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Space Weather
Instrumentation

Space weather from lunar orbit: The Deep Space Gateway as a platform for space plasma instruments

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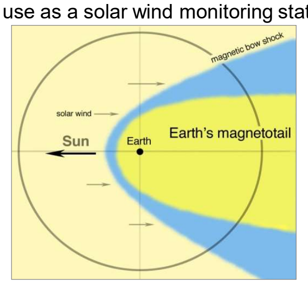
Abstract

Space weather monitoring instruments at Sun-Earth L1 allow to sample the pristine solar wind, to have continuous coverage, and to issue an advance warning in the case of a space weather event. Disadvantages include the need for a dedicated platform and the lack of serviceability. Recently another opportunity has popped up in the form of the Deep Space Gateway, a crewed platform to be built by ESA, NASA and other international partners in order to enable lunar surface excursions as well as remote and in situ measurements, orbiting the Moon (probably in an elongated orbit in the plane perpendicular to the Earth-Moon line). ESA has convened a Topical Team for Plasma Physics on the Gateway that has reviewed the science potential of hosted payloads. This is particularly relevant for space weather instruments because telemetry, power, volume, and mass constraints may be relaxed compared to a Sun-Earth L1 mission. Instrument serviceability may be a bonus.

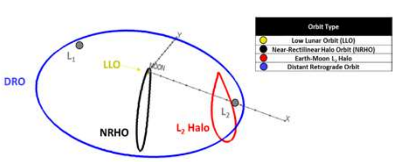
Challenges

Using the Gateway for space weather measurements poses some difficulties:

- The Gateway is roughly 50% of the time in the solar wind, 25% in the foreshock, 25% in the magnetosheath or tail, which limits its use as a solar wind monitoring station.



- The Gateway is in a NRHO orbit, with its long axis nearly in the ecliptic plane, rotating around the solar panel axis during a lunar month, so instruments have to take care of their own pointing.



- The electromagnetic environment may be perturbed
  - Neighborhood of large solar panels
  - Ion thruster propulsion
  - Spacecraft charging could be a problem
- The chemical cleanliness is not at all guaranteed.
- The radiation environment is altered by the presence of the Moon near pericenter.

Targets

Solar wind: Observations from lunar orbit can directly sample the solar wind during most of the Moon's orbit around the Earth, except when the Gateway is in the lunar wake or in the Earth's magetotail. When the Moon is located in the morning local time sector, foreshock-processed solar wind is observed. While the electrostatic environment of the Gateway is expected to be far from clean, the solar wind particles with their energies of 200-400 eV should be detectable, unless electrostatic perturbations are too strong.

Interplanetary magnetic field: The Gateway can be a suitable platform for measuring the interplanetary magnetic field. The main challenge is to deal with electromagnetic compatibility issues by combining multiple sensors and possibly using a boom.

Energetic particles: The lunar vicinity is typical of deep space and suitable for studying galactic cosmic rays, solar energetic particles, and Jovian energetic electrons. Monitoring radiation inside and outside the Gateway is essential.

Magnetosphere: During 5–6 days around full Moon the Earth's magnetotail and escaping particles of atmospheric origin can be studied, but the lack of time continuity makes this less interesting for space weather applications. However, the magnetosphere can be monitored through remote sensing, using ENA imaging, solar wind charge exchange X-rays, plasmasphere EUV imaging, or exosphere Lyman-α imaging. Such techniques are less sensitive to the Gateway's electromagnetic environment. They will view the magnetosphere from a constantly different angle. This could be extremely interesting in combination with magnetospheric imaging from, for instance, a polar platform in view of the possibility to do stereoscopic imaging.

Lunar environment: Measurements from the lunar orbit also provide information about the lunar exosphere and about the solar wind interaction with the lunar surface, adding the lunar environment to the realm of space weather prediction that has up to now focused on Earth and its immediate vicinity.

Science Objective	Measurement Requirement	In situ instrument	Remote Sensing
Monitor solar wind as driver for the magnetosphere, terrestrial and lunar exospheres, lunar surface sputtering, charging	Solar wind density and velocity 1-10^2 cm^{-3}, 200-1000 km/s	Faraday Cup Electrostatic Analyser	
	IMF: 10000 nT range 1 nT / 0.1 nT absolute/relative resolution	Magnetometer	
Monitor and characterise SEPs & GCRs for radiation environment and as lunar surface sputtering sources	40 keV – 100 MeV ions (SEP) Up to ~5 GeV (GCR) 500 MeV/nucleon for composition	Energetic particle detectors	MeV ENA imager
Monitor and characterise the response of the terrestrial magnetosphere to the solar wind with a wide geospace coverage	Detect and image solar wind charge exchange X-rays (0.2-2.0 keV) FOV 10° x 10°, resolution 0.3 R_E		Soft X-ray imager ENA Imager
Monitor solar wind interaction with lunar exosphere, regolith & magnetic anomalies	Detect and image low-energy ENAs 0.1-10 keV, 30% $\Delta E/E$, ~5° resolution Strong UV suppression (10^{-8})		LENA Imager
Reveal the solar wind ion dynamics in the vicinity of lunar magnetic anomalies	Detect and image low-energy ENAs 0.01-3 keV, 30% $\Delta E/E$, ~5° resolution FOV ~5° x 120°		LENA Imager
Monitor the terrestrial and lunar exospheres and plasmasphere	Detect and image EUV emissions 30.4, 83.6, 121.6, 130.4 nm, 5 arcmin resolution		UV/EUV Spectro-imager
Monitor ambient plasma in different environments (solar wind, magnetosheath, terrestrial magnetotail, lunar wake)	Plasma density & temperature 10^{-4}-10^2 cm^{-3}	Langmuir probe	
	Magnetic field: 10000 nT range 1 nT / 0.1 nT absolute/relative resolution	Magnetometer