USING FUTURE OBSERVATIONS TO DETERMINE WHETHER THE SOURCE OF MERCURY'S MAGNETIC FIELD IS AN ACTIVE DYNAMO. S. Stanley[1], M.T. Zuber[1], J. Bloxham[2], and W.E. Hutchison[1], [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 77 Massachusetts Ave., Cambridge, MA 02139 (sstanley@mit.edu), [2]Department of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA, 02138.

Introduction: Mariner 10's observations during the first and third flybys of Mercury in 1974-1975, revealed the presence of a magnetic field of internal origin [1,2]. The inferred magnetic dipole moment of approximately 300 nT-R_M^3 is not well constrained due to the spatial distribution and limited quantity of the data [3], but even with this uncertainty, the inferred field strength appears problematic for all typical sources of planetary magnetic fields.

One possibility is that the field is due to crustal remanent magnetization from a dynamo operating in Mercury's past [4-6]. If this is the case, then Mercury's crustal magnetism is quite different from that of Earth and Mars where crustal magnetic fields are short wavelength (i.e. non-dipolar) features.

Another possibility is that the dipole field is the result of a presently active dynamo. Recent Earth-based radar measurements of Mercury's librations in longitude [7] have demonstrated that the core and mantle of Mercury are decoupled, and hence that the core must be at least partially fluid. This provides the basic necessary (although by no means sufficient) condition for an active dynamo to be the source of the observations.

Expected Magnetic Field Strength: An active dynamo source has been viewed as problematic because of discrepancies between the observed field's magnitude and theoretical estimates of the magnetic field strength produced by an Earth-like dynamo. Using two independent methods for obtaining theoretical estimates of the magnetic field strength produced by a dynamo (energy balance and magnetostrophic balance), toroidal magnetic field values (B_T) in Mercury's core of 10^5-10^7 nT [8-10] are found. Using the observed dipole field strength at spacecraft altitude to determine the strength of the dipole at Mercury's core-mantle boundary (B_{Dip}) and comparing this value to the theoretical toroidal field value in the core, we find $B_{Dip}/B_T \sim 10^{-2}$-10^{-4}. If a similar analysis is carried out for Earth's field this ratio is $B_{Dip}/B_T \sim 10^{-1}$. This is why a dynamo solution for Mercury's field has been considered problematic since it appears that Mercury's dynamo produces a much smaller poloidal dipole field compared to its toroidal field than does the Earth and it is unclear why this should be the case.

Because typical sources for Mercury's magnetic field are problematic, alternatives such as a thermoelectric dynamo [8,11] have been considered.

Thin Shell Dynamo Solution: Stanley et al. [10] have examined whether Earth's and Mercury's differences in field partitioning between toroidal and dipolar poloidal field can be explained by a difference in their convective region geometries. Thermal evolution models have shown that Mercury's core may be comprised of a thin fluid outer core surrounding a relatively large solid inner core [9,12-14]. This geometry is different from the thick shell geometry of Earth's core which may lead to differences in the magnetic fields produced.

In a series of dynamo simulations using the Kuang and Bloxham numerical dynamo model [15,16], Stanley et al. studied the effects of varying the fluid outer core shell thickness and Rayleigh number on the resulting magnetic fields. It was found that some thin shell dynamos produce weak surface magnetic fields similar to those observed at Mercury. In these dynamos, both the ratio of poloidal to toroidal field inside the core and the ratio of dipole poloidal field to total poloidal field were smaller than dynamos operating in Earth-like geometries.

The numerical Mercury-like dynamos only occur when the outer core is relatively thin and the Rayleigh number is relatively low (but still large enough to produce a strong-field dynamo). The difference in field partitioning in these Mercury-like dynamos is a result of two factors. First, a stronger axisymmetric toroidal field is generated inside the tangent cylinder as a result of strong differential rotation in this region. Second, as a result of a relatively low Rayleigh number and the thin-shell geometry, the dominant mode of convection (Busse rolls) are unable to effectively convert toroidal field into poloidal dipolar field. This is because the convective rolls only form outside the tangent cylinder where the toroidal field is relatively weak. Convection is not strong enough inside the tangent cylinder to convert the strong toroidal field there into poloidal dipolar field.

Implications for Future Observations: These numerical studies have shown that a dynamo solution for Mercury's weak observed dipole field is possible, however they do not rule out crustal magnetization or a

thermoelectric dynamo as the source of the observations. Here we use the characteristics of our numerical dynamo models to examine whether future observations by the MESSENGER and Bepi-Colombo missions could determine if the field is dynamo generated.

If secular variation of the field is observed then an active dynamo source would be the most likely solution. We examine the time variability in our Mercury-like numerical dynamos in order to determine the feasibility of observing secular variation in the upcoming MESSENGER and Bepi-Colombo missions. We find that the dipole and non-dipole components of the field have different time variation rates with certain non-dipolar features near the equator changing much faster in time than the dipolar component of the field. This suggests that it is important to obtain good observations of the field near the equator in order to determine if the field is dynamo generated.

We also examine whether certain structural features in the field at the surface could be used to assert an active dynamo as the source of the field. One possibility is that evidence of an effect due to the tangent cylinder might be observed. Since the core is separated into three dynamical regimes by the tangent cylinder, convection patterns are likely different in these regions possibly leading to differences in the magnetic field patterns in these regions. For example, the intensity and scale of the field may be different inside and outside the tangent cylinder. Another possibility is that intense flux patches associated with convection columns that form adjacent to the inner core boundary outside the tangent cylinder may be observed (as they are for Earth). These observations could also provide information on the size of the solid inner core in Mercury. The feasibility of observing these features with MESSENGER will be discussed.

References:

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