SEISMOLOGY OF EUROPA AND THE SOLAR SYSTEM'S OCEAN WORLDS. S. Kedar[1], S. D. Vance[1], M. P. Panning[2], W. T. Pike[3], S. C. Stähler[4], B. Bills[1], W. B. Banerdt[1], [1]Sharon.Kedar@jpl.nasa.gov, Jet Propulsion Laboratory, California Institute of Technology, [2]University of Florida, [3]Imperiacl College of London, [4]Ludwig-Maximilians-Universität München

Introduction: Seismic investigations offer the most comprehensive view into the deep interiors of planetary bodies. The InSight mission and concepts for a Europa Lander and a Lunar Geophysical Network present unique opportunies for seismology to play a critical role in constraining interior structure and thermal state. In oceanic icy worlds, measuring the radial depths of compositional interfaces using seismology in a broad frequency range can sharpen inferences of interior structures deduced from gravity and magnetometry studies, such as those planned for NASA's proposed Europa Mission and ESA's JUICE mission. Seismology may also offer information about fluid motions within or beneath ice—which complements magnetic studies—and can record the dynamics of ice layers, which would reveal mechanisms and spatiotemporal occurrence of crack formation and propagation. A summary of possible seismic sources and what they might reveal about Europa's deep and shallow interior is shown in Figure 1.

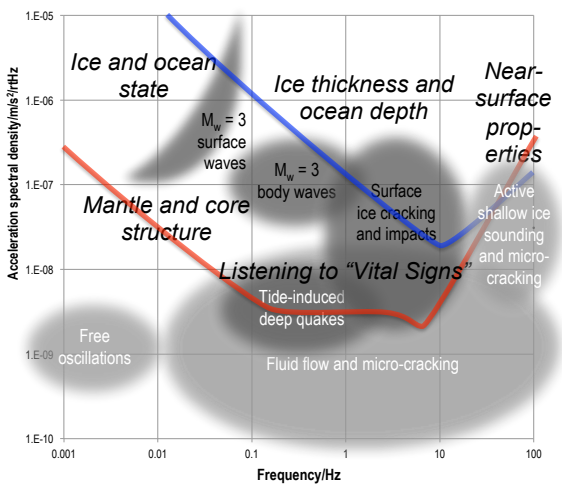

Figure 1: Europa is expected to be seismically active requiring a sensitive, broad-band, high-dynamic-range seismometer such as the SP (red). The expected sources are located in their relevant frequency and amplitude ranges, based on Earth analog (black text) and models (white text) [1-5], with italicized text indicating the science investigations that are enabled by recording these sources. The sensitivity of a 10 Hz geophone is shown in blue for comparison. Note that most of the expected signal will not be observeable by a high-frequency geophone.

Simulations of Seismic Wave Propagation: Investigating these structures and processes in the future calls for detailed modeling of seismic sources and signatures. We present results of simulations of plausible seismic sources and wave-field propagation in Europa (Figure 2), with extension to other icy ocean worlds.

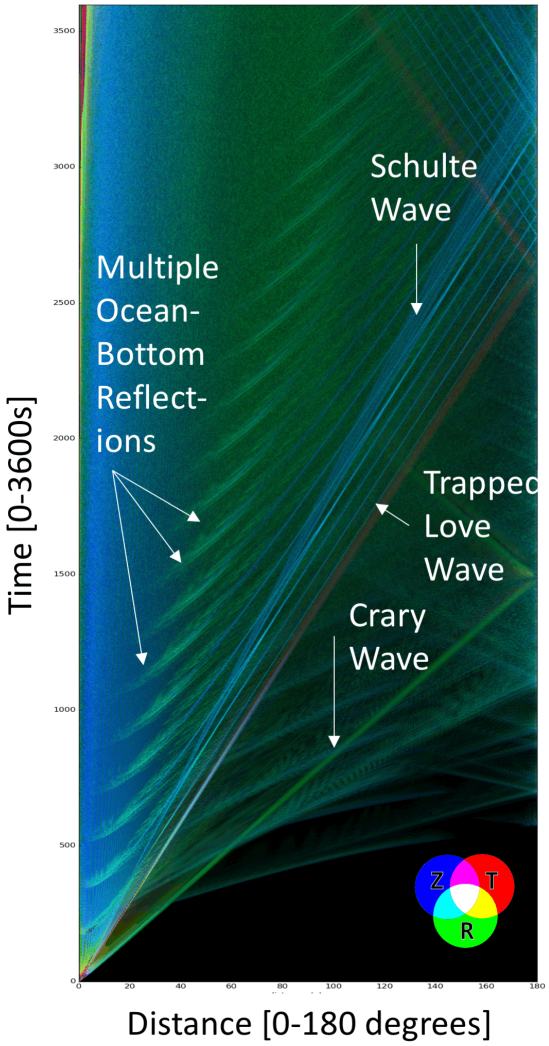

Figure 2: Simulation of seismic wave propagation in a Europa model with a 5km thick ice shell and 100km deep subglacial ocean using AxiSEM [6] reveals a seismic signature dramatically different from Earth's. Vertical component data are plotted in blue, while horizontal component data are displayed in green for the com-

ponent in the source-receiver plane and red for the transverse direction (see color guide). Key phases unique to Europa are labeled.

Fluid-Flow Induced Seismicity: Fluid flow generates a unique and distinguishable class of seismic sources. Unlike brittle failures in rock or ice, that are associated with distinct P, S, and surface waves, flow-driven seismicity results from a continuous interaction between the moving fluid and the surrounding rock or ice. Such seismicity can be caused by a range of fluid states, and flow regimes, yet they commonly appear as a continuous, quasi-monochromatic, low amplitude background vibration (Fig. 3). Fluids are likely present in tidal flexed ice shells like Europa that are undergoing solid state convection. Ocean worlds may share common attributes with terrestrial ananlogs (geysers, sub-glacial flow, volcanos, cryovolcanos, and ocean resonance) whose frequencies and amplitudes represent underlying physical processes and fluid properties. Following the example of Spencer and Nimmo [7], Figure 4 illustrates what information a seismometer in the vicinity of an Enceladus plume could reveal from volatile-induced seismicity in a hypothesized conduit system.

References:

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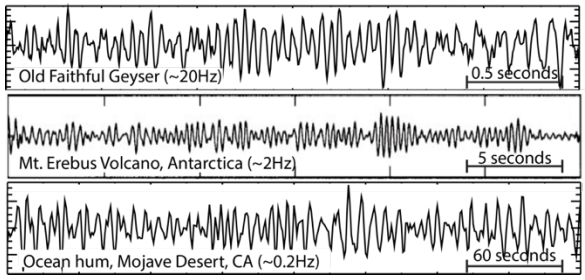

Figure 3: Fluid flow induced seismicity, easily recognizable by its appearance as a continuous background "hum", can reveal fundamental processes within Europa and other ocean worlds.

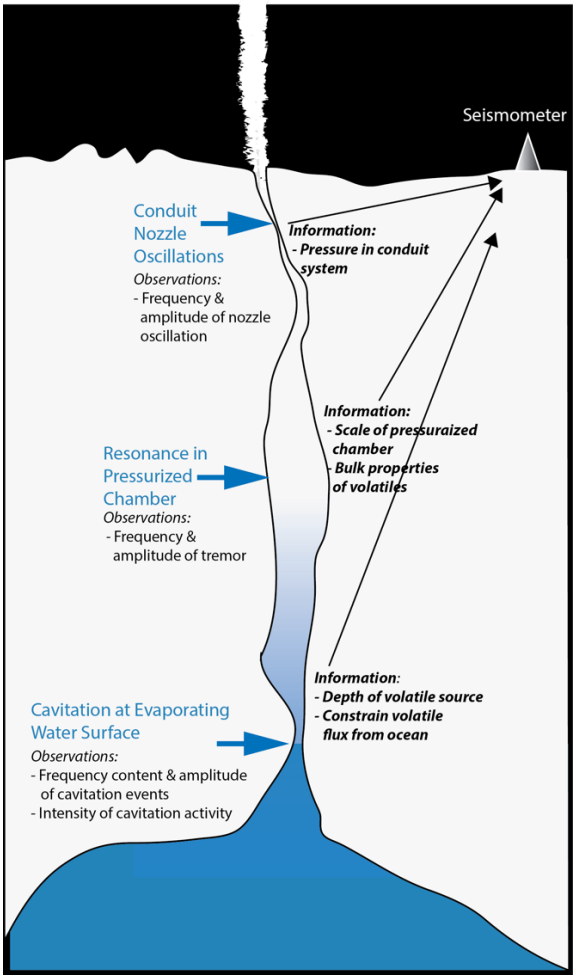

Figure 4: Following Spencer and Nimmo (2013), an illustration of potential seismic sources (blue text) and how they might be used to constrain the physical properties and parameters of a cryovalcano system. The hypothesized seismic sources of cavitation, chamber resonance, and nozzle oscillations are based on terrestrial analogues of geysers, volcanoes and volcanic nozzles respectively.