RESULTS FROM INSIGHT'S FIRST FULL MARTIAN YEAR.

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Introduction: The InSight mission landed on Mars in November of 2018 and completed installation of a seismometer (SEIS) on the surface about two months later [1]. In addition to SEIS, InSight carries a diverse geophysical observatory including a heat flow and physical properties package (HP^3), a geodesy (planetary rotation dynamics) experiment (RISE) and a suite of environmental sensors measuring the magnetic field and atmospheric temperature, pressure and wind (APSS). For approximately 2 years, SEIS has been providing near-continuous seismic monitoring of Mars, with background noise levels orders of magnitude lower than that achievable on the Earth. Since the first detection of a marsquake in April of 2018, the SEIS team has identified more than 450 events that appear to be of tectonic origin. We present a summary of observations and results from the SEIS instrument as well as a summary of other geophysical observations made by InSight during the past 2 years.

Seismicity of Mars: SEIS is capable of resolving extremely small amplitude signals on Mars, in the absence of the microseismic energy observed on Earth. Despite SEIS being highly sensitive to local martian winds leading to noisy portions in mid-day through much of the martian year, and through most of the day during the current dust storm season (**Figure 1**), hundreds of suspected teleseismic marsquakes have been recorded [2,3], a number of which are strong enough to be located. Some of the highest-quality events have been localized to Cerberus Fossae [2], a region of geologically recent extensive volcanism, as well as remote observations of boulder trails interpreted as evidence of seismicity before InSight's arrival [4]. These events are characterized by long duration signals on the order of 10's of minutes, with frequencies ranging from approximately 0.1-10Hz. Event distances range from within a few degrees of the lander to about 100 degrees, with magnitudes spanning from Mw1.5 to 4.0. Further, a second class of very short duration events is regularly being identified that is likely due to local thermal cracking.

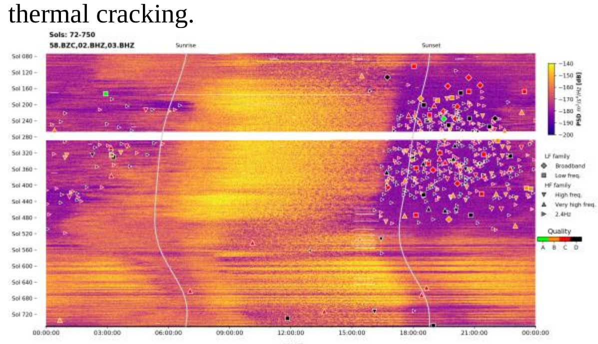

Figure 1: Visualization of the spectrograms for every sol of the mission starting from full deployment on sol 72 through sol 750. White lines represent sunrise and sunset each day. Purple areas represent low noise portions of the sol, while yellow and orange colors are higher noise. Symbols indicate different event types detected. The horizontal white bar represents a data gap during solar conjunction.

The interior structure of Mars: Determining martian crustal thickness, mantle velocity and core radius were primary science objectives of the InSight mission. After the first martian year, data from SEIS and RISE have allowed the mission to address all three objectives.

Crustal thickness. Results are mainly based on Ps-receiver functions from three events with magnitudes between 3.1 and 3.6 at distances between 27.5° and 47° (±10°) from the lander, originating in the Cerberus Fossae region, the only events, so far, with clear, impulsive P-wave onsets and known epicenter (results from two events are shown in Figure 2. Ps-receiver functions use converted phases in the P-wave coda to derive information on discontinuities beneath the seismometer. Due to the limited number of events and the small epicentral distance range covered, inversions of the data are still ambiguous, but can be explained by either a 2- or 3-layer crust [5,6]. When combined with global gravity and topography data, globally averaged thickness is constrained to be less than 72 km, excluding the densest proposed crustal models [7].

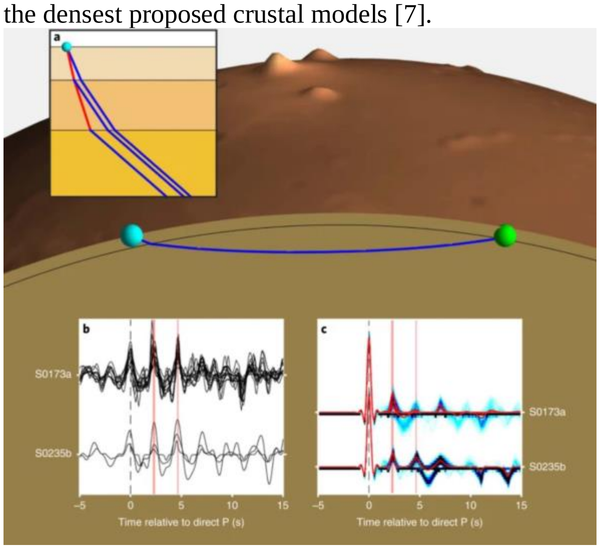

Figure 2: Examples of receiver function calculations from 2 events in the Cerberus Fossae region, showing modeled ray paths beneath the station (a), as well as multiple methods for computing the receiver functions (b and c). Figure from [8].

Mantle velocity. While surface wave observations were anticipated to be the primary means of determining mantle velocity structure [9], no events observed have shown clear surface wave energy to date. However, it is possible to identify P and S phases with multiple surface bounce points in the data (PP, PPP, SS, and SSS phases) of several events [10]. When combined with the P and S phases used for location, these can be used to constrain upper mantle velocity structure down to a few hundred km.

Core Radius. After one full martian year of precision radio tracking through the RISE experiment, InSight has provided estimations of the precession rate, as well as the prograde semi-annual and retrograde ter-annual nutations. These permit us to confirm the presence of a liquid core and constrain the core radius and density.

HP^3: The HP^3 is designed to measure heat flow from the interior using its 'mole', a self-hammering burrowing device, to pull an instrumented tether to a depth of 3-5 m. Early in the mission a ~10 cm layer of duricrust encounter by the mole has limited progress of the mole to depth because it prevented soil from fully surrounding the mole and providing the friction needed to reduce the recoil motion of the hammer. Recovery efforts involving the use of the lander arm to push soil into the hole and provide additional friction are underway and in their final stages. With luck the mole will soon begin digging on its own.

Other results: While the top-level science objectives for the InSight mission focused on internal structure and processes, the additional pressure, wind, temperature, and magnetic sensors of the mission have also produced important results. The high-rate meteorological data permits unprecedented surface views of martian atmospheric phenomena [11]. Fluxgate magnetometer observations have shown a significantly stronger crustal field than observable from orbit, and magnetic field variations on a wide variety of time scales [12]. Geological interpretations of panoramas and thermal inertia from the HP^3 have helped define the physical properties of surface materials and their subsurface stratigraphy, which have aided the interpretations of measurements from the geophysical payload [13].

Conclusions: The InSight mission continues to operate on Mars after more than one full martian year (2 Earth years) on the surface, and has had an extended mission for an additional 2 Earth years approved by NASA. The data returned shows us the seismic activity of the planet and constrains martian interior structure from the crust to the core.

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