FLIGHT READINESS OF MOCHII ISS-NL PORTABLE SPECTROSCOPIC ELECTRON MICROSCOPE. C. S. Own[1], J. Martinez[2], T. DeRego[1], L. S. Own[1], Morales Z[1], K.T. Thomas-Keprta[2], Z. Rahman[2], S. Clemett[2], T. Graff[2], D.R. Pettit[3], M. Reagan[4];
[1]1001 26th Ave E, Seattle, Wa 98112, csown@voxa.co. [2]Jacobs, Johnson Space Center, Houston, TX 77058; [3]FOD Johnson Space Center, Houston, TX 77058; [4]EISC Johnson Space Center, Houston TX 77058.

Introduction: Electron microscopes (EM's), are workhorse tools serving diverse fields such as materials science, biological science, and engineering. Scanning EM's (SEM's) in particular enable high magnification study and pinpoint chemical analyses of structures down to the nanoscale by providing a powerful blend of strong optical scattering, high native resolution, large depth of focus, and energy-dispersive X-ray spectroscopy (EDS). Mochii is the world's smallest production electron microscope, scheduled to travel to the International Space Station (ISS) this spring where it will serve as an ISS National Laboratory (ISSNL) microgravity facility on successful demonstration [1].

We previously reported on progress preparing Mochii for space flight, in particular flight integration verifications and science application testing [1]. These included standard integration testing such as electromagnetic interference and flight vibration, and extend to unique functional testing such as magnetic susceptibility and extreme analog environment testing under the sea. Presently, Mochii payload flight hardware has completed testing and was handed over to NASA's ISS payload processing facility in Houston. It will make its way to the the east coast for launch currently scheduled on Space-X CRS-20 for Mission increment 62 in March 2020.

Undersea Flight Analog Testing: NASA's Extreme Environment Mission Operations (NEEMO), is a unique space environment operations and equipment test program implemented 63 ft. underwater at the Aquarius Reef Base in the Florida Keys [3]. NEEMO missions bring together mission operators, astronauts, scientists, technology developers, and vehicle specialists to a flight-like environment to conduct extravehicular activity (EVA), perform mission science and conservation on gathered samples, test new technology, and perform medical evaluations benefiting both space and terrestrial applications. Mochii recently participated in the 23rd NEEMO mission (June 11-21, 2019), where it received dedicated crew feedback on training, procedures, and end-to-end operability [4]. NEEMO offered the Mochii team full immersion in a NASA operational flight-like environment, enabling practice providing the engineering support needed by NASA and public researchers (Fig 1). Potential ISSNL customers operated Mochii while on-vehicle from across the continent, echoing planned ISS utilization.

Over NEEMO's 10-day mission, crew members Drs. Ari, Pomponi, Watkins, and Cmdr. Cristoforetti (Fig. 2) each conducted *in-situ* analyses on samples acquired from the marine environment on-board and during EVA, using model crew procedures under test for use on ISS. These analyses – of cnidaria skeleton, brine shrimp eggs, sediment, and marine sponge as well as pre-prepared samples – model activities at the forefront of exploration on other worlds, for example for future crewed missions to the Moon and Mars.

Over multiple visits by crew mirroring ISS activities, plus simultaneous remote analyses by researchers at mission control and across the country, we were able to sample the diversity and chemistry of the local reef environment. In the cnidarian skeleton, C, O, Na, Ca, and P compounds were identified, common where Ca-shelled organisms are abundant, while sediment consisted primarily of coral and reef crustacean shells and skeletons, plus silica. Marine sponges sampled during EVA had Ca shells and silicate spines. Sulfur and metals important to the ecosystem such as Ni, Fe, Mg, and Al were detected in trace amounts in organic structures. Surprisingly, marine samples imaged well without need for the metal coating capability of Mochii, expediting results. Fig. 3 shows an analysis on sediment gathered by crewmember Watkins showing compounds from the local geology. The ability to pinpoint at sub-micron scale where these compounds con-

Figure 1. Mochii S installed underwater in Aquarius Reef Base in the Florida Keys.

centrate will have significance for exploration activities beyond low earth orbit (LEO), for which sample return will be highly selective, and instantaneous analyses can be crucial for time-sensitive decisions.

The Mochii team was fortunate to achieve all target mission objectives, ranging from end-to-end crew operations testing for ISS (including remote telemetry outages and planned loss-of-signal), to crew-driven *in-situ* exploration of the environment at the microscopic scale. In addition to reducing mission risk, NEEMO XXIII marks the first time EM and spectroscopy have operated successfully in an undersea environment, benefiting new areas such as ocean exploration, natural resources prospecting, and ocean vessel safety.

Vehicle certifications, science verifications, and final preparations: Mochii has now passed all ISS-required flight certifications, including power quality, EMI/EMC, radiation safety, acoustic, thermal, command & data handling, and human factors integration. Despite reduced requirements afforded to modified commercial off-the-shelf (COTS) payloads like Mochii, special non-required functional testing was crucial. In particular, due to sensitivity of electron optical instrumentation, iterative flight vibration testing was conducted over several design cycles, with final acceptance testing conducted in flight foam to achieve two-vehicle certification (Cygnus and Dragon).

The impact on the imaging beam by Earth's magnetic field in LEO–which varies 200-650 mG over the ~90 min ISS orbit with gradients up to 25 mG/min [5]–required additional measures to avoid beam shifts and distortions. We constructed a custom magnetic test apparatus called Monarch to perform iterative testing of passive magnetic shielding in Mochii, and achieved low beam drift levels expected to support sub-micrometer EDS microanalysis in LEO.

Engineering, geological, and reference calibration samples were selected and prepared into a specialized on-orbit sample preparation field kit. On-ground reference analyses were performed using both Mochii and larger laboratory SEM's for comparison with upcoming orbital results. We now look forward to conducting the first demonstration of high-resolution analytical microanalysis on ISS, which we expect will open new opportunities to explore phenomena in microgravity at the micro- and nanoscales. [5]

References:

[1] Own, et al, LPSC 2018.
[2]https://www.nasa.gov/mission_pages/NEEMO/index.html
[3] Own, et al, Microscopy & Microanalysis (2019), https://www.microscopy.org/MandM/2019/program/abstracts/PDP-6.pdf.
[4] http://eea.spaceflight.esa.int/portal/exp/?id=9446
[5] Work supported by Voxa, NASA, Jacobs, and ARES.

Figure 2. NEEMO XXIII crew members on EVA outside Aquarius Reef Base, located 63 ft. underwater off Conch Reef in the Florida Keys National Marine Sanctuary. https://aquarius.fiu.edu/

Figure 3. Spectroscopy and image of sediment particle gathered on EVA and analyzed *in-situ* in the underwater Aquarius habitat by NEEMO XXIII crew member J. Watkins. Some sediment contained calcium carbonate from deceased organisms, whereas others (not shown) were silicate-based.

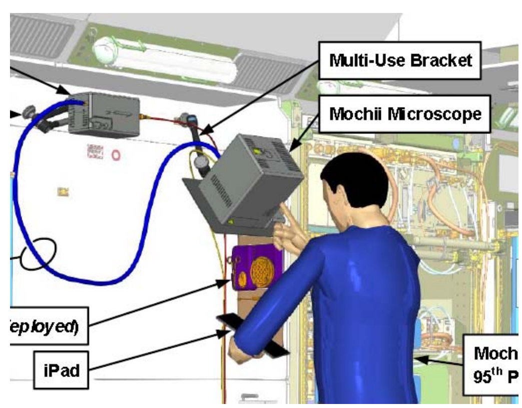

Figure. 4. Mochii ISS-NL installation plan in the Japanese Experiment Module on ISS. 95th-percentile male user shown operating Mochii using ISS-supplied iPad tablet. Sample prep field kit is mounted right of Mochii on cabin bulkhead.