AresWave: Source parameter estimation of Martian seismic events via waveform matching and stochastic optimization

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Planetary seismology faces significant challenges when constrained to single-station data, as is the case with the InSight mission on Mars. We present AresWave, a Python-based computational framework that estimates marsquake source parameters, depth, and focal mechanism through waveform matching. Synthetic seismograms are generated from layered 1-D velocity models of Mars, and the optimal source configuration is determined via Particle Swarm Optimization (PSO), guided by a cost function that combines waveform variation and mean square error within windows centered on the P and S phases.

We applied this approach to the marsquakes S0173a, S0185a, and S0235b, obtaining best-fit depths of 10.00 km, 30.37 km, and 19.53 km, respectively, and focal mechanisms consistent with faulting patterns mapped in the epicentral regions. The resulting waveform fits show good agreement with the observed data, particularly in the vertical component for P arrivals, and reproduce the main characteristics of the recorded seismograms despite the intrinsic instability of S phases on Mars. The inferred depths are consistent with previous estimates of crustal and upper-mantle seismicity derived from independent approaches.

In addition to deterministic inversion, we implemented a Bayesian module for depth estimation using S–P differential time, providing uncertainty quantification and posterior distributions that are used to constrain the PSO search space and improve convergence. Finally, AresWave includes an experimental module for waveform-based iterative refinement of 1-D velocity models. The combined results demonstrate that waveform fitting with stochastic optimization is a powerful tool for estimating planetary source parameters, even with limited datasets. This method complements classical arrival-time inversions, offering improved resolution and robustness in low-coverage scenarios and opening pathways for future applications to other planetary bodies.

Keywords: Mars, marsquake, waveform matching, particle swarm optimization

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