ARCHIMEDES—Direct Laser Penetration of Ice for Ocean Worlds, Martian Polar Caps, and Terrestrial Ices

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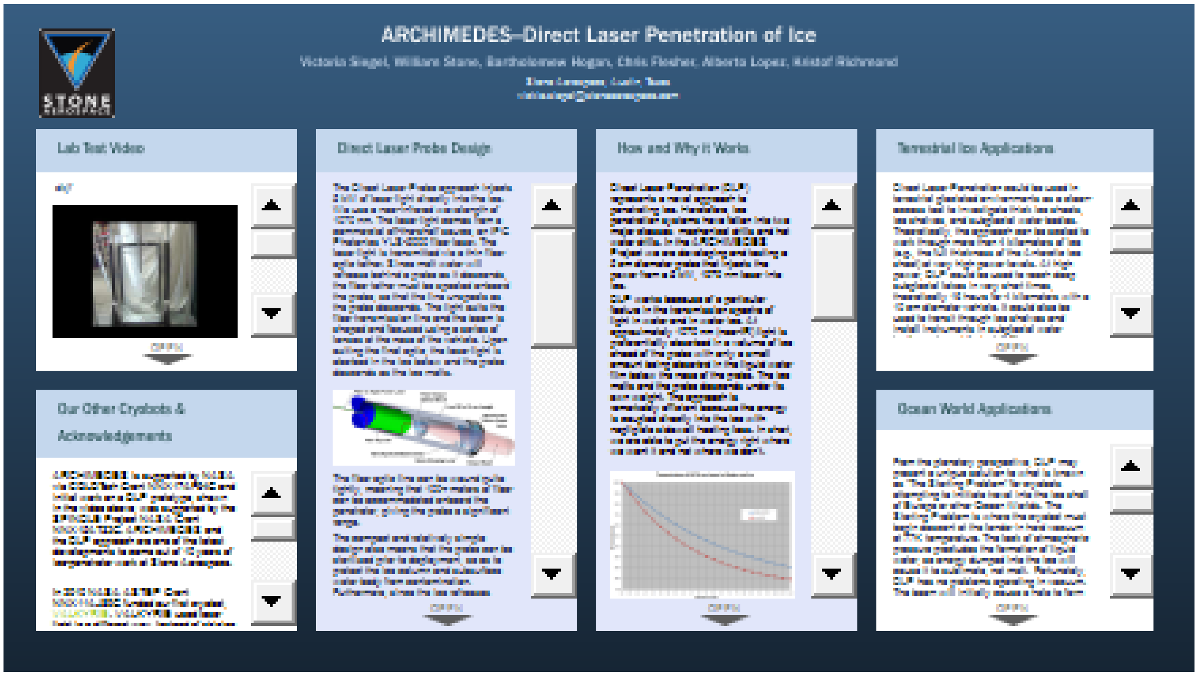
Abstract

Over the past three years Stone Aerospace has developed a novel ice penetrating technology known as a Direct Laser Penetration (DLP). DLP uses laser light carried by an optical fiber to a vertically descending ice penetrator and emitted from the nose to melt the ice in front of it at extremely high power levels and melt rates. A penetrator can be made with an onboard fiber spool connected to a surface-based laser, allowing the hole to re-freeze behind, drastically increasing efficiency and providing isolation from the surface. A parallel spool can pay out a communications fiber to carry information from imagers, fiber-based sensors (e.g. temperature, pressure, seismic), and other optical sensors (e.g. fluorescence or Raman). Laser power levels of up to 100 kW (continuous) at 1070 nm wavelength are now available and can be coupled to these probes. Successful laboratory test results at Antarctic ice temperatures show that this approach could lead to the fastest ice penetration rate available to terrestrial targets, with access to any Antarctic sub-glacial lake in under 16 hours. In this way, DLP offers an alternative to traditional, logistically intense ice drilling: a small footprint system that is fast and can deploy sensor strings through the deepest ice in a short period of time. DLP also shows promise in addressing the 'starting problem' for extraterrestrial targets such as Europa or Mars where low pressures prevent the formation of water at the surface and thus heat transfer for traditional melt probe architectures. In order to test the effectiveness of this concept, a Europa environment 'cryovac' test facility has been built at Stone Aerospace in Austin, Texas. We will discuss quantitative results from initial lab and chamber tests of the DLP concept, including in an ice column at 100 K temperature subjected to vacuum.

ARCHIMEDES–Direct Laser Penetration of Ice



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PRESENTED AT:

LAB TEST VIDEO

dkjf

[VIDEO] https://www.youtube.com/embed/y33mNUctn78?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0
This video shows an early Direct Laser Probe (DLP) test in "warm" ice (-10 C). The video has been sped up 5X. The purple flash you see in the ice ahead of (below) the probe is not visible to the human eye, however, the camera does pick it up. In this test we ran 5 kW of power out of the laser. The descent rate, at this power, in this temperature of ice, was 22 m/hr. This prototype probe is 5 cm in diameter.

OUR OTHER CRYOBOTS & ACKNOWLEDGEMENTS

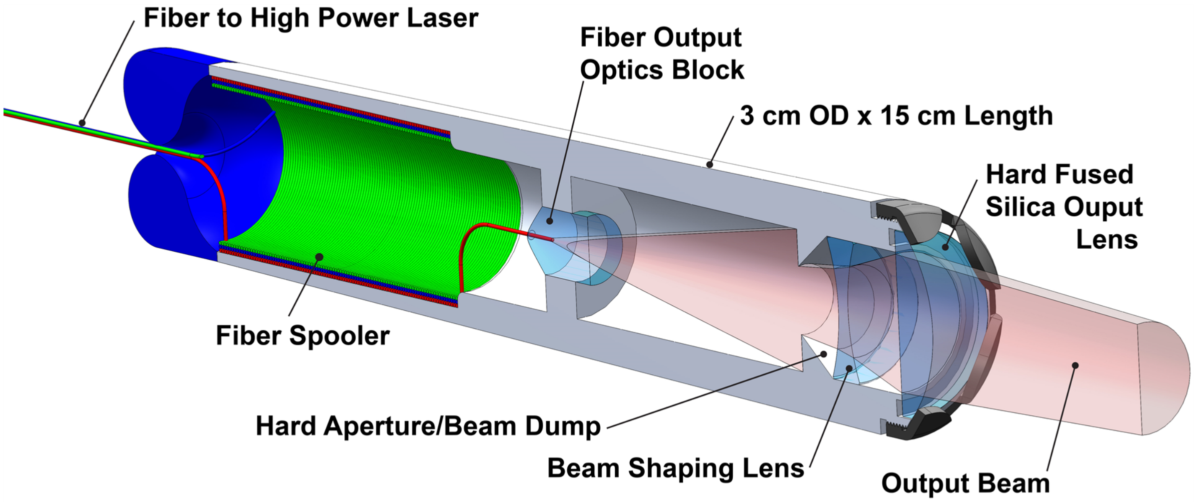
ARCHIMEDES is supported by NASA via COLDTech Grant NNX17AF64G and initial work on a DLP prototype, shown in the video above, was supported by the SPINDLE Project NASA Grant NNX15AT32G. ARCHIMEDES and the DLP approach are one of the latest developments to come out of 10 years of ice-penetrator work at Stone Aerospace.

In 2010 NASA ASTEP Grant NNX11AJ89G funded our first cryobot, VALKYRIE (http://stoneaerospace.com/valkyrie/). VALKYRIE used laser light in a different way. Instead of shining the light directly into the ice, we spread the laser beam (5 kW, 1070 nm) evenly over the inside wall of a tubular heat exchanger. Meltwater was drawn in from the nose of the probe, routed through the side walls of the heat exchanger, and, now heated, the water was then pumped out through jets in the nose, creating a closed-cycle hot water drill. The project was coupled with astrobiological investigations and the entire system was fielded to the Matanuska Glacier in Alaska in 2014 and 2015.

Finally, we are just now starting work on a new type of cryobot system, THOR, funded by NASA PSTAR Grant 80NSSC18K1738. Stay tuned!

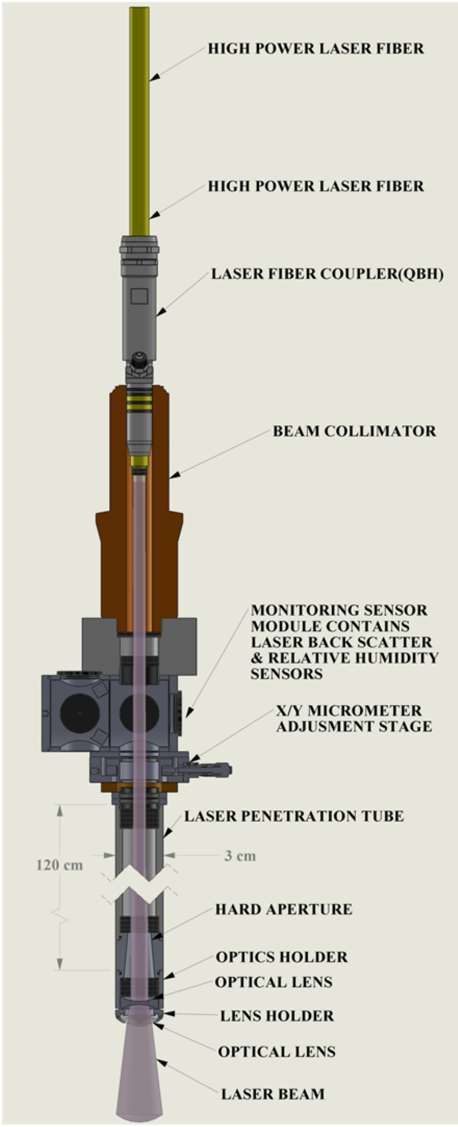
DIRECT LASER PROBE DESIGN

The Direct Laser Probe approach injects 5 kW of laser light directly into the ice. We use a near-infrared wavelength of 1070 nm. The laser light comes from a commercial off-the-shelf source, an IPG Photonics YLS-5000 fiber laser. The laser light is transmitted via a thin fiber optic tether. Since melt water will refreeze behind a probe as it descends, the fiber tether must be spooled onboard the probe, so that the line unspools as the probe descends. The light exits the fiber transmission line and the beam is shaped and focused using a series of lenses at the nose of the vehicle. Upon exiting the final optic, the laser light is aborbed in the ice below and the probe descends as the ice melts.



The fiber optic line can be wound quite tightly, meaning that 100+ meters of fiber can be accommodated onboard the penetrator, giving the probe a significant range.

The compact and relatively simple design also means that the probe can be sterilized prior to deployment, so as to protect the ice column and subsurface water body from contamination. Furthermore, since the ice refreezes behind the probe as it descends, it is likely that forward contamination through the ice column (i.e., upper melt water mixing with deeper melt water) is minimized.

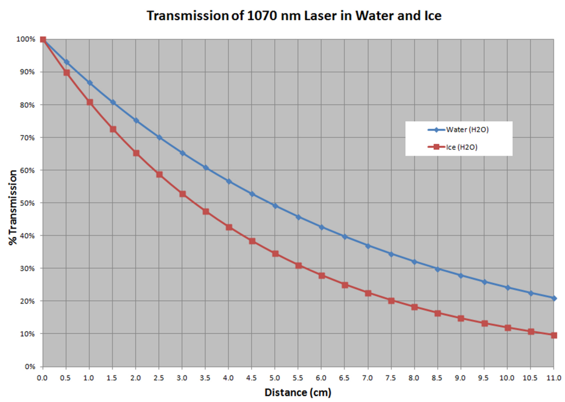


Our next step in this effort will be to test a prototype in water ice in Europa temperature and pressure conditions. Cryovac testing of a 5 cm x 15 cm DLP probe at the Stone Aerospace *Europa Tower* cryovac chamber facility will begin in January 2019.e

HOW AND WHY IT WORKS

Direct Laser Penetration (DLP) represents a novel approach to penetrating ice. Heretofore, ice penetration systems have fallen into two major classes: mechanical drills and hot water drills. In the ARCHIMEDES Project we are developing and testing a 5 cm diameter probe that injects the power from a 5 kW, 1070 nm laser into ice.

DLP works because of a particular feature in the transmission spectra of light in water and in water ice. At approximately 1070 nm (near-IR) light is preferentially absorbed in a volume of ice ahead of the probe with only a small amount being absorbrd in the liquid water film below the nose of the probe. The ice melts and the probe descends under its own weight. The approach is remarkably efficient because the energy is coupled directly into the ice with negligible sidewall heating loss. In short, we are able to put the energy right where we want it and not where we don't.

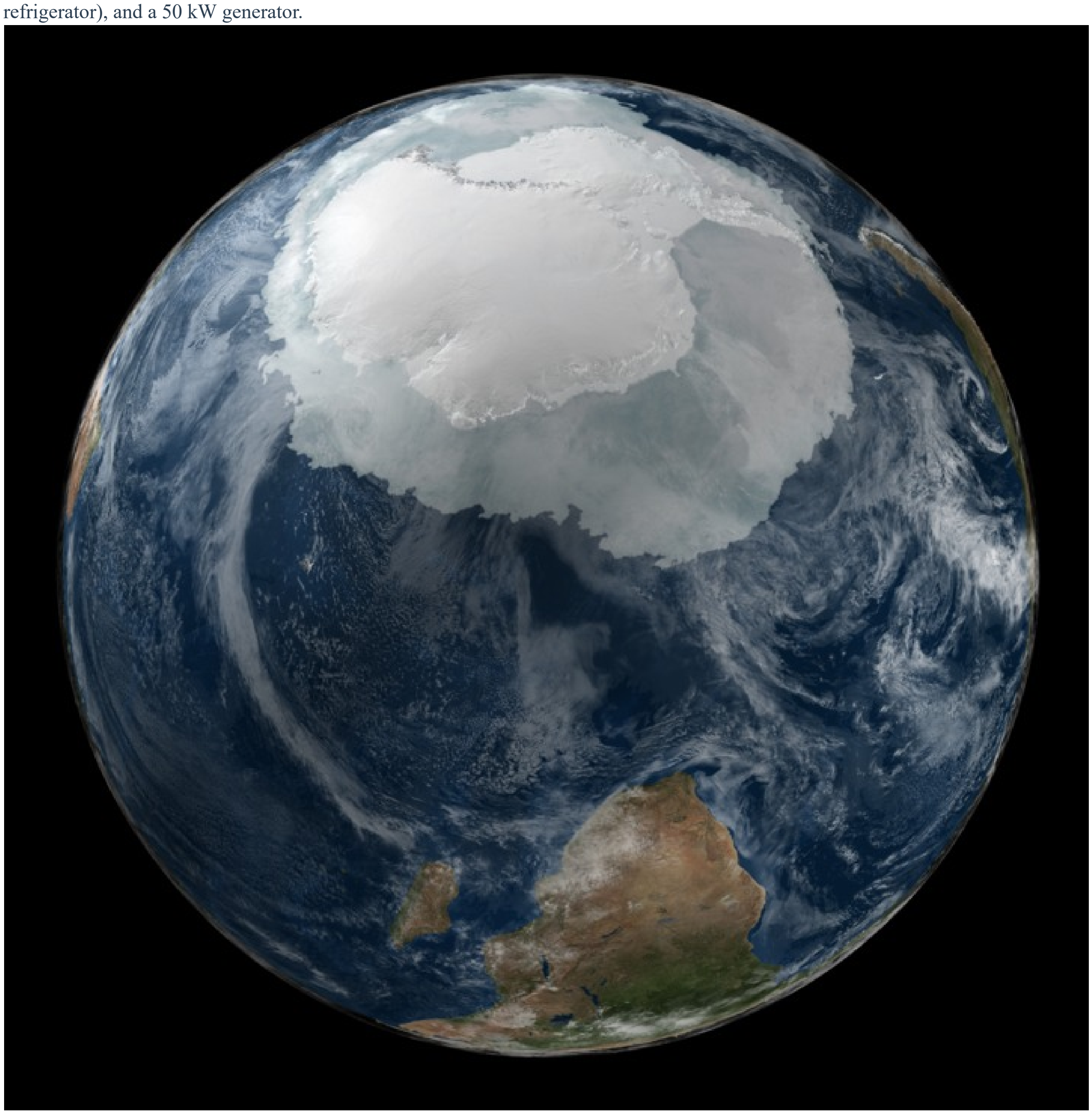


There are downsides and limitations to DLP. First of all, while laser light transmission through the fiber optic line and from the probe into the ice both boast very high efficiency, the laser source itself must be powered. The conversion from electrical energy used by the laser source to optical energy in the laser beam output is only about 50% with current technology. Second, DLP has only been tested in pure water ice at this point. It's likely that impurities may pose problems. We plan to perform tests of DLP performance in briny ice as part of the ARCHIMEDES project. Solid impurities will likely stop forward progress of the probe entirely.

Another enabling factor for DLP is the use of fiber optic line to transmit the laser light from a laser source on the ice surface to the probe. Laser light is transmitted very efficiently over fiber. In 2010 we conducted tests relating to high power optical energy transmission through silica fibers. In the photo above 11 kW of optical power was transmitted through 1.1 kilometers of such fiber. Power attenuation was found to be 12% of total power lost per kilometer of fiber. Such attenuation must be taken into acount in mission planning but otherwise fiber can be spooled onto a DLP cryobot at relatively small diameters, allowing for a highly efficient probe.

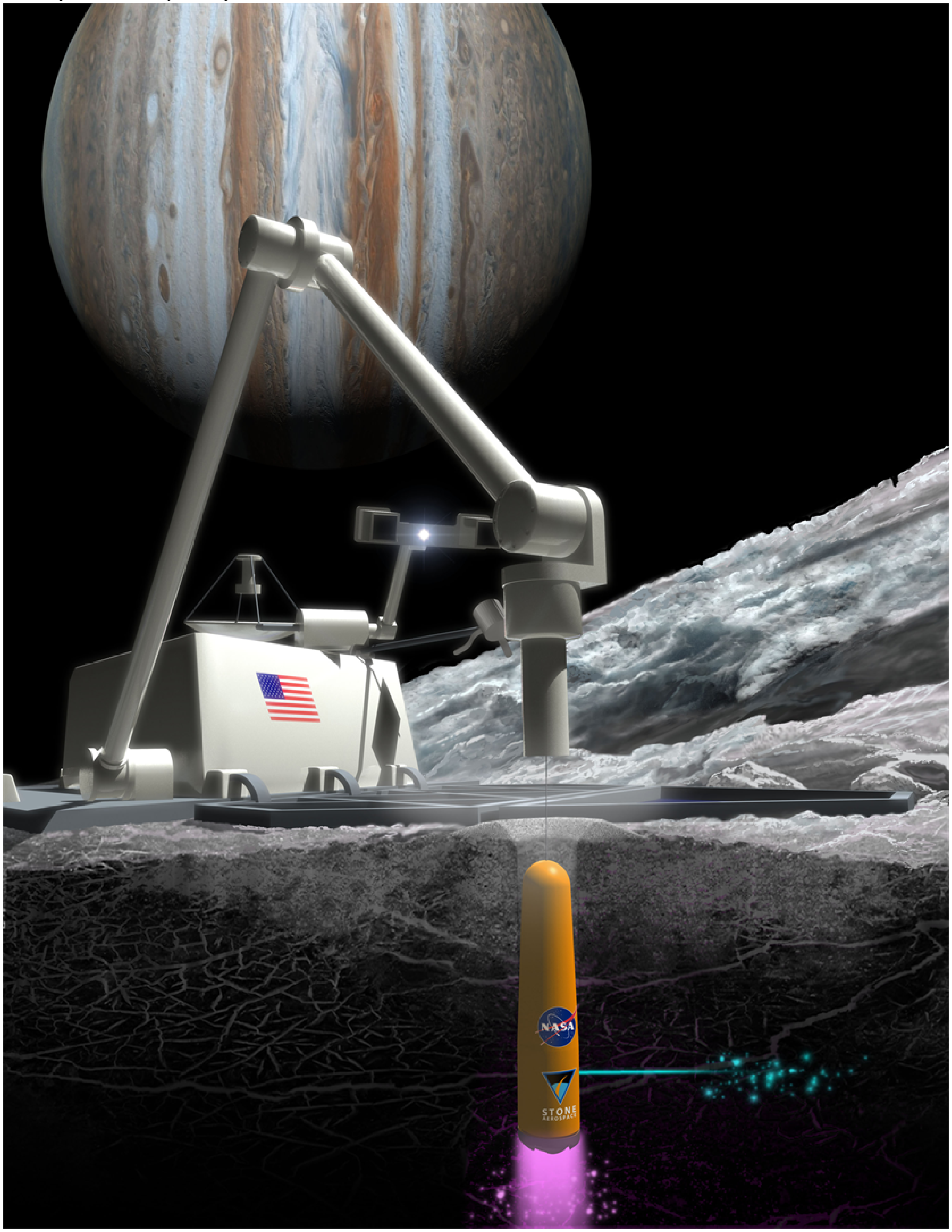
TERRESTRIAL ICE APPLICATIONS

Direct Laser Penetration could be used in terrestrial glaciated environments as a clean-access tool to investigate thick ice sheets, ice shelves, and subglacial water bodies. Theoretically, the approach can be scaled to work through more than 4 kilometers of ice (e.g., the full thickness of the Antarctic ice sheet) at very high power levels. At high power, DLP could be used to reach deep subglacial lakes in very short times, theoretically 16 hours for 4 kilometers with a 10 cm diameter vehicle. It could also be used to transit through ice shelves and install instruments in subglacial water bodies or to rapidly install fiber sensor arrays. Used in the field, DLP would be easily deployable and have a much smaller logistics footprint than a typical deep ice mechanical or hot water drilling rig. The field DLP equipment would mainly consist of a laser source unit (typically about the size of an average refrigerator), and a 50 kW generator.



OCEAN WORLD APPLICATIONS

From the planetary perspective, DLP may present a unique solution to what is known as "The Starting Problem" for cryobots attempting to intitiate travel into the ice shell of Europa or other Ocean Worlds. The Starting Problem is where the cryobot must begin descent at the lander in hard vacuum at 77K temperature. The lack of atmospheric pressure precludes the formation of liquid water, so energy dumped into the ice will cause it to sublimate, not melt. Fortunately, DLP has no problems operating in vacuum. The beam will initially cause a hole to form with the ice sublimating to space, but after a short descent distance the sublimatred ice will refreeze on the upper sidewalls of the hole and will eventually close it off, allowing vapor presure to build. Once that happens the DLP probe will proceed downward in a fashion similar to how it would behave on Earth. While the limitations of DLP may prreclude it's use as a means to access the ocean, it may be a useful tool for investigations of the top ten to 100 meters of ice on Europa or the Mars polar caps.



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