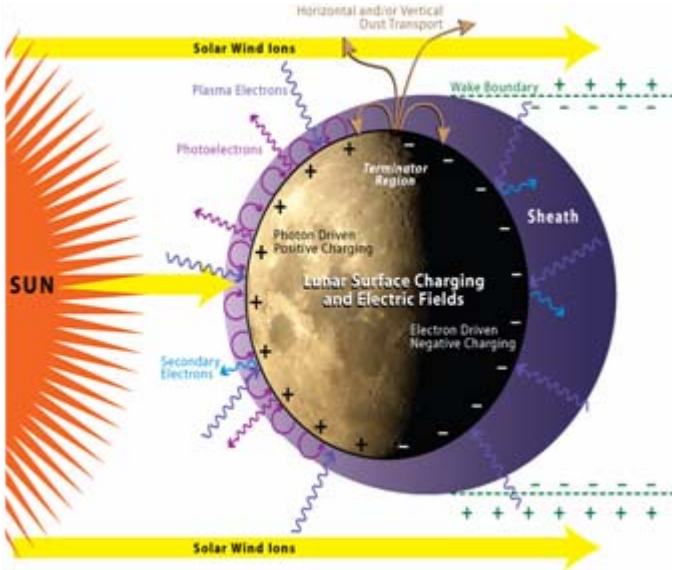
PINK

Comments:

- Subset of complete mENVCH10 objective.
- Magnetic field important for the local plasma, dust, and particle environment.
- New science in unique plasma parameter regimes.
- Relates to history of the moon; analog for Mars.
- Magnetic shielding may influence site selection of some exploration activities.
- Similar instrumentation needed for other objectives.

Suitability of Single Site Architecture: Orbital in initial stages (low perilune). In situ rover studies around base and during sorties to supplement; selected oriented sample returns.

Space Weather,Safeguarding the Journey



Interaction of dust and plasma on the surface of the Moon and in the exosphere

ID# : mENVCH4 - Characterize the dust environment at several locations on the lunar surface to better understand the operational environment of the Moon.

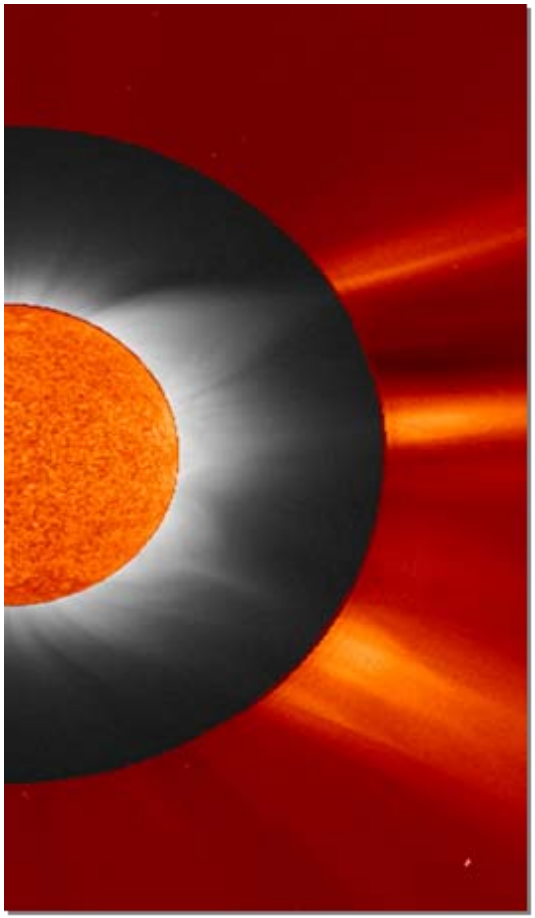
Relative Assessment : High

Green

Comments: There is a highly variable plasma environment at the orbit of the Moon due both to the changing conditions of the impinging solar wind and traversals of the magnetosphere. The moon can enter the hot and tenuous plasma sheet in the Earth's magnetotail, causing increased electrostatic potentials. The resulting surface charging can drive the electrostatic transport of charged lunar dust. The lunar dust-plasma is highly susceptible to space weather. Therefore, we need to observe the dust/plasma environment during range of different solar and magnetospheric activity conditions.

Suitability of Single Site Architecture: Consider strategic location (South Pole), as well as, or in addition to, distributed sites.

Space Weather, Safeguarding the Journey



Space weather impacts on robotic and human productivity

ID# : mENVMON1a - Monitor space weather in real time to determine and mitigate risks to lunar operations. Utilize the coordinated, distributed, simultaneous measurements by the heliospheric great observatory for predictive models of space radiation at the Moon.

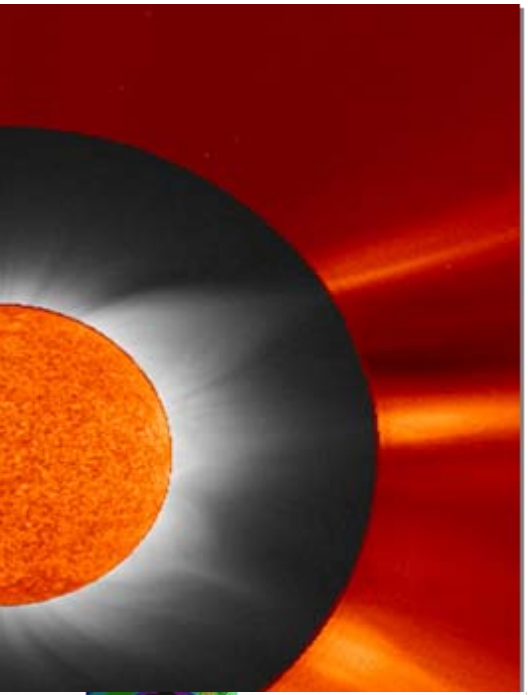
RED

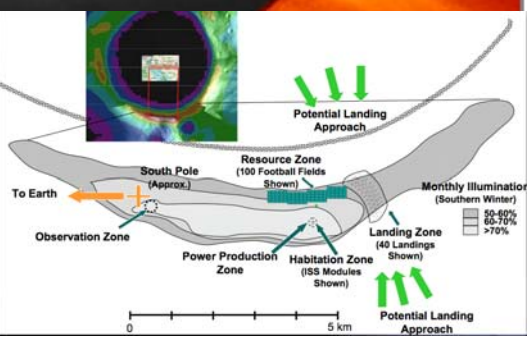
Relative Assessment : High

Comments: (1) Mitigating the exposure risk requires the delivery of reliable operational products, based on monitoring of hazardous radiation, to mission operators, planners and crews. It will also require a dedicated effort to generate near-real-time operational data that are supported by a fundamental understanding of the underlying physics. The infrastructure to monitor space weather over timescales of days - hours - minutes exists. This science is of high intrinsic value because developing such a predictive capability requires the solution of many long-standing problems in heliophysics. High in terms of scientific discovery potential, as well as for practical (operational) considerations.
(2) This science objective will probably be achieved only partly by the time of the first lunar landings and will be improved upon continually with more capable instrumentation and higher fidelity models. Nevertheless, the accomplishments will be of high scientific value and very valuable predictive capabilities will be developed in time to support crewed lunar operations.

Suitability of Single Site Architecture: not on the Moon, upstream monitoring as close to the solar source as is feasible.

Space Weather, Safeguarding the Journey





Space weather impacts on robotic and human productivity

ID# : mENVMON1b - Monitor space weather in real time to determine and mitigate risks to lunar operations. Utilize real-time measurements on the moon to provide redundant forecasting/now-casting of space weather.

Relative Assessment : Medium

RED

Comments: Although deployment of instrumentation on the moon for space-weather monitoring is unlikely to yield major scientific advances, even simple full sun sensors can provide valuable on-site information about the x-ray flux, and on particle acceleration in the low corona. More detailed imaging instruments can provide a redundant forecasting capability and training for the Mars outpost. These measurements provide direct input to predict the effects on the lunar dust/plasma environment.

Suitability of Single Site Architecture: Instrument suite can be designed to fit in the existing architecture. A major goal is learning how to run an operational system in a harsh environment. On site operations need to be carried out by a trained scientist-astronaut at the lunar site, with a view to more independent operation during Mars missions.

Space Weather, Safeguarding the Journey

Operational Environmental Monitoring

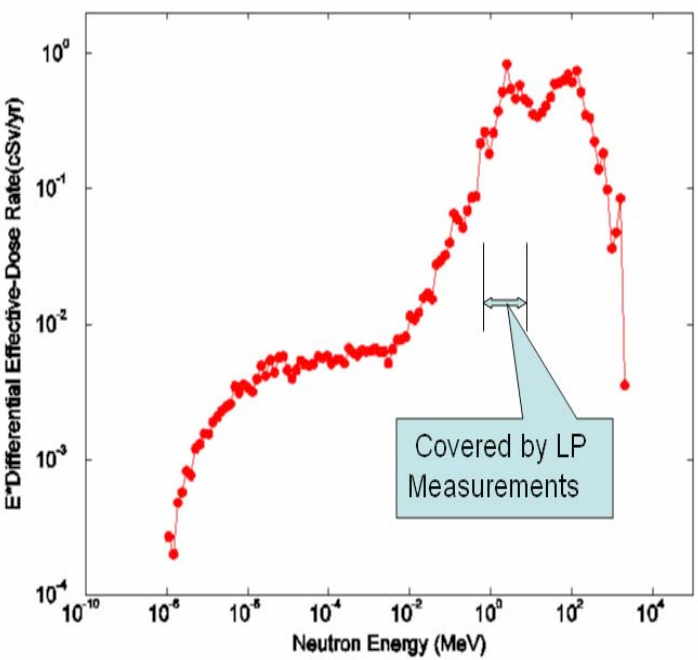
ID# : mENVMON2 - Monitor lunar environmental variables in real time to determine and mitigate risks to lunar operations. Utilize real-time observations on the moon to determine the radiation hazards, the electrodynamic plasma environment, and effects of dust dynamics and adhesion.

Relative Assessment : High Green

Comments: (1) Monitoring the radiation environment will require dosimetry and a solar proton telescope. It is this telescope that SMD can provide. It must measure protons from 20 to 1000 MeV. In addition to its use for assessing crew radiation exposures, it will provide scientific data for basic research in heliophysics. Further, the moon's electrodynamic plasma and dust environment must be monitored in real-time to determine electrostatic and dust hazards. (2) The likelihood of successful operation is excellent and the likelihood of achieving science is good. (3) Important for crew safety

Suitability of Single Site Architecture: implementation co-located with human operations

Space Weather, Safeguarding the Journey



Radiation bombardment on the lunar surface and subsurface

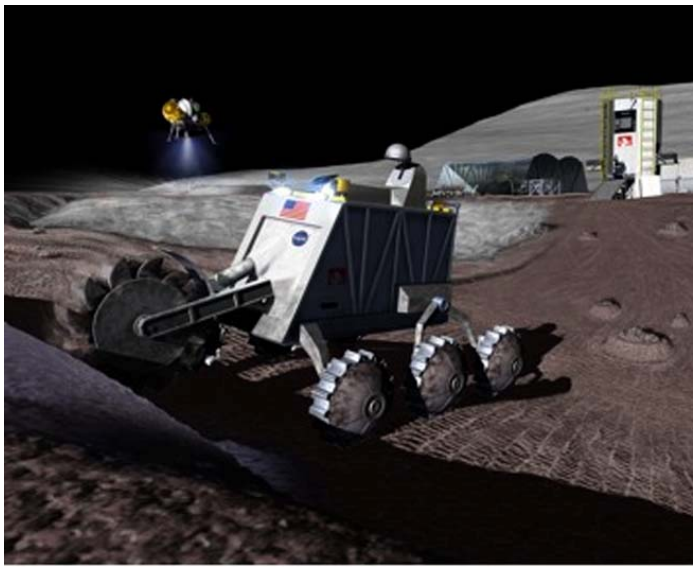
ID# : mENVCH2 - Characterize radiation bombardment at several locations on the lunar surface and subsurface to better understand the operational environment of the Moon.

Relative Assessment: Medium Green

Comments: (1) The only intrinsic value is the validation of transport code calculations of lunar neutron albedo. It will be helpful to validate the model predictions for the radiation environment on the lunar surface. The biggest uncertainty is thought to be the contribution of neutron albedo to the radiation dose to the crew. Low importance in terms of scientific discovery potential, but important for crew safety. (2) The likelihood of achieving this goal is very high because it relies on the use of well understood and proven detector technologies.

Suitability of Single Site Architecture: The objective can be completely addressed at a single site. It would have been enough to do it at only one site even if the crew were visiting multiple sites on the moon.

The Moon as an Historical Record



Lunar trenching operation

ID# : mGEO5 - Understand the nature and history of solar emissions and galactic cosmic rays.

Relative Assessment : High

Green

Comments: The lunar regolith carries a record of the history of solar energetic particles, galactic cosmic rays, and the motion of the heliosphere through the Milky Way. Shaded areas may form cold traps for volatiles. Intrinsic scientific value is high. Samples to be extracted to study lunar geology can be used. However, for dating purposes, samples should be chosen in the context of the lunar stratigraphy. Trenching is the preferred approach.

Suitability of Single Site Architecture: A comprehensive historical picture would require samples illustrating a range of dates, and limitation to a single site may limit the variety of samples available. However, the apparent ubiquity of ejecta layers on the lunar surface indicate a single site should be sufficient.

Moon as a Heliophysics Science Platform

Imaging of the Heliospheric Boundary

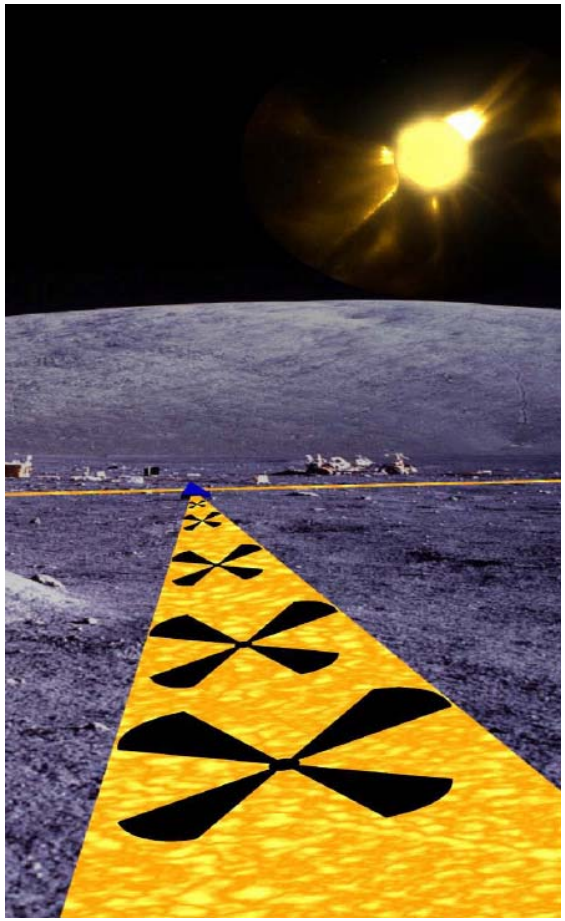
ID# : mHEO1 - Image the interaction of the Sun's heliosphere with the interstellar medium to enable identification and comparison of other heliospheres**.**

Relative Assessment : Medium Green

Comments: The heliospheric boundary can be imaged from the moon using energetic neutral atoms, extreme ultraviolet, and soft x-ray fluxes. The study of the global structure of the heliosphere and its interaction with the local interstellar medium is of high value. However, the presence of neutral atoms in the lunar exosphere will cause a significant foreground for Energetic Neutral Atom (ENA) Imaging. Not compelling to do from the Moon.

Suitability of Single Site Architecture: ENA technique requires remote (satellite) perspective.

Moon as a Heliophysics Science Platform



Low-frequency radio observations

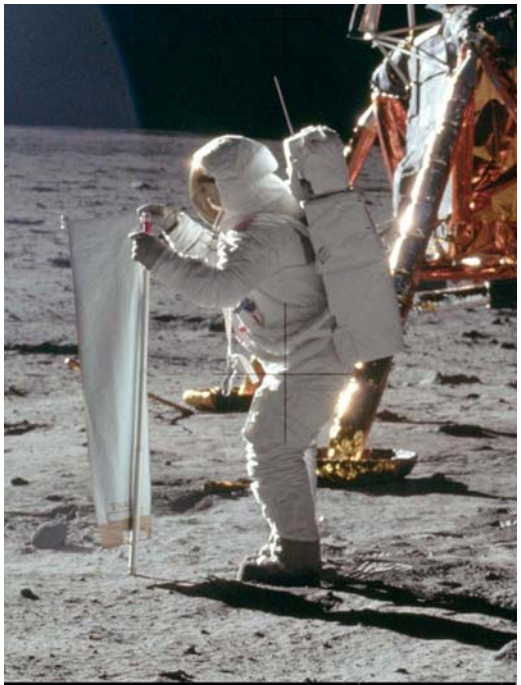
ID# : mHEO2 - Perform low-frequency radio astronomy observations of the Sun to improve our understanding of space weather.

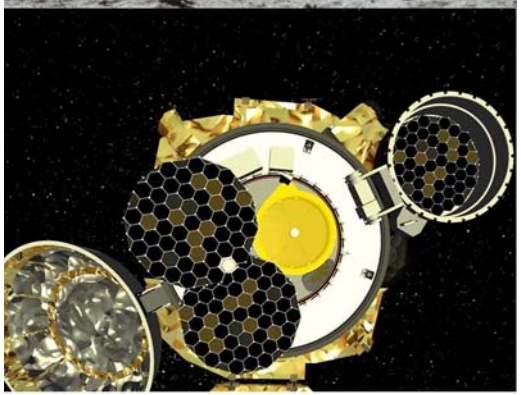
Relative Assessment : High Yellow

Comments: Probe particle acceleration in the tenuous upper solar atmosphere and in interplanetary space. This is accomplished by imaging the low-frequency plasma radiation produced by the accelerated particles. An array of small radio telescopes covering spanning tens of km would provide the necessary spatial resolution. Kapton roll deployment technology may turn assessment to Green.

Suitability of Single Site Architecture: For full sky coverage, multiple sites would be required.

Moon as a Heliophysics Science Platform





Collection media
old & new

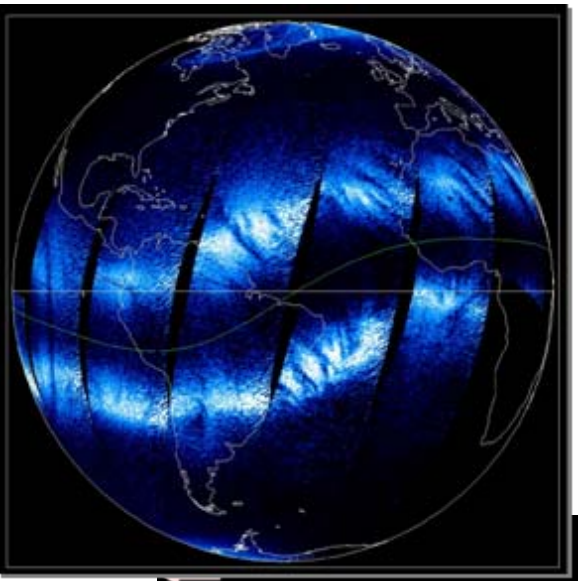
ID# : mHEO5: Analyze the composition of the solar wind to improve our understanding of the composition and processes of the Sun.
Composition and flux of interplanetary / interstellar grains should also be considered

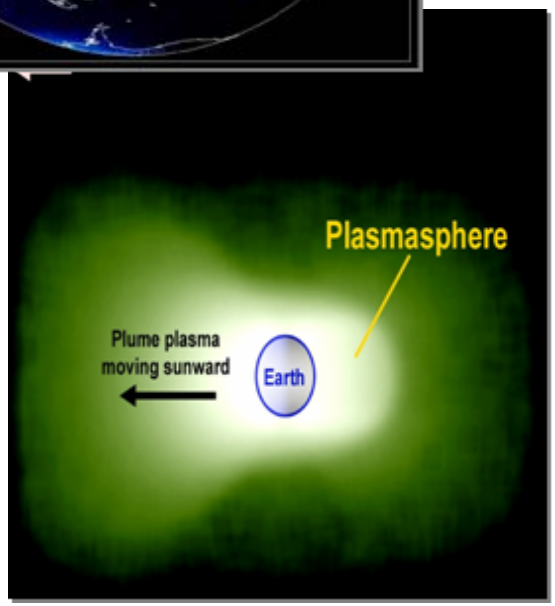
Relative Assessment : High Green

Comments: (1) Solar wind composition has recently been measured by Genesis, with less than complete success due to its hard return to Earth. Lunar observations would complete the necessary reservoir of samples for 21st century science. (2) The flux and composition of the interplanetary and interstellar grains bombarding the lunar surface are important measurements to both the Heliospheric and the Astrophysical communities, and are a fundamental source of maintaining the lunar atmosphere and gardening of the lunar soil.

Suitability of Single Site Architecture:
Observation site requires long intervals of exposure to the solar wind.

Moon as a Heliophysics Science Platform





Ionosphere/Magnetosphere Imaging

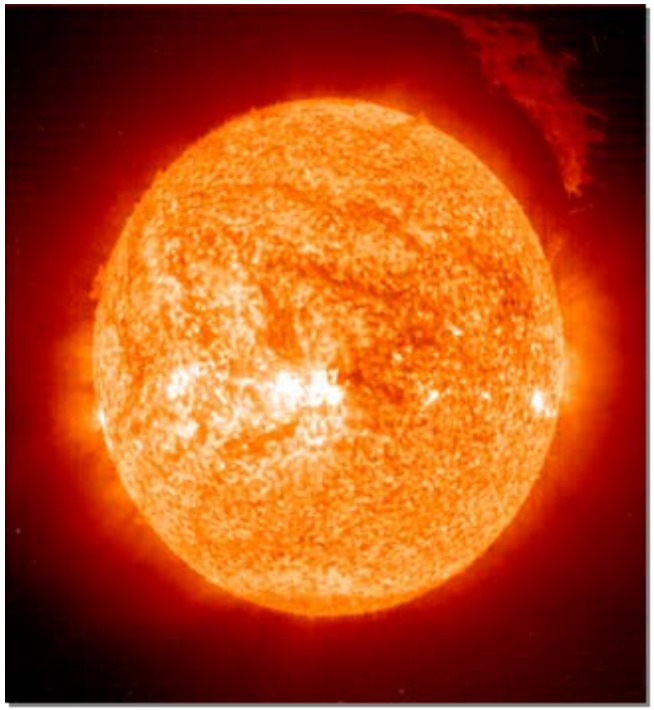
ID# : mHEO6 - Image the interaction of the ionosphere and magnetosphere to understand space weather in the regions of space where most commercial and military space operations occur.

Relative Assessment : High Green

Comments: Imaging of the geospace environment from the moon has high intrinsic science value and contributes to operational space weather products. Observations from the moon give excellent full disk coverage of the Earth unavailable from LEO and GEO orbits. Lunar surface observations of plasma distributions and flow in geospace enable comprehensive diagnostics of space weather processes.

Suitability of Single Site Architecture: The instrument site must maximize view of Earth.

Moon as a Heliophysics Science Platform



High-Energy Solar Observatory and an Optical Solar Observatory

ID# : mHEO7 - Perform high-energy and optical observations of the Sun to improve our understanding of the physical processes of the Sun.

Relative Assessment : Gamma ray Observatories - High; Optical observatories - Low

Green

Comments: Studies of very high energy process require imaging of high energy x-ray and gamma rays that cannot be imaged using conventional optics. However, collimators and grid techniques can provide data that can be used to form images. Grids and detectors must be extremely stable and separated by long distances, which is difficult to achieve in space. The near vacuum of the moon would allow the construction of an ideal gamma ray observatory because stability is the primary driver of the design.
While scientifically important and essential for safe lunar operations, Solar Optical Observatories are better done by a constellation of observatories in Sun synchronous orbit.

Suitability of Single Site Architecture: A site a few hundred meters in length in the sunlight would be sufficient.

Moon as a Heliophysics Science Platform

Sun's Role in Climate Change

ID# : mHEO8 - Analyze the Sun's role in climate change to gain a better overall understanding of climate.

Relative Assessment : High

Green

Comments: The Moon is a platform from which one can measure the three fundamental components of climate (change) – the solar constant, terrestrial reflectance and Earth's thermal emission. The required technologies are mature and robust. The Moon is not considered to be the best place to measure the solar irradiance although measurements of the Earth's albedo may be. Measurements of the Earth's albedo fall within the purview of the Earth science.

Suitability of Single Site Architecture:
The objective can be fully addressed at a single site. Long term calibration is an issue.

Solar and Space Physics at the Moon: Summary

- The lunar surface and lunar orbits provide good vantage points for investigating the lunar environment, particularly crustal magnetization and dust-plasma interactions.
- Excavation of the lunar regolith could provide unique and unprecedented data on the particle and irradiance history of the Sun.
- The lunar surface and lunar orbits offer good vantage points for imaging of the Sun, Geospace, and the boundaries of the heliosphere.
- Lunar-based instrumentation would allow measurements of plasma transport in the magnetotail and would provide important space weather monitoring capabilities in support of exploration missions.

Thank you!

The realm of heliophysics is the perilous ocean through which explorers, both robotic and human, must journey to reach the dusty shores of the Moon, then Mars.