HYPERSPECTRAL ORGANIC DETECTION IN THE NEAR SUBSURFACE WITH ULTRAVIOLET FLUORESCENCE SPECTROSCOPY.

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Introduction: Icy locations on Earth have been found to contain habitable environments [1] and microorganisms with adaptations to cold environments [2]. Martian ice, found in polar layered deposits and in mid-latitude glaciers, is therefore a high priority target for future landed missions with organic and astrobiological science objectives [3]. New technologies and instruments are desired to access these near subsurface icy environments that meet the accommodation limitations of small robotic platforms while still providing the measurement capabilities needed for trace organic detection, characterization, and contextualization. The PERISCOPE instrument, currently under development, is intended to enable in situ organic detection and classification in these environments. Here we report on the status of technology maturation efforts to advance PERISCOPE to TRL 5, and science validation efforts to demonstrate measurement capabilities in icy environments.

PERISCOPE Technology Maturation and Instrument Overview: PERISCOPE has been funded under NASA Small Business Innovation Research grants (Phase I and Phase II, Contract No. 80NSSC20C0456) to mature key subsystems to TRL 5. The scope of this technology development includes breadboarding, science validation activities, and brassboarding of key subsystems including environmental testing (thermal vacuum and vibration) under Mars-relevant conditions.

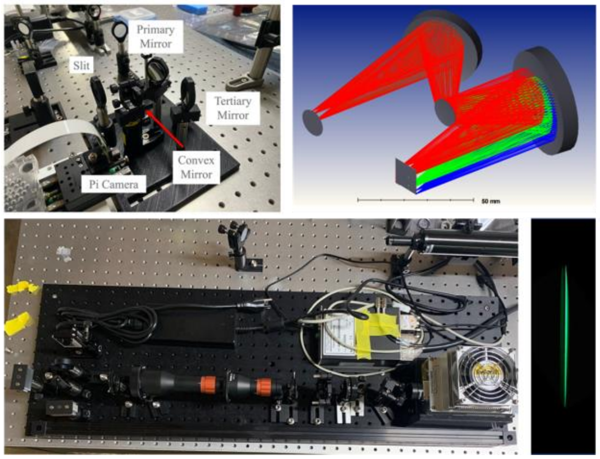

Figure 1. PERISCOPE breadboard hardware (top: spectrometer breadboard and optical ray trace; bottom: ultraviolet laser breadboard and push-broom laser line).

The key PERISCOPE subsystems are the Laser, the Spectrometer, and the Optical Probe. The Optical Probe delivers the laser light to a subsurface borehole wall and collects the resulting sample fluorescence, and the Spectrometer disperses the returned light spatially and spectrally, generating a hyperspectral image as the Optical Probe descends into the borehole.

257 nm ultraviolet laser. An ultraviolet wavelength is required to generate fluorescence from many organic compounds, including microorganisms, relevant to the search for life on planetary surfaces [4, 5]. PERISCOPE's 257 nm excitation was generated using a non-linear BBO crystal from a 515 nm nanosecond laser pulsed at 10 kHz. Figure 1 shows the laser breadboard hardware, and the laser line profile following beam shaping into a 100 µm x 12.5 mm pushbroom line. The laser was co-boresighted with the spectrometer to enable hyperspectral fluorescence measurements.

Imaging Spectrometer. PERISCOPE's spectrometer was custom-designed as a compact hyperspectral imaging spectrometer based on the Offner-Chrisp design form [6]. This format provides for a fast f/# and compact size without compromising imaging performance. The spectrometer was designed against the requirements in Table 1.

Table 1. Spectrometer Design Requirements

Parameter	Requirement
Spectral window	276 nm – 850 nm
Spectral resolution	5 nm (final design: 3 nm)
Sensor size	12.5 mm
Spatial extent	12.5 mm
Spectrometer footprint	100 x 100 mm
Entrance fiber	100µm fiber (100x line)

Zemax was used to develop the optical model following an analytical solution for the Offner-Chrisp design described by Prieto-Blanco et al. [7]. This solution minimizes aberrations over a large spectral range at a fast *f*/#. The resulting optical prescription is shown in Figure 1, and exceeds the design requirements.

Down-hole Optical Probe. To access the near subsurface, an optical relay system (Optical Probe) was developed to deliver the laser to the sample and collect the resulting fluorescence. Figure 2 shows the prototype Optical Probe. An external actuator (linear motorized stage) was used to translate the optical probe (and pushbroom laser line) down the borehole wall.

Science Validation: In July, 2022 the PERISCOPE prototype was deployed to the Gilkey Glacier in Juneau, Alaska. During this 8-day deployment PERISCOPE scanned the interior wall of several hand-cored boreholes on the glacier ice sheet. The field prototype used a 265 nm LED as an excitation source and a concave imaging grating. Figure 2 shows images of the deployed instrument in a sediment-laden region of the glacier surface. In this configuration, PERISCOPE was able to scan up to a 200 mm depth.

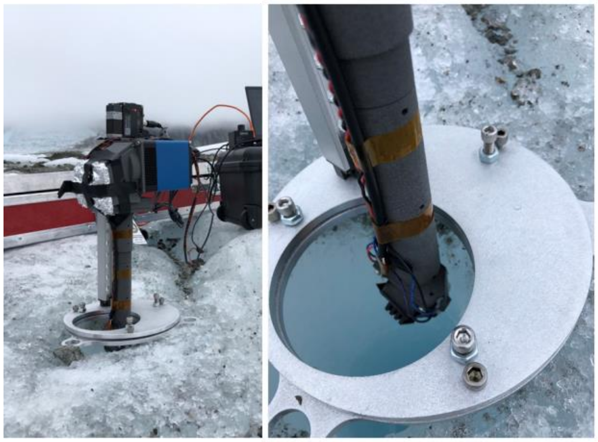

Figure 2. PERISCOPE field prototype deployed to the Gilkey Glacier, Juneau, AK. Left: PERISCOPE performing a scan inside a manually cored borehole.

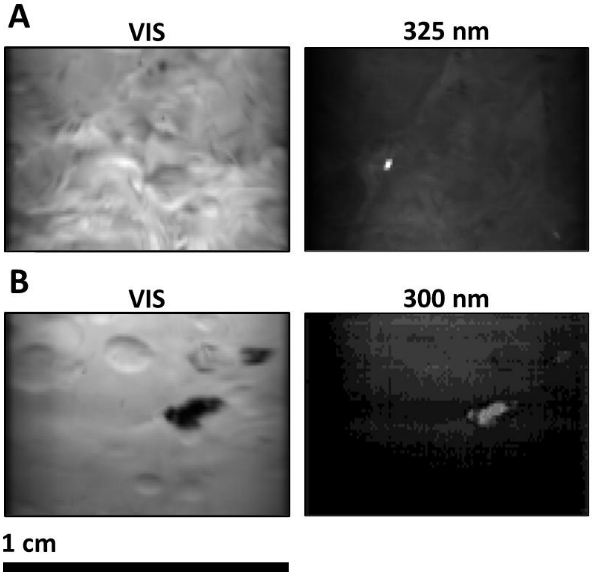

Figure 3. PERISCOPE hyperspectral images obtained during in situ borehole scanning during the Gilkey Glacier, AK deployment. Reconstructed images from the hyperspectral scan are shown.

Figure 3 shows data products obtained from in situ scanning. Two regions in the ice are shown (Fig. 3 A and B). Each region is shown as an image reconstructed from the hyperspectral dataset, covering approximately a 10 cm x 8 mm spatial extent. The VIS images (approximately 500 nm) show the ice morphology and embedded sediment. Two ultraviolet images are shown that indicate localized regions in the ice that exhibited fluorescence when excited by the laser. In B, this region appears spatially correlated with sediment.

Conclusions: Hyperspectral imaging using ultraviolet fluorescence can be deployed in a compact instrument package to subsurface icy environments. Future work is required to determine the sensitivity of this platform to priority organic compounds, and further technology maturation is needed to demonstrate survival and operation under planetary conditions.

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References:

[1] Foreman CM, Sattler B, Mikucki JA, Porazinska DL, Priscu JC, "Metabolic activity and diversity of cryoconites in the Taylor Valley, Antarctica," J Geophys Res Biogeosciences 112(G04S32):1-11 (2007)

[2]Uhlig, C., Kilpert, F., Frickenhaus, S., Kegel, J.U., Krell, A., Mock, T., Valentin, K., and Beszteri, B. (2015) In situ expression of eukaryotic ice binding proteins in microbial communities of Arctic and Antarctic sea ice. IMSE J 9:2537–254

[3] McKay CP, Stoker CR, Glass BJ, Davé AI, Davila AF, Heldmann JL, Marinova MM, Fairen AG, Quinn RC, Zacny KA, Paulsen G, Smith PH, Parro V, Andersen DT, Hecht MH, Lacelle D, Pollard WH. The Icebreaker Life Mission to Mars: a search for biomolecular evidence for life. Astrobiology. 2013 Apr;13(4):334-53.

[4] E. Eshelman et al. WATSON: In situ organic detection on subsurface ice using deep-UV fluorescence spectroscopy. Astrobiology. Jun 2019.771-784. http://doi.org/10.1089/ast.2018.1925

[5] E. Eshelman, et al. Detecting aromatic compounds on planetary surfaces using ultraviolet time-resolved fluorescence spectroscopy. Planetary and Space Science, 151:1-10, 2018.

[6] T. Carlson. Design of an Offner-Chrisp Imaging Spectrometer for a Planetary Fluorescence Instrument. Thesis, Washington University in St. Louis. 2022. https://doi.org/10.7936/9mb7-tp85

[7] X. Prieto-Blanco, C. Montero-Orille, B. Couce, and R. de la Fuente. Analytical design of an Offner imaging spectrometer. Optics Express, 14(20):9156, 2006.