The effect of giant impactors on the magnetic field energy of an early Martian dynamo

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Introduction

Of all the planets in our solar system, only Mars and Venus currently have no active magnetic field. Mars is interesting because we know that there was once a strong magnetic field due to the observed remanent magnetisation locked in the planets crust (Figure 1) [1].

Similar timing for the estimated cessation of the magnetic field (~4Ga) and the Late Heavy Bombardment (3.7-4.1Ga) have lead to theories that a single, or multiple, giant impacts could have killed the Martian dynamo through saddle heating and a decrease in the average CMB heat flow [2,3,4].

Previous studies have investigated this theory but do not take into account the initial shock heating that causes an increase in average heat flux [5,6,7]. Here, we chose six time points with a varying average heat flux and heat flux heterogeneity size to show that the time-averaged magnetic field energy decreases to below pre-impact values.

Method

Impact model results were used from the study by Julien Monteux and Arkani-Hamed [7]. Their outputs are in the form of a 2D temperature field from 0.22Myrs after impact for an impactor of diameter 750km. The data was transformed to find the heat flux at the CMB, shown below for six chosen post-impact time points.

The variation of the total heat flux at the CMB, $Q$, also varies the remanent Rayleigh number, $Ra$, with the following relation where $R_s$ is used as a time stepped control parameter for the dynamo model:

$$R_A = R_Q g R_s^{-1/2} w_{min}^{-1}$$

The evolution of the Rayleigh number is shown in Figure 2 along with the heat flux anomaly properties and its effect on the CMB heat flux.

Results

These three sets of models were simulated:

1. Polar impact with varying Rayleigh number.
2. Equatorial impact with varying Rayleigh number.
3. Homogeneous heat flux with varying Rayleigh number.

Initial simulations show that the time-averaged magnetic field energy decreases below the pre-impact value after a few of the chosen time steps (Figure 4a).

The initial simulations only lowered the time-averaged energy where the aim is to kill the dynamo. To do this, a new pre-impact model was brought closer to conventional onset by lowering the Rayleigh number.

Furthermore, we lowered the Ekman number closer to planetary values and ran the simulations longer to increase the accuracy of the time-averaged energy.

These simulations are currently on-going but initial results (Figure 4b) for the first two chosen time points show similar unexpected behaviour as the initial simulations which did eventually lead to a general decrease in dynamo action (Figure 4a).

Conclusions

- An impactor of diameter 750km would have caused disruption to the early Martian dynamo.
- We have shown that the core begins to recover from the impact, the time-averaged magnetic field energy has decreased to below pre-impact values.
- Initial results for the ongoing simulations follow the same trend where the expected result should kill the dynamo and decrease the magnetic field energy to zero.
- These results add weight to the theory that giant impacts were the cause of the cessation of the Martian dynamo.

Further research

- Two new sets will be simulated which will determine the effect of only the heat flux heterogeneities on the dynamo:
  - 1. Polar impact with fixed Rayleigh number;
  - 2. Equatorial impact with fixed Rayleigh number.
- Potential extra investigations could include:
  - 1. Can the dynamo be restored by increasing the Rayleigh number back to pre-impact values?
  - 2. If the heterogeneity alone has a small effect on the dynamo, what size and amplitude is required to kill it?
  - 3. Simulate the effects of multiple impact events or impact locations at various latitudes.

References