SIMULATIONS OF PARTICLE IMAPCT AT LUNAR MAGNETIC ANOMALIES AND COMPARISON WITH SPECTRAL OBSERVATIONS.

E. M. Harnett[1] and G. Y. Kramer[2], [1]University of Washington, Earth and Space Sciences, Box 351310, Seattle, WA, 98195-1310 (eharnett@ess.washington.edu), [2]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058 (kramer@lpi.usra.edu).

Introduction: Lunar swirls are high albedo regions on the lunar surface which appear to correspond to surface magnetic anomalies. (See review by [1]). While the origin of the lunar swirls is not yet resolved, one of the main theories is that the anomalous magnetic field deflects incoming ions, which would otherwise impact the surface and alter the spectral properties of the lunar regolith through the creation of nano-phase iron [2]. These incoming particles may be completely deflected away from the surface or they may be deflected to other regions on the surface. It is thought that the dark lanes, regions of very low albedo adjacent to swirls, may correspond to locations of enhanced particle flux associated with the nearby partible deflection (For a more in depth discussion see [2]).

In this work, we present results of particle tracking studies following the interaction of ions and electrons with modeled 3D vector magnetic fields of actual magnetic anomalies, generated from satellite observations. Impact maps for each simulated anomalous region are generated and compared with spectral observations of the same regions. The objective is to assess the relationship between the surface pattern and maturity of the high albedo swirls and dark lanes and the flux of charged particles interacting with the magnetic field and density reaching the surface.

Method: Simulated anomalous magnetic field were generated by [3-4]. The resolution of the magnetic field in all cases is 0.1^o and map projection is simple cylindrical. The simulated region varied for each case, and included the full region plus several degrees surrounding. The results presented here are for the Ingenii, Gerasimovich, and Reiner Gamma anomaly regions. The total magnetic field simulated included just the anomalous magnetic field and the anomalous magnetic field plus a superposition of several different interplanetary magnetic fields ($B_{vertical} = \pm 2$ nT, $B_{horizontal} = \pm 2$ nT).

For the particle tracking studies, 400,000 non-interacting ions or electrons were launched at the magnetized surface for the variety of total magnetic field configurations. Particle trajectories were computed until all the particles either impacted the surface or left the simulation area. The velocity distributions for all cases are Maxwellians with a mean speed of 200 km s^{-1} and a thermal speed of 75 km s^{-1}.

Total densities and fluxes at the surface were computed by distributing the particles, in a weighted manner, on to a grid with the same resolution as the magnetic field data, and summing over the collected particles. Densities and fluxes were normalized so that the superparticle density in the initial launch region corresponded to 5 particles cm^{-3}, nominal solar wind densities at 1 AU.

Images and mapping of the swirls used Clementine multispectral data (Fig. 1a), projected and co-registered to match the magnetic field maps. Qualitative analysis of surface maturity used the OMAT algorithm of [5].

Results and Discussion: For all the anomalous regions simulated, maps of particle flux to the surface for each anomalous region showed little difference between the cases with an interplanetary magnetic field (IMF) and the case without an IMF, and little difference between the different IMF cases. The results shown here are for the cases without an IMF, in order to remove any magnetic field offset from the superposition.

Mare Ingenii. Figure 1 shows the results for the swirl region at Mare Ingenii. The strongest surface magnetic field (~ 35^{o}S and 160^{o}E, Fig. 1b) is seen to correspond with a void in the flux (Fig. 1c) and the low particle densities at the surface (Fig. 1d). Not only is the number of particles impacting that region small, the speed of those that do, has been reduced. Central to this void region is the portion of the lunar swirl with the highest optical albedo (Fig. 1a). This corresponds with the brightest, bluest (flat spectral continuum), and most optically immature swirl surface at Ingenii.

Both to the north and south of this void are regions of enhanced surface flux and density. It is harder to correlate these regions of enhanced flux with dark lanes purely from the optical image alone in part because these locations are coincident with the rims of the mare-filled craters Thompson and Thompson M, which, being rich in the plagioclase, cannot darken like the dark lanes on the maria.

The simulations begin to describe the interactions that occur between the particles and the magnetic field that are pattern manifested as complex patterns of bright and dark on the surface. This is demonstrated by comparing the simulation results and swirl outlines within Thompson Crater. Unfortunately, the simulations stops short of describing the intricacy of the dark lanes observable in the optical images likely because of the coarser resolution of the magnetic field data.

Reiner Gamma and Gerasimovich Similar to Ingenii, the particle tracking for both these cases shows reduced flux and density at the surface in the vicinity of the strongest magnetic field. The flux to the surface at the peak field strength at Reiner Gamma is not zero though, like the void region for Mare Ingenii. Instead it is on the order of 5×10^9 particles cm^{-2} s^{-1}, approximately $1/10^{th}$ the peak flux seen in Figure 1c. For Gerasimovich, the flux at the region of strongest magnetic field is on the order of 10^{10} particles cm^{-2} s^{-1}, or $1/5^{th}$ the peak flux in Figure 1c. This can not be explained by surface magnetic field strength alone as the peak magnetic field strengths at Gerasimovich are comparable to those at Mare Ingenii and approximately 20% stronger than the peak field strengths at Reiner Gamma.

Interpretation and Next Steps For all cases, the electrons show significantly more deflection than the ions. Taking this into account, means the flux maps for hydrogen ions shown here are worst case scenarios. In reality, an electric field would be generated as the electrons are stopped while the ions continue towards the surface. This electric field will pull the ions back towards the electrons, leading to more deflection of the ions than shown in these results. The next step will be to run simulations that incorporate this effect.

The results also point to the need for higher resolution magnetic field data. Many of the features in Figure 1d, particularly the dark lanes, are smaller than the 0.1° grid spacing of the magnetic field. 3D magnetic field data with much higher resolution than that currently available will be necessary to fully understand the formation of these structures.

References: [1] Blewett D T. et al. (2011) *JGR, 116,* E02002, doi:10.1029/2010JE003656, [2] Kramer G. Y. et al. (2011) *JGR, 116*, E04008, doi:1029/2010JE003669, [3] Purucker M. E. and Nicholas J. B. (2010) *JGR, 115,* E12007, doi:10.1029/2010JE003650. [4] www.planet-mag.net/index.html. [5] Lucey et al. (2000) *JGR 105,* p. 20,377.

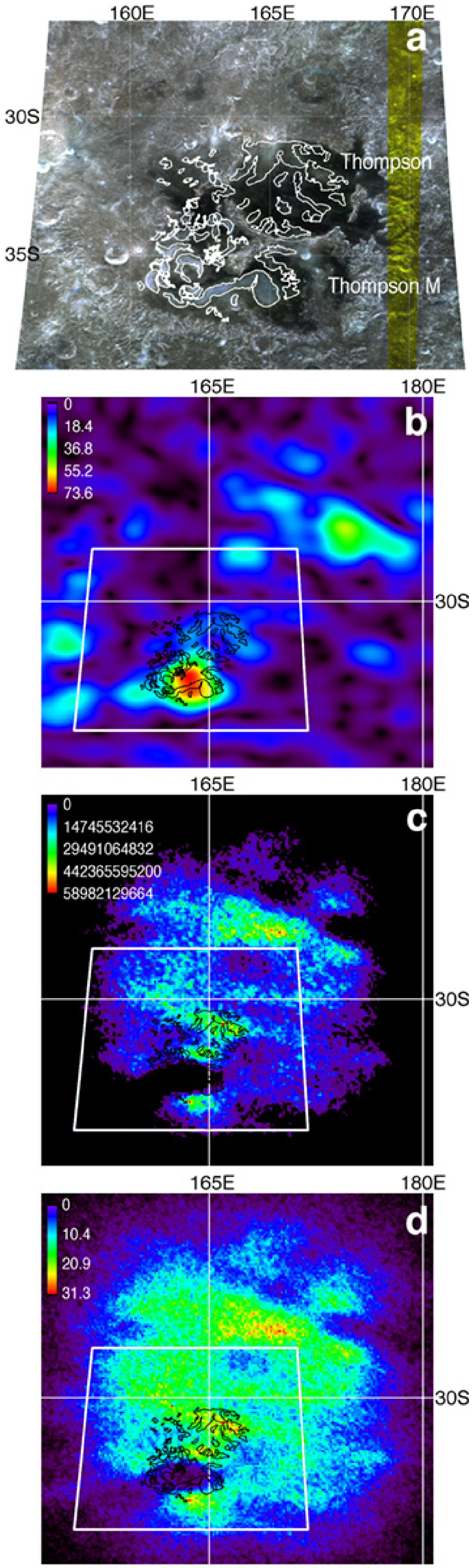

Figure 1: (a) Ingenii region and outlines of swirls. Basemap is Clementine simulated true color (R=900 nm, G=750 nm, B=415 nm). There are more swirls to the NW of Ingenii, but have not yet been mapped as of submission of this abstract. The white box and black contours in (b)-(d) correspond to the extent of the map and outlined swirls, respectively, in (a). (b)-(d) Simulation results for Ingenii swirl region. (b) Magnitude of the anomalous magnetic field at the surface (values in nT), (c) the particle flux at the surface (particles cm^{-2} s^{-1}), (c) the particle density at the surface (particles cm^{-3}).