Preparing to image the Martian subsurface: planetary active-source seismology vs. radar, and the ARES concept

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Why should the planetary science community develop technology for planetary active-source seismology when ground-penetrating radar (GPR) exists? This skepticism is common among geophysicists studying Mars. Yet, we demonstrate with numerical simulations that active source seismology is superior at surveying two high priority subsurface targets: buried water ice and lava tubes. Whereas radar is sensitive to subsurface dielectric permittivity contrasts and suffers from mineralogical attenuation, seismic waves are sensitive to acoustic impedance contrasts and suffer minimal attenuation in comparison. Ultimately, since the two methods provide complementary data, we propose that they should be applied in tandem to survey the Mars underground.

In our study, we compare simulated orbital radar, GPR, and active source seismic data from subsurface water ice and lava tube models using a 1D reflectivity-method approach. There are two main results: (1) compared to low frequency (MHz) orbital radar sounding, active-source seismic provides higher vertical subsurface resolution with similar depths of penetration through crustal rocks; and (2) although surface-based high frequency (GHz) GPRs provide higher resolution, it comes at the tradeoff of reduced penetration depth due to mineralogical attenuation of electromagnetic waves. Additionally, radar systems typically only collect vertical sounding data. Independent seismic sources and receivers can record multiple offset data which includes angled and oblique ray paths. This allows for true 3D subsurface imaging, which is necessary to map targets with complex shapes like lava tubes. We show through numerical simulations that a collection of seismic sources and receivers on an Autonomous Roving Exploration System (ARES), could efficiently conduct a 3D seismic survey on Mars.

When active-source seismic imaging is combined with the excellent near-surface resolution of GPR, an ARES would provide the ultimate planetary subsurface surveying tool. Whereas radar sounding instruments have enjoyed recent development, little research has advanced active-source seismic instrumentation for planetary missions. Our work provides an argument and a method to ensure active-source seismology is developed concurrently with radar for surveying the Martian subsurface.