IMPACT AMPLIFIED MAGNETIC FIELDS AS A POSSIBLE SOURCE OF CRUSTAL MAGNETIZATION

R. Oran, and B. P. Weiss, Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA (roran@mit.edu)

Introduction: Although the Moon does not presently have a core dynamo magnetic field, spacecraft measurements have revealed the presence of remanent magnetization in the lunar crust. The formation of the crustal magnetic anomalies remains a mystery. Much of this magnetization is thought to have been produced by cooling in the presence of a core dynamo magnetic field [1]. However, the identification of lunar crustal magnetic anomalies at the antipodes of four of the five youngest large (>600 km diameter) impact basins [2-5] has motivated the alternative hypothesis that the lunar crust could have been magnetized by the impacts. The question whether the crustal magnetization is a record of ancient intrinsic fields or of external carries broad implications to our understanding of the Moon's history and internal structure. Furthermore, the lunar crustal field serves as a test case for understanding magnetization of other solar system bodies, such as Mars, Mercury, and asteroids.

Hypothesis: The theoreal picture that was suggested as an explanation of the antipodal anomalies can be described as follows. During the impact, lunar and impactor material are vaprorised and ionized. The resulting ionized vapor cloud interacts and compresses the surrounding solar wind towards the antipode, causeing the field there to amplify. Heated or shocked lunar rocks at the antipode would subsequently record these transient field amplifications [6-9]. Although this hypothesis has been studied for several decades using hydrodynamic and impact simulations, a conclusive answer can only be obtained by simulating the coupled interaction of the ionized vapor with the magnetized solar wind.

A natural framework for describing magnetized plasmas self-consistently is the system of magnetohydrodynamic (MHD) equations. The development of high performance MHD codes in the last decade allows us to revisit these previous important studies. We performed three-dimensional (3D) MHD simulations of a vapor cloud embedded within a background solar wind, and examined how these will effect the previous estimations of the strength and duration of the magnetic field enhancement at the antipodal points. The MHD simulations will also allow us to estimate the importance of removal of magnetic flux due to reconnection and expansion of the vapor cloud. This will help in assessing how likely it is for impacts to trigger remnant crustal magnetization.

Method: We use BATS-R-US [9], a highly parallelized, 3D MHD code, to simulate the coupled evolution of the vapor cloud and the magnetized solar wind plasma. BATS-R-US is capable of simulating ideal- and resistive-MHD regimes, as well as a single fluid or several fluids/species. Our effort currently focuses on the plasma phase of the cloud and does not aim to model the formation of the cloud from the impact itself. The initial cloud properties are taken from detailed impact simulations appearing in the literature.

We will consider different MHD processes, such as: 1) the finite resistivity of the lunar mantle and magnetic diffusion inside the body, 2) magnetic reconnection at the antipode, and 3) the transport of magnetic flux due to solar wind motion. This allows us to systematically examine whether impact-generated fields can indeed be responsible for the formation of crustal field enhancements on the Moon.

Results: We present a set of MHD simulations of this process. The strength of the amplified field depends on the rate of convergence of vapor in the antipode, as well as the time scale for diffusion of magnetic field, the strength of the solar wind field, and its direction. From scenarios explored thus far, impacts produce peak fields of ~0.2-1 μT, compared to the 30-100 μT required for shock remnant magnetization. We demonstrate that the level of field amplification is limited by the vapor expansion speed and magnetic field reconnection, which both act to remove magnetic flux from the system.

Discussion: Our simulation results suggest that the compression of the solar wind magnetic field at the antipodes of impacts is insufficient to explain the magnetization on the lunar crust. We propose that the source of magnetization is more likely to have been an internal core dynamo. This implies that the Moon formed an advecting metallic core in its early history.

References:

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