LUNAR SWIRLS AND MINI-MAGNETOSPHERES: LABORATORY EXPERIMENTS AND KINETIC SIMULATIONS OF THE PLASMA PROCESSES OF THE VERY SMALL.

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Introduction: The altered albedo formations of lunar swirls, such as Reiner Gamma, are related to the co-located crustal magnetic field anomalies [1]. The albedo alterations provide time-integrated evidence that the small regions of magnetic field structures perturb the solar wind plasma environment [1]. In-situ observations from spacecraft provide quantified data about those changes to the plasma environment [1-4]. These include collisionless shocks occurring as low as ~10-20 km above the surface from magnetic field intensities of ~10nT (at the shock altitude) [2]. The sizes of the crustal magnetic anomalies are too small to be analyzed using large-scale plasma models such as MHD. With overall dimensions of ~300km, and with detailed surface contrasts less than 1km apart, the ion deposition processes must operate well within the solar wind ion gyro radius of ~20-10,000km. Here we explore the distinctive processes important to this small-scale plasma, where large-scale approximations such as frozen-in-field and single fluid mechanics, are no longer applicable. In this regime the plasma has to be treated by kinetic theory and a particle-in-a-cell (PIC) code is necessary to model the complex dynamics taking place between the solar wind and the crustal magnetic fields. We will describe results of PIC simulations and compare them to in-situ observations from multiple lunar missions as well as laboratory experiments.

Laboratory Experiments: We have carried out laboratory experiments using a plasma wind tunnel to investigate mini-magnetospheres and find that they show characteristics similar to the lunar mini-magnetospheres [5]. A quantified comparison between the observations, both in space and in the laboratory, with theoretical values shows excellent agreement.

OSIRIS[6] is a mature three dimensional, fully relativistic PIC code used for modeling plasma kinetics under a variety of conditions. OSIRIS solves the full set of Maxwell's equations, including Poisson's equation, using currents and charge densities and weighted discrete particles. Each particle's position and momentum is calculated via self-consistently calculated fields. The result is that once a scenario is composed within a simulation box, the result evolves fully self consistently. Two-dimensional OSIRIS simulations results show a flowing solar wind plasma impacting small-scale magnetic field representing a simple lunar magnetic anomaly. The overall extent of the magnetic field within the simulation box is less than the simultion ion gyro radius.

Conclusions: The simulations confirm the laboratory findings and the theoretical predictions [5] that a collisionless shock forms at the altitude expected from the kinetic theory of collisionless shocks. The thickness of this shock is approximately equal to the electron skin depth ~ c/ω_{pe} (where ω_{pe} is the electron plasma frequency) again in agreement with theory. The characteristic observations of electron and ion density enhancements and depletions accompanied by magnetic field intensity pile-up at the shock coincide with the formation of a narrow interface region where a dynamically stable electric field exists. The simulations confirm the earlier findings of the laboratory experiment [5] that it is this electric field that controls the behaviour of the solar wind ions impacting the magnetic structure. The characteristic structures of the collisionless shock, in which the ions are reflected from a narrow layer by an electrostatic field is a consequence of the magnetized electrons and unmagnetised ions. The narrow discontinuity in the shock structure produces a specular reflected ion component with a velocity equal to or greater than the incoming solar wind velocity. Depending upon the Alfven Mach number, the reflected ions form a counter-propagating component to the solar wind flow that stimulates the growth of the modified two-stream plasma instability whose characteristic frequencies explains the observed turbulence spectrum particularly the lower hybrid electrostatic waves, the non-thermal particle distributions and heat exchange between species seen by spacecraft [3,4].

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