Impact-Induced Demagnetization of Martian Crust with High-Resolution MAVEN Data

Zain Eris Kamal; Advised by Lujendra Ojha
Department of Earth and Planetary Sciences, Rutgers University, Piscataway NJ

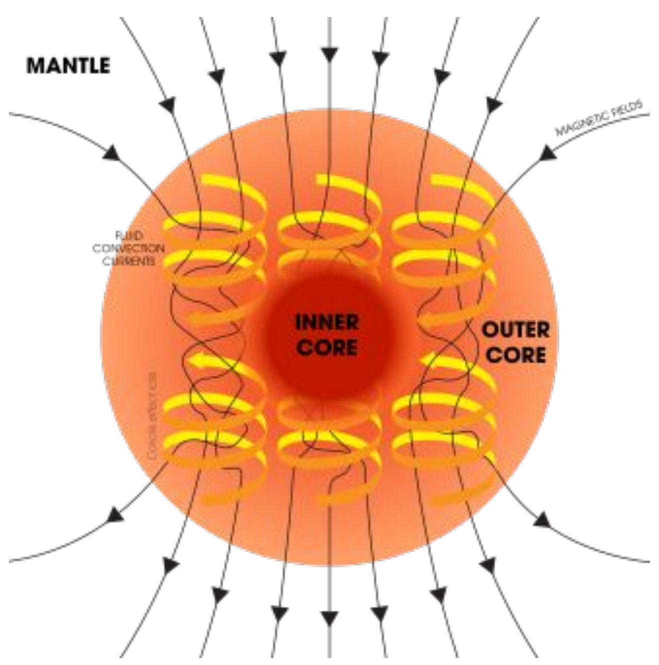
I. Background

The (Once-Active) Martian Dynamo

A celestial body's **global magnetic field (dynamo)** is closely tied to the structure and evolution of its core, mantle, lithosphere, surface, and atmosphere.

Studies of fragmented Martian meteorites found on Earth show the **Martian dynamo was active until about 4 Ga** (gigannums, or 4 billion years) ago [1], but the precise timing of its demise is still debated.

The Mars Global Surveyor (MGS) satellite mission (1996-2006) confirmed the **absence** of a presently active Martian core field. But notably, it detected unexpectedly **strong crustal magnetic field features** [1].



Where's the Crater Demagnetization?

Since certain minerals can preserve magnetization acquired by their planetary field for billions of years, studying them can give us a window into the planet's earliest conditions [2].

Iron-bearing minerals heated past a certain temperature called the Curie point can acquire a **thermal remanent magnetization (TRM)** with direction/amplitude determined by the presence of a **background magnetic field** (i.e. the dynamo) as they cool [2]. Notably, **crater impacts** cause sudden TRM as opposed the slow, enigmatic TRM of volcanoes.

We expect the shock wave pressure produced by impacts that created craters of diameters 300-1000 km to significantly demagnetize the underlying crust. However, a 2007 study of MGS data found **no signature of appreciable demagnetization** in craters of that size range [3].

A Closer Look with MAVEN

The **Mars Atmosphere and Volatile EvolutioN (MAVEN)** satellite operated by NASA has been collecting data from Mars's orbit from 2014 to present day.

MAVEN's magnetometers are able to measure the crustal magnetic field at altitudes as low as 130 km with **high resolution**, allowing us to detect signals that were too weak or had wavelengths too short to be observed by MGS.

Additionally, global nighttime coverage at altitudes under 200 km cover 93% of the planet as opposed to MGS's <20% coverage.

II. Methodology

Objective

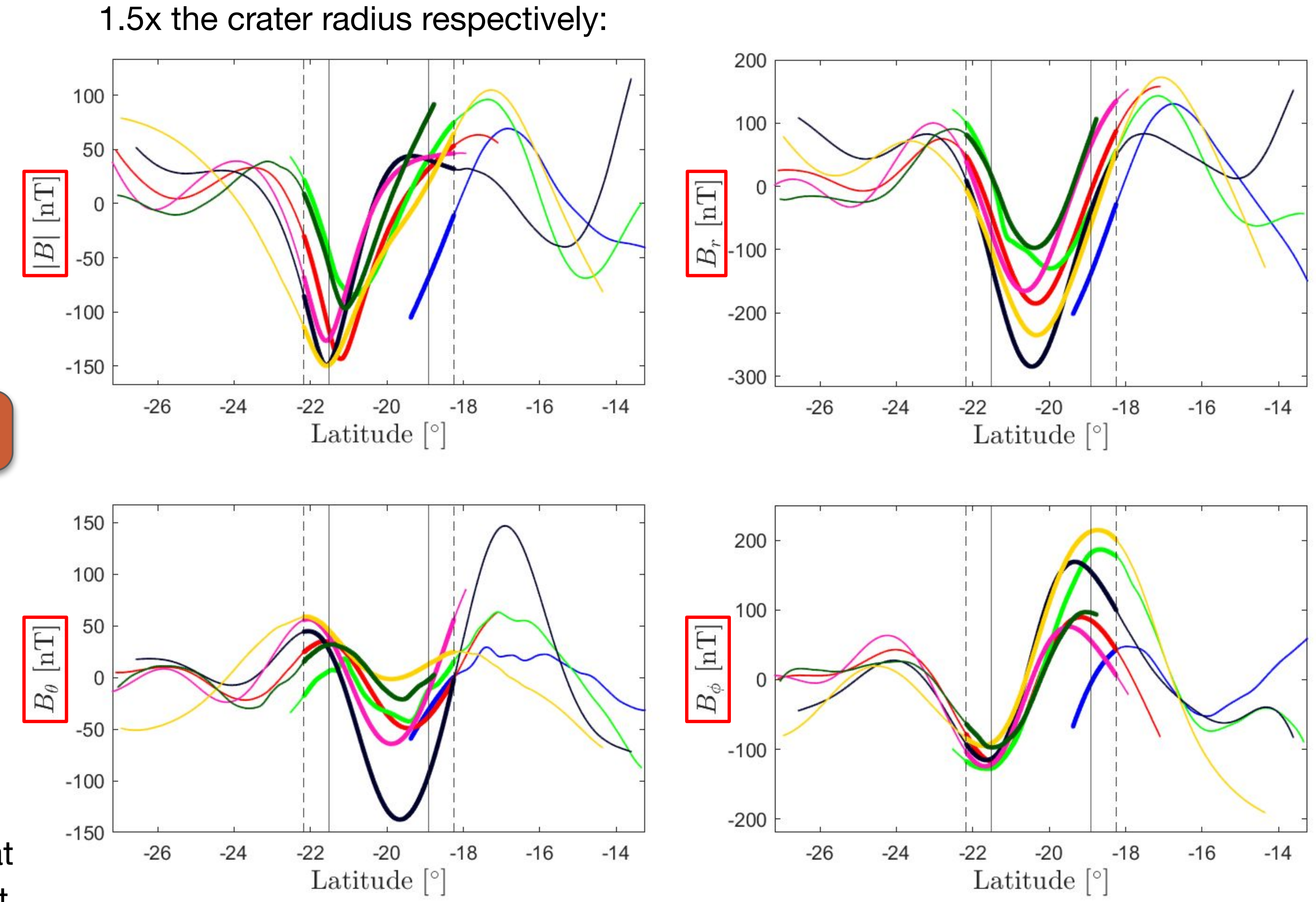
In this work, we analyze high-resolution **MAVEN magnetic field tracks** in/around 857 craters of diameters 70 - 1,000 km to revisit previous interpretations of **impact-induced demagnetization** and ultimately shed light on the **history of the Martian dynamo**.

Data

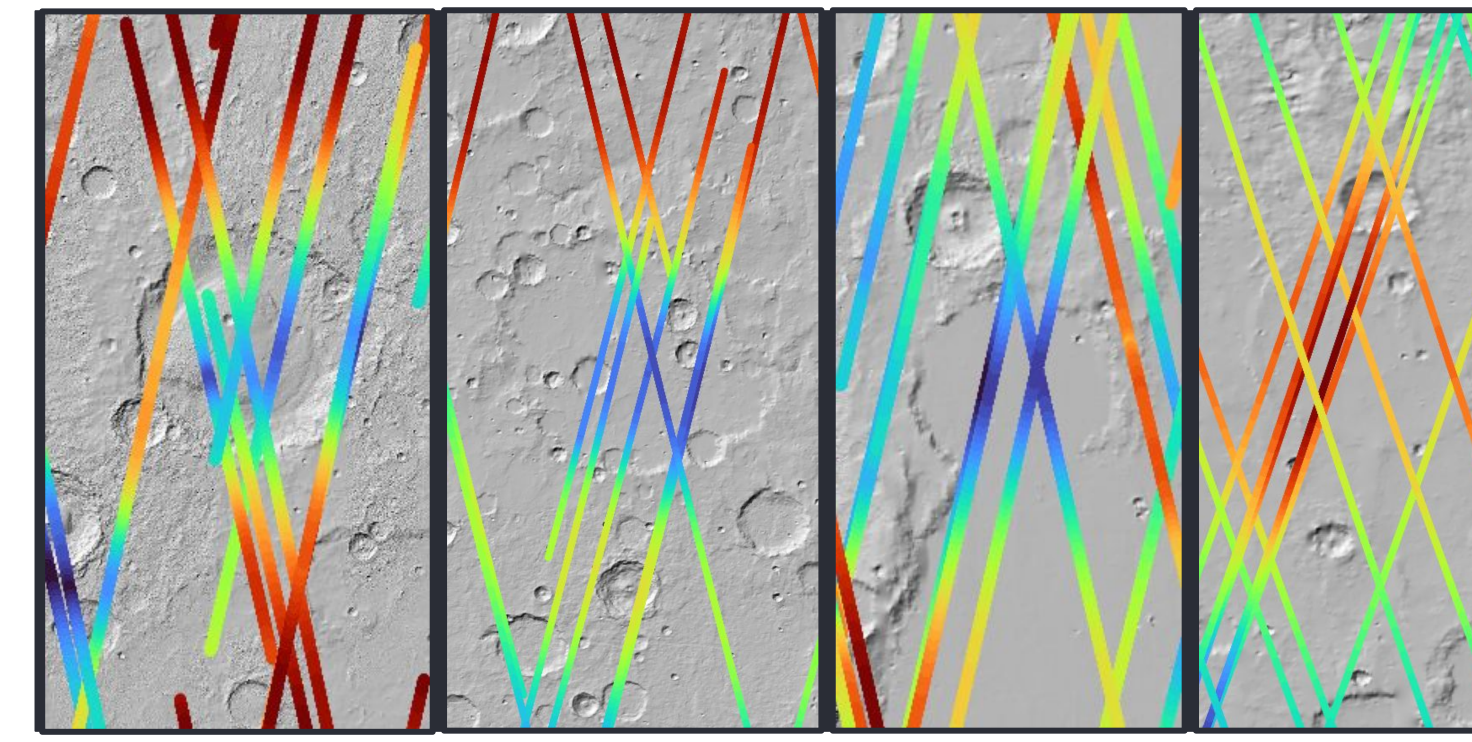
1. In 2012, Robbins and Hynek published a comprehensive **global database** of Mars impact craters ≥ 1 km in diameter. We extract information for craters with **diameters between 70-1000 km**, which comes out to 857 total craters.
2. We focus on MAVEN magnetometer **nighttime data** (20:00 - 09:00) collected at **altitudes less than 200 km**. This is because solar radiation causes electric currents to be induced in the ionosphere which generate their own magnetic fields, introducing longwave biases that muddle/intensify MAVEN's measurements of sunny terrain.

Analysis

(1. Cross-sectional magnetic field analysis) For each crater, we isolate MAVEN tracks that pass through the crater and plot the linearly detrended **magnitude + vector spherical components** of the magnetic field. Below, we see a ~150 km diameter crater with strong evidence for impact-induced demagnetization. The solid and dashed lines represent the crater radius and 1.5x the crater radius respectively:



(2. GIS surface visualizations) After removing craters with noisy/incoherent signals and/or no clear demagnetization, we convert **all magnetic field data surrounding the crater** (not just tracks that pass through the crater) to shapefiles for visualization with QGIS. Some compelling examples are pictured below (normalized |B|, where blue is ~0 and red is 1):



*(Note the rightmost example uniquely exhibits **remagnetization**.)*

This is less quantitative than the cross-sections, but still necessary to ensure we're not misinterpreting a longitudinal strip of magnetization that happens to coincide with a crater as an impact-induced anomaly.

(3. Crater dating) Once we have our final candidates, we attempt to find **when in Mars's geological history the impact occurred**. This is done with a GIS database of Martian surface features dated in the Noachian, Hesperian, and Amazonian periods published by Tanaka et al. in 2014 [4].

III. Conclusions

Results, Discussion, and Future Work

Out of 857 total craters with diameters 70-1,000 km, we found **24 with significant impact-induced demagnetization** and **1 with remagnetization**. About half lined the equator. Out of these impacts, **16** occurred in the **Noachian** era, **5** occurred in the **Hesperian** era, and **4** occurred in the **Amazonian** era.

The reason for the lack of unambiguous demagnetization around craters is unclear. **Martian dust is known to be magnetized**, so one hypothesis is that depositional remanent magnetization (DRM) remagnetized impact-sites.

In the future, we can:

- Use Alain Plattner's vector Slepian functions toolkit [1] to produce high-resolution **local spherical harmonic models** around craters to better understand field variations and remove noise.
- Investigate chemical (as opposed to thermal) remanent magnetization by looking around **valley network and hydrated mineral deposits**, which have been catalogued into a GIS database by Hynek [5].

References

[1] A. Plattner and F.J. Simons, Journal of Geophysical Research: Planets 120, 1543 (2015).
[2] A. Mittelholz, C.L. Johnson, J.M. Feinberg, B. Langlais, and R.J. Phillips, Science Advances 6, eaba0513 (2020).
[3] H. Shahnas and J. Arkani-Hamed, Journal of Geophysical Research: Planets 112, (2007).
[4] K.L. Tanaka, S.J. Robbins, C.M. Fortezzo, J.A. Skinner, and T.M. Hare, Planetary and Space Science 95, 11 (2014).
[5] B.M. Hynek, M. Beach, and M.R.T. Hoke, Journal of Geophysical Research: Planets 115, (2010).

***Github:** scan to access the computational tools used for data analysis, as well as download processed MAVEN/crater data.*