# SPACE WEATHERING DOMINATED BY SOLAR WIND AT EARTH-MOON DISTANCE.

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**Introduction:** Although it is generally agreed that micrometeorites and solar wind ions are the agents largely responsible for weathering the surfaces of airless bodies, it is still a matter of debate as to which of these plays a more important role in causing a surface to mature [e.g., 1-5]. However, the lunar swirls demonstrate the dominance of the solar wind on space weathering, at least at the Earth-Moon distance. This is based on mounting evidence that the lunar swirls and their characteristic properties are manifestations of the solar wind's interaction with the complex patterns and variable field intensities of the lunar magnetic anomalies [e.g., 6-15]. As such, the swirls are ideal for distinguishing space weathering effects from solar wind ions versus micrometeorites because the former are influenced by the magnetic anomalies, while the latter are not.

**Discussion:** Evidence that the swirls mature at a much slower rate, and that adjacent, off-swirl regions mature at an accelerated rate (compared with maturation rates at non-swirls regions) was demonstrated using spectral data from Clementine [10], Moon Mineralogy Mapper [11] by showing that there are different spectral maturation trends and different immature crater densities for regions on-swirl vs. off-swirl. Immature craters on-swirl exhibited a wide range in albedos, and only slight spectral reddening compared to the mature (off-swirl) soil. This is evidence of retarded weathering on the swirls. In contrast, spectra sampled from fresh craters and the mature regolith in off-swirl regions were all very dark, had a very limited range in albedos, and exhibited little to no spectral reddening. This is evidence of accelerated weathering at off-swirl regions.

Diviner Radiometer data shows an anomaly in the position of the silicate Christiansen Feature consistent with reduced space weathering [15]. In addition, these data show that swirl regions are not thermophysically anomalous, which strongly constrains their formation mechanism. The conclusion from this study [15] was that solar wind sputtering and implantation are more important than micrometeoroid bombardment in the space-weathering process.

Nanophase iron ($npFe^0$) is the space weathering product that has the strongest influence on reflectance spectra, and its abundance in a soil is correlated with that soil's exposure age [16]. $NpFe^0$ is created in three ways: (1) sputtering, (2) impact vaporization and deposition, and (3) agglutination [e.g., 17-21]. The first two ways create $npFe^0$ by breaking the Fe-O bond, liberating O, and depositing native iron. These two processes typically work on very small scales (i.e., grain surfaces up to a few molecule layers deep), and create npFe0 particle sizes usually <10 nm in diameter. The third way involves micrometeoroid impacts of sufficient size to provide the energy for melting to occur, and generates a much broader size distribution of $npFe^0$ particle sizes. Here, smaller $npFe^0$ particles are created through chemical reduction by implanted solar wind hydrogen, while larger sizes are created via coalescence of smaller particles. Sputtering is largely caused by solar wind particles, 95% of which are protons. Micrometeorites are responsible $npFe^0$ created by impact vaporization and agglutination. A solar wind proton is the only space weathering agent that can be influenced by the lunar magnetic anomalies. Magnetic shielding deflects solar wind ions away from the on-swirl surfaces and diverts them onto off-swirl surfaces. On-swirl maturation is retarded because (1) the flux of space weathering agents that create $npFe^0$ is reduced and (2) the creation of larger $npFe^0$ by agglutination is restricted by the decreased availability of small $npFe^0$. Spectrally, this retarded space weathering process begins with a slow spectral reddening in the UV-VIS as the abundance of smaller $npFe^0$ created by sputtering and vaporization deposited on grain surfaces increases. Eventually, the spectral effects of larger $npFe^0$ particle sizes are observable once the abundance of $npFe^0$ is sufficient to create these particle sizes by agglutination. Sampled off−swirl craters exhibit only spectral darkening (and accompanying reduction in absorption band depth) with little to no reddening. Off-swirl regions do not simply experience an increased flux in solar wind ions, the deflected protons create a greater proportion of larger $npFe^0$ particles off-swirl relative to both on-swirl and lunar surfaces not influenced by a magnetic field.

**Conclusions:** These results underscore the importance of the solar wind as an agent of space weathering. Studying the swirls and magnetic anomalies on the Moon is ideal for distinguishing the optical, chemical, and physical effects of space weathering by solar wind ions vs. micrometeorites. The dominance of one of these agents over the other may be very different at locations other than the Earth-Moon distance, but the knowledge gained from studying space weathering at lunar swirls will improve interpretation of remote sensing observations of other airless bodies. Indeed, it has been suggested that anomalous color on asteroids could be indicative of the presence of a magnetic field [22].

**References:** [1] Jedicke, R. et al. (2004) *Nature 429*. [2] Willman, M. et al. (2008) *Icarus 195*. [3] Mothe-Diniz, T. and Nesvorny, D. (2008) *Astron. Astrophys. 486*. [4] Strazzulla, G. et al. (2005) *Icarus 174*. [5] Marchi, S. et al. (2005) *Astron. Astrophys. 443*. [5] Hood, L. and Schubert, G. (1980) *208*. [6] Hood, L. and Williams, C. (1989) *PLPSC 19*. [7] Richmond, N. et al. (2005) *J. Geophys. Res. 110*. [8] Wieser M. et al. (2010) *Geophys. Res. Lett., 37*. [9] Blewett, D. et al. (2011) *J. Geophys. Res. 116*. [10] Kramer, G. et al. (2011) *J. Geophys. Res. 116*. [11] Kramer, G. et al. (2011) *J. Geophys. Res. 116* [12] Neish, C. et al. (2011) *Icarus 215*. [13] Hemingway, D. and Garrick-Bethell, I. (2012) *J. Geophys. Res. 117*. [14] Poppe, A. et al. (2014) *Geophys. Res. Lett. 41*. [15] Glotch, T. et al. (2015) *Nat. Comm. 6*. [16] Morris, R. (1976) *PLPSC 7,*. [17] Hapke, B. et al. (1975) *The Moon 13*. [18] Keller, L. and McKay, D. (1993) *Science 261* [19] Keller, L. and McKay, D. (1997) *GCA 61*. [20] Hapke, B. (2001) *J. Geophys. Res. 106*. [21] Noble, S. et al. (2007) *Icarus 192*. [22] Vernazza et al. (2006) *Aston. Astophys. 41*.