IMPACT-SEISMIC INVESTIGATIONS PLANNED FOR THE INSIGHT MISSION. Ingrid J. Daubar[1], P. Lognonné[2], N. A. Teanby[3], K. Miljkovic[4], T. Kawamura[5], J. Stevanović[6], J. Vaubaillon[7], J. Clinton[8], M. Golombek[1], D. Banfield[9], A. Lucas[2], M. Drilleau[2], M. van Driel[8], G. S. Collins[10], T. Gudkova[11], S. Rodriguez[2], N. Fuji[2], S. Kedar[1], C. Yana[12], J. Maki[1], M. Banks[13], M. Panning[1], R. F. Garcia[14], E. Sansom[4], S. May[12], J. Wookey[3], N. Schmerr[16], M. Lemmon[17], B. Kenda[2], M. Böse[8], V. Ansan[18], H. Kanamori[19], F. Karakostas[2], W. B. Banerdt[1], S. Smrekar[1]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA (ingrid@jpl.nasa.gov). [2]IPGP, Université Paris Sorbonne, France. [3]University of Bristol, UK. [4]Curtin University, Perth, Australia. [5]National Astronomical Observatory of Japan. [6]Bristol, now at AWE, Aldermaston, Berkshire, UK. [7]IMCCE, Paris, France. [8]ETH Zurich, Switzerland. [9]Cornell University, Ithaca, NY. [10]Imperial College, London, UK. [11]Schmidt Institute of Physics of the Earth RAS, Moscow, Russia. [12]Centre National d'Etudes Spatiales, France. [13]NASA Goddard Space Flight Center, Greenbelt, MD. [14]ISAE-Supaero, Toulouse, France. [16]University of Maryland, College Park, MD. [17]Texas A&M Univ., College Station, TX. [18]LPG Nantes, France. [19]California Inst. of Technology, Pasadena, CA.

Introduction: The InSight NASA Discovery mission [1] will study the interior of Mars using seismic signals. These will emanate from both interior tectonic sources as well as from meteoroid impacts. Here we describe the impact-related investigations planned for the InSight mission, and how seismic detection of impact events will further the scientific goals of the mission. For one, measuring the rate of crater formation at the surface will achieve the mission goal of determining the impact flux at Mars. Additionally, impacts will inform the major goal of investigating the interior structure of Mars, as each impact located on the surface will provide known seismic ray paths through the interior.

Role of the Impacts STG: The Impacts Science Theme Group (STG) was formed to oversee all impact-related science of the InSight mission. The purpose of the group is to coordinate scientific analyses before and during the landed mission, and support operations to ensure acquisition of impact-related data. Impact-related scientific analyses include the seismic source and waveform modeling of impact generated seismic signals; detection, localization, and characterization of impact sources; detection of meteors; modeling of meteor infrasound and acoustic source and shock signals; and comparative analyses between Mars, Earth and Moon.

Effects of the atmosphere: Unlike the Moon, Mars has an atmosphere; thus we must consider the seismic effects of airbursts and fragmentation.

Airbursts: An airburst occurs when a bolide undergoes failure during flight through a planetary atmosphere, as dynamic stresses overcome the intrinsic compressive strength of the material. [2] predicted ~10-200 seismically detectable airburst events per year. This estimate contains an order of magnitude uncertainty resulting from unknowns in the background noise level, the air-ground coupling efficiency factor, seismic and atmospheric attenuation, and source population.

Fragmentation: The seismic source for a cluster of simultaneously-forming impacts would behave differently than a singular impact [3]; the energy of the impacts will be distributed over a larger area, typically between 10-1000 meters [4]. [3] found that clusters have smaller peak amplitudes and more short-period energy in their source spectra compared to single crater impacts. With such diffuse signals, it will be more difficult to identify P wave arrivals, which will add uncertainty to the identification of source location. However, differentiating between single crater impacts and clusters will inform orbital imaging of the surface.

Discriminating impacts from quakes: One of the most challenging aspects of studying impacts in seismic data will be differentiating their signals from those of marsquakes. We plan to use a combination of the following features to make this discrimination:

(1) *First motion:* An impact event will create a positive pressure impulse at the source, resulting in a positive first motion, away from the source. Therefore, a negative first motion can rule out an impact event.

(2) *S wave energy:* Impacts are likely to produce more P-waves than S-waves, so high S-wave energy could be used to reject an impact source.

(3) *Magnitude ratio:* On Earth, one of the most reliable diagnostics for explosive versus natural sources is comparing the body wave magnitude to the surface wave magnitude. An impact produces fewer surface waves than other quake sources.

(4) *Frequency content:* Impacts and quakes differ in their source mechanisms, resulting in different frequency content of the seismic spectra. An impact will have a much smaller cutoff frequency than a quake of the same magnitude.

(5) *Depth phases:* For deep marsquakes, in addition to the direct wave, reflections are expected within the interior. If these reflection phases can be identified in an event, then an impact source can be rejected.

In principle, these features will be discriminators; however, with a single seismic station and realistic noise, each of these alone are unlikely to be definitive. By combining multiple diagnostics, many non-impact events could be rejected, and a probability of impact determined.

Orbital imaging: Once InSight detects an impact in seismic data, images will be requested from spacecraft orbiting Mars with the goal of pinpointing the exact impact location via visual detection of newly formed crater(s). This will provide a definitive source location, something that will most likely not be possible for tectonic seismic sources. Orbital imaging of these sites will be of high scientific importance for several reasons:

(1) Exact locations of the new craters will allow for determination of the ray paths and thus calibrate interior structure models and seismic attenuation. Impacts with a known location will enable the direct inversion of all differential travel times with respect to P arrival times. Known epicentral distances and origin times will allow body wave travel time inversions for 1D crust and mantle velocity structure along the ray path.

(2) Any successful impact detections will provide a calibration of the seismic source parameters (Moment, frequency cutoff, and seismic efficiency, the ratio of impact energy to radiated seismic energy). The latter value in particular is not well constrained, with values in the literature ranging from 10^{-6} to 10^{-2} [5–13].

(3) High resolution images will also characterize the craters' morphology. With the accumulation of significant numbers of detected impacts with measured diameters, a calculation of the current impact rate will be possible. This will be independent of those based solely on orbital imaging, and free of the observational biases inherent in that technique [14], albeit with other biases.

Because of the high value of locating these new impacts, orbital images will be manually searched for new craters. As a supplement to manual searching, and to assist in difficult searches, software is also being developed to perform automated image searching.

Predicted frequency of impact detections: The frequency of impact seismic signals InSight will detect is based on several factors: the current bombardment rate, the efficiency of partitioning the impact energy of those impacts into seismic energy, the nature of an impact's source-time function, and the amplitude of the resulting signals compared to environmental and instrument noise levels. The regolith layer is also expected to have a major effect in the strength of the signal. Large uncertainties in these factors makes it very difficult to determine the efficacy of detecting natural impacts. In general, the larger the impact, the farther away it will be able to be detected. Small impacts will only be detectable within a very limited range of the InSight landing site; only impacts producing craters >~30-40 m in diameter will be detected at large distances. When the dependence between size and distance for detectable impacts is combined with the best measurements of the current impact rate [15], we can calculate an overall estimate of the number of impacts detectable by SEIS per year [14,16–18]. The resulting estimates are uncertain to several orders of magnitude because of uncertainties in the seismic properties of Mars (*e.g.* attenuation, seismic efficiency), the current impact rate, and the background noise level. Given those uncertainties, [17] estimates between ~0.1–30 impacts/year will be detectable at moderate distances <~1,000 km, while [18] estimated ~10 total impacts/year. [14] determined a similar estimate of ~4-8 total impacts detected/year. Large events that could be detected globally only occur once every ~1 to 10 years [16].

Conclusions: Impact investigations will be an important aspect of the InSight mission. We can predict the frequency of impacts and the seismic response of Mars based on terrestrial, lunar, and experimental impacts. However, the true martian seismic properties such as seismic efficiency, attenuation, and subsurface velocity structure will not be known until we reach Mars, detect an impact seismically, and test our predictions with orbital images. With enough such detections, we will achieve one of the scientific goals of the InSight mission, to measure the impact flux at Mars. We predict this measurement will be possible within the timeframe of the prime mission (one Mars year) with the detection of a few to several tens of impacts. Locating seismically detected impacts on the surface in orbital images will inform seismic ray paths, seismic velocities, and the physical properties of the material through which the rays traveled. Thus, impacts will give us a better understanding of the shallow subsurface structure of Mars, constrain physical and seismic properties, and determine the seismic-impact coupling efficiency.

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