Probing the Thermal State of Mars Using InSight Seismic Data. Y. Zheng[1] and F. Nimmo[2], and T. Lay[2] [1]Department of Earth and Atmospheric Sciences, University of Houston, Houston, TX, USA, [2]Department of Earth and Planetary Sciences, University of California, Santa Cruz, Santa Cruz, California, USA.

Summary: Information on the global mantle potential temperature of Mars and its current thermal state are important in understanding planet evolution and the cooling rate of a smaller planet compared to the Earth.

Mars has a stagnant lid (lithosphere) overlying a convective mantle. There is expected to be a large thermal gradient across the stagnant conductive lid (lithosphere) of Mars [1]. This gradient should decrease seismic-wave velocities with increasing depth, with this effect dominating the opposing tendency caused by increasing pressure with depth due to Mars' low gravity. An upper mantle lithosphere with a low velocity zone (LVZ) beneath a thin high velocity "seismic lid" can thus be predicted for Mars. This link between the lithospheric thermal gradient and seismic LVZ enables us to use seismology to constrain Mars thermal structure. The upcoming NASA InSight mission [2-4] in 2016 may thus provide an unprecedented opportunity to determine globally averaged mantle potential temperature. The InSight heat-flow probe will also provide a local measurement of the heat flow at shallow depth.

The InSight mission will include a broadband three-component seismometer. For a single seismometer and, possibly, a paucity of marsquakes, the most diagnostic waves that can be used to evaluate a lithospheric LVZ are intermediate-period global Rayleigh waves, which travel along the great circle from a seismic source to the seismometer. An LVZ produces distinctive group-velocity dispersion, with a Rayleigh-wave Airy phase around ~100s period. The group-velocity dispersion depends on the lid thickness and the mantle potential temperature and thus can be used to constrain Mars internal thermal state.

Preliminary Mars Seismological models. Existence of an LVZ depends on the thermal gradient in Mars' lithosphere [5-9] and mineralogy. The model we adopt here is based on that described in [1] and [10]. We briefly summarize key elements and rationale in this model. Our model matches the observed bulk density and moment of inertia of Mars; it also satisfies the measured k_2 Love number and the tidal dissipation factor Q inferred from observation of Phobos' orbit [11]. The Love number k_2 inferred from solar tides indicates the existence of at least an outer liquid core [12]. Whether Mars has a solid inner-core or not is uncertain. However the presence of a solid inner core will have a significant effect on seismic normal mode frequencies [13], which may be detected by the InSight seismometer. In our model, we do not include a solid inner core. A range of core radii is permitted when modeling the tidal k_2 and moment of inertia [12]; we fix the core radius to be 1650 km, similar to that employed by Nimmo and Faul [1].

Tidal Q is sensitive to mantle potential temperature and grain size. We use 1cm as the grain size for a mantle mineralogy of dry Fo90. The mantle potential temperature is inferred to be 1625±75K [1] for a stagnant thermal lid thickness of L=125 km, in good agreement with some recent petrological studies based on remote-sensing observations [14, 15]. This thermal structure predicts an LVZ in the lithosphere. Mars may be iron enriched relative to the Earth [16, 17]. To account for this effect, we treat the reference density of Fo90 as a free parameter to match the bulk density of Mars. For the LVZ, however, iron enrichment will only increase the magnitude of any seismic LVZ [18]. Therefore in our model, the magnitude of the LVZ is conservative. Olivine phase changes, olivine-wadsleyite and wadsleyite-ringwoodite are also considered. To extrapolate Q at the tidal frequency to the seismic frequency ~1.0Hz, an extended Burgers model is used for a specified temperature profile [1, 19]. Figure 1 shows our preliminary model. We also show a noLVZ model where the seismic velocities are linearly extrapolated upward from below the LVZ and the lid thickness is 0km.

Results: To detect the existence of the LVZ using one seismometer with possibly just a few marsquakes, seismic normal-mode frequencies and body-wave raytracing to detect the shadow zone are of limited use [10]. Conversely, seismic Rayleigh wave dispersion is very diagnostic of the existence of an LVZ in the lithosphere (Figure 2). For the noLVZ model, the Rayleigh-wave group velocity monotonically increase for periods 50s-300s. However, for models with different lid thicknesses, the group velocity peaks at some period around 100s and then decreases with increasing period. To measure the group velocity dispersion with one seismometer, we can use multi-orbit Rayleigh waves traveling along the source-receiver great circle. The Rayleigh wave amplitude will decrease as it propagates. However, our calculations using our Q model show that it is possible to detect an R5 Rayleigh wave for a marsquake (double-couple source) with seismic moment 10^{18} Nm, with the InSight seismometer specification.

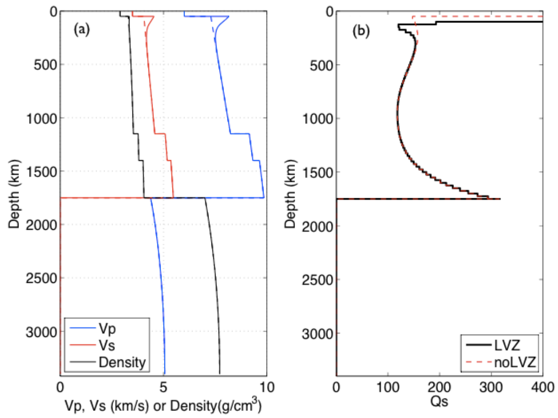

Figure 1. Our preliminary Mars seismic velocity model. (a) Seismic velocities: *Vp* (blue), *Vs* (red), and density (black) for *LVZ* model (solid lines) and for *noLVZ* model (dash lines). Olivine phase transitions are included and give mantle discontinuities. (b) Q_S at 1.0 Hz for the LVZ model and noLVZ model.

Conclusions: We have constructed a preliminary Mars seismological model and we predict an LVZ in the Martian lithosphere due to a large temperature gradient in the thermal lid. We further propose to use multi-orbit Rayleigh waves to detect the LVZ. Precise measurment of the Rayleigh wave dispersion can constrain the Mars temperature profile. NASA's InSight mission provides an important opportunity to test our prediction.

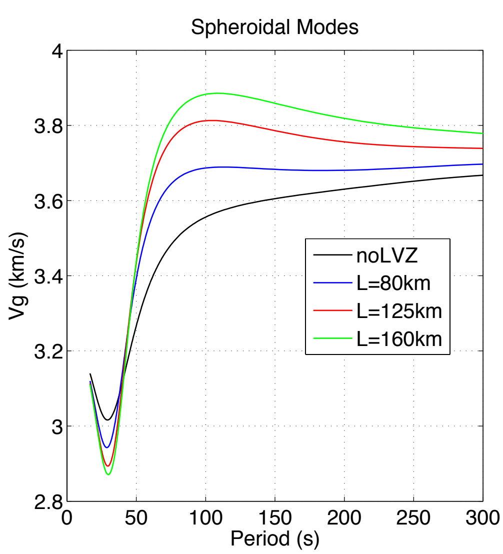

Figure 2. Fundamental-mode Rayleigh-wave group velocities with the period for Martian seismic velocity models with different lid thicknesses, *L*, but with the same mantle potential temperature.

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