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The Feedback Dynamo of Mercury

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Abstract

The observed weakness of Mercury's magnetic field poses a long-standing puzzle to dynamo theory. Using numerical dynamo simulations we show that it can be explained by a negative feedback process between the planet's magnetospheric and internal fields. Without the feedback a small internal field is amplified by the dynamo process until it reaches Earth-like values. With the feedback, however, the field strength levels off at a much lower strength that is compatible with the observations at Mercury. The resulting surface field is clearly dominated by a dipole component. This will allow to discriminate the feedback model against other candidates once MESSENGER and BepiColombo data allow to construct more accurate field models.

1. Introduction

The recent flybys of the MESSENGER spacecraft at planet Mercury confirm the existence of a large-scale magnetic field (Anderson et al., 2010). The dipole surface field, however, is roughly one to two orders of magnitude too weak to be commensurable with classical dynamo theory (Olson and Christensen, 2006; Wicht et al., 2007). Here, we examine the feedback dynamo scenario suggested by (Glassmeier et al., 2007), in which the magnetic field from the magnetosphere gives rise to a negative feedback on the internal dynamo process.

2. The Feedback Dynamo Concept

Mercury, the innermost planet in the solar system, is subject to an intense solar wind flux. Due to the interaction of the solar wind with the planetary dipole field the magnetopause is created. The magnetic field of the magnetopause currents contributes significantly to the overall field within the magnetosphere (Johnson et al., 2009; Glassmeier et al., 2007) and the planet's interior. As visualized in Fig. 1, the external field is parallel to the internal dipole field at the magnetopause. But at the core-mantle boundary, external and internal dipole fields are inherently anti-parallel.

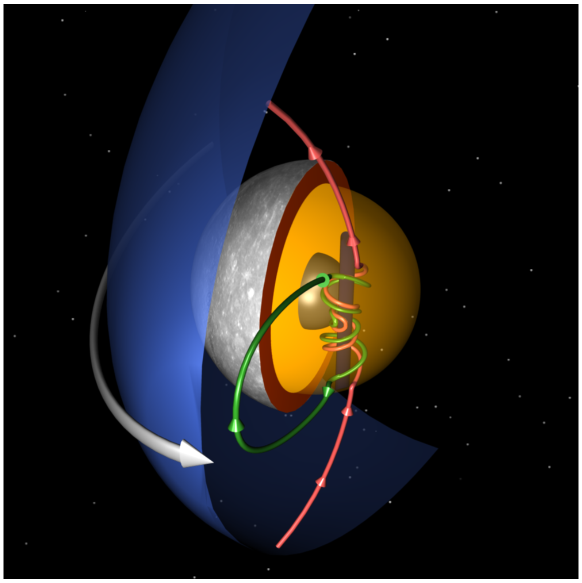

Figure 1: The feedback dynamo mechanism. Mercury is in the center and the solar wind enters from the lower left corner. Due to the interaction with the planetary dipole field (green) the magnetopause (blue) is created. The external field (red) due to the magnetopause currents (white) reaches through the planetary mantle (dark red) and enters the fluid outer core (orange sphere). There the dynamo dipole field and the external field are anti-parallel. The anti-cyclones (blue column) in the core convert the poloidal field into an azimuthal one, stretch it at the same time due to a secondary poleward flow away from the equator and thereby enhance the field amplitude. At this point, internal and external fields become mixed and weaken each other.

The external field diffuses into the finitely conducting core and the skin-effect suppresses the solar and orbit induced variations. Thus, the magnetospheric field can be approximated by an axial, uniform field.

3. Modelling and Results

In order to model the dynamo process under the influence of the magnetospheric field, we solve the Navier-Stokes equation, the induction equation and an equation for the heat transport using the benchmarked code of (Wicht, 2002). The external field is introduced by a modification of the magnetic boundary condition at the core-mantle boundary. We chose to model a dynamo, which is slightly super-critical with respect to the onset of dynamo action. An additional dynamo model with the same initial conditions and control parameters but without an external field serves as a reference run, here. We compare also the results of the 3D dynamo simulations with the results from kinematic $\alpha\Omega$ modelling by Heyner et al. (2010, 2011).

We find, that if the dynamo is weakly initialized and not driven too strongly, it can by stabilized by the external field at this weak level. The role of the Lorentz-force, which usually levels off the growth of a dynamo, is much more diminished compared to the strong-field reference dynamo. Thus, the structure of the core flow is more geostrophic. Since the Lorentz force is weak, the outcome of the 3D simulation is similar to the kinematic simulations of Heyner et al. (2010, 2011). From our 3D simulations, we work out characteristic spotting features as e.g. the magnetic surface spectrum that can be compared to the MESSENGER and Bepi-Colombo data.

4. Conclusion

The feedback mechanism can succeed to establish a weak field state when the internal field is very weak to start with, most likely in the start-up phase of super-critical dynamo action.

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