EVIDENCE FOR REMANENT MAGNETIC FIELDS ON MERCURY FROM MESSENGER'S LOW-ALTITUDE CAMPAIGN. Catherine L. Johnson[1,2], Michael E. Purucker[3], Lydia C. Philpott[1], Haje Korth[4], Brian J. Anderson[4], Nikolai A. Tsyganenko[6], Steven A. Hauck, II[7], Brett W. Denevi[4], Paul K. Byrne[8], James W. Head III[9], Matthew A. Siegler[2,10], Roger J. Phillips[11] and Sean C. Solomon[12,13], [1]Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada, cjohnson@eos.ubc.ca. [2]Planetary Science Institute, Tucson, AZ 85719, USA, cjohnson@psi.edu. [3]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA. [4]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA. [6]Institute and Faculty of Physics, Saint Petersburg State University, Saint Petersburg, Russia. [7] Department of Earth, Environmental and Planetary Sciences, Case Western Reserve University, Cleveland, OH, 44106, USA USA. [8]Lunar and Planetary Institute, Houston, TX 77058, USA. [9]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA. [10]Department of Earth Sciences, Southern Methodist University, Dallas, TX 75205, USA. [11]Planetary Science Directorate, Southwest Research Institute, Boulder, CO 80302, USA. [12]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA. [13]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA.

Overview. Magnetic field measurements made by the MESSENGER spacecraft in orbit around Mercury have been obtained at altitudes less than 200 km since April 2014. The observations are dominated by fields resulting from the internal offset-axial dipole field, the magnetopause and magnetotail current systems, and other external sources [1-4]. We examine the remaining signals for evidence for short-wavelength fields of internal origin. Small-amplitude (a few nT to about 15 nT) residual signals consistent with fields from sources at crustal or upper mantle depths have been clearly identified over regions covered by MESSENGER's lowest periapsis altitudes (25 km). We discuss the implications of these results for Mercury's magnetic field history and for the magnetic mineralogy of the silicate portion of the planet.

Methodology. We analyzed portions of all MESSENGER orbits taken at altitudes below 400 km to facilitate identification of short-wavelength magnetic field signals of possible internal origin.

Extracting Short-Wavelength Signals. Magnetospheric models developed with MESSENGER data [1,3] allow the contributions from the magnetopause, magnetotail, and offset axial dipole (OAD) fields to be estimated for each orbit and subtracted from the vector magnetic field measurements. The remaining signals are typically about 10% of the original signal and are a few tens of nT in amplitude (Figure 1a). These are dominated by long-wavelength fields that are inferred to be external in origin: they are organized in local time [1,3] and increase in amplitude with increasing magnetospheric activity [5]. Furthermore, fields resulting from Birkeland currents [4] increase in amplitude with decreasing spacecraft altitude. We estimated and subtracted the long-wavelength signals empirically on an orbit-by-orbit basis using a high-pass filter, with a roll-off between 0.002 and 0.01 Hz; i.e., for near-periapsis spacecraft speeds, wavelengths longer than 2000 km were removed entirely, and those shorter than 400 km were completely retained. We verified that the results are insensitive to the precise choice of the high-pass filter characteristics.

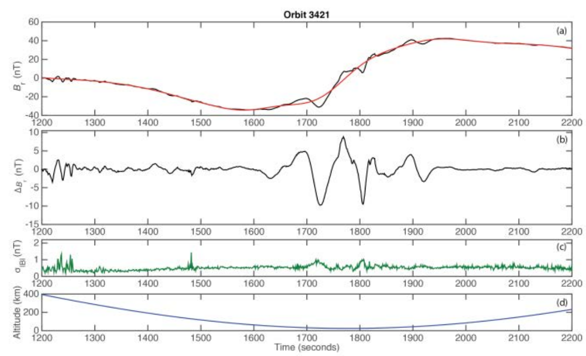

Figure 1: Portion of orbit 3421 on 8 September 2014. (a) Radial magnetic field, B_r, in nT (black) after subtraction of the magnetopause, magnetotail, and OAD model fields. Low-pass filtered signal (red). (b) High-pass filtered signal, ΔB_r, in nT. See text for filter details. (c) High-frequency (> 1 Hz) variability in the total field, σ_B, in nT. (d) Spacecraft altitude in km. Periapsis altitude was 25 km.

Identification of Signals of Internal Origin: Typically, the high-pass filtered data show no remaining signal or show signals that are clearly correlated with an increase in the variability in the total field at frequencies above 1 Hz. The latter are thus not of internal origin, e.g. the signals during the time period 1200–1260 s in Figures 1b and 1c. However, for some orbits the high-pass filtered data show smoothly varying signals that have amplitudes more than three times that of the high-frequency variability, hereafter the signal-to-noise ratio, that occur close to periapsis (Figure 1d) and are observed on multiple adjacent orbits. Signals with these characteristics have been detected over the two regions where MESSENGER periapsis altitudes were close to 25 km in 2014, and weaker signals have been detected over a third region at higher spacecraft altitudes (~100 km). So far, clear detections have been made on nightside or dawn-dusk portions of orbits, where the external high-frequency variability is on average lower than on the dayside. Signals have been detected in the radial and the north-south components of the field; the east-west field component is typically noisier.

Results. Figure 2 shows results for the high-pass-filtered radial field (ΔB_r) from orbits in September 2014 over the Suisei Planitia region. Coherent signals are observed across the region with peak amplitudes (~12 nT) occurring north of Shakespeare basin. The dominant wavelength of the signals is ~320 km, but shorter-wavelength signals are also observed. Calculations confirm that signals of these amplitudes and wavelengths would not be detectable at the higher altitudes of the MESSENGER spacecraft during previous coverage of this region, as indeed they are not present in the higher altitude data. The eastern extent of the signals is well-constrained by the MESSENGER data, with no signals observed at ~60°N east of Kosho crater even though periapsis altitude was below 30 km eastward to -120°E. The western extent corresponds to an orbit-correction maneuver (OCM) that raised periapsis altitude from 25 km to 95 km altitude. No short-wavelength signals were detected on orbits immediately following the OCM, consistent with upward continuation of the signals from the westernmost orbit in Figure 2 to the higher spacecraft altitudes.

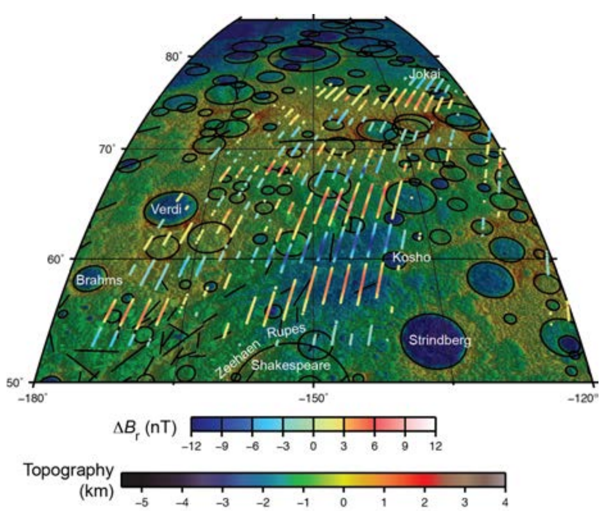

Figure 2: High-pass filtered radial field (ΔB_r) signals over Suisei Planitia. Signals are shown only if the magnitude of ΔB_r is at least 1 nT and if the signal-to-noise ratio is at least 3. Spacecraft altitudes were 25 – 50 km over the region. Impact craters with diameters greater than 50 km and contractional structures with lengths greater than 50 km are shown in black. The underlying image is topography derived from the Mercury Laser Altimeter.

Discussion. In the regions where signals have been observed so far, there is no obvious large-scale correlation with surface geology, such as with smooth plains, intercrater plains, or impact basins (*e.g.,* Figure 2). Source depths of 10-50 km are inferred from the dominant wavelengths of the signals, consistent with subsurface magnetization contrasts. We take a plausible estimate for the age of remanence acquisition as the surface age inferred for the smooth plains, 3.7-3.9 Ga [7], recognizing that younger or older ages are permitted, particularly if the remanence is associated with deep-seated intrusives or structures that could pre-date or post-date surface units [7, 8]. Magnetization–thickness products inferred from the peak anomalies [e.g., 6] imply weak minimum magnetization contrasts (~ 0.1 Am^{-1} over ~5 km vertical extent). Mercury's highly reduced composition suggests iron, iron alloys, or sulfides as the likely remanence carriers. To assess whether a crustal remanence can be preserved over billions of years, we use as an end-member case the low Curie temperatures associated with sulfides such as pyrhhotite (330°C) and calculate the minimum depth to the Curie isotherm for a surface heat flow of 40 mWm^{-2}, appropriate for ~3.9 Ga and for orbital eccentricities between 0.0 and 0.4, values that affect surface temperatures [10]. Calculations show that even for such low Curie temperatures thermal preservation of remanence is possible in the top ~20 km of crust northward of 50°N.

MESSENGER periapsis altitudes will remain below 25 km from early March 2015 until the end of mission, yielding substantially increased coverage of the northern hemisphere at altitudes below 100 km. Analyses of these data for crustal fields will allow investigations of fields possibly associated with the Borealis basin, the northern rim of Caloris, the northern rise, and major fold and thrust belts.

References. [1] Anderson B. J. et al. (2012) *JGR*, *117*, E00L12. [2] Johnson C. L. et al. (2012) *JGR, 117*, E00L14. [3] Korth H. et al. (2014), *AGU Fall Meeting*, abstract P21C-3927. [4] Anderson B. J. et al. (2014) *Geophys. Res. Lett.*, *41*, 7444-7452. [5] Anderson B. J. et al. (2013) *Geochem. Geophys. Geosyst.*, *14*, 3875-3886. [6] Parker R. L. (2003), *JGR*, *108*, 5006. [7] Denevi B. W. et al. (2013), *JGR Planets*, *118*, 891-907. [8] Byrne P. K. et al. (2014), *Nature Geosci., 7*, 301-307. [9] Williams J.-P. et al. (2007), *Geophys. Res. Lett.*, *34*, L21201. [10] Correia A. C. M. & J. Laskar (2009) *Icarus*, *201*, 1-11.