PORTABLE ELECTRON MICROSCOPY FOR ISS AND BEYOND. C. S. Own[1], J. Martinez[2], J. Cushing[1], 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: 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 an example of 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. 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 [1]. 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.

Despite exquisite optical performance and versatility, EM's are traditionally large, heavy, and have high power consumption. They are also expensive so they tend to be housed at universities and large research institutions, or at major industrial laboratory sites with support staff, supplies, and skilled operators. Since most organizations cannot support their own EM, samples are often sent to these large institutions and service centers to be imaged, at great expense and often with delay of weeks to months for complex analyses. Complexity, high cost, and maintenance associated with collecting EM image data has until now severely limited fields in which EM is used [2]. Making EM accessible outside constrained terrestrial laboratory environments will bring EM's performance and versatility to a much broader range of scientific and engineering endeavors, including in space.

Portable SEM demonstrator on ISS: Mochii™ is a novel portable commercial scanning EM (SEM) developed by coauthors at Voxa in Seattle, WA to address the need for EM outside the laboratory (Fig. 1) [3]. This tiny low voltage microscope, which can fit in the overhead bin of an airplane, has features that bring 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 hand-carryable form-factor and low power consumption (0.25m tall, <12 kg, <80 W), user-friendly native wireless tablet interface, multi-user and remote capabilities, an integrated metal evaporator for on-site sample preparation, and optional energy-dispersive X-ray analyzer (EDS) for chemical identification (Fig. 2).

We are in process to prepare a spectroscopy-enabled Mochii "*S*" for manned spaceflight, supported by NASA's SBIR program, Jacobs/JETS, and private funding. Many of NASA's core inquiries will be significantly enhanced by on-site analyses including on manned vehicles and robotic missions, enabling NASA to address a current blind spot (e.g., micronic particles and structure-chemical relationships) in its detection and analysis toolset.

Mochii will demonstrate real-time, on-site imaging and compositional measurements aboard the International Space Station (ISS), accelerating answers to many scientific inquiries and mission decisions. The Mochii ISS demonstrator will also serve as a research platform for novel microgravity research facilitating materials development in terrestrial applications, 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 (LEO).

Example space applications: Mochii is an excellent analytical tool for the 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, evidenced by small rectangular features on the surface, were micro-milled out for later analysis by high-resolution transmission EM.

A second example highlighting advantages of EM in space is in the study of microgravity crystallization dynamics [4-5], shown in Fig. 3. NaCl is optically transparent and its fine faceted surfaces are difficult to clearly image using light microscopy. EM elucidates these tiny structures and is equisitely sensitive to differences in experimental conditions during crystal growth. While these samples were imaged post-mission on Earth by Mochii, Mochii S will enable these and other experiments to be conducted on-vehicle, including those in which irreversible phase or chemical transitions occur in the presence of gravity or atmospheric conditions. Such studies would be impossible if re-entry back to Earth is required before analysis.

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 brapid and accurate identification of microscopic mission threats, especially in time-critical situations where samples cannot be sent back.

On-vehicle crew time is extremely precious, and innovations in user experience and interface facilitate effective use on ISS. Collaborative easy-to-use and responsive multi-user interfaces enable scientists on the ground to remotely operate the system while minimizing the impact to crew time. Another innovation is a quick-release optical column cartridge system that enables instant removal and insertion of factory pre-aligned full column cartridges with pre-packaged optical configurations [6]. These innovations minimize impact to end users' cognitive and service load and support more efficient analyses and reduce overhead, a key in field use where time can be essential.

Portable EM is a significant paradigm shift in microscopy, taking high-resolution analytical microscopy and microanalysis out of the lab and into novel environments, and increasing access to important scientific phenomena at the micro- and nanoscale [7]. At the meeting we will share these and other applications, and explore with attendees opportunities for new applications for Mochii as a future facility on ISS.

References:

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[7] 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.

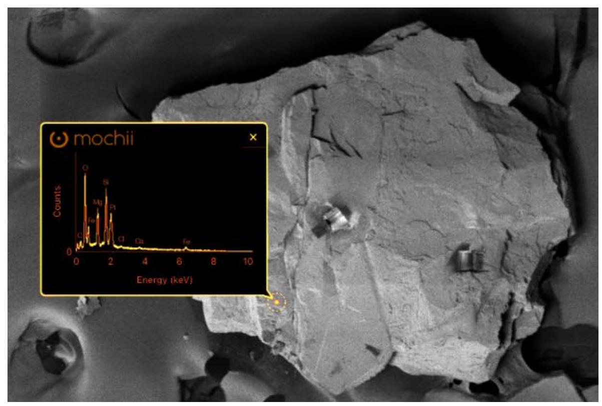

Figure 2. Energy-dispersive X-ray (EDS) spectrum acquired with Mochii S on a ~1mm fragment of Martian meteorite Nakhla. Compounds necessary for supporting life are detected on the surface.

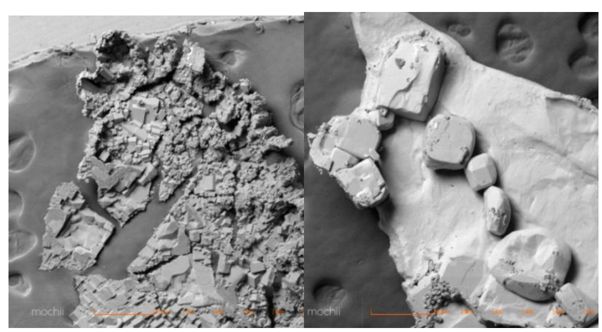

Figure. 4. (left) NaCl polycrystals formed in earth gravity by evaporation, and (right) large single crystals of NaCl formed in microgravity by evaporation, both imaged in Mochii at same magnification. A small number of nucleation sites form large stable monolithic crystals in microgravity.