SLUSH: AN ICE DRILLING PROBE TO ACCESS OCEAN WORLDS

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Introduction: Ice shelves more than a kilometer deep conceal large bodies of water beneath the surfaces of Europa, Enceladus, and Mars [1,2]. These bodies of water are primary targets in the search for past or present life in the solar system. The Search for Life Using Submersible Heated (SLUSH) probe is a hybrid, thermo-mechanical probe capable of penetrating kilometers of ice to deliver science instruments to the subsurface liquid water (**Figure 1**). To improve efficiency and drilling speed over traditional melt probes, SLUSH combines the two existing methods: thermal (melting) and mechanical (cutting) [3]. "Slushing" uses drilling to break the ice and heat to partially melt the ice chips to form slush to enable the efficient transport of ice chips behind the probe. Once SLUSH reaches the subsurface water, integrated science instruments send data to the surface lander for transmission back to Earth. SLUSH baselines a tethered approach to communicate through kilometers of ice. The tether system uses two conductive microfilaments and an optical fiber. The fiber provides high bandwidth and the accurate depth of the probe. If the tether breaks, for example, from the diurnal tidal stresses expected on Europa, the broken microfilaments can be used as an antenna for a so called "Tunable Tether" approach. The tether is wound inside several spool bay pucks that are left behind in the ice once the spool is depleted. The pucks act as transceiver and receivers to enable radio frequency (RF) communication through the microfilaments and decrease the probe length as they are released.

Prototype Probes: Honeybee Robotics has developed prototype probes to advance the drilling technology and communication technology for a future ocean world probe. A stand-alone SLUSH prototype probe has been developed to demonstrate the slushing approach in a compact design and was tested in an ice tower inside Honeybee's walk in freezer. Rate of penetration and specific power was measured to compare speed and efficiency metrics.

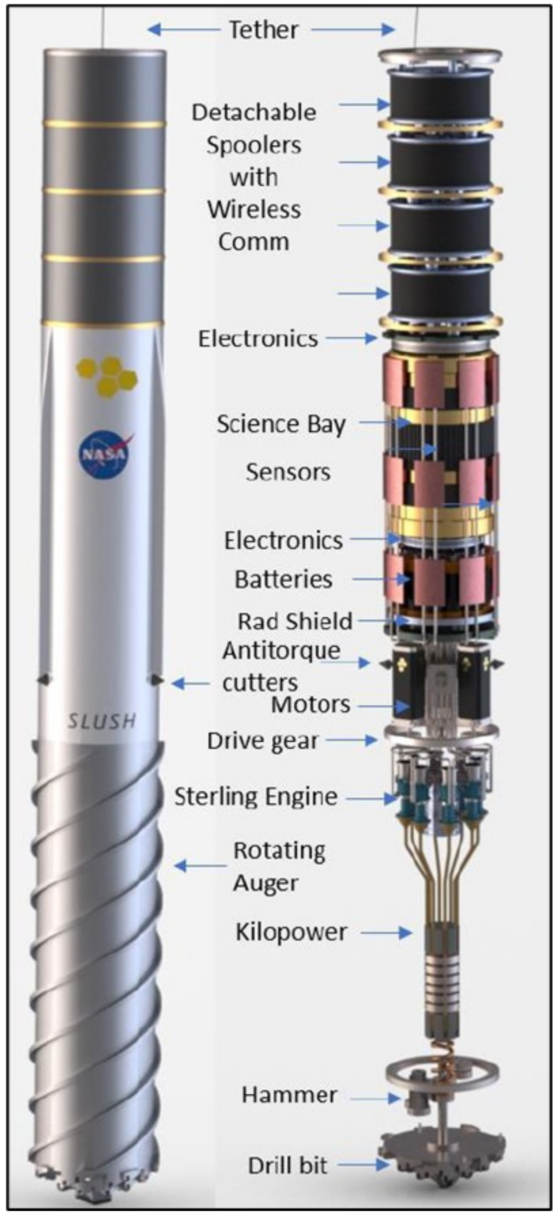

Figure 1. Conceptual design of SLUSH.

In parallel, to develop the tether communication technology, Honeybee Robotics is designing several iterations of melt probes for testing in analog environments. The first iteration, called the Salmon Probe, carries a passively-unspooling, hybrid tether that uses the 2 conductors to power the probe and a plastic fiber optic to transmit data. In summer of 2022, the probe was taken to Devon Island in the Canadian high

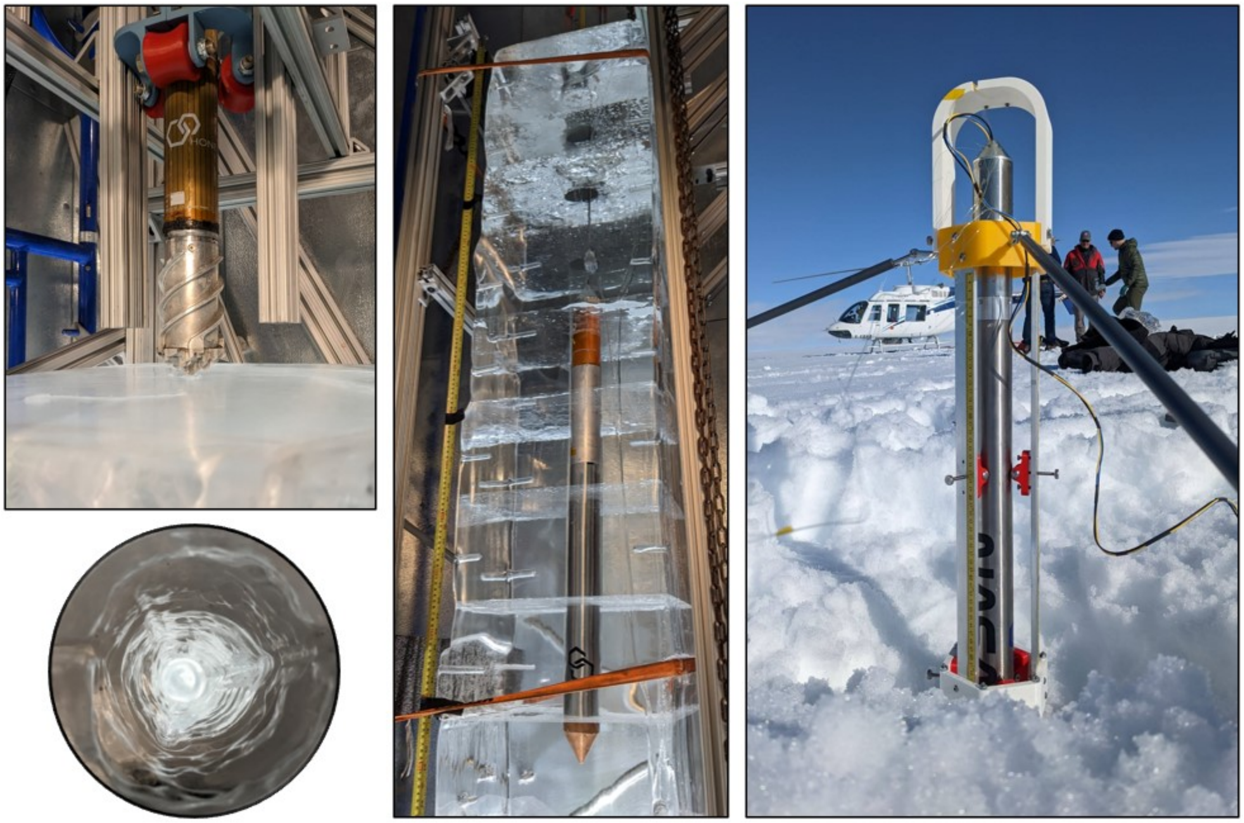

Figure 2. Top Left: SLUSH prototype probe set up over an ice tower. Bottom left: Top view of 1.4 m borehole created by the SLUSH prototype probe. Middle: Dolphin Probe being tested inside an ice tower. Right: Salmon Probe being tested on top of Devon Island Ice Cap.

arctic and successfully tested on top of the ice cap to a depth of about 1.8 meters). The Devon Island ice cap is 100's of meters thick, allowing for testing at depths not attainable in the lab [4]. The next probe iteration, the Dolphin Probe, was designed for up to 100 m depths with a higher fidelity tether and spooler, pressure sensor, and a topside Distributed Temperature Sensor (DTS) to measure temperature over the 100 m tether with. The Dolphin Probe was similarly deployed to Devon Ice Cap in 2023, but due to logistics challenges was limited to testing to depths of about 2 m in sea ice. The DTS performed well and enabled monitoring of probe depth, melt pocket temperature, and internal probe temperature.

Honeybee is now developing the Narwhal Probe and adding a modular science bay and a deployable tether puck. Instrumentation includes a side-looking camera and electrical conductivity sensor. The deployable puck is a flight-forward design replicating those that may be used for communicating through thick ocean world ice shells (up to tens of km, e.g., Europa or Enceladus) [5]. The Narwhal Probe is designed to profile the Devon Ice Cap to a depth of 100 m.

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References: [1] Howell, S., et al. (2021) Ocean Worlds Exploration and the search for life. Bulletin of the AAS, 53(4). [2] Lauro, S. E., et al. (2020). Nature Astronomy, 5(1), 63–70. [3] Bar-Cohen and Zacny (2020) "Advances in Terrestrial and Extraterrestrial Drilling: Ground, Ice, and Underwater". [4] Rutishauser, et al. (2021) The Cryosphere, vol. 16, no. 2, pp. 379–395. [5] Hendrix, Amanda R., et al. (2019) Astrobiology 19.1: 1-27.