# DIHEDRAL: DOWNHOLE REGOLITH INTERROGATION WITH HELIUM-ASSISTED DRILL AND LASER INDUCED BREAKDOWN SPECRTOSCOPY SYSTEM

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**Introduction:** Future landed robotic missions to the lunar poles will seek to characterize the properties of subsurface regolith: elemental composition, geochronology, and the presence of water and other volatile compounds. Typical instruments for such *in-situ* analysis, however, require that geological samples be brought to the surface by a coring tool, drill, or excavator, and subsequently crushed, sieved, allotted, or otherwise processed and presented to the analyzer.

The "bring-the-sample-to-the-instrument" model has some significant limitations:

- Volatile molecules may evaporate or sublime before they reach the analytical instrument
- Stratigraphic information is compromised or lost altogether
- Unintended particle-size or density-dependent sorting causes sample bias
- Adhesion of sample material to mechanism parts (exacerbated by triboelectric charging) causes cross-contamination
- Sophisticated sample acquisition, processing and handling mechanisms required to operate in uncontrolled, dusty environments are expensive and failure-prone

For this reason, we are developing an alternative approach: bringing the instrument to the sample (instead of a sample to an instrument). Specifically, our approach is using a downhole laser-induced breakdown spectroscopy (LIBS) system, integrated into a 3m-class drill. The approach is significantly simpler and the data can be acquired in real time.

**Figure 1** shows a schematic of the DIHeDRAL: Downhole regolith Interrogation with Helium-assisted DRill And LIBS integrated onto a small planetary lander. The two main parts of the DIHeDRAL are a drill, which enables subsurface access, and the LIBS, which can perform elemental analysis in-situ.

**Drilling Technology:** The drilling process consists of two steps: breaking the formation and moving broken material (cuttings) out of the hole. Both steps are crucial: if a bit cannot break the formation, the hole will not be extended; if the cuttings are not removed, they will be ground into progressively finer sizes and the bit will fail to extend the hole. The bit also reaches extreme temperatures in the latter scenario because ~70% of the heat generated during rock cutting is trapped in the cuttings [1].

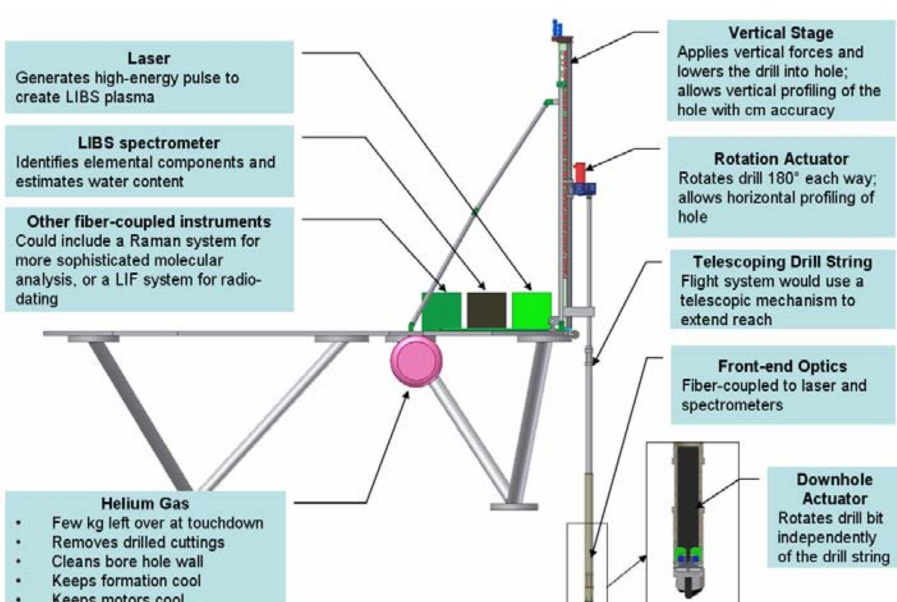


**Figure 1: Dihedral: Down hole regolith interrogation with helium assisted drill and LIBS.**

On Earth, one of the conventional methods of cuttings removal is to flush them out with compressed air [2]. Until recently it was believed that the use of gas on planetary landed missions would not be feasible due to the large quantity of gas required. Instead, planetary drills were designed with augers for moving cuttings to the surface. However, recent work has showed that the amount of gas required to efficiently clear the rock cuttings is actually very small. A number of tests in pneumatic transfer of granular material in vacuum (2-3 Torr) and reduced gravity (1/6th G) showed that with 1g of gas over 5000g of rock powder can be lifted out at high speed [3]. Even assuming a very modest efficiency of 1g gas for each 100g of rock powder, the required mass of gas to lift all the cuttings from a 1 inch diameter and 3m deep hole is only ~40g.

All propulsion systems use helium as a pressuring gas for the propulsion system. The high pressure helium (>1000 psi) is contained in a separate tank; during the burn, it is allowed to flow into a propulsion tank to keep the propellant pressurized (this is especially important in a low gravity environment). After the touchdown, residual high pressure helium is left in the tank and can be used for other applications. Thus, for the proposed drill system, a helium flushing system will come essentially at no cost to the payload.

The use of flushing gas as opposed to an auger for cuttings removal also means that it is not necessary for the entire drill string to rotate. This naturally lends itself to the incorporation of downhole instruments, as the routing of electrical harnesses and, more importantly, optical fibers becomes much simpler for a non-rotating drill string. The use of optical sliprings becomes unnecessary, greatly increasing optical signal transfer efficiency. **Figure 2** shows a schematic of a drill head configuration; the drill rotation drive train is a self-contained unit at the end of the string, leaving plenty of room for sensor front-end optics farther up the drill string.

Additional benefits of a He flushing system are efficient cooling of downhole actuators, and “cleaning” of the borehole wall. Thus the instruments will be able see the virgin formation rather than rock powder adhered to the hole wall.

**LIBS:** LIBS (Laser Induced Breakdown Spectroscopy) uses a high-energy laser pulse to generate a plasma on the surface of the sample under test. In the case of DIHeDRAL, the laser itself is located on the body of the lander; the pulse is carried to the downhole sensor head over a large-diameter optical fiber. Optics in the sensor head focus the pulse onto the borehole wall, where it ablates a small amount of material and excites it, creating a plasma. The atoms in the plasma emit photons at wavelengths that are characteristic for each element. This emitted light is collected by the sensor head optics and conveyed via fiber to a broadband spectrometer, located like the laser on the lander body. The resulting spectrum yields elemental composition and water content information.

DIHeDRAL allows profiling an entire borehole wall, centimeter by centimeter, from the top to the bottom. By rotating the drill string ±180° using a second actuator at the top of the drill string, the hole can also be scanned in a horizontal plane, for complete coverage of the borehole wall.

While not in the scope of the current work other fiber-coupled instruments could ultimately be incorporated into the same platform, depending on the requirements of the mission. Possibilities include Raman spectroscopy, which would provide more sophisticated analysis of organics and other molecules; and Laser Induced Fluorescence (LIF), which could provide radioisotopic information for geochronology. In this scenario, the high-powered LIBS laser doubles as a sort of sample preparation tool; firing a burst of “cleaning shots” exposes fresh sample (including volatiles that may have been lost from the outer surface layer).

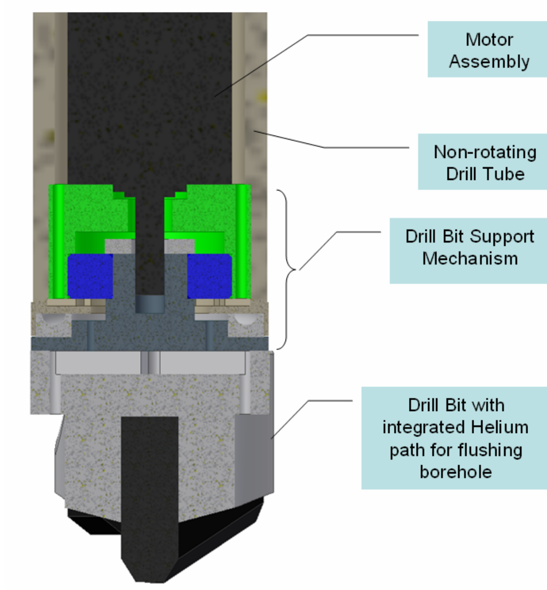


**Figure 2: Schematic of downhole-actuated drill head.**

**References:** [1] E. Uhlmann, et al., More efficient cutting process due to the heatspreading effect of CVD diamond. IDR, pg 25–29, Jan. 2003. [2] Bar Cohen, Y., and K. Zacny, Drilling in Extreme Environments: Penetration and Sampling on Earth and other Planets, Wiley-VCH (Sept 15, 2009). [3] Zacny, K., et al., Pneumatic Excavator and Regolith Transport System for Lunar ISRU and Construction, Paper No: AIAA-2008-7824.