Using Data from InSight to Locate and Explain Marsquakes

Maddy Sita[1] & Suzan van der Lee[2]
[1] University of Virginia, [2] Northwestern University

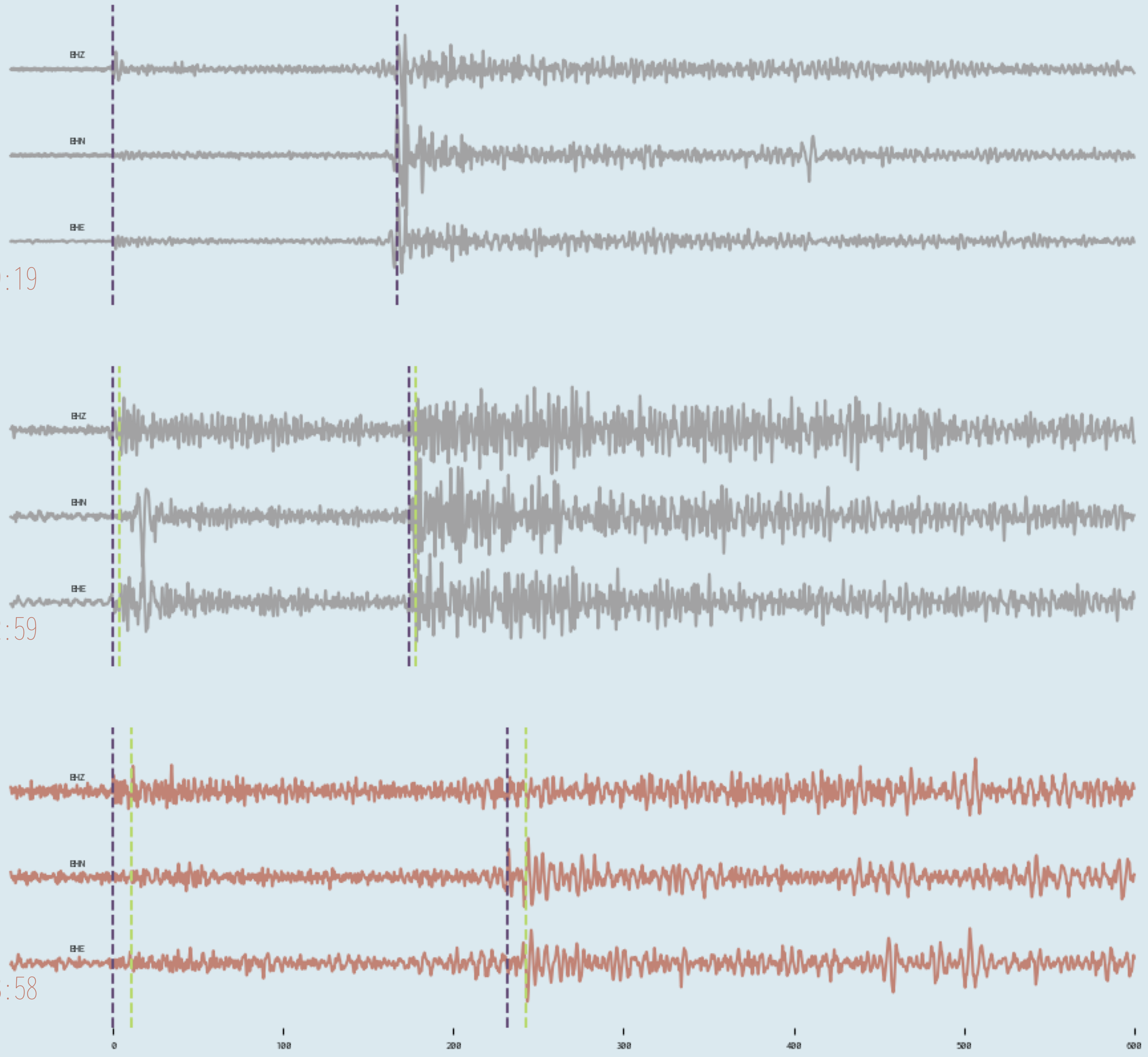
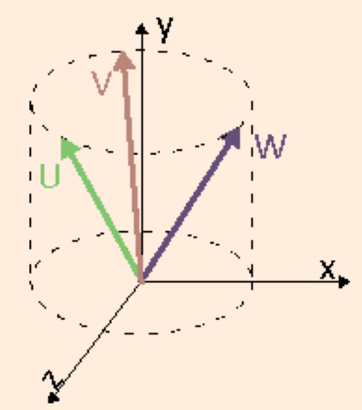


Figure 1. All three seismograms are provided for each event after being rotated to the east, north and vertical direction, plotted relative to the initial arrival of a *P*-wave at time 0. There is a clear *P* and *S* wave arrival for each event with the S0173a For S0325a and S0325ab the *P*-wave arrived at 06:58:57 UTC and 06:59:08 UTC and the *S*-wave arrived at 07:02:49 UTC and 07:03:00 UTC respectively

Collecting and analyzing data from IRIS Webservices



The instrument of interest for this project is the very broadband (VBB) seismometer, which is a part of the seismometer package, Seismic Experiment for Internal Structure (SEIS). The waveform data was downloaded directly from the Incorporated Research Institutions for Seismology (IRIS) database web service using the python package ObsPy.

$$\begin{pmatrix} D_E \\ D_N \\ D_Z \end{pmatrix} = \begin{pmatrix} \cos(\varphi_U)\sin(\theta_U) & \cos(\varphi_U)\cos(\theta_U) & -\sin(\varphi_U) \\ \cos(\varphi_V)\sin(\theta_V) & \cos(\varphi_U)\cos(\theta_U) & -\sin(\varphi_V) \\ \cos(\varphi_W)\sin(\theta_W) & \cos(\varphi_U)\cos(\theta_U) & -\sin(\varphi_W) \end{pmatrix}^{-1} \begin{pmatrix} D_U \\ D_V \\ D_W \end{pmatrix}$$

Using this equation, we reoriented the data such that each data stream pointed in the north, east and vertical direction before analysis[1].

Event:	Distance:	Back Azimuth:	Mechanism Types:	Fault Planes:
S0173a	29°	90°	Strike-Slip & Normal	
S0173ab	-	86°	Strike-Slip, Normal & Reverse	
S0235b	27.5°	74°	Vertical Dip-Slip & Normal	
S0235bi	15°	-	Strike-Slip & Vertical Dip-Slip	
S0325a	38.5°	123°	Strike-Slip & Vertical Dip-Slip	
S0325ab	-	139°	Strike-Slip	

Locating Marsquakes with a single detector

Using our observed difference in arrival time between the *P* and *S* wave, we then estimated the distance to the epicenter using travel time plots created from the previously published velocity models[6]. The back azimuth was calculated by rotating the three data streams to minimize the energy on the transverse component[7]. This provided an optimal arrival angle of the *P*-wave energy.

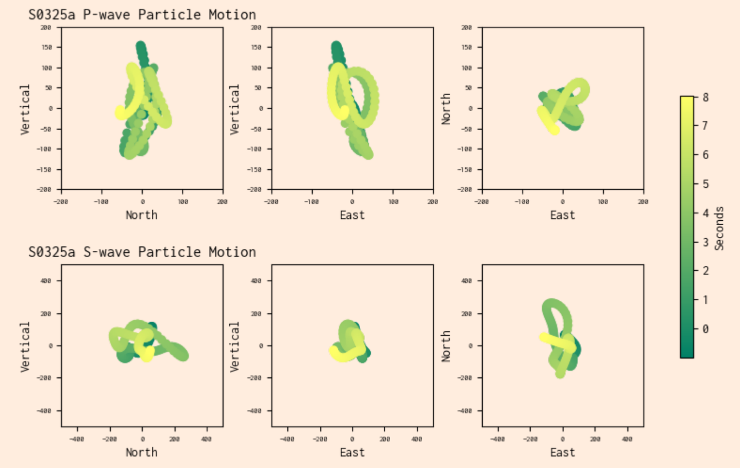


Figure 2. S0325a begins 1 second before the reported waveform arrival times and ends 8 seconds after and shows the beginning of S0325ab, whose *P*-wave arrives 11 seconds after S0325a.

Particle Motion

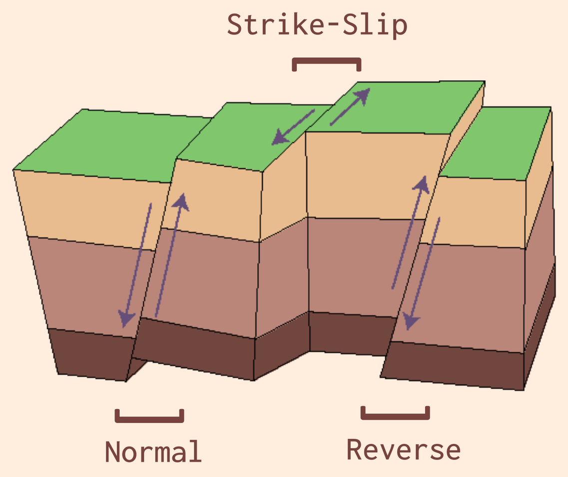
We looked at the particle motion caused by the arrival of the *P* and *S* wave to estimate the direction, relative to the lander, from which the signals originated.

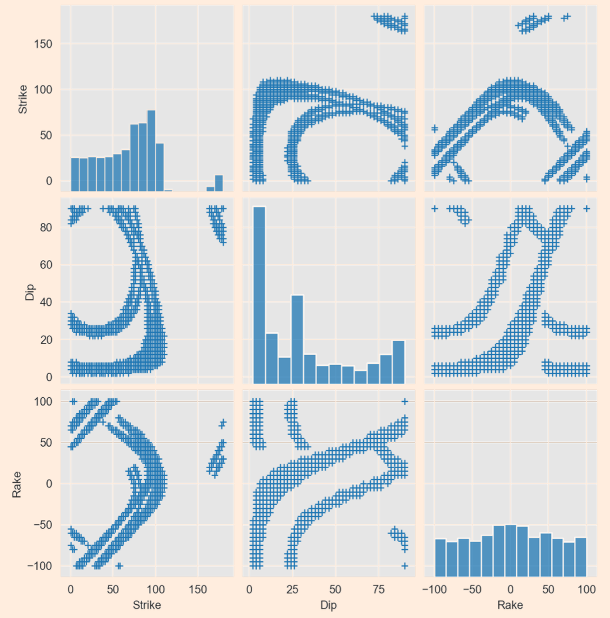
This particle motion shows the apparent "movement" of the event over time from the south-east to the north-east. It is possible that not all of the energy in this time window is purely *P*-wave energy.

Investigating possible double-couple mechanisms

Mars' crust is composed of a single tectonic plate and therefore intraplate tectonics, such as faulting, and impacts are expected to be the major contributors to the seismicity of the planet[2,3]. The lander is located about 1600km west of the Cerberus Fossae region, which is hypothesized to be an active tectonic structure and a major contributor to Mars' seismicity[4,5].

S0173a and S0235b were both found to fall in the Cerberus Fossae region while the epicenter of S0325a is estimated to be near the boundary between the southern highland and the northern lowlands[5]. Our proposed faulting mechanisms shown below incorporated the information about these regions in our investigation.





Grid Search

Using a modified version of the Gudkova model and an estimated source depth of 35km, we began modeling the *SV*, *SH* and *P* amplitudes that resulted from a range of double-couple focal mechanisms[6].

A grid search was then performed over a range of strike, dip and rake combinations to determine which could reproduce the observed *P*, *SH*, and *SV* amplitudes. The best fitting fault plane orientation is shown in Figure 3 adapted from Giardini et al. (2020)[5].

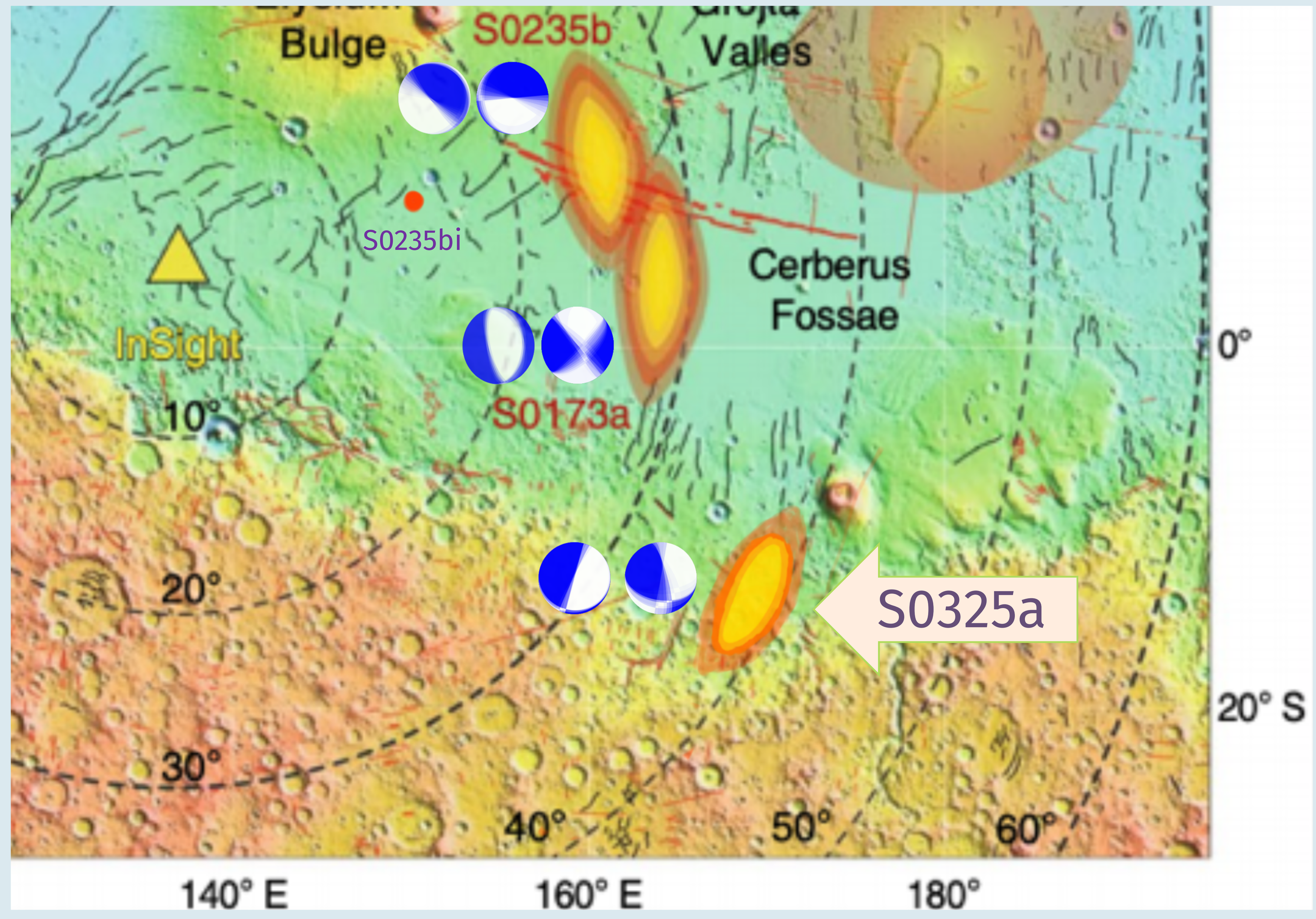


Figure 3. The figure was adopted from Giardini et al (2020) to include the new event S0325a at an approximate latitude and longitude of -15°N, 168°E as well as the possible fault planes.

This material is based upon work supported by the National Science Foundation under Grant No. AST-1757792, a Research Experiences for Undergraduates (REU) grant awarded to CIERA at Northwestern University. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

1. Suemoto, Y., Ikeda, T., & Tsuji, T. (2020). Temporal variation and frequency dependence of seismic ambient noise on Mars from polarization analysis. *Geophysical Research Letters*, 47, e2020GL087123. https://doi.org/10.1029/2020GL087123
2. Lognonné, P., Banerdt, W.B., Giardini, D. et al. SEIS: Insight's Seismic Experiment for Internal Structure of Mars. Space Sci Rev 215, 12 (2019). https://doi.org/10.1007/s11214-018-0574-6
3. Banerdt, W.B., Smrekar, S.E., Banfield, D. et al. Initial results from the InSight mission on Mars. Nat. Geosci. 13, 183–189 (2020). https://doi.org/10.1038/s41561-020-0544-y
4. Taylor, J., Teanby, N. A., and Wookey, J. (2013), Estimates of seismic activity in the Cerberus Fossae region of Mars, J. Geophys. Res. Planets, 118, 2570– 2581, doi:10.1002/2013JE004469.
5. Giardini, D., Lognonné, P., Banerdt, W.B. et al. The seismicity of Mars. Nat. Geosci. 13, 205–212 (2020). https://doi-org.proxy01.its.virginia.edu/10.1038/s41561-020-0539-8
6. J. F. Clinton, D. Giardini, P. Lognonné, B. Banerdt, M. van Driel, M. Drilleau, N. Murdoch, M. Panning, R. Garcia, D. Mimoun, M. Golombek, J. Tromp, R. Weber, M. Böse, S. Ceylan, I. Daubar, B. Kenda, A. Khan, L. Perrin, A. Spiga; Preparing for InSight: An Invitation to Participate in a Blind Test for Martian Seismicity. *Seismological Research Letters* 2017;; 88 (5): 1290–1302. doi: https://doi.org/10.1785/0220170094
7. Olugobji, T., Moser, E. *Sesmic Waveform Polarization Analysis*, ROSES 2020, organized by F. Dannemann & S. van der Lee, https://connect.agu.org/seismology/roses2021

University of Virginia
Northwestern
CIERA
Center for Interdisciplinary Exploration and Research in Astrophysics
NSF