New Insights into Mercury's Core Dynamics from Numerical Dynamo Simulations. H. Cao[1,2], J. M. Aurnou[1], K. M. Soderlund[3], J. Wicht[4], and C. T. Russell[1,2], [1]Department of Earth, Planetary and Space Sciences, University of California, Los Angeles, CA 90095, USA (haocao@ucla.edu), [2]Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095, USA, [3]Institute for Geophysics, John A. & Katherine G. Jackson School of Geoscience, The University of Texas at Austin, Austin, TX 78758, USA, [4]Max-Planck Institute for Solar System Research, Max-Planck-Strasse 2, 37191 Katlenburg-Lindau, Germany.

Introduction: Recent MESSENGER measurements show unambiguously that Mercury has a global-scale magnetic field that is axially aligned yet strongly asymmetric with respect to the equator: the field in the northern hemisphere is approximately three times stronger than that in the southern hemisphere [1, 2]. The north-south asymmetry is derived from the in-situ measured northward displacement of the magnetic equator by ~0.2 Mercury radii, where 1 Mercury radius is 2440 kilometers, both near the planet and in the distant magnetotail [2]. This north-south asymmetry is further confirmed with proton-reflectometry based on MESSENGER ion spectrometer measurements [3]. Such a significant north-south asymmetry resembles none of the magnetic fields of other active planetary dynamos [4], and has not been reproduced or predicted in previous Mercury dynamo models [5-10].

The iron core of Mercury comprises 85% of the planet's radius and is at least partially liquid [11], but the size of a solid inner part is highly uncertain [12]. Within the convecting fluid core, the buoyancy forcing can be more complex than that of Earth's core. This complexity comes both from the nonmonotonic trend of the FeS melting curve under the pressure range of Mercury's core [13] and the possible precipitation of Si , in addition to S, into Mercury's core during the global core-mantle differentiation [14]. The lower mantle temperature of Mercury is likely north-south symmetric, given that degree-1 (north-south asymmetric) mantle convection is unlikely to develop within Mercury's thin mantle and any thermal perturbation on the lower mantle temperature from giant impacts is unlikely to persist to the present [15].

With no evidence for a north-south asymmetry in Mercury's lower mantle temperature, we ask the question: Can a quasi-steady Mercury-like (axial dominant, dipolar, and equatorially asymmetric) magnetic field be generated in a planetary dynamo model with north-south symmetric thermal boundary conditions?

Numerical Dynamo Model: A series of numerical dynamo models are performed to explore the effects of buoyancy forcing, CMB heat flow heterogeneity, and inner core size on Mercury's core dynamo. Numerical dynamo code MagIC [16, 17] version 3.44 is employed to conduct all of the numerical experiments in this study.

Two end-member modes of buoyancy forcing are tested: the first is volumetric buoyancy (VB) in which buoyancy sources are distributed within the entire volume, the second is bottom driven (BD) in which buoyancy sources are concentrated near the inner boundary.

Two groups of CMB heat flow heterogeneities are tested: the first features local excess equatorial CMB heat flow, and the second features local depleted equatorial CMB heat flow.

Different inner core sizes are tested: inner core to outer core radius ratio are varied from 0.2 to 0.75.

Magnetic Fields and Flow Structures in our Dynamo Models: We find that a quasi-steady, axial dominant, north-south asymmetric magnetic field similar to Mercury's can be generated even with north-south symmetric thermal boundary conditions. The necessary ingredients for such a steady equatorial symmetry breaking are volumetric buoyancy and excess equatorial CMB heat flow. The north-south asymmetric magnetic fields in our dynamo models result from north-south asymmetric kinetic helicity. Mutual excitation of two different modes of columnar convection, the even-parity eigenmode and the odd-parity eigenmode, gives rise to the symmetry breaking in kinetic helicity.

Steady equatorial symmetry breaking of the flow and the magnetic fields occur with all inner core sizes tested given that volumetric buoyancy is the dominant forcing mode and excess equatorial CMB heat flow is applied. However, dipole-quadrupole dominant magnetic field solutions have only been achieved with inner core to outer core radius ratio smaller than 0.5.

Implications for the Interior of Mercury: The necessary ingredients in our numerical dynamo models to get quasi-steady Mercury-like (axial dominant, dipolar, and equatorially asymmetric) magnetic fields imply that Mercury's present day dynamo is powered by volumetrically distributed buoyancy sources, which is different from the classical bottom-up inner core growth scenario. Local excess equatorial CMB heat flow is favored by our dynamo model, given that it helps promote and stabilize the equatorial symmetry breaking. To reproduce the dipole-quadrupole dominancy, a relatively small inner core with inner core to outer core radius ratio smaller than 0.5 is favored by our dynamo model. These implications can be assessed by gravity, topology and thermal measurements from ongoing and future missions (e.g. BepiColombo) and investigations on mantle dynamics and thermodynamic properties of Fe-S-Si system under the core conditions of Mercury.

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