Revisiting the mass-radius relation of super Earth with new ice EOS measurement
Chenliang Huang 1, Zachary M. Grande1, Dean Smith1, Jesse S. Smith2, John H. Boisvert1, Oliver Tschamner1, Jason H. Steffen1, Ashkan Salamati1
1University of Nevada, Las Vegas, 2Argonne National Laboratory

Abstract
In a broadly adopted terrestrial planet model, Zeng et al. (2016) derived the mass-radius relation of fully differentiated, two-layer planets. As a large analog of the icy satellites in the solar system, water/ice can be a major component of planets. Hakim et al. (2018) showed that the modeling uncertainty due to equation of states (EOS) applied can dominate over the observational uncertainties for best observed super-Earths. Using the laser heating and quenching techniques, we significantly improve the measurement accuracy of the phase diagram and EOS of water ice under pressures up to 88 GPa. We show that the phase transition from a newly identified ice-VIII to ice-X occurs just above 30 GPa and that the bulk modulus of ice-X is much larger than previously believed. We obtain the three-phase ice VII-VIII-X EOS by fitting to the measured P-V data.

New Ice EOS and Extrapolation
Using the laser heating and quenching techniques, we identify a new ice transition phase-IV-III, proceeding the phase transition to ice-X just above 30 GPa. At room temperature that we performed the measurement, the bulk modulus of ice-X is much larger than previously believed. We obtain the three-phase ice VII-VIII-X EOS by fitting to the measured P-V data.

Rapid-Melt Quench Technique
The main challenges, thus far, for measuring the true EOS of the different phases of water ice have been due to the geometry constraints of the diamond anvil cell (DAC), which leads to deviatoric stress conditions. Furthermore, water ices often crystallize over large domain sizes that lead to poor statistics when dealing with X-ray diffraction. By using a CO2 laser to directly couple with the water ice inside the DAC, we have been able to use a rapid-melt quench technique to produce small domains of ice that lead to a very significant improve on the averaging statistics when using X-ray diffraction, as well as annealing the deviatoric stress at the grain-grain boundaries of neighboring domains. In using this new and powerful technique we are also able to annul the pressure market (gold) to ensure a more reliable pressure determination for a given volume.

References

Fig. 1: X-ray diffraction pattern of the traditional cold compression method (left) and the laser heating and quenching method (right).

Fig. 2: Compare EOSs extrapolated to high pressure.

Fig. 3: The planet interior density map for 50 wt% water/rocky planet.

Fig. 4: Mass-radius curve of planet models compared to observational data.

Fig. 5: The planet mass-radius relation caused by the systematic difference between different composition or phases. The rocky part of the planet in three panels apply the same EOS, which is the direct extrapolation from Earth’s seismic model: the Preliminary Reference Earth Model (PREM) following Zeng et al. (2016). Three panels show planet models using the ice EOS I, II, and III respectively. The ice in the pressure range that studied in this work can occupy a substantial planet volume for water-rich planets.