

TRACING SEISMIC PHASES ACROSS THE MOON

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Introduction: During the Apollo missions, many seismic experiments were deployed on the Moon [1,2]. Using AxiSEM3D [3], a full-waveform seismic propagation tool, we trace seismic phases across the Moon. Lunar seismograms are very different from their terrestrial counterparts [1]. As expected, we find that the seismic waves propagate very differently from seismic waves on Earth.

Observations: During the Apollo missions, several of the Saturn IV boosters and the used Lunar Ascent Modules were deliberately targeted at the Moon to provide artificial impacts for the experiments [2]. Figure 1 shows the seismograms of these impacts plotted against epicentral distance from the station. We use a recently archived version of the lunar seismic data [4]. We also calculated the estimated arrival time of the direct P-wave, using Model 1 from Garcia et al., 2019 [5]. Lunar seismograms have a characteristic shape, with an emergent arrival, a slow rise time and an even longer decay time. The wavefield is highly scattered,

and the events last for over an hour (we plot the only the first half an hour). The first direct arrival is often hidden in the noise, and this problem becomes more significant at greater epicentral distances. The energy is distributed between the vertical and horizontal components of the seismogram.

Simulations: We use AxiSEM3D to simulate the global wavefield (Figure 2). We simulate the artificial impacts because the locations, velocities, mass and trajectories of the impactors are known. The impacts are modeled as pure explosions at 10 m depth, and we use a delta function which is the width of the time interval (0.059 s in the simulation shown in Fig. 2). The simulations shown here use Model 1 from Garcia et al, 2019 [5] and do not include any topography or 3D inhomogeneities. Even with this simple 1D model, Figure 2 shows that the wavefield is extremely complex. Scattering occurs from the base of the crust, which is at 40 km in the model. As the wave progresses across the Moon, the wavefield becomes more complex.

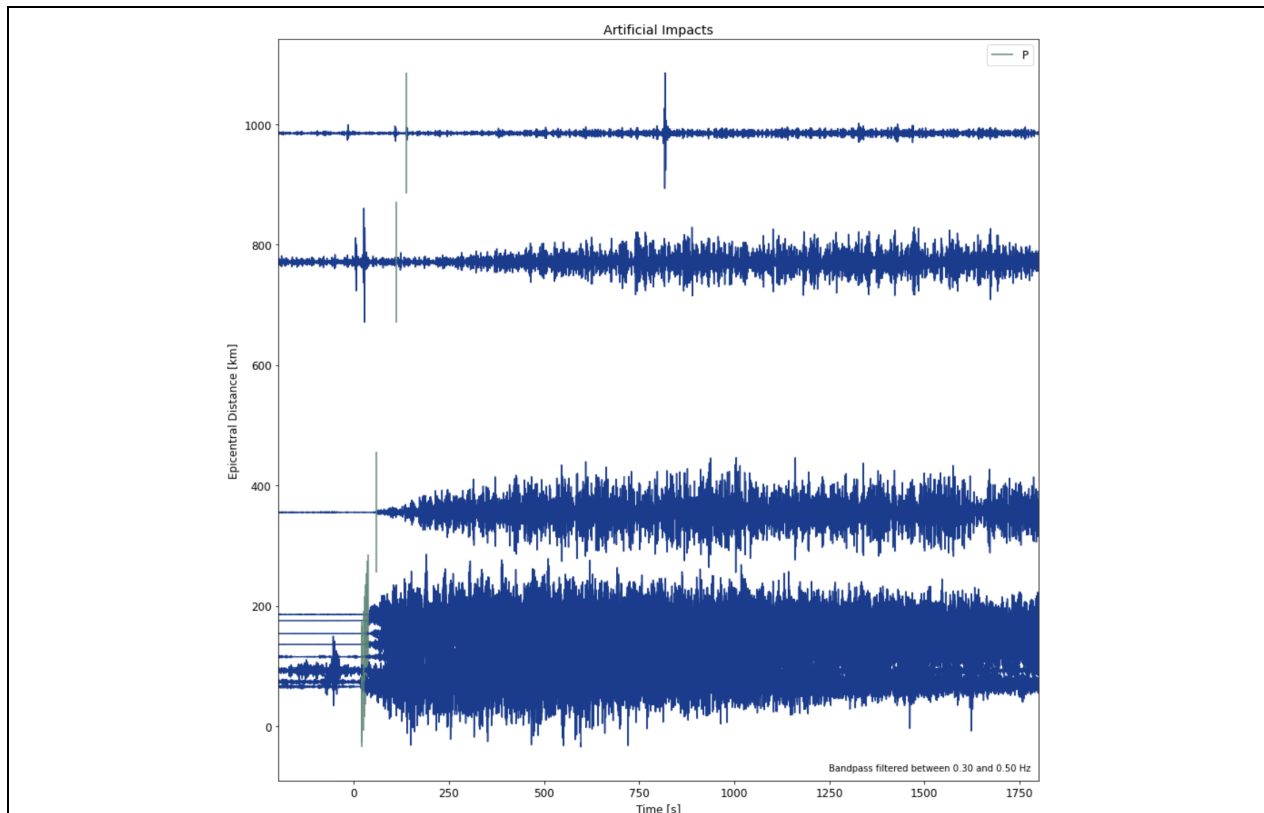


Figure 1: Artificial Impacts recorded at Apollo seismic stations. The plot shows the vertical component and impacts are plotted by epicentral distance from the station. The green line shows the direct P-wave, calculated from Model 1 [5].

Preliminary Findings: In the simulations, no shear waves travel from the source. This is consistent with the observations, where no clear shear wave is observed.

The current models do not contain scatter and do not match the rise and decay times of the observations. The next simulations will quantify whether the most important scatter is from topography or inhomogeneity.

Filtering is important when matching observations to simulations.

Far from the source, initial simulations show that direct arrivals may be too small to be observed, but later arrivals may be observed. We should take care when labeling seismic phases, since later phases could be mislabeled as direct arrivals.

Next Steps: We need to trace the seismic phases in these simple cases. Once we have completed this task, we will add complexity to the models. Since the Moon has very strong surface topography, we will begin by adding surface topography to the models. We will try to match the envelope functions on the vertical radial and transverse components. We will also simulate the propagation with a more realistic explosive source.

Outlook: By better understanding the propagation of seismic phases across the whole Moon, we will be in a better position to understand seismic data from future seismic missions. This work will support the Farside Seismic Suite (due to launch in 2025 [6]).

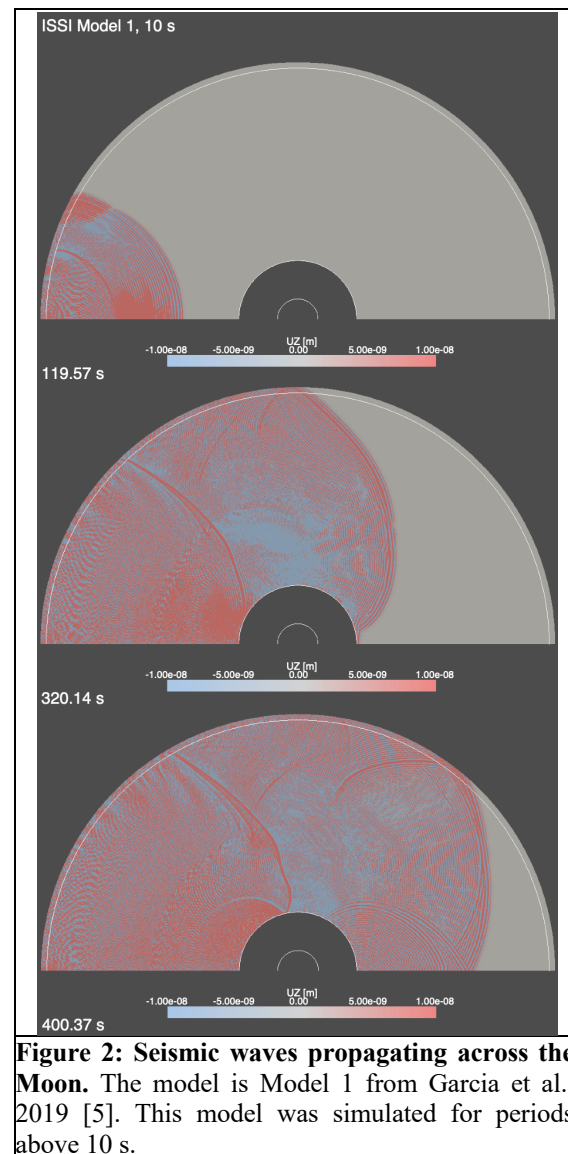


Figure 2: Seismic waves propagating across the Moon. The model is Model 1 from Garcia et al., 2019 [5]. This model was simulated for periods above 10 s.

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