IN-SITU ANALYSIS OF ROCK CORES USING ON-BOARD MICRO-CT AND RADIOGRAPHY. P. Sarrazin[1], R. Obbard[1], N. T. Vo[2], K. Zacny[3] and D. Blake[4], [1]SETI Institute, 189 Bernardo Ave, Mountain View CA 94043 psarrazin@seti.org, [2]Diamond Light Source, Harwell Science and Innovation Campus, Didcot, Oxfordshire OX11 0DE, UK, [3]Honeeybee Robotics, 398 W Washington Blvd., Pasadena, CA 91103, [4]NASA Ames Research Center, MS239-4, Moffett Field CA 94036

Introduction: In X-ray Computed Tomography (CT), radiographic images of a solid sample are collected through a range of orientations and a 3-dimensional model of its internal structure is computed. X-ray CT allows the non-destructive analysis of internal features that would otherwise only be revealed by physically sectioning the material. Micro-CT is a micron-scale variant of CT that combines a microfocus X-ray source (X-ray tube or synchrotron source) with geometric magnification. Micro-CT has attracted the interest of geologists as a result of its ability to resolve individual grains or pores in rock samples. Micro-CT has been recommended as the 1st technique to be applied to returned Mars samples [1]. Risks of radiolytic damage to putative Martian organics present in the sample are being assessed [2].

We propose the deployment of a micro-CT instrument on the surface of Mars for in-situ analysis of rock cores, either as a robotic science instrument, or for investigation of cores in their canisters prior to return to earth.

PIXI: We are developing a planetary instrument concept for rock-core micro-CT analysis on Mars. PIXI (Planetary In-situ X-ray Imager) is based on a cone-beam geometry and simple architecture shown in Figure 1. X-ray images collected at small angular steps are downlinked for processing and 3D reconstruction.

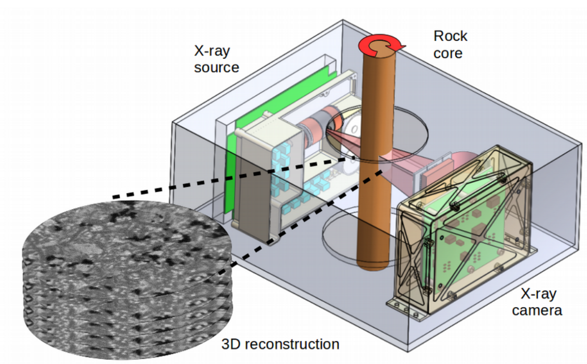

Figure 1: Notional design of the PIXI flight instrument with microfocus 50kV X-ray source, sample rotation stage and X-ray detector (CCD or CMOS with scintillator).

PIXI will also provide X-ray fluorescence (XRF) data of the surface of the core with limited spatial resolution via the use of a collimated silicon drift detector (SDD).

PIXI will enable 3D-reconstructions of rock fragments or rock cores to evaluate grain size distribution, mineral spatial distribution, porosity, fragmentation etc. The study of rock microstructures will elucidate rock formation processes and reveal potential biosignatures or biological affinities.

Proof-of-concept: A breadboard prototype was built by combining a commercial microfocus X-ray tube (60µm spot size), a stepper-motor based sample rotation stage and an X-ray camera based on a APS-C format CMOS sensor with a CsI scintillator. Attenuation images were collected at angular steps of 0.9° over a full revolution (400 angular positions). Image preprocessing steps were integrated in the data analysis pipeline: zinger removal, flat-field correction, ring artifact removal, and beam hardening correction [3]. A dedicated calibration method was developed to compute instrument geometry parameters that couldn't be practically measured on the breadboard. 3D reconstruction software was based on a Filtered Back-Projection (FBP) method.

Fig. 2 shows a single slice (among about 1000 produced in a single scan) of a 3D reconstruction of an 8 mm dia. Saddleback basalt core compared with equivalent data collected with a laboratory instrument (Bruker Skyscan 1173). The breadboard data shows all but the very finest features found in the laboratory instrument data.

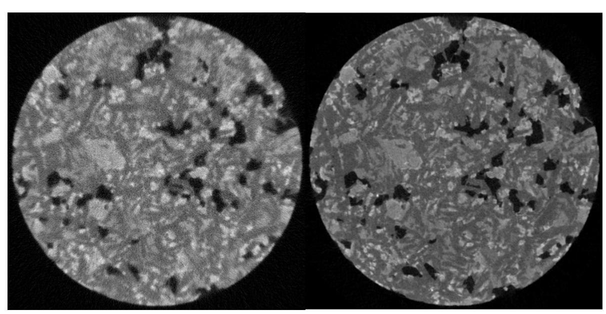

Figure 2: Equivalent slices of 3D reconstructions of a Saddleback basalt core (8mm diam) with PIXI at 50kV-5W (left) and a laboratory micro-CT Bruker Skyscan 1173 at 100kV-8W (right). Voxel size 10µm. Black areas: voids, light gray: higher absorption minerals.

A similar dataset is shown in Figures 3 and 4 from a sandstone sample. The measured resolution of the breadboard data is better than 40µm. This figure will be improved with future generations instruments.

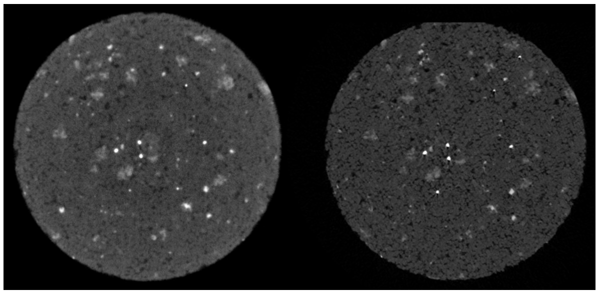

Figure 3: Equivalent slices of 3D reconstructions of a sandstone core (8.2mm diam) with PIXI at 35kV-7W (left) and a laboratory micro-CT Bruker Skyscan 1173 at 100kV- 8W (right). Voxel size 10µm. Dark spots: voids; white and light gray spots: inclusions.

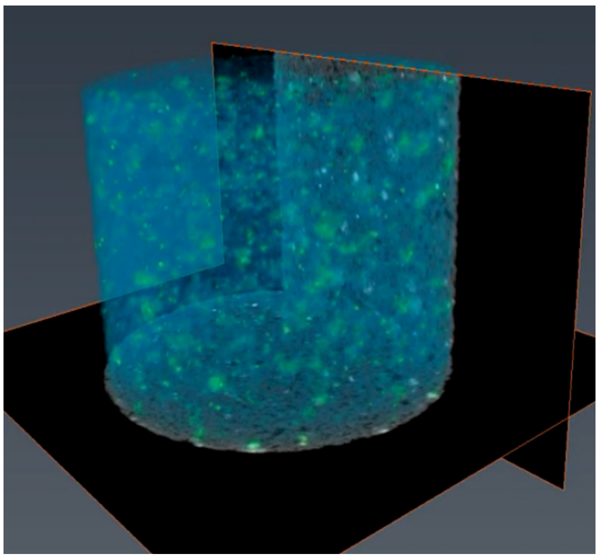

Figure 4: 3D visualization of the sandstone core reconstruction. A dynamic representation reveals a clear angled layering of the higher absorbing inclusions.

Radiographic analysis of cores in their coring tubes: Micro-CT is demanding in terms of downlink bandwidth, mechanical precision and analysis time. However, simple radiographic images can be very informative on the internal structure of rock core. To demonstrate this, we used the PIXI breadboard without fine step rotations to image the content of titanium tubes similar in design to the Mars 2020 coring tubes. Examples of such images are provided in Figure 5 for several type of rock cores, with a steel screw for reference. In all cases, the morphology of the core is clearly visible. The core X-ray absorption properties, dimensions and fragmentation state could be assessed through such images covering the full length of the coring tube, possibly from several orientations. A PIXI instrument dedicated to this type of core radiographic analysis would not require high mechanical precision nor high bandwidth.

The substantial X-ray absorption of the titanium alloy used for Mars-2020 coring tubes requires the highest voltage settings available with the PIXI breadboard (50kV) for quality images to be collected. Micro-CT analysis through the coring tube has not been demonstrated but appears feasible and will be attempted in upcoming studies. The choice of coring tube materials with lower X-ray absorption for future sampling missions would greatly improve in-situ micro-CT analysis capabilities, and will be the subject of a future investigation.

Figure 5: Attenuation images of a Ti6Al4V coring tube / canister with 13mm diameter cores inserted; from left to right: sandstone, gypsum, calcite in 2 fragments, basalt, 6.35mm diameter steel screw for reference. X-ray tube setting 50kV at 10W, 8s integrations.

Further development: The development of PIXI inherits from a number of image-based planetary X-ray instruments for in-situ diffraction and fluorescence analysis on Mars. A particular aspect of PIXI, and the main technical challenge foreseen toward its development for flight, is the requirement for a high voltage X-ray source. While laboratory micro-CT instruments typically use voltages >80kV, our results with the PIXI breadboard and our computer modeling demonstrate that X-ray tube voltages of 35-50kV allow quality data from core cores. 25kV X-ray sources have been developed for flight (CheMin XRD/XRF on MSL, PIXL on Mars-2020). Our future efforts will include the development of a 50kV planetary X-ray source. Upcoming PIXI prototyping efforts will focus on optimizing the instrument resolution and throughput.

Acknowledgements: This development is funded by a NASA SBIR 2018 to eXaminArt, LLC. Funding was also obtained from the PICASSO 2017 program for the parallel development of an ice-core micro-CT instrument (PI R. Obbard, SETI).

References:

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