MOCHII PORTABLE SPECTROSCOPIC ELECTRON MICROSCOPE ON ISS: PROGRESS TOWARD FLIGHT.

C. S. Own[1], J. Martinez[2], T. DeRego[1], L. S. Own[1], G. Weppelman[1], K. T. Thomas-Keprta[2], Z. Rahman[2], D. R. Pettit[3];
[1]1001 26th Ave E, Seattle, Wa 98112, csown@voxa.co. [2]Jacobs, Johnson Space Center, Houston, TX 77058; [3]FOD NASA Johnson Space Center, Houston, TX 77058.

Introduction: Advances in space exploration have evolved in lockstep with key technology advances in diverse fields such as materials science, biological science, and engineering risk management. Research in these areas, where structure and physical processes come together, can proceed rapidly in part due to sophisticated ground-based analytical tools that help researchers develop technologies and engineering processes that push frontiers of human space exploration.

Electron microscopes (EM) are such a workhorse tool, lending a unique blend of strong optical scattering, high native resolution, large depth of focus, and spectroscopy via characteristic X-ray emission, providing exquisite high-magnification structural imaging and chemical analysis.

We previously reported on Mochii™ "S" (Fig. 1), an award-winning novel portable EM with (Energy-dispersive X-ray spectroscopy (EDS) spectrometer developed by coauthors at Voxa in Seattle, WA, that we are preparing for manned flight for demonstration on the International Space Station (ISS) in 2019 [1-3]. This novel low-voltage instrument, which can fit in the overhead bin of an airplane, miniaturizes by orders of magnitude previously bulky, expensive, and difficult-to-use ground-based SEM features in a cost-effective portable package making EM accessible outside constrained terrestrial laboratory environments for the first time. These features will bring EM's performance and versatility to a much broader range of scientific and engineering endeavors, including manned spaceflight.

Ground-based EM's have been essential in NASA research for many years. In particular, in mineralogy and petrology, EM is used to understand the origin and evolution of the solar system, particularly rocky bodies [4]. In microbiology, EM has helped visualize the architecture of tissues and cells. In engineering/materials science, EM has been used to characterize particulate debris in air and water samples, determine pore sizes in ceramics/catalysts, understand the nature of fibers, determine composition and morphology of new and existing materials, and characterize micro-textures of vapor deposited films. EM is highly effective at investigating a wide variety of nanoscale materials/biomaterials at the core of many of NASA's inquiries.

On-orbit SEM+EDS for microgravity research and vehicle engineering: For the first time, real-time imaging and compositional measurements will be available on-orbit, enabling novel scientific inquiries in microgravity and accelerating critical mission decisions. Mochii's hand-carryable form-factor and low power consumption (0.25m tall, <12 kg, <80 W); friendly native wireless tablet interface; remote multi-user capabilities; integrated metal evaporator (on-site sample preparation); and EDS analyzer (Fig. 2) provide a rich analytical feature set facilitating microgravity science and increased crew and vehicle safety.

An important use of Mochii S is in morphological, textural and chemical characterization of extraterrestrial samples and impact craters produced by exposure to the space environment. Of particular interest are lunar, cometary, asteroidal, and Martian samples. Fig. 2 shows a small ~1 mm fragment of Martian meteorite Nakhla, analyzed in Mochii for surface composition. In addition to medium and heavy elements (Fe, Mg, Si, Cl, and Ca), Mochii's EDS detector is able to detect compounds containing light elements such as carbon and nitrogen, elements necessary for supporting organic life, in freshly cleaved surfaces. Tiny micrometer-size sections of the meteorite – small rectangular features on the surface – were micro-milled out for later analysis by high-resolution transmission EM. This result was obtained by coauthors on-site at LPSC 2018 in the speaker ready room in just 30 minutes using Mochii.

As a microgravity research facility on-board ISS, Mochii aims to also facilitate materials development benefiting terrestrial applications such as industrial crystal growth [5-7], and for validating and learning best practices to serve as a springboard for future planetary and lunar missions science, on both manned and robotic missions beyond Low Earth Orbit.

A primary engineering need for Mochii S on ISS is the rapid and accurate identification of wear and debris particles that can be causes or byproducts of malfunctions in vehicle and payload systems. These can take several months to return to earth for analyses to guide mission decisions. Mochii S can enhance crew and vehicle safety by rapid and accurate identification of microscopic mission threats, especially in time-critical situations where samples cannot be sent back.

Progress toward flight and demonstration: The Mochii payload will be stationed in the Japanese Experiment Module (JEM) powered by 120VAC inverter and connected to station ethernet and wifi (Fig. 3). The path to flight for a high-sensitivity analytical instrument includes challenging integration with ISS vehicle systems, incorporating hundreds of integration and safety requirements, each requiring independent rigorous verification and consultation with NASA experts, regulators, and crew. To date the Mochii S payload has undergone testing for command and data handling, power quality, flight vibration, and radiation testing at Johnson Space Center (JSC). The safety of Mochii's high-RPM rotating vacuum pumps and high voltage systems have been reviewed with Engineering Structures division at JSC, and topology of the system in the JEM module has been baselined. Digital controls to and from ISS over Joint Station Lan uplink have been simulated and the latencies and data rates have been found to be sufficient for successful operation of the payload from ground.

In addition to safety requirements, we are conducting performance verifications supporting mission science. A unique effect of operating a sensitive analyzer on-station is the impact of Earth's magnetic fields on the imaging beam. The Earth's magnetic field varies between 200-650 milliGauss over the ~90-minute ISS orbit, with gradients as high as 25 mG/min, which we have analyzed with experts at the European Space Agency [7]. These gradients can cause beam shifts and distortions, which we counter with extensive magnetic shielding. These measures will undergo verification testing at Goddard Space Flight Center.

The lower 10 kV accelerating voltage of Mochii, which in part enables its compact size, requires slightly different calibration standards for use off-world than the 15 kV standards common in ground instruments. Our team is producing new calibration standards that will enable semi-quantitative analysis of alloys and compounds, which we will report on at the meeting.

High-resolution analytical microscopy and microanalysis on ISS enables investigation of important new phenomena at micro- and nanoscales, and we look forward to explore opportunities for Mochii utilization as a future facility on ISS with meeting attendees. [8]

References:

[1] Own, et al, LPSC 2018.
[2] Own, et al, Microscopy & Microanalysis **23** (2017), 1082-1083.
[3] Eds, Microscopy Today **26** (2018), 34-38.
[4] Chiaramonti, Goguen, Garboczi. Microscopy & Microanalysis **23** (2017), 2194-2195.
[5] https://www.nasa.gov/sites/default/files/atoms/files/fo-technology-story-spaceice.pdf
[6] Nardini, et al. Acta D: Biological Crystallography **58** (2002), 1068-1070.
[7] http://eea.spaceflight.esa.int/portal/exp/?id=9446
[8] This work was supported by Voxa, NASA, Jacobs, and ARES.

Figure 1. Voxa's Mochii™ Electron Microscope (left) with iPad controller (right) with high resolution image of the head of a wheat plant.

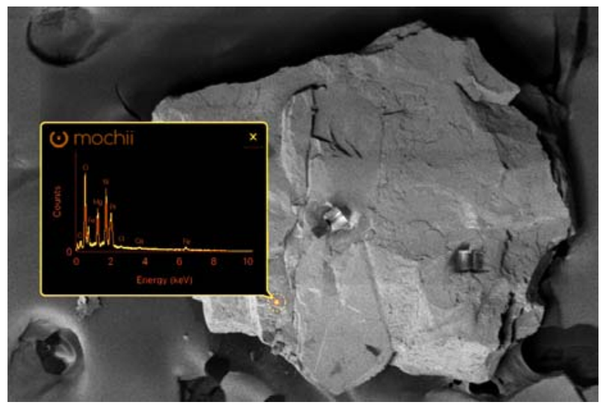

Figure 2. Energy-dispersive X-ray (EDS) spectrum acquired with Mochii S on a ~1mm fragment of Martian meteorite Nakhla. Compounds needed to support life have previously been detected on cleaved surfaces of Nakhla.

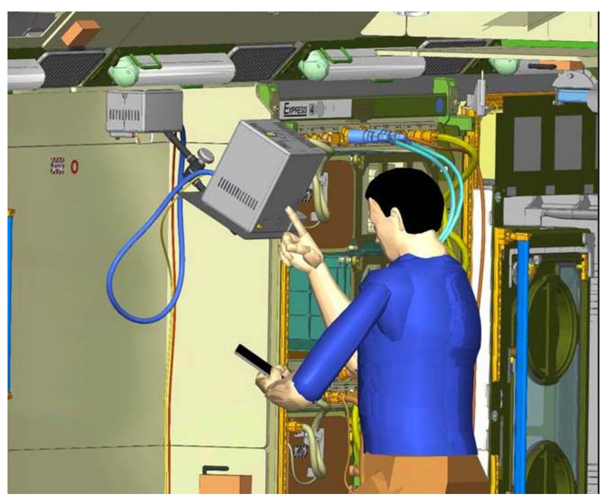

Figure. 3. Mochii topology in the Japanese Experiment Module within ISS. 95th Percentile male user shown operating Mochii with ISS-supplied iPad tablet. Mochii will be powered by 120VAC inverter and connected to station Ethernet and Wifi.