SEARCHING FOR IMPACTS WITH INSIGHT: A NEW APPROACH. Ingrid J. Daubar[1], P. Lognonné[2], N. Teanby[3], J. Clinton[4], M. Malin[5], A. S. McEwen[6], K. Miljković[7], M. Banks[8], G. S. Collins[9], and the InSight Impacts Science Theme Group. [1]Brown University, Providence, RI, USA (Ingrid_Daubar@brown.edu).[2]IPGP, Université Paris Sorbonne, France. [3]University of Bristol, UK. [4]ETH Zurich, Switzerland. [5]MSSS, San Diego, CA, USA. [6]University of Arizona, Tucson, AZ, USA. [7]Curtin University, Australia. [8]NASA GSFC, MD, USA. [9]Imperial College London, UK.

Introduction: Detecting an impact in both seismic and imaging data would be a scientific breakthrough – seismic signals from an impact located precisely on the surface would provide certain location and depth, allowing modeling of seismic ray paths through the interior that can constrain seismic velocities and the physical properties of the material through which the rays traveled. We could then calibrate models of interior structure and seismic attenuation of Mars. An impact clearly observed in both orbital and seismic data would also provide a calibration of the seismic source parameters, moment, cutoff frequency, and seismic efficiency (the ratio of impact energy to radiated seismic energy). The seismic efficiency, for example, is not well constrained, with values in the literature ranging from 10^{-6} to 10^{-2} [1]. Numerical impact modeling work suggests values of ~10^{-3} in bedrock to ~10^{-4} in regolith [4]. High resolution images of newly formed craters (e.g. Fig. 1) would characterize crater sizes, leading to an empirical relationship between impact size and observed seismic amplitudes. Such observations would also result in an independent measurement of the current impact rate, anchoring absolute bombardment rates. Thus identifying an impact in seismic data that could also be imaged from orbit would satisfy many important scientific goals.

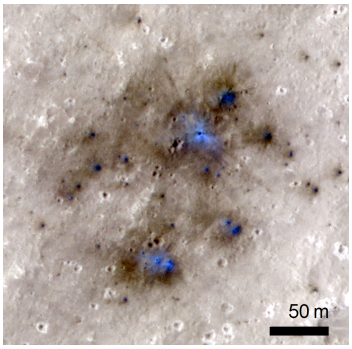

Figure 1: *An impact that occurred near the final landing site of InSight between 9/15/15 and 10/13/15, before InSight landed on Mars [5]. HiRISE image ESP_043605_1845 credit NASA/JPL/University of Arizona.*

Before InSight [2] got to Mars, we had some ideas about what martian impacts might look like in seismic data [e.g. 1, 3]. However, 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 signals we can expect from impact cratering. This process is ongoing, and we will report our most recent results at the meeting.

Before Landing – Plans: Before landing, we predicted that a few to several tens of impacts would be detectable by InSight during the primary mission phase (one Mars year) [1]. Our plan before landing was that once a likely impact source had been identified in the seismic data using a set of impact discriminators [1 and below], we would use MarsQuake Service [6] estimates of distance and azimuth to the event [7] to request orbital images to confirm an impact origin.

After Landing – Reality:

Reevaluation of Impact Discriminators: InSight has accumulated a substantial catalog of seismic events [12]. Over the first months of the InSight mission, we have learned that marsquakes (whatever the source is) differ from our previous experience with either terrestrial or lunar analogs and observations. Although meteoroid impacts remain a possible explanation for some of the signals, there are not yet any definitive indicators of an impact origin in the seismic data.

The impact discriminators we planned on using before arriving at Mars [1] have limited utility given the reality of martian seismic signals recorded thus far. All marsquakes observed so far are small in amplitude with surprisingly long durations, with apparently low attenuation / high Q. This makes many of these characteristics difficult to observe. We have *re-assessed* (*in italics*) each of those planned discriminators in light of real seismic data from InSight.

1) First motion: Impacts create positive pressure impulses, creating a positive first motion, in a direction away from the source.
   - *Despite the low noise recorded by InSight during periods of the day, marsquake signals have proven to be very small. In all but the largest signals seen so far, phase arrivals are emergent, so noise obscures the direction of first arrivals. Scattering in the regolith randomizes the energy.*
   - *Even with perfect data, quakes would have a positive first motion 50% of the time anyway, assuming a random orientation of sources.*

2) S-wave energy: Impacts produce more P-waves than S-waves.
   - *A quake could also have low S energy for an unfavorable source orientation.*
   - *S-waves are obscured by scattered P energy, so this is hard to determine for small events.*

3) Magnitude ratio: Impacts produce fewer surface waves, so magnitudes based on body vs. surface waves should differ significantly.
   - *Surface waves are not being detected for any martian events, possibly related to a near-surface low-velocity layer. So the absence or depleted presence of surface wave energy cannot be used as an impact discriminator, because all events lack surface waves.*

4) Frequency content: Different source mechanisms lead to a smaller cutoff frequency for impacts.
   - *Cutoff frequencies for large events, where they can be measured, are ~6 Hz up to 12 Hz – much higher than ~1-2 Hz expected for impacts [1].*

5) Depth phases: Impacts occur at the surface, implying no depth reflected phases.
   - *Additional phases beyond P and S have not been identified in any events because of scattering and resulting extended codas, so a lack of depth phases cannot be used to indicate an impact.*

Updated Predictions of Impact Detections: Based on measured noise levels of the InSight seismometer SEIS on the ground at Mars, we can revise our pre-landing estimates of the number and size of impact detections to expect. [8 and 9] estimated seismic impact detection rates with predicted Mars seismic noise. We can now update these predictions using measured noise levels from the first few months of InSight operations. Model results for large impacts [8] predict their peak seismic energy will be in the 1-2 Hz frequency range, while observations of small impacts and explosions [9] suggest that their peak seismic energy will be in the 1-8 Hz frequency range. Typical SEIS noise levels are 0.3-10x10^{-9} m/s^2/Hz$^{1/2}$ in the 1-8Hz range [13], although during much of the martian day SEIS sees considerably higher noise than these levels. Using scaling relationships from [8,9] we can predict P-wave amplitudes for different size impacts at various distances (Fig. 2). To get the expected frequency of impacts of different sizes, we use the production function developed by [9] that uses new dated craters from [10] extrapolated to smaller diameters to account for observational rollover using the fragmentation model of [11].

The result is a predicted rate of detections at the noise level of ~8 large, global-scale impacts per Earth year and ~2 smaller regional-scale detections per Earth year. As signals at the noise level are very difficult to detect, and noise levels have a large temporal variation, we use a more conservative restriction of SNR~3 to be realistic. This reduces the number of detections we expect to ~3 total impact events per Earth year, during times when 100 sps data are collected. There are still large uncertainties on this number, at least an order of magnitude.

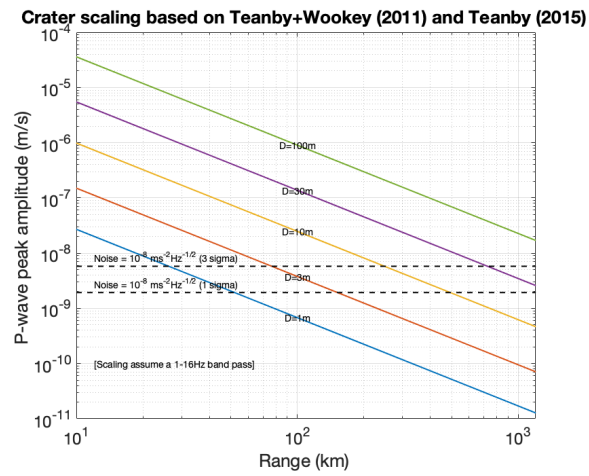

Figure 2: *Predicted P-wave amplitudes for craters 1-100 m diameter along with representative noise levels in this frequency range. Scaling relationships as developed in [8,9] are valid for regional impacts within ~1200 km and extrapolated to 3000 km. This assumes the main frequency content of the P-wave is in 1-16 Hz bandpass.*

New Approach: We are now pursuing this investigation in reverse. Orbital images from the Mars Reconnaissance Orbiter are being analyzed for newly-appearing albedo features near the InSight lander. For each newly-detected feature, the seismic and pressure data during a constrained time is then investigated using a known distance, azimuth, and impact size. Any candidate seismic signals are reevaluated as potential impact events using our understanding of impact generated waves [e.g. 1] and scenario-based numerical modelling [e.g. 3]. A confirmed impact detection will be an extremely exciting occurrence with important scientific implications.

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