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An impact driven dynamo for the early Moon

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Magnetic field measurements from orbit about the Moon have shown that portions of the lunar crust are strongly magnetized, and paleomagnetic analyses of lunar rocks show that some possess a stable remanent magnetization [1]. Nevertheless, after more than 40 years of analysis, the origin of the magnetic fields that magnetized the lunar crust are still debated [2].

Two observations lead us to propose a new model for the generation of a global long-lived magnetic field. First, six Nectarian aged impact basins have central magnetic anomalies [3] that are most likely a result of their impact melt sheets having acquired a thermoremanent magnetization as they cooled though the Curie temperature of metallic iron. Given the slow conductive cooling timescales of these thick deposits, a stable magnetic field is required to have been present for thousands of years following the impact event. Second, each of these impact basins would have significantly affected the rotational state of the Moon. These events could have either unlocked the Moon from synchronous rotation, and/or set up large amplitude librations that would have lasted for several 10s of thousands of years [4].

Here, we propose an alternative mechanism for generating a lunar dynamo, where the energy for dynamo action comes from the rotation of the Moon rather than from thermal effects. In this scenario, large impact events unlock the Moon from synchronization, giving rise to large-scale fluid motion in the core driven by the so-called tidal instability. Tidal instability comes from a parametric resonance between two inertial waves of the rotating flow and the tidal deformation at the core-mantle boundary. We have performed a systematic experimental study of this instability in a deformable rotating fluid sphere [5]. A fully three-dimensional turbulent flow is excited as soon as the ratio between the ellipticity of the core-mantle boundary and the square root of the Ekman number is larger than a critical value of order one. Established flows are then similar to flows set up in the core by solid body precession, which are known to be dynamo capable [6]. Flow velocities are of the order of magnitude of the differential rotation between the fluid and the tidal deformation. The typical amplitude of the generated magnetic field intensity can then be evaluated by adapting the works of Christensen and co-workers [7,8] to our case of mechanical forcing, by supposing that the field strength is controlled by the available mechanical power rather than by any force balance.

As shown by a standard three-layer model of the Moon in hydrostatic equilibrium, a tidally driven instability in its core can be excited over its entire history, as soon as an instantaneous non-zero differential rotation between the tidal deformation and the rotating fluid is imposed. We envision this differential rotation being an impulsive change in the rotation of the lunar mantle following a basin forming impact. If the Moon's rotation was desynchronized by a large impact, our scaling laws demonstrate that a dynamo could have been active for durations of 1000 to 100000 years with magnetic field strengths of some microTeslas, comparable to some paleomagnetic estimates. Transient tidally driven dynamos following large impacts thus constitute a plausible source for the fields that magnetized some portions of the lunar crust.

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