RESULTS FROM THE INSIGHT FLUXGATE MAGNETOMETER: THE CRUSTAL MAGNETIC FIELD AND TIME-VARYING EXTERNAL FIELDS AT THE INSIGHT LANDING SITE. Catherine L. Johnson[1,2], Anna Mittelholz[1], Benoit Langlais[3], Philippe Lognonné[4], William T. Pike[5], Steven P. Joy[6], Christopher T. Russell[6], Yanan Yu[6], Peter Chi[7], Matthew Fillingim[7], Robert J. Lillis[7], Véronique Ansan[3], Suzanne E. Smrekar[8] and William B. Banerdt[8]. [1]Dept. of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada, cjohnson@eoas.ubc.ca. [2]Planetary Science Institute, Tucson, AZ 85719, USA, cjohnson@psi.edu. [3]Laboratoire de Planétologie et Géodynamique, UMR-CNRS 6112, Université de Nantes, Faculté des Sciences et Techniques, Nantes, France. [4]Univ Paris Diderot-Sorbonne Paris Cité, Institut de Physique du Globe de Paris, Paris Cedex 13, France. [5]Dept. of Electrical and Electronic Engineering, Imperial College, London, United Kingdom. [6]Earth, Planetary and Space Sciences, University of California, Los Angeles, CA 90095, USA. [7]Space Sciences Laboratory, University of California, Berkeley, CA 94720. [8]Jet Propulsion Laboratory, 4800 Oak Dr, Pasadena, CA 91109, USA.

Overview: Mars' magnetic field provides a window into the planet's interior and evolution, as well as the space environment surrounding the planet. Satellite missions that have orbited Mars above the atmosphere have shown evidence for crustal magnetization acquired in an ancient global field. However, surface measurements are needed to identify weak and/or small-scale magnetizations undetectable at satellite altitude. These in turn provide key constraints on crustal structure and the timing of the martian dynamo. Satellite missions have also monitored time-varying magnetic fields that result from the interplanetary magnetic field and electric currents generated in the uppermost atmosphere (ionosphere). These fields could induce electrical currents in the martian interior, and the resulting secondary fields can in turn be used to probe the electrical conductivity structure of the martian crust and mantle. The InSight Fluxgate magnetometer (IFG) is the first magnetometer deployed on the surface of Mars and thus affords unique opportunities for magnetic field-based studies of the martian interior, the ionosphere, and the extent to which conditions in the solar wind affect the martian surface environment.

The Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission landed successfully on Mars on 26 November, 2018 at 4.50°N, 135.62°E in Elysium Planitia The IFG is part of the Auxiliary Payload Sensor Suite (APSS) of instruments that monitors environmental conditions at the lander, for the primary purpose of accounting for sources of wind, temperature, pressure and magnetic field noise in the seismic data [1,2]. Here we summarize results from the first few months of IFG instrument operations, including the static crustal magnetic field, and periodic time variations in the field driven by external sources. We compare these results with the predictions for *e.g.*, ionospheric [3,4] and crustal [5,6] fields.

IFG Operations and Initial Data: After initial instrument checkouts, APSS began routine operations on 11 December, 2018. Continuous, vector magnetic field data are provided at a sampling rate f_{sc} = 0.2 Hz. Higher sample rate data, up to 20 sps, can be requested for specific periods of interest. The IFG is designed to a noise requirement of less than 0.1 nT/sqrt(Hz) in the frequency band 0.01 – 20 Hz. However, no magnetic cleanliness program was employed for the spacecraft or instruments, and thus at frequencies above f_{sc} in particular, magnetic signals comprise contributions from both martian and lander sources. Prior to launch the spacecraft static fields were measured in two different tests, yielding an average spacecraft field of (549, -434, 26) nT [7]. Substantial ongoing work by the IFG science and instrument team has included refining the pre-flight temperature calibration, and developing empirical models to account for spacecraft fields generated by e.g., the solar array currents. These efforts include careful examination of quiet (no or minimal lander activity) nighttime data, as well as times of specific lander and instrument operations to characterize these high frequency signals.

The Crustal Field at the InSight Landing Site: We first summarize recent predictions for the crustal field at the martian surface from satellite data and then outline approaches for estimating the crustal field from IFG data.

Satellite-Derived Estimates: Satellite magnetic field observations allow estimates of the surface magnetic field from inversions that include regularization (smoothness) constraints to mitigate the effects of downward continuation. The caveat is that only the field at wavelengths greater than minimum resolvable wavelength in the satellite data can be captured; more spatially localized fields cannot be assessed. The substantial increase in nightside (i.e., quiet) magnetic field data available at altitudes below ~250 km altitude from the Mars Atmosphere and Volatile EvolutioN mission (MAVEN) compared to the earlier Mars Global Surveyor (MGS) data has greatly facilitated construction of crustal field models. The low altitude data in these new models provide essential control on structure in the crustal magnetic field at scale lengths of 150 – 400 km . New global [6,8] and regional [5,8] surface field models, that capture wavelengths greater than ~120 km, suggest surface field strengths in the vicinity of the InSight landing site of a few hundred nT [4-6]. The actual surface field could be stronger or weaker than this, depending on the nature of shorter-wavelength signals superposed on these regional-scale fields.

Ground-based estimates: IFG data can provide a direct estimate of the crustal field at the InSight landing site through the DC field. Results suggest residual DC fields larger than satellite predictions. The field direction also shows some differences with surface predictions from the satellite-based models. If these measured static fields are entirely crustal in origin (i.e., contain no residual spacecraft fields), they suggest modest contributions from wavelengths shorter than ~100 km.

A second approach uses the ~3Hz resonant vibrations of the InSight lander resulting from daily winds. These have been recorded by the SP on the InSight lander deck prior to the deployment of SP onto the martian surface. The vibrations will produce magnetic field perturbations ($\delta\mathbf{B} = \boldsymbol{\omega} \times \mathbf{B}_0$, where $\mathbf{B}_0$ is the static crustal field, and $\boldsymbol{\omega}$ is the tilt). Measurement of such horizontal accelerations and perturbations to the magnetic field in the resonance frequency band of the lander could allow the vertical component, B_{Z0}, of the ambient crustal field to be estimated. Stochastic testing of this is described in [9]. Surface magnetic fields with a B_{Z0} component from satellite-based predictions [5,6] and somewhat larger values corresponding to additional contributions from shorter wavelength crustal fields, were used. The results indicate that crustal fields with $|B_{Z0}|$ ~1000 nT magnitude can be recovered to within ~10%. Furthermore, crustal fields with $|B_{Z0}| <$ ~100 nT are indistinguishable from zero. Accordingly, over 40 hours of simultaneous daytime SP and IFG data at $f > 1$ Hz, taken while SP was on the lander deck were requested. In principle discrete lander tilts could also result in changes in the magnetic field due to rotation of the IFG in the static field and provide an estimate of the crustal field, however lander tilts observed to date are small and unlikely to result in measurable IFG signals.

Time-Varying Fields: Time-varying signals in the IFG data were expected to contain contributions from both naturally occurring (martian) and spacecraft sources. Of particular interest are naturally-occurring daily variations in the field as these can result from the combined effects of ionospheric currents and the draped interplanetary magnetic field (IMF). However, on average spacecraft operations also result in magnetic fields with day-night variations; careful identification of the sources and magnitudes of these results in residual fields that can be confidently ascribed to natural sources. Here we report on the average daily periodic signal in the martian field seen in IFG data as well as its variability. Recent predictions suggest that the amplitude of the daytime ionospheric field at the martian surface could be tens of nT [3,10], and occasionally as high as 100 nT [10], with a high degree of variability in the direction as well as strength, resulting from changes in the draped magnetic field pattern in the dayside ionosphere as well as changes in the neutral winds [10]. We investigate whether there is any evidence in the first few months since instrument deployment of a 27-day period in the data, indicative of the influence of Carrington (solar) rotations and the corresponding variation in the IMF at Mars. We also report observations of higher frequency variations, such as continuous nighttime pulsations with a frequency of ~10 mHz, and at lower frequencies of ~1 mHz in the early morning, that may have exogenic sources. The time-varying surface fields, in particular the periodic daily signal provide the foundation for future magnetic sounding of the martian interior.

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