SLUSH: Search for Life Using Submersible Heated drill

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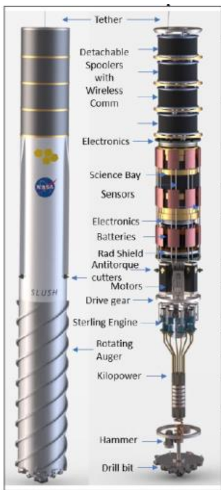
Introduction Europa is a primary target in the search for past or present life because it is potentially geologically active and likely possesses a deep global ocean in contact with a rocky core underneath its outer ice shell. Galileo spacecraft observations and theoretical models predict that the ice shell is 3-30 km thick and overlays an ocean ~100 km deep.

To reach the subsurface ocean where life may be most prevalent, a probe would need to penetrate the ice shell while moving the excavated material aft. This can be achieved by melting the material (thermal penetration) and cutting the material (mechanical penetration). Mechanical systems break the icy material efficiently but transport ice chips inefficiently. Thermal systems have an effective chip removal approach but a power intensive ice-melting step. The Search for Life Using Submersible Heated (SLUSH) drill (Figure 1) is a hybrid thermo-mechanical drill probe system that combines the most efficient aspects of these two techniques.

SLUSH is 5 m long, 57 cm diameter probe with a heated drill bit in front, antitorque cutters on the side, and several tether bays on top. The probe is partially flooded to achieve negative buoyancy. Critical subsystems are inside a pressure vessel.



System	Mass (kg)	Length (cm)	Technology Status	Entry/Exit TRL
Tether	39	N/A	Exist but not tested. Will procure and fabricate various tethers. Will perform strength and resistivity tests at various temperatures.	3/4
Wireless Comm	4	N/A	Exist but not proven for Europa environment. Will test COTS hardware under Europa conditions.	3/4
Spooler	41	20	Basic components exist. Requires design.	3/4
Science Bay	N/A	65	Not investigated under this project.	N/A
Electronics	10	20	Rad tolerant exist. Commercial exist for 200°C. Venus electronics under development via HOTTech.	N/A
Batteries	20	50	Under development for Oil&Gas	N/A
Thermal design	11	N/A	Done for melt probe. Will use ThermalDesktop and COMSOL.	4/5
Anti-torque	3	10	Numerous high TRL options exist. Can be used for direction control.	5/5
Motor	12	20	TRL6 (Zacny et al., 2013).	5/6
Percussion	13	30	Developed and tested at Venus (500C) T, P. CO2.	6/6
Kilopower	N/A	130	Provided by NASA.	5/
Heated bit/auger	14	15	Various options exist. Tested under SBIR Phase 1 (Zacny et al., 2018). Momentive manufactures high flux heaters.	5/6
TOTAL	189	~5 m	Mass includes structure (22 kg)	

Figure 1. SLUSH with component details and placement.

SLUSH utilizes a mechanical drill to break the ice and a reactor to partially melt the fragments, enabling the efficient transport of material behind the probe. The resulting slush behaves like liquid despite being partially frozen, significantly reducing the power required for melting the full volume of ice. Further, because the mechanical approach generates higher penetration rates than melting, SLUSH can reach the ocean in a much shorter time than a pure melt probe. Once SLUSH passes through the top cryogenic ice and penetrates deeper into warmer ice, it can use a purely thermal approach to melt through this warmer ice without the need for mechanical cutting.

SLUSH incorporates the Kilopower reactor for both thermal and electrical needs. The fission reactor can be turned on/off and is self-moderating, significantly simplifying thermal management. The probe is physically connected to a surface lander by a communications tether, housed in several spool bays that are left behind in the ice once the spool is depleted. This allows each tether section to be purpose-designed. For example, the top section, which may see 150 kPa shear stresses on a diurnal cycle, will be reinforced with Kevlar and or Vectran. Leaving the spools behind also shortens the probe length as it descends, making penetration more efficient.

While Kevlar/Vectran reinforcement and the refrozen channel left behind by the probe may provide protection from the diurnal stress environment, if the tether does break, broken sections could become tune antennas to form "Tunable Tether". In-line RF communications nodes would sense the broken tether and adjust from wired to wireless mode for communication. A mixture of in-line RF and acoustic communication nodes may potentially comprise the backup communications link by incorporating frequency adjustable transceivers combined with transducers into each spool section at frequency selected distances.