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Explaining Mercury's peculiar magnetic field

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MESSENGER magnetometer data revealed that Mercury's magnetic field is not only particularly weak but also has a peculiar geometry. The MESSENGER team finds that the location of the magnetic equator always lies significantly north of the geographic equator, is largely independent of the distance to the planet, and also varies only weakly with longitude. The field is best described by an axial dipole that is offset to the north by about 20% of the planetary radius. In terms of classical Gauss coefficients, this translates into a low axial dipole component of g10= -190 nT but a relatively large axial quadrupole contribution that amounts to roughly 40% of this value. The axial octupole is also sizable while higher harmonic contributions are much weaker. Very remarkable is also the fact that the equatorial dipole contribution is very small, consistent with a dipole tilt below 0.8 degree, and this is also true for the other non-axisymmetic field contributions. We analyze several numerical dynamos concerning their capability of explaining Mercury's magnetic field. Classical schemes geared to model the geomagnetic field typically show a much weaker quadrupole component and thus a smaller offset. The onset only becomes larger when the dynamo operates in the multipolar regime at higher Rayleigh numbers. However, since the more complex dynamics generally promotes all higher multipole contributions the location of the magnetic equator varies strongly with longitude and distance to the planet. The situation improves when introducing a stably stratified outer layer in the dynamo region, representing either a rigid FeS layer or a sub-adiabatic core-mantle boundary heat flux. This layer filters out the higher harmonic contributions and the field not only becomes sufficiently weak but also assumes a Mercury like offset geometry during a few percent of the simulation time. To increase the likelihood for the offset configuration, the north-south symmetry
must be permanently broken and we explore two scenarios. Increasing the heat flux through the northern hemisphere of the core-mantle boundary is an obvious choice but is not supported by current models for Mercury's mantle. We find that a combination of internal rather than bottom driving and an increased heat flux through the equatorial region of the core-mantle boundary also promotes the required symmetry breaking and results in very Mercury like fields. The reason is that the imposed heat flux pattern, though being equatorially symmetric, lowers the critical Rayleigh number for the onset of equatorially anti-symmetric convection modes. In both scenarios, a stably stratified layer or a feedback coupling to the magnetospheric field is required for lowering the field strength to Mercury-like values.