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Introduction: We propose the Lunar Solar Origins Explorer (LunaSOX) as a remote sensing suite of telescopes for exploring physics of the solar corona onboard Deep Space Gateway (DSG). Our goal is to capitalize on the unique observing conditions offered by total solar eclipses to achieve breakthroughs in the exploration of the corona and the source regions of the solar wind through imaging in coronal emission lines with rich diagnostic capabilities, over a distance range covering the first few solar radii, starting from the surface. Onboard DSG in lunar orbit, with periodic solar eclipses at cadences of hours to days depending on the orbit, our proposed imaging solar coronagraph would observe the solar corona to low solar altitudes with solar disk occultation by the lunar limb. Here we describe only the visible wavelength coronagraph, but other telescopes could be added as part of LunaSOX for limb-occulted observations of the solar corona, the geocorona, and lunar gas & dust at other wavelengths.

The highest spatial resolution images of the solar corona are achieved at present only by ground-based coronal observations during total solar eclipses (Figure 1). Emission from coronal forbidden lines in the visible to near-infrared range 400 – 1000 nm traces density and temperature of coronal plasma through excitation of heavy ions. Although dominated by Fe, spectral lines also include the weaker yet resolved Ni, Ar, and S line. Ratios of lines from ions with low (Fe, Ni) to high (Ar, S) first ionization potential at similar plasma temperatures, respectively, trace the evolution of abundances from closed to open magnetic field lines. The spatial evolution of coronal electron temperatures can be determined from ratios of Fe X (Fe+9) – Fe XIV (Fe+13) line emission. Altitude evolution of Fe charge states and corresponding electron temperature can be tracked across coronal structures and out into solar wind acceleration along open field lines. Since collisional excitation falls off rapidly with coronal density, whereas detectable radiative excitation continues into the outer corona beyond three solar radii, observations can track transition to collisionless plasma where charge states and temperature become “frozen-in” and correlated to solar wind ion charge state measurements near Earth. Such observations are fundamental for determining the location of the transition from closed to open field lines, essential for understanding coronal heating and solar wind ion acceleration.

In addition to these diagnostics, eclipse observations have also led to the discovery of the dynamic evolution of plasma instabilities, ranging from vortex rings, twisted helices, expanding loops, faint nested loops, turbulence structures, and plumes, all occurring in the immediate neighborhood of prominences [2], which are invariably surrounded by the hottest coronal material. Forming in the stronger magnetic field near the Sun, the features are likely to expand in the weakening magnetic field with the solar wind to become larger density structures observed at 1 AU [3]. Textural inhomogeneity of solar wind structures [4] is likely born in these small-scale nonuniformities. Tracking outward evolution in size, density, speed, and temperature of these features, otherwise invisible to currently operating space coronographs, could inform space weather forecast models for the geospace environment.

There is currently no operational capability for multi-wavelength imaging of coronal structures spanning several solar radii starting from the solar surface. The still operational LASCO C2 and C3 coronographs
use external occulters, with a maximum white-light sensitivity only beyond $2$ and $3 \, R_s$ respectively, have no multi-wavelength imaging capability. The same applies to the Sun Earth Connection Coronal and Heliospheric Investigations (SECHI) on the twin Solar Terrestrial Relations Observatory (STEREO) A and B spacecraft, and SECHI.

Two international missions, currently slated for operation around 2020, could significantly advance the state of the art for multi-wavelength imaging of the inner solar corona. The dual PROBA-3 satellites of the European Space Agency will operate in 2021 – 2022 with two narrow-band filters for He and Fe emission lines, and a resolution of 5.6 arcsec. They would fly in formation with one satellite carrying the ASPIICS coronagraph [7] and the other acting as an external occulter for coronal observations at 1.08 – 3 $R_s$. The 100-meter spacecraft separation would minimize vignetting effects that normally degrade sensitivity and spatial resolution. India will launch the 5-year mission Aditya satellite to L1 in 2020 – 2021. It will include coronal measurements at 1.05 – 3 $R_s$ with the Visible Emission Line Coronagraph (VELC) and an internal occulter to minimize vignetting. It will have one spectral channel for white-light imaging at 1.25 arcsec and three for narrow-band imaging.

From the United States, however, there are no plans to develop and launch comparable coronagraphs. Currently, NASA heliophysics decadal survey priorities and funding are focused on the Parker Solar Probe (PSP) whose Wide-field Imager (WISPR) will image the inner white-light corona only beyond 2.3 $R_s$ at perihelion [8]. Other coronagraphs capable of inner corona imaging may conceivably be developed for small satellites that could launch in the PSP epoch or thereafter. But current developmental focus at NASA and NOAA seems to be on compact coronagraphs of lower spatial resolution for space weather applications.

**LunaSOX High-Resolution Inner Coronagraph:**

To fill a critical gap in the exploration of the physics of the inner corona, we propose a high-resolution coronagraph, using the Moon as an occulter. It would take advantage of the unique vantage point from a lunar orbit on DSG and return spectroscopic images at daily to hourly cadence comparable to those of Figure 1. We propose a 200-mm optical telescope, with a ~ 1 arcsec resolution for white light imaging and ~ 4 arcsec for coronal emission lines, using a rotating wheel of narrow-band filters. This would allow detection of small-scale density structures down to ~ 1.1 $R_s$ and tracking of coronal density, temperature, and compositional evolution with increasing altitude into the solar wind acceleration region at 2 – 6 $R_s$. All of this would be done at a daily to hourly cadence, depending on the DSG orbit, far surpassing that provided by ground-based solar eclipse observations.

For equatorial or polar orbits the consecutive lunar limb crossings, as viewed from DSG, would allow viewing of the east-west or north-south hemispheres of the solar corona with complete images for each pair of limb crossings in circular to elliptical orbits. A low altitude orbit would provide full images every two hours, while an elliptical orbit 1x10 $R_M$ would do so every 24 hours. Higher perilunes would generally give slower cadences. Viewing times of the occulted corona at 3 $R_s$ [1] would vary accordingly from 20 seconds per limb crossing in the low-altitude orbit to twenty minutes in the 1x10 $R_M$ elliptical case.

Observations at lowest solar altitude would need to contend with Bailey’s Beads arising from solar disc light scattering through the irregular topography ±8 km of the lunar limb and seen by ground observers just prior to and after totality. However, the topography has been precisely mapped by NASA’s Lunar Reconnaissance Orbiter (LRO) so the particular topographic configuration could be anticipated for each limb crossing.

Another unique challenge of the lunar orbital environment would be clouds of small dust particles produced mainly by meteoritic impacts and producing local optical scattering backgrounds with scale heights up to 20 km in lunar surface altitude. As viewed from 10 $R_M$ in an elliptical DSG orbit, this background would be present at solar distances up to 1.2 $R_s$. The lunar dust environment has now been extensively measured by LRO and by the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission. Background dust brightness, $\leq 10^{-12}$ of solar brightness $B_s$ [9-11] is similar to maximum sensitivity of LASCO C3 [5] > 3 $R_s$ as an upper limit on coronal brightness sensitivity that the DSG coronagraph might achieve, as compared to $10^{-9} B_s$ from ground eclipse telescopes.