MOCHII PORTABLE SPECTROSCOPIC ELECTRON MICROSCOPE: A NEW ISS NATIONAL LABORATORY FACILITY FOR MICROGRAVITY SICENCE. 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];
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Introduction: The forefronts of human technology development and our understanding of the physical world have throughout history been expanded with the aid of sophisticated analytical tools. Many of these involve accurate and sensitive measurement of processes beyond the detection of our natural senses. Electron microscopes (EM) are such a workhorse tool, enabling efficient advances in diverse fields such as materials science, biological science, and applied physics – fields where small structures and physical processes come together. EM characterization provides a unique blend of strong optical scattering, high native resolution, large depth of focus, and spectroscopy via characteristic X-ray emission, delivering exquisite high-magnification structural imaging and simultaneous chemical analysis.

EM is highly effective at investigating a wide variety of micro- and nanoscale materials/biomaterials at the core of many academic and commercial inquiries. Ground-based EM's have been essential in mineralogy and petrology, and for understanding the origin and evolution of the solar system, particularly rocky bodies [1-2]. In microbiology, EM has helped visualize the architecture of tissues and cells. In engineering/materials science, it 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 microtextures of vapor deposited films.

Despite its strengths, the historically large size, high cost, and operating difficulty of traditional EM's has forced them to be housed at large research centers or industrial research facilities, making this powerful capability out of reach of researchers conducting work in the remote or extreme field applications, including in microgravity, until now.

On-orbit SEM+EDS for microgravity research and vehicle engineering on ISS: Mochii™ is an award-winning novel commercial scanning EM (SEM) developed by coauthors at Voxa in Seattle, WA to address the need for EM outside the laboratory (Fig. 1) [3-5]. It is the world's first portable EM, and we are preparing a spectroscopy-enabled Mochii "*S*" to serve researchers as part of the International Space Station National Laboratory (ISS NL).

This tiny low voltage microscope, which can fit in the overhead bin of an airplane, brings accessible and on-demand EM imaging to new applications previously hindered by size, complexity, and cost, including harsh remote environments including space. Among these features are a hand-carryable form-factor and low power consumption (0.25m tall, <15 kg, <100 W), user-friendly native wireless tablet interface, multi-user and remote capabilities, an integrated metal coater for on-site sample preparation, and energy-dispersive X-ray analyzer (EDS) for chemical identification (Fig. 2).

As a microgravity research facility on-board ISS, Mochii will facilitate materials development benefiting terrestrial applications such as industrial crystal growth [6-7], and support crew / vehicle safety engineering. Mochii will also support research in the biological sciences, for which we invite partners to work with us to validate novel soft material sample preparation protocols for new microgravity experiments. Mochii will further serve as a springboard for future planetary and lunar mission science, on both manned and robotic missions beyond Low Earth Orbit (LEO).

Mochii NL users will explore detailed image and spectroscopy data simultaneously with each other on iPads and iPhones from their home locations, achieving impactful collaborative scientific results real-time. An example of Mochii capabilities is in real-time 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.

Preparation for flight: The path to flight for this high-sensitivity analytical instrument includes integration with ISS vehicle systems and extensive testing to achieve flight certification. Mochii has undergone command and data handling, power quality, flight vibration, radiation, acoustic, and EMI testing at Johnson Space Center (JSC). Safety of Mochii's high-RPM rotating vacuum pumps and high voltage systems has been reviewed with domain experts, and the topology in JEM was baselined (Fig. 3). Digital uplink latency and data rates are sufficient for effective operation of payload from ground.

In addition to safety and integration, we have been conducting performance verifications to validate the ability to support mission science. Coauthors at Astromaterials division at JSC are working to evaluate imaging and spectrometer resolution using references including samples of historical significance [2]. The spectrometer has been found to have excellent sensitivity to low atomic number elements, exceeding the performance of many of NASA's ground instruments, and also has sufficient imaging resolution to study chemical composition of sub-micrometer structures paralleling past studies. The 10 kV accelerating voltage of Mochii, which in part enables its compact size, requires slightly different calibration standards than the 15 kV standards common in ground instruments. Our team is producing new standards that enable semi-quantitative analysis of alloys and compounds.

A unique challenge of operating SEM in LEO is that Earth's magnetic field presents continuous magnetic field gradients as high as 25 mG/min, and spanning over 450 mG peak-to-peak through the ISS orbit. This can cause the beam to shift position or distort, impacting measurement accuracy. We have analyzed these effects with experts at the European Space Agency [8] and mitigate it with integrated magnetic shielding which will be tested before deployment.

High-resolution analytical microscopy and microanalysis on ISS enables investigation of important new phenomena at micro- and nanoscales in microgravity for the first time. We look forward to explore opportunities for high–impact microgravity science utilizing Mochii ISS NL facility with meeting attendees. [9]

References:

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

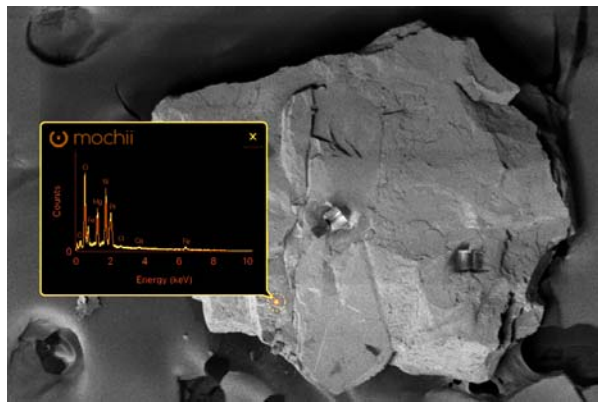

Figure 2. Energy-dispersive X-ray (EDS) spectrum acquired with Mochii S on a ~1mm fragment of Martian meteorite Nakhla. Compounds needed to support life have previously been detected on cleaved surfaces of Nakhla.

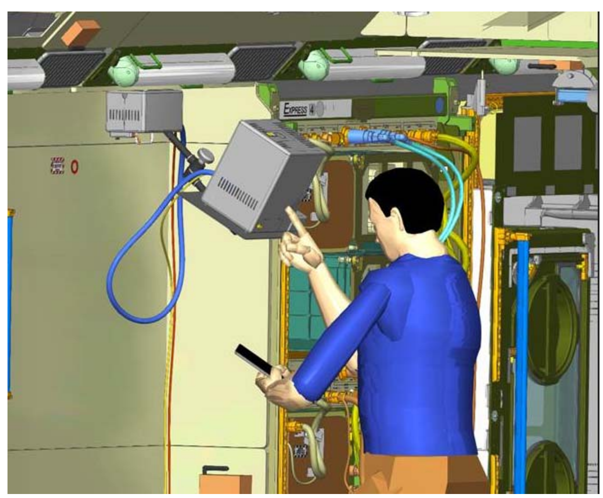

Figure. 3. Mochii topology in the Japanese Experiment Module within ISS. 95th Percentile male user shown operating Mochii with ISS-supplied iPad tablet. Mochii will be powered by 120VAC inverter and connected to station Ethernet and Wifi.