THE EXTREME ACOUSTIC ANISOTROPY AND FAST SOUND VELOCITIES OF CUBIC HIGH-PRESSURE ICE POLYMORPHS AT MBAR PRESSURE. J. S. Zhang[1], M. Hao[2], and B. Chen[3], [1]Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico jinzhang@unm.edu, [2]Department of Earth and Planetary Sciences, University of New Mexico, [3]Hawaii Institute of Geophysics and Planetology, Department of Geology and Geophysics, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa

Introduction: Ice is a major component of icy planets, satellites, and exoplanets[1-3], as well as a possible minor component in the interior of terrestrial planets like Earth and Mars[4], thus its thermoelastic properties at high pressures are of fundamental importance for Earth and planetary sciences. Under room-temperature (T) condition, Ice crystallizes in to a disordered molecular phase ice VII at pressure (P) >2.5 GPa, and subsequently transforms into an ordered ionic form ice X at between 40-80 GPa [5-6]. However, the sharp jumps of the thermoelastic and optical properties across this transition remain controversial [7-9].

Experiments and results: Here we presented the first experimentally determined single-crystal elasticity model of ice up to 103(3) GPa, based on the sound velocity measurements of high-P ice polymorphs within multiple diamond anvil cells (DACs) using Brillouin spectroscopy. We have used symmetric DACs with 60° optical opening, and diamonds are with cutlets about 300 μm. The experiments were performed in the high-P laser spectroscopy laboratory at University of New Mexico (UNM) (Fig. 1), and the system is calibrated using a stand silica glass [10]. As shown in Fig. 1, the Vp and Vs peaks remain clear and sharp over the entire pressure range(Fig. 2). The Brillouin peak positions are linearly proportional to the sound speeds of the sample.

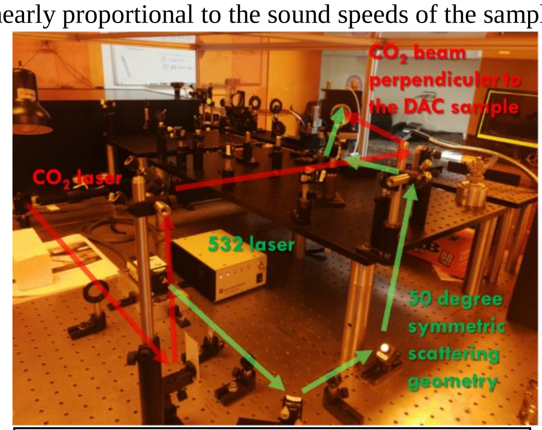

Figure 1. Brillouin spectroscopy system at UNM

We have not observed any clear discontinuities of the P-wave (Vp) or S-wave (Vs) velocities beyond experimental uncertainties. Ice VII and ice X are indistinguishable from the sound velocity data presented in this study. Our experimentally determined velocity

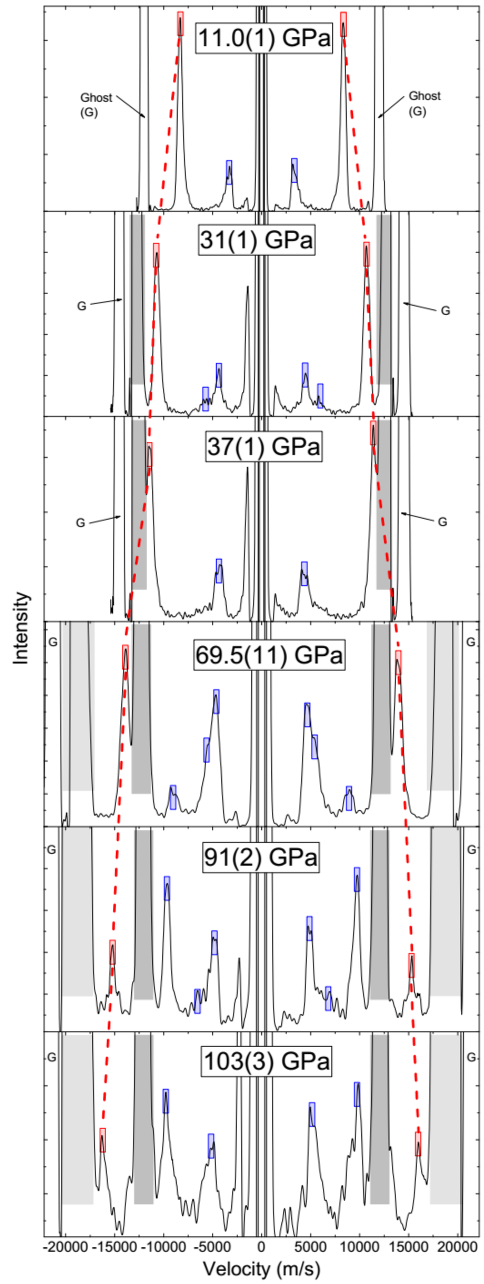

Figure 2. Typical Brillouin spectra of ice at different pressures. G represent ghost peak on the size of the Brillouin spectra. The light grey and grey area represent the Vp and Vs of the diamond anvil, red and blue squares indicate the Vp and Vs of ice.

extremum agrees well with the previous single-crystal study up to 7.3 GPa [11]. On the other hand, the Vp and Vs values obtained from previous polycrystalline sound velocity measurements, are within the extremum bonds yet approaching Vpmax and Vsmin at high pressures. As a result, previous studies significantly overestimated the bulk modulus (K) and underestimated the shear modulus (G) of cubic ice at high-P condition.

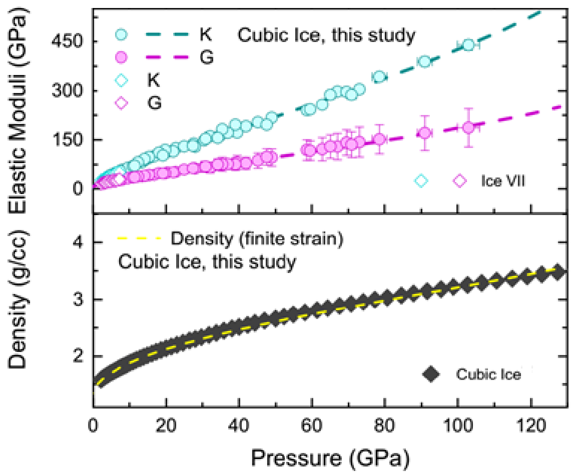

Figure 3. Aggregate elastic properties and densities of ice at high-P conditions. Previous measurements of K and G on ice VII are plotted with open symbols [11], and previous density measurements using X-Ray diffraction are ploted in the bottom with dark grey diamonds [9].

We also calculated the universal elastic anisotropy index AU of high-pressure cubic ice up to Mbar pressure. It is about 5 times to an order higher than the terrestrial high-P silicates ferropericlase and bridgmanite. The AU of ice quickly increased to 1.7-1.9 at 14-16 GPa, and then follow a more gradual increasing trend at higher P. This change at ~14-16 GPa coincide with a previously reported transition of the cubic ice VII into an intermediate tetragonally distorted structure, although further studies are needed to clarify this issue [12]. The absolute Vp and Vs anisotropy of ice reaches 27% and 74% at ~100 GPa, which are comparable to the serpentine minerals at ambient condition[13].

Implications: Many icy planets and satellites in the solar system are believed to have active tectonic systems. For example, in addition to the dilational bands (analog to the mid-ocean-ridges on the Earth's surface) that creates new surfaces on Europa[14], a recent study using Galileo spacecraft images suggested that the ongoing subduction processes are currently recycling the surface ice shell into Europa's interior[3]. Long-term cooling induced thermal volume contraction could also deform the icy lithosphere of Titan and produce the mountain belts on its surface, which are observed by Cassini Radar instrument[2]. Moreover, recent planetary simulations revealed the important role of the high-P ice polymorphs on the internal dynamics in the water-rich "super-Earth" exoplanets[1]. Therefore, the carefully constrained elastic properties of high-P ice in this study are crucial for studying the tectonic activities and convection in the icy planetary interiors. In the terrestrial planetary bodies, due to its extreme elastic anisotropy, the presence of even a very small amount of ice can lead to observable anisotropic seismic signatures.

References:

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