WHEN THE MOON HAD A MAGNETOSPHERE. James Green[1], David Draper[1], Scott Boardsen[2], and Chuanfei Dong[3]; [1]NASA Headquarters, [2]University of Maryland Baltimore County, [3]Princeton University

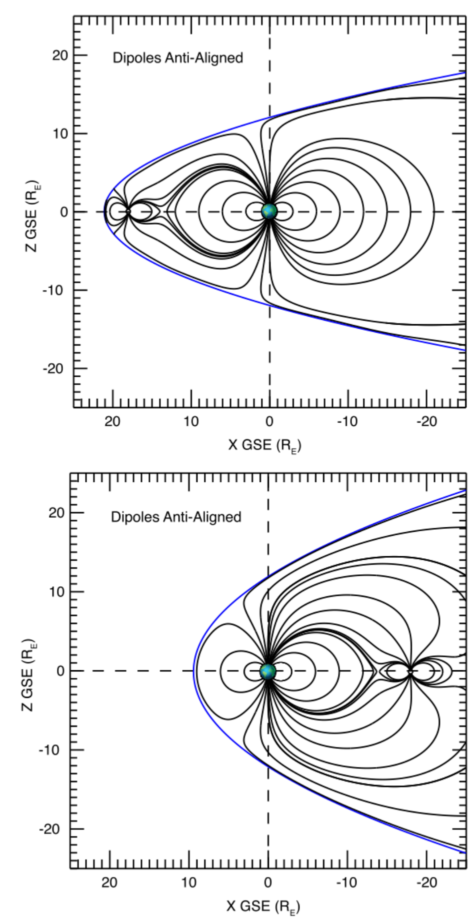
Introduction: Over the last several years as paleomagnetists began a careful reexamination of all of the returned Apollo lunar samples using modern analysis techniques, a new transformational concept has emerged. These paleomagnetic measurements now make clear that a significant lunar magnetosphere must have existed for the first several hundred million years of the Moon's history. *Mighani et al*. [1] indicated that in the age range from 4.2 to 3.4 Gya, the Moon's field was at least as strong, or possibly stronger, than Earth's magnetic field of today on their respective surfaces.

The prevailing model for the generation of the Moon is the giant impact hypothesis in which an approximately Mars sized object, named Theia, impacted the proto-Earth during the early formation of the solar system [2]. The resulting debris formed Earth and the Moon, ending with the Moon lying just outside the Roche limit of ~2.9 R_E [3]. *Zharkov* [4] estimated that the Earth-Moon distance was only 21 R_E about 3.9 Gya, based on gravity measurements made by the Clementine spacecraft data. Thus, Earth and the Moon were in comparatively close proximity at a time when the Moon had a significant magnetic dynamo operating. How would these two magnetospheres interact, and what protection would such a combined magnetosphere provide to the atmospheres of early Earth and Moon?

Model Assumptions: We modeled two dipole fields simulating the main field of the Earth and the Moon when the Moon was at 18 R_E from Earth, and under two diurnal configurations in a solar wind environment. The top panel of the accompanying figure has the Moon at noon local time and the bottom panel midnight.

Modeling Results: The major features shown in the top panel are consequences of the reconnected field lines between Earth and the Moon, which occur primarily at high and mid-latitudes. Direct solar wind precipitation occurs through the location of the two field lines that split their direction from dayside to nightside, termed the *polar cusp*. When comparing the top panel with the bottom panel, it is clear that for the Moon on the dayside, the cusp moves poleward by ~10º, largely cutting off direct solar wind access. In addition, the top panel clearly shows how the lunar magnetosphere would take the brunt of the solar wind and provide a significant additional effective shield to Earth's atmosphere. On the nightside, the bottom panel shows the extensive reconnection of the lunar magnetic field which disrupts the conventional near-Earth plasma sheet and captures much of the evaporated Earth's ionospheric plasma onto the Moon.

Conclusions: The results of our magnetic field topological modeling demonstrate a critical and previously unrecognized condition: that Earth-Moon coupled magnetospheres work together to protect the early atmospheres of both Earth and the Moon. At times when the Moon is on the dayside of Earth, the lunar magnetosphere would provide a significant additional buffer from the expected intense solar wind, reducing Earth's atmospheric loss to space. In addition, magnetic reconnection would create a critical pathway for the atmosphere of the early Earth to be implanted into lunar soils. Our hypothesis of a conjoined magnetosphere protecting these early atmospheres will be testable upon the return of volatile-bearing regolith cores from the lunar poles as part of NASA's Artemis program.



References:

1. Mighani, S., et al. (2020), *Sci. Adv.*, Vol. 6, no. 1.
2. Canup, R. & E. Asphaug (2001), *Nature*, 708.
3. Kokubo, Ida, & Makino (2000), *Icarus,* 436.
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