The Deep Space Gateway Lightning Mapper (DLM) - Monitoring Global Change and Thunderstorm Processes through Observations of Earth's High-Latitude Lightning from Cis-Lunar Orbit.
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Background: The Deep Space Gateway (DSG) is a proposed manned mission to orbit near Earth's moon. It is anticipated that the DSG will be able to host science payloads of a variety of types, including Earth-observing instruments. While a lunar orbiter is not at first glance an obvious choice for performing dedicated Earth observations, in fact a previous workshop[1] found that a lunar-based mission would be able to fulfill important Earth science objectives, and would serve a useful complementary role to geostationary orbit (GEO) and low-Earth orbit (LEO) Earth-observing missions. One of the Earth science roles that received the highest grade in that workshop was to observe lightning occurring in the Earth's atmosphere.

Instrument Description and Justification: We propose the DSG Lightning Mapper (DLM) instrument. The primary goal of the DLM is to optically monitor Earth's high-latitude (50° and poleward) total lightning not observed by current and planned space-borne lightning mappers. While lightning is concentrated in the Earth's tropics, as the Earth warms, scientific studies[e.g., 2, 3] have found that thunderstorms will increase in frequency and severity at higher latitudes. This reflects the fact that a warming planet likely will see poleward shifts of mean frontal system positions, as well as an earlier onset to spring and a later onset to autumn. This has important implications for the distribution of global precipitation; for changes in vertical transport of heat, moisture, and pollutants from low-levels to the upper troposphere and lower stratosphere (UTLS); for the global distribution of lightning nitrogen oxide (LNO_x) production; and for the increasing risk of lightning-ignited wildfires in boreal forests. Moreover, lightning is under consideration as a new essential climate variable by the World Meteorological Organization, as it is related to changes in the frequency and distribution of temperature, humidity, and storminess.

Thus, there is a critical need to understand and monitor lightning and thunderstorms at higher latitudes of the Earth. Meanwhile, current GEO (e.g., the Geostationary Lightning Mapper - GLM[4]) and LEO (e.g., the Lightning Imaging Sensor - LIS[5]) lightning mappers do not provide sufficient coverage of higher latitudes to address this need. Furthermore, simply adding a lightning mapping instrument to a circular polar-orbiting Earth satellite cannot provide long-lived (i.e., multi-hour) continuous views of the same storm, limiting the ability to do process studies on poorly understood high-latitude thunderstorms. Highly elliptical orbits (HEO; e.g., Molniya, Tundra) do offer longer-lived, high-latitude coverage; however, field of view (FOV) and spatial resolution are highly variable during each orbit, which leads to difficulties in developing effective flash detection algorithms as well as difficulties in performing unbiased climatological and process study analyses. Finally, ground-based networks require unrealistic sensor densities to achieve comparable detection efficiency of total lightning relative to space-borne optical methods.

DLM will address all of these limitations and thus complement the existing lightning-observing constellation. It is expected that the carefully designed cis-lunar orbit options for DSG (e.g., Near Rectilinear Halo Orbit - NRHO) will offer periodic, long-lived views of the Earth's high latitudes (Fig. 1). This enables continuous sampling of individual thunderstorms throughout their lifetimes, similar to coverage provided at lower latitudes by GEO lightning mappers. This periodic sampling can be integrated in time to enable coherent monitoring of global changes in thunderstorms and lightning at higher latitudes, as well as to facilitate investigations into thunderstorm response to solar activity and other extremes in space weather.

Additional DLM science opportunities can be opened up by temporary sampling changes. These could include selective targeting of lower latitudes to assist with cross-validation with other lightning sensors, or occasional longer integration times to create a day/night band, which would be very helpful for high-latitude regions that experience long winter nights. DLM will thus provide multiple direct benefits to NASA's Earth Science Focus Areas in Weather, Climate, and Atmospheric Composition.

Design Requirements: We anticipate that DLM's design would be qualitatively similar to existing lightning mappers[4, 5], with a narrow band (777 nm) optical detector, operating at a frame rate of ~500 fps. The 777-nm frequency band enables high-detection efficiency (> 70%) of lightning during Earth's daytime or nighttime. DLM would connect externally to the DSG spacecraft. We expect that a gimbal system would be needed in the attachment to enable adaptive staring at Earth's high latitudes, thereby maximizing utility of the cis-lunar orbit. The DSG crew would need to mount the instrument to the hull. We anticipate that this process would be qualitatively similar to the mounting of LIS on the International Space Station (ISS), which took only a few hours. After that, DLM would run largely autonomously, with periodic commands and adjustments relayed remotely from Earth.

The ability to transmit data in near real-time to Earth would be highly desired. We anticipate that data rates could be significantly reduced (to ~1 mbps or less) relative to the current state of the art (GLM) with additional onboard processing for DLM, as well as a reduced FOV to focus mainly on higher latitudes. DLM would utilize new focal plane and field programmable gate array (FPGA) technology that has come of age since the development of GLM, as well as a recently acquired airborne optical validation dataset, to develop an upgraded approach to lightning detection that can account for the decreased lightning signal-to-noise ratio (SNR) expected from cis-lunar orbit.

Power requirements for the DLM instrument are anticipated to be significantly reduced compared to GLM, likely < 100 W, due to recent improvements in focal plane technology that have reduced power consumption. Relative to GLM, the DLM telescope size would need to be increased (to ~100 cm) in order to achieve the desired ~10-km instantaneous FOV. However, GLM required a large baffle to remove solar glint from nearby instruments. DLM would be designed to not require the extra baffle, and would have reduced electronics size, thereby keeping the instrument comparable in size (~150x60x60 cm^3) and mass (~100 kg) to GLM despite the longer telescope. Total cost of DLM is expected to be < $10M, due to recent technological improvements and lessons learned from GLM development.

References: [1] Final Report, NASA Advisory Council Workshop on Science Associated with the Lunar Exploration Architecture, Tempe, Arizona, 2007, 138pp. [2] Veraverbeke, S., et al. (2017). Lightning as a major driver of recent large fire years in North American boreal forests. Nature Climate Change, 7(7), 529-534. [3] Finney, D. L., et al. (2016), Response of lightning NOx emissions and ozone production to climate change: Insights from the Atmospheric Chemistry and Climate Model Intercomparison Project, Geophys. Res. Lett., 43, 5492–5500, doi:10.1002/2016GL068825. [4] S. J. Goodman et al., The GOES-R Geostationary Lightning Mapper (GLM), Atmospheric Research, Vol. 125–126, 2013, Pages 34-49, ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2013.01.006. [5] Blakeslee, R. J., et al. (2014). Lightning Imaging Sensor (LIS) for the International Space Station (ISS): mission description and science goals. https://ntrs.nasa.gov/search.jsp?R=20140011702

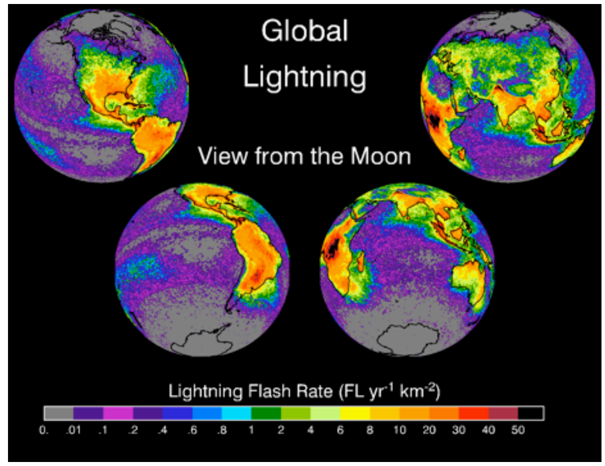

Figure 1. Global lightning climatology from LIS and the Optical Transient Detector (OTD), as viewable from a lunar-based orbit.