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Geodynamo modeling: successes and challenges

U.R. Christensen

Max-Planck-Institute for Solar System Research, Katlenburg-Lindau, Germany
(christensen@linmpi.mpg.de)

In the past ten years self-consistent numerical simulations of the geodynamo had a remarkable success. In many of these models the magnetic field properties closely match those of the geomagnetic field in terms of spatial spectra and magnetic field morphology, or the time scales and amplitudes of secular variation. Some models exhibit dipole reversals whose temporal behaviour agrees with what is known for geomagnetic reversals from the paleomagnetic record. Scientists progressively use dynamo models as a tool to explain specific properties of the geomagnetic field or to study second order effects, for example those arising from the coupling between the Earth's mantle and core. While the recent geodynamo models rely only on the fundamental laws of magnetohydrodynamics, some conditions differ strongly from those in the Earth's core. In all models the viscosity is fixed to values far in excess of realistic ones in order to suppress small-scale turbulence of the flow, which cannot be resolved with present computational means. Whether this seriously corrupts the essential physics of the dynamo process is an open question. Also, different models with similar structure of the external (observable) field may differ significantly in their internal field structure. It is not fully understood why the magnetic field is dipole-dominated in some models and not in others. A well-founded theory that explains the variability in strength and morphology of different planetary magnetic fields in the solar system is still missing. Attempts for improving this situation consist of pushing the model parameters in the direction of Earth values and to quantify the dependence of key properties of the dynamo solution on the control parameters. The first results on such scaling laws are encouraging and may suggest that current models do in fact capture the essential physics of the geodynamo. The next generation of laboratory dynamos working with a free turbulent flow of liquid sodium will play an important role for testing the extrapolation of model-based scaling laws to core conditions.