IMPACT SCIENCE ON THE INSIGHT MISSION – CURRENT STATUS. I. J. Daubar[1], P. Lognonné[2], N. Teanby[3], M. Lemmon[4], N. Schmerr[5], L. Posiolova[6], M. E. Banks[7], and the InSight Science Team. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA (ingrid@jpl.nasa.gov). [2]IPGP, Université Paris Sorbonne, France. [3]University of Bristol, UK. [4]Texas A&M University, College Station, TX, USA. [5]University of Maryland, College Park, MD, USA. [6]MSSS, San Diego, CA, USA. [7]GFSC, Greenbelt, MD, USA.

Introduction: Before InSight got to Mars, we had some ideas about what martian impacts might look like in seismic data [1]. Mars has surprised us once again, and we now need to reshape our ideas about the martian interior, the impact environment at Mars, and the seismic and atmospheric effects of impact cratering. This process is ongoing, and we will report our most recent results at the meeting.

Background: The InSight mission is studying the interior of Mars using seismic signals [2]. These could emanate from either interior tectonic sources, meteoroid impacts on the surface [1] or airbursts in the atmosphere [3], wind [4], the passage of dust devils [5,6], landslides [7], motions of the lander, or even possibly other as-yet unknown processes.

Before Landing – Plans: Our plan before landing was to identify impacts in the seismic data using a set of "impact discriminators" [1]: (1) a positive first motion away from the source; (2) relatively low S-wave energy; (3) low surface wave to body wave magnitude ratio; (4) smaller cutoff frequency than tectonic events; (5) lack of depth phases. We knew that each of these conditions alone would be unlikely to determine the source, so we planned to consider all discriminators together. Even then, we expected that the final definitive identification of an impact would rely on identification of a new crater in before and after orbital images.

Once a likely impact source had been identified using these discriminators, we planned to use Marsquake Service [8] estimates of distance and azimuth to the event [9] to request orbital images. Such images would pinpoint the exact impact location of newly formed crater(s), allowing for determination of ray paths and thus calibrate interior structure models and seismic attenuation of Mars.

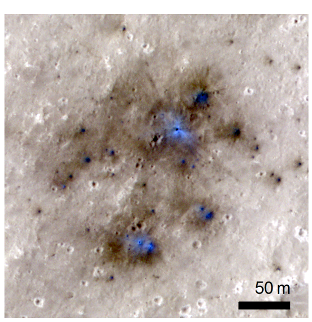

***Figure 1:** An impact that occurred near InSight between 9/15/15 and 10/13/15, before InSight landed. [10]*

An impact observed in both orbital and seismic data would also 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} [1]. Finally, high resolution images (Fig. 1) would characterize crater sizes, eventually leading to an independent calculation of the current impact rate.

Further constraining the impact flux for small impactors, we planned to use the cameras on the InSight lander to image the night sky during peaks of predicted meteor showers, as well as make measurements of the background flux on typical martian nights [1]. The InSight Instrument Deployment Camera (IDC) has similar sensitivity and 8x the field of view of the MER Pancam [11]. With 20 minutes of exposure time, we could reproduce previous results [12]; longer would further constrain the meteor flux.

After Landing – Reality: *Updated Predictions of Impact Detections:* With real measurements of the ambient seismic noise, we can now say that the typical noise level for the Very Broadband (VBB) sensors from 0.2–2Hz is $0.4–4x10^{-9}$ $m/s^2/Hz^{1/2}$, and for the Short Period (SP) sensors from 1–8 Hz it is $0.4–4x10^{-8}$ $m/s^2/Hz^{1/2}$ [13,14]. Based on compiled observations from terrestrial and lunar impacts and explosions [15,16], the peak seismic energy for large impacts is expected to be in the 1 - 2 Hz frequency range (SEIS-VBB), and for small impacts 1 - 8 Hz (SEIS-SP). Thus the 0.2–2Hz noise is relevant for large, global-scale impacts (>~30-40 m in diameter), and the 1 - 8 Hz seismic noise relevant for smaller, regional scale (<1000 km) impacts. Using these measured noise levels, the predictions of [1,15,16] can be updated (Fig. 2). We expect impact events to be near the detection limit at a rate of ~8 (0.1-200) per year on SEIS-VBB and ~2 (0.2-20) per year on SEIS-SP [17]. Using a more conservative threshold of S/N~3, we predict ~3 detected impact events per year. There is still at least an order of magnitude uncertainty on these estimates.

Noise during the day is higher than at night [18], so the sensitivity of the instrument to a given size signal also varies with time of day. Small signals could be lost if they occur during the day.

For airbursts, [3] predicted ~10-200 seismically detectable airburst events per year (with an order of magnitude uncertainty). The noise levels used to make this prediction are close to measured noise levels, so we don't anticipate revising those numbers drastically. However, work is ongoing to improve these estimates by coupling the kinetic energy into seismic waves via numerical modelling.

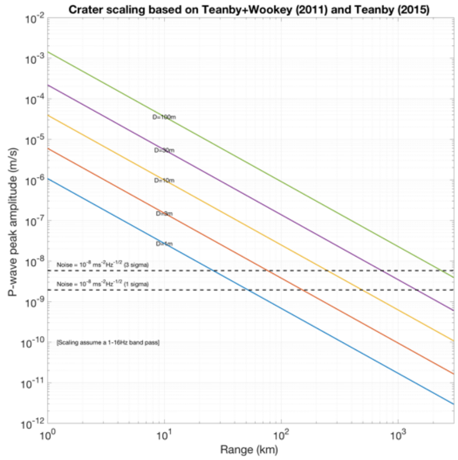

Figure 2: *Predicted p-wave amplitudes for craters 1-100 m diameter along with representative noise levels in this frequency range. Scaling relationships as developed in [15,16] are valid for regional impacts within ~1200 km and extrapolated to 3000 km. Assumes the main frequency content of the p-wave is in 1-16Hz bandpass.*

Approximately half of the currently observed impacts on Mars occur as clusters when the impactor fragments in the atmosphere [19] (Fig. 1). Synthetic experiments show that the seismic source peak corner frequency of impact clusters will move to higher frequencies as a result of energy contributed by smaller craters. Thus we expect clusters to be detectable at greater epicentral distances than singular impacts. At large distances (>10º), the signature of the cluster is dominated by the largest crater in the cluster and resembles that of a single large impact. We also find that the time separation between individual impacts in a cluster is small and individual impact events cannot be resolved unless the instrument is situated close (<10 km) to the impacts. Clusters are likely associated with the fragmentation and breakup of a bolide as it traverses the martian atmosphere and may thus have an associated atmospheric pressure signal.

Current status: Thus far, InSight has detected four possible signals [20]. The origin of the signals is currently a hot topic of debate. Possible candidates for each event include marsquakes of tectonic origin or meteoroid impacts. The above criteria are being applied when possible, however the small size of the signals and surprising nature of the martian crust makes identifying discriminating features challenging. Thus we are also pursuing this investigation in reverse: orbital images are being analyzed for newly-appearing albedo features that could possibly fall within the time frames of the seismic signals. If such features are observed, the seismic and pressure data during that time could be further investigated using a hypothesized distance, azimuth, and impact size.

Nighttime imaging searches for meteors have begun (Fig. 3). In the background measurements, many cosmic ray signals were detected, but no confirmed meteors thus far. The next predicted meteor shower from comet 49P will occur on 11 June 2019; results from those observations will be presented.

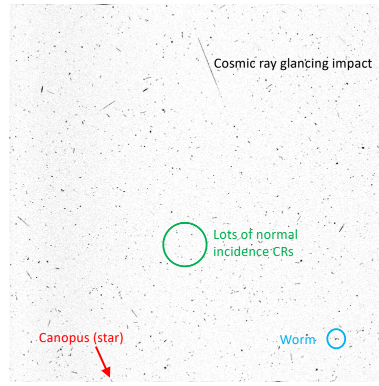

Figure 3: *Negative night IDC image searching for meteors. Many cosmic ray (CR) hits (green) are seen at ~normal incidence to the detector, along with at least one long glancing CR impact (black). "Worms" (blue) are local beta decay and Compton scattered gamma rays. Seven stars are present including Canopus (red).*

Conclusions: Impact science is an exciting active area of investigation by the InSight mission. We look forward to achieving the mission goal of determining the impact flux at Mars, ranging from the smallest to the largest current impactors. Impacts will also 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, constraining seismic velocities and the physical properties of the material through which the rays traveled.

References: [1] I.J. Daubar et al. (2018) *SSR* **214**, 132. [2] S.E. Smrekar et al. (2019) *SSR* **215**, 3. [3] J. Stevanović et al. (2017) *SSR* **211**, 485–500. [4] A. Spiga et al. (2018) *SSR* **214**, 109. [5] B. Kenda et al. (2017) *SSR* **211**, 501–524. [6] R.D. Lorenz et al. (2015) *Bull. Seismol. Soc. Am.* **105**, 3015–3023. [7] A. Lucas et al. (2019) *LPSC 50* Abs 2441. [8] J. Clinton et al. (2018) *SSR* **214**, . [9] M. Böse et al. (2017) *Phys. Earth Planet. Inter.* **262**, 48–65. [10] I.J. Daubar et al. (2016) *LPSC 47* Abs 2984. [11] J.N. Maki et al. (2018) *SSR* **214**, 105. [12] A. Domokos et al. (2007) *Icarus* **191**, 141–150. [13] M.D. Mimoun et al. (2019) *LPSC 50* Abs 1879. [14] W. Thomas Pike et al. (2019) *LPSC 50* Abs 2109. [15] N.A. Teanby & J. Wookey (2011) *Phys. Earth Planet. Inter.* **186**, 70–80. [16] N.A. Teanby (2015) *Icarus* **256**, 49–62. [17] N.A. Teanby et al. (2019) *LPSC 50* Abs 1565. [18] D. Mimoun et al. (2017) *SSR* **211**, 383–428. [19] I.J. Daubar et al. (2019) *JGR* **124**.
[20] https://mars.nasa.gov/news/8430/nasas-insight-detects-first-likely-quake-on-mars/