IN SITU DETECTION OF MICROBIAL AND NON-CELLULAR ORGANIC MATTER HOTSPOTS IN SUBSURFACE GLACIAL ICE: FIELD TESTING AT SUMMIT STATION, GREENLAND AS AN ANALOG TO THE ICY CRUSTS OF THE OCEAN WORLDS.

M. J. Malaska[1], R. Bhartia[1], K. S. Manatt[1], J. C. Priscu[2], W. J. Abbey[1], B. Mellerowicz[3], J. Palmowski[3], G. L. Paulsen[3], K. Zacny[3], E. J. Eshelman[4], J. D'Andrilli[5]. [1]Jet Propulsion Laboratory / California Institute of Technology, Pasadena, CA. [2]Montana State University, Bozeman, MT. [3]Honeybee Robotics, Altadena, CA. [4]Impossible Sensing, St. Louis, MO. [5]Louisiana Universities Marine Consortium, Chauvin, LA. (email: Michael.J.Malaska@jpl.nasa.gov)

Introduction: Glacial ice is an important environment for life on Earth and possibly elsewhere in the Solar System [1]. Many of the microbes found living deep inside terrestrial ice are in liquid brine microhabitats that exist between the ice grains [2-3]. By further developing techniques to explore these environments on Earth, we can understand how organic and microbial materials are distributed inside ancient and modern terrestrial ice and then translate those processes to future astrobiology missions to the Ocean Worlds.

Deep-UV fluorescence: Deep UV fluorescence spectroscopy of ice has been shown to be a powerful tool for the identification and localization of low concentrations of chromophoric molecular species [4-12]. We coupled a deep UV fluorescence mapping spectrometer with a wireline-coring robotic drill system to create a down-borehole instrument-drill combination, (referred to as WATSON [11], for in situ exploration of terrestrial ice sheets.

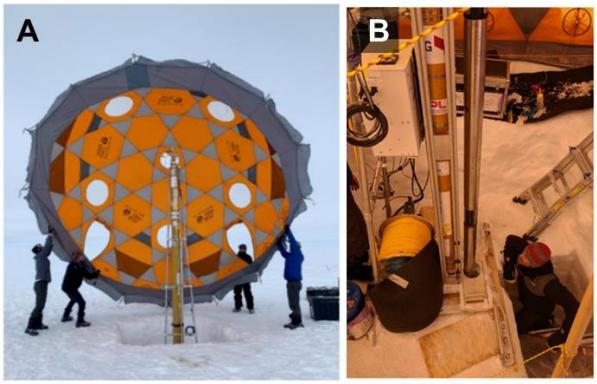

Fig. 1. A: Placing the Drill Tent over the drill in June 2019 at Summit Station, Greenland. B: View inside the drill tent during operations showing drill-instrument combination lowering into the ice borehole at lower center in the image. The instrument optical window is visible at image center.

Summit Station, Greenland field campaign: We tested WATSON at Summit Station, Greenland in the summer of 2019 (Fig. 1). This location was selected for field trials because snow deposition and compression coupled with minimal lateral movement and fluid percolation, make this an ideal location to study the how organic and microbial materials are distributed as firn converts to glacial ice. These field trials also allowed us to demonstrate the ability of our combined drill-instrument system to penetrate and explore microbes and non-cellular organics in firn and glacial ice, paving the way for deeper and more sophisticated exploration. We drilled to 105 m in the ice sheet which is below the firn-glacial ice transition at 80-90 m.

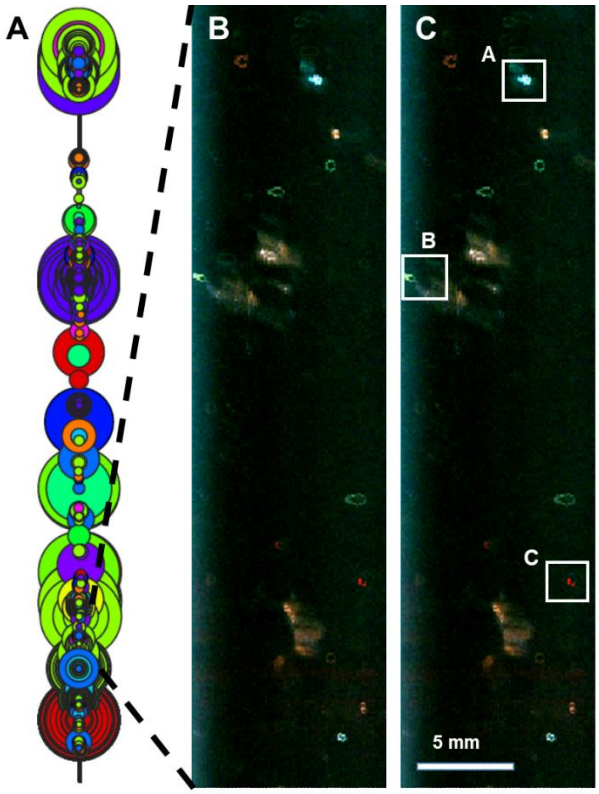

Fig 2. A: Graphical representation of 100 m borehole scan made using QGIS software. Bubbles on left indicate detected hotspots. Size and color of bubble indicate spectral intensity and spectral type, respectively, of hotspot. B and C: Detailed map collected in situ at borehole depth of 93.8 m and 53 degrees clockwise rotation from magnetic north. Colors indicate fluorescence emission at RGB: 412.9 nm, 385.3 nm, and 313.7 nm following excitation at 248.6 nm. Map is 1 cm by 4 cm. In Fig. 2C, annotations A, B and C cross-reference to detailed maps and spectra in Fig. 3 panels A, B, and C.

Detection and mapping of organic and microbial hotspots: We operated WATSON in two modes. One

was a series of sequential detection pulses while lowering or raising the drill; this created a point cloud of linear discrete points along the borehole. The other mode was a raster mapping mode where the drill was held static (using retractable skids for rotational stability) and the Deep UV laser scanned across the ice borehole interior wall to build up a two dimensional map.

Fig 2A represents the combined point cloud data from the borehole scans. WATSON detected a plethora of hotspots that were consistent with both microbial and non-cellular organic signatures that were present in both firn and glacial ice. Several detailed raster maps were made inside the borehole. Fig 2B shows one of these maps from glacial ice at a depth of 93.8 m and a rotation 53 degrees clockwise relative to magnetic north. The hotspots are present as 1 mm blobs of diverse spectral characteristics, three of which are annotated in Fig. 2C.

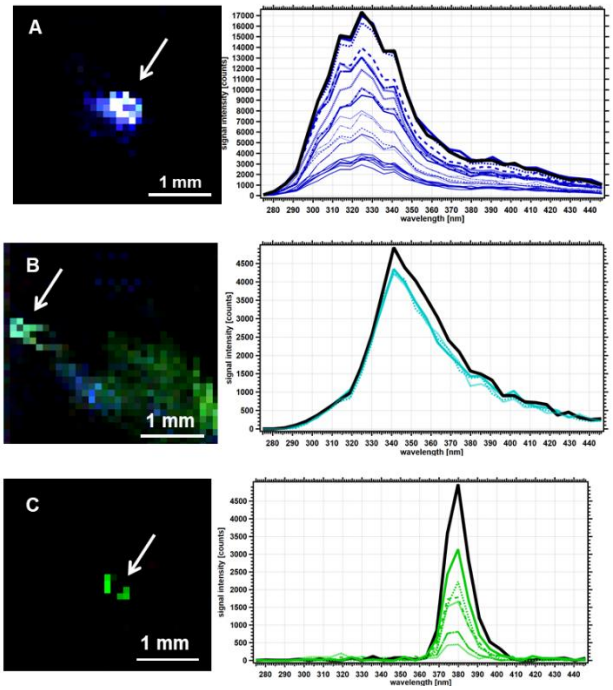

Fig 3. Detailed maps (left) and spectral responses (right) of pixels from selected hotspots from raster map taken at 93.8 m depth. Arrows indicate hotspots that were analyzed. Scale as shown. Panels A, B and C refer to locations A, B, and C in Fig 2C, respectively.

In situ spectral analysis of microbial and diverse organic matter hotspots: The WATSON instrument excites at 248.6 nm and measures fluorescence emission from 275 nm to 450 nm in 32 bands. This allows in situ spectral classification based on emitted fluorescence characteristics. In general, fluorescence emission maxima between 300 – 360 nm are consistent with pure cultures of bacterial cells. Fluorescence maxima longer than this are consistent with three or more fused aromatic ring or more complicated organic frameworks. Fig 3 shows detailed maps of selected hotspots from Fig 2C at fine scale (100 micron per pixel) as well as fluorescence spectra extracted from individual map pixels. Most of the hotspots were spectrally homogeneous.

Results: We found diverse spectral features from 0-105 m within the ice borehole. Most of the features were blob-like hotspots <2 mm in size. We saw no clear evidence of layering at this fine scale. During our analysis we noted that parallel tracks had different detection patterns, also consistent with punctate discrete features. This distribution of fluorescent material had previously been noted during scanning of extracted glacial ice by Rohde (2010) [8]. Our targeted sampling of fluorescent organic hotspots results in a two order of magnitude signal increase relative to the diluted signal that would be obtained by analysis on traditional melted ice samples [12].

In summary, we successfully demonstrated in-situ detection and spectral analysis of diverse punctate chemical signals similar to microbial and organic molecules in a drilled ice borehole at Summit Station, Greenland. Data obtained from this site shows that our Deep UV fluorescence mapping spectrometer with 100 micron spacing can spatially resolve spectrally unique features that may otherwise go undetected without targeted sampling.

Acknowledgements: The authors would like to thank the entire staff of Summit Station for all their support. We would also like to thank CH2M and the National Science Foundation for their support during the field season. This work was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology under the NASA PSTAR program. Government sponsorship is acknowledged. Copyright 2019.

References: [1] Priscu and Hand, *Microbe 7* (2012 167-172. [2] Price, PNAS *97* (2000) 1247-1251. [3] Junge et al., *Appl. Env. Microbiol 70* (2004), 550-557. [4] Bhartia et al., *Applied Spectroscopy 62* (2008), 1070-1077. [5] Rohde and Price, *PNAS 104* (2007), 16592–16597. [6] Rohde et al., *PNAS 105* (2008) 8667–8672. [7] Price, *Canadian Journal of Microbiology 55* (2009) 1-11. [8] Rohde, R.A., Ph.D. thesis UC. Berkeley, 2010. [9] Barletta and Roe *Polar Record 48* (2012) 334–341. [10] Barletta et al., *Journal of Glaciology 58* (2012) 1109-1118. [11] Eshelman et al., *Astrobiology 19* (2019) 771-784. [12] Malaska et al., submitted.