In-situ MicroCT Instrument for the North Polar Layered Deposits of Mars

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1- SETI Institute, Mountain View CA, USA, 2- eXaminArt, LLC, Los Altos, CA, USA, 3- Diamond Light Source, Didcot, Oxfordshire, UK, 4- Honeybee Robotics, Pasadena, CA, USA, 5- Lunar & Planetary Laboratory, University of Arizona, Tucson, AZ, USA

Background and Introduction

The North Polar Layered Deposits (NPLD) are a multi-kilometer thick sequence of dusty-ice layers thought to record previous climate conditions much like Earth's ice sheets (Figure 1). Deciphering this polar record has been, and remains today, a major goal of Mars research[1]. A 1 m core of the Mars NPLD sampled by MIST would provide information about approximately 1000 Martian years of climate history. Our objective is to develop a sampling and analysis system to characterize the porosity and distribution of dust in the Mars NPLD with higher resolution and to greater depths than is possible with current techniques.

Based on X-ray attenuation, X-ray micro computed tomography (microCT) provides nondestructive three-dimensional visualization and characterization of internal features of multiphase materials with spatial resolution down to several microns. MicroCT is already used to analyze micron-scale porosity and sediment distribution in terrestrial ice sheets[2] and sea ice[3].

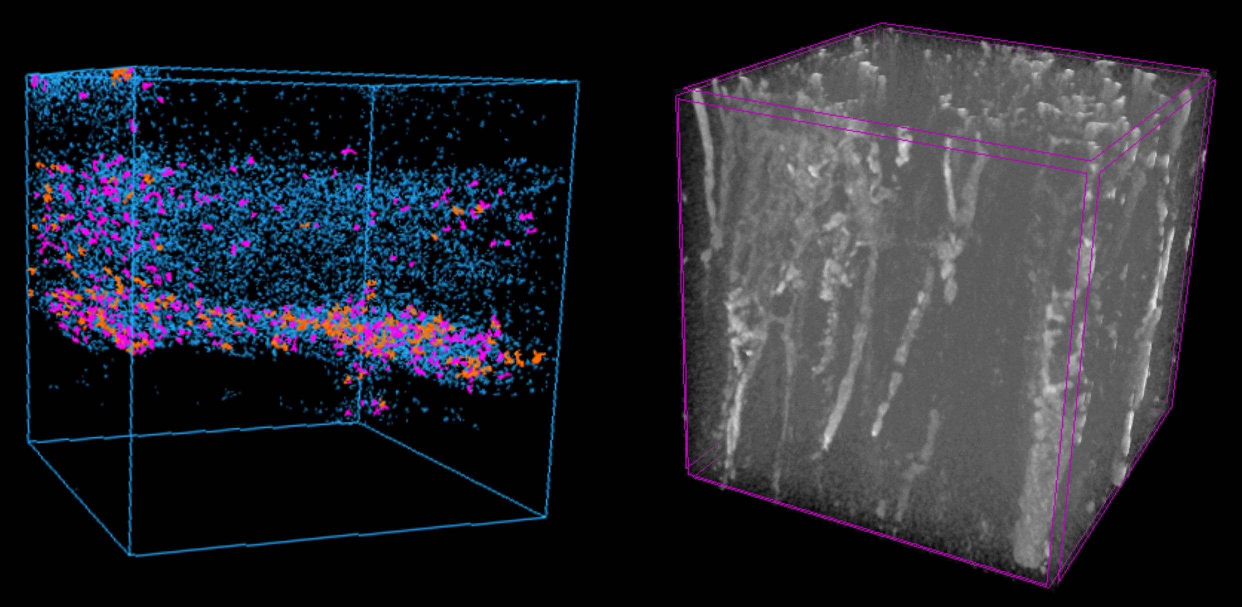

Figure 1. MicroCT reconstructions (each 1-2 cm^3) of relevant Earth systems. (Left) Tephra particles, color-coded by size (5-40 µm), in ice (made transparent) from 3149 m depth in the West Antarctic Ice Sheet (Right) Porosity (brine channels) in sea ice from 130 cm depth, Ross Sea, Antarctica

Instrument Concept

Micro In Situ Tomography (MIST) is a coupled coring and microCT-analysis system (Fig. 2). A coring drill produces a sample core 2.5 cm in diameter and 0.5 − 1 m in length and captures it within an X-ray transparent carbon fiber tube. As this tube is withdrawn from the surface, a miniaturized microCT system rotates around it collecting X-ray attenuation images. The microCT subsystem is based on a cone-beam geometry with a simple architecture combining a microfocused X-ray tube, a core scanning stage, and an X-ray image sensor.

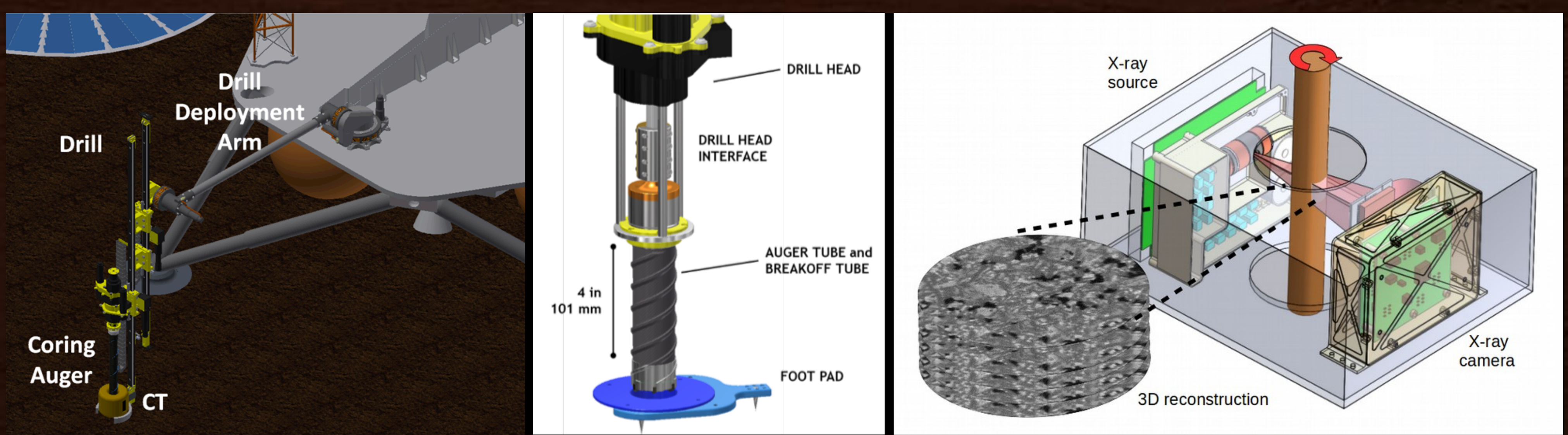

Figure 2. (Left) MIST operational concept. (Middle) Breadboard corer design, showing the auger tube and (nested) breakoff tube integrated with the Honeybee drill test bed. (Right) Architecture of the analytical head of MIST microCT subsystem.

Concept Demonstration

A breadboard prototype was built using a commercial microfocus X-ray tube (60 µm spot size), a stepper-motor based sample rotation stage and an X-ray camera based on a APS-C format CMOS sensor fitted with a CsI scintillator on fiber optics plate.

Paraffin wax was used as an ice simulant for tests at room temperature, with 0.8 mm Al spheres embedded to represent inclusions. X-ray attenuation images were collected at angular steps of 0.9 ° over a full revolution (400 angular positions). These projections were combined to form a sinogram. Image preprocessing included flat-field correction, ring artifact removal, and beam hardening correction[4]. A dedicated calibration method was developed to compute instrument geometry parameters that couldn't be measured with high precision on the breadboard. Reconstruction was done using a NVIDIA Tesla K20C graphics card with a GK110 graphics processing unit (GPU) and 5 GB memory. 3D reconstruction software was based on a Filtered Back-Projection (FBP) method. Results were compared to those from a commercial instrument (Fig. 3).

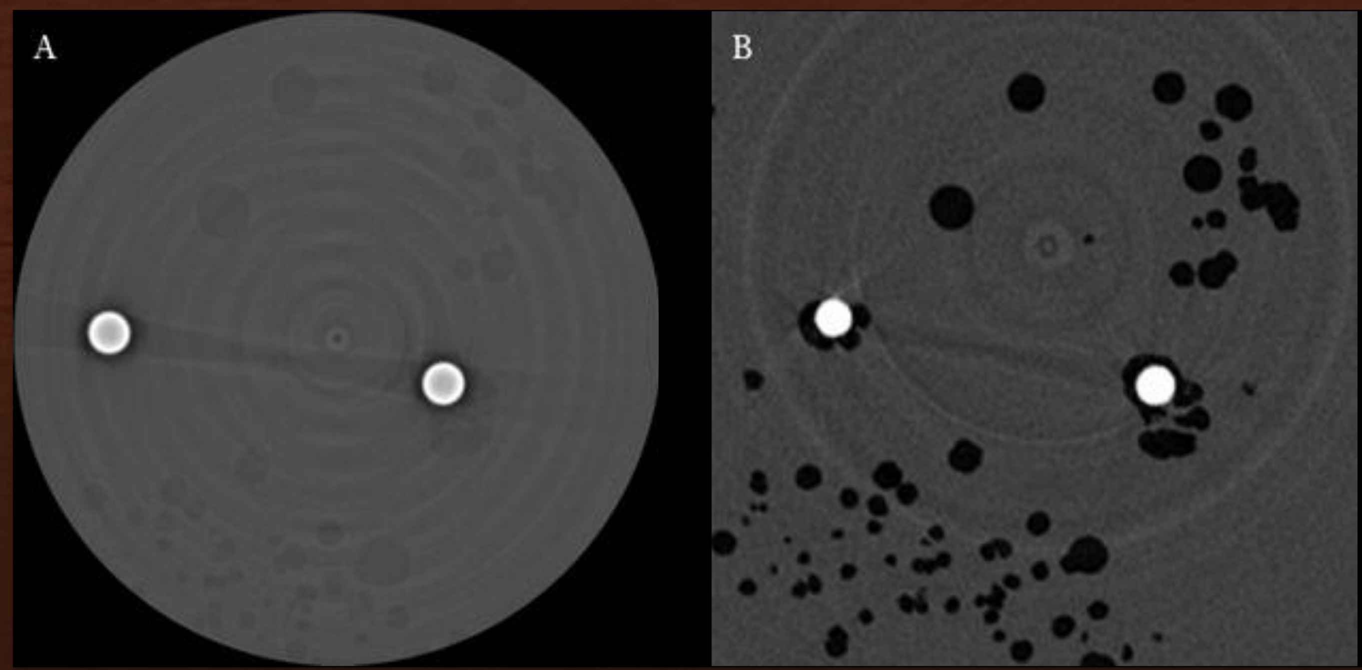

Figure 3. Reconstructed 2D images of ice core simulant (wax rod with 0.8 mm Al spheres). (Left) from breadboard instrument operated at 25 kV. (Right) For comparison, an image at approximately the same depth in the sample produced by a commercial desktop microCT instrument (Skyscan 1173). Note the positions not only of the two Al spheres, but also of the voids.

Next, the breadboard system was tested in a -15 °C freezer. The sample was a 25 mm diameter rod of ice with large sand grains. Again results were compared to those from a commercial desktop microCT, this time at -15 °C (Fig. 4).

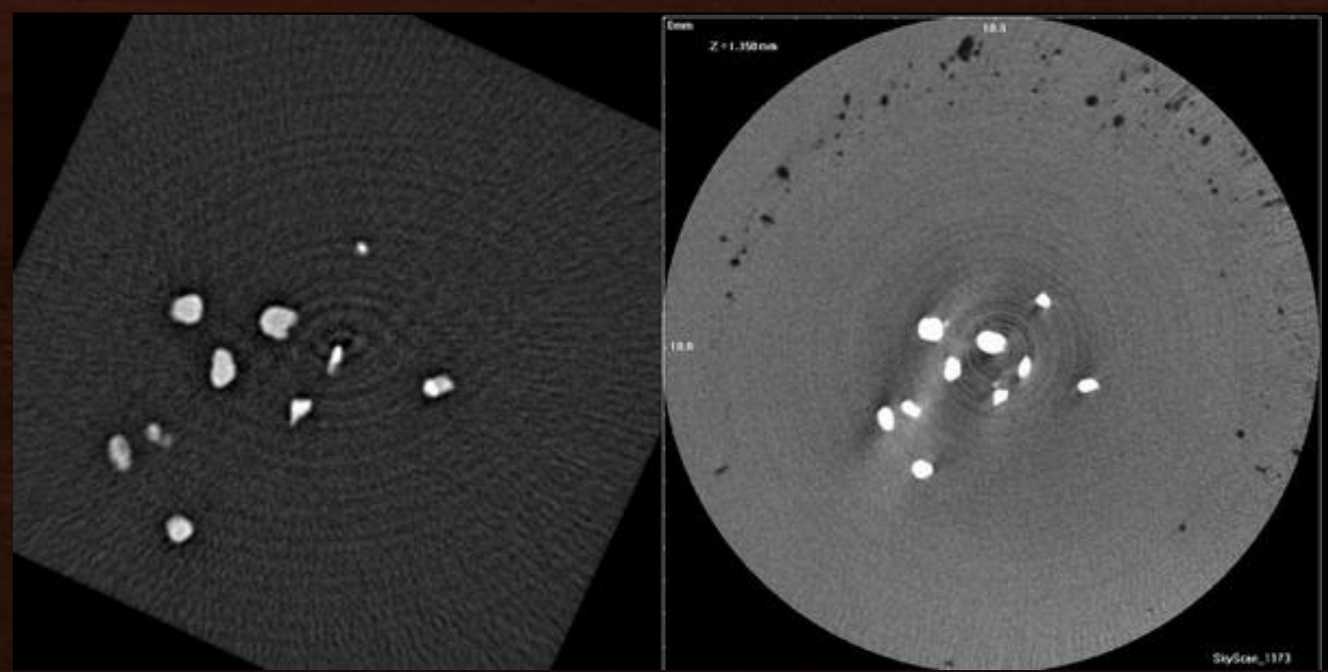

Figure 4. Reconstructed 2D images of sand grains in ice imaged at -15 °C. (Left) from breadboard instrument operated at 25 kV. (Right) For comparison an image at approximately the same depth (but different magnification) produced with a Skyscan 1173 at Montana State University. (Ring artifacts are the result of inappropriate image corrections for the early data set.)

Future Work

We are improving the breadboard design with a new source and a better detector. We next plan to design and build a transportable brassboard of the microCT subsystem which we will test at NASA Ames. We will then fabricate a full scale (1 m long) auger and test it with the HoneybeeTRIDENT drill in a -15 °C cold room.

References

1. Byrne, S. (2009) Annual Review of Earth and Planetary Sciences, 37
2. Iverson, N. et al. (2017) Nature Scientific Reports, 7: 11457
3. Obbard, R.W., G. Troderman, and I. Baker (2009) J. Glaciol., 55, 194
4. Vo, N.T., Atwood R.C., and Drakopoulos, M. (2018) Opt. Exp., 26, 28396-28412

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