EXPLORING DEEP SEA HYDROTHERMAL VENTS ON EARTH AND OCEAN WORLDS.

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The Mission: InVADER (In-situ Vent Analysis Divebot for Exobiology Research, Figure 4.1, https://invader-mission.org/) is NASA's most advanced subsea sensing payload, a tightly integrated imaging and laser Raman spectroscopy/laser-induced breakdown spectroscopy/laser induced native fluorescence instrument capable of *in-situ*, rapid, long-term underwater analyses of vent fluid and precipitates.

Such analyses are critical for finding and studying life and life's precursors at vent systems on Ocean Worlds. To demonstrate the scientific potential and functionality of the instrument, in July 2021 our team will deploy InVADER on the Ocean Observatories Initiative's (OOI) Regional Cabled Array (RCA), a power/data distribution network off the Oregon coast, at the underwater hydrothermal systems of Axial Seamount, the largest and most active volcano on the western boundary of the Juan de Fuca tectonic plate.

InVADER will perform unprecedented, high resolution *in-situ* laser measurements at two active hydrothermal vents located at a water depth of 1500 m and over 300 miles offshore. Data will be sent back to shore over the RCA fiber-optic cable for immediate analyses. The power and bandwidth provided by the RCA allow real-time evaluation of InVADER sensor data and testing science collection protocols.

In 2021-2021, InVADER will record *in-situ*, online (continuous) data from two test sites in the ASHES hydrothermal field of Axial seamount. InVADER will be placed on the ground ~0.5 meters from chimney precipitates showing exposed minerals and organic content. The UNOLS ROV will use our coring tool and its own manipulator and cameras to take ground truth samples as part of the InVADER deplotment.

In contrast to existing methods, InVADER allows *in-situ*, autonomous, non-destructive measurements of these vent characteristics. InVADER will fill these gaps, and advance readiness in vent exploration on Earth and Ocean Worlds by simplifying operational strategies for identifying and characterizing seafloor environments. We will use statistical analysis tools for the fusion of multi-sensor datasets, and develop real-time science data evaluation and payload control routines to establish, and then validate, adaptive science operations strategies that maximize science return in a mission-like scenario.

InVADER features a powerful combination of rapid, in-situ, standoff (non-contact) analyses and sampling techniques for the co-registered, context preserving, geo/bio/mineralogical characterization of vent fluids and precipitates. The sensor package is articulated to allow study of region of interest on a vent of ~2m × 2m.

This project will transform the technological and operational arsenal available for future Ocean Worlds exploration. More immediately, it will broaden the scientific knowledge and techniques available to terrestrial science and exploration today through transformative innovations in both technology and science operations. First, we will integrate a science payload into a cost-effective underwater platform.

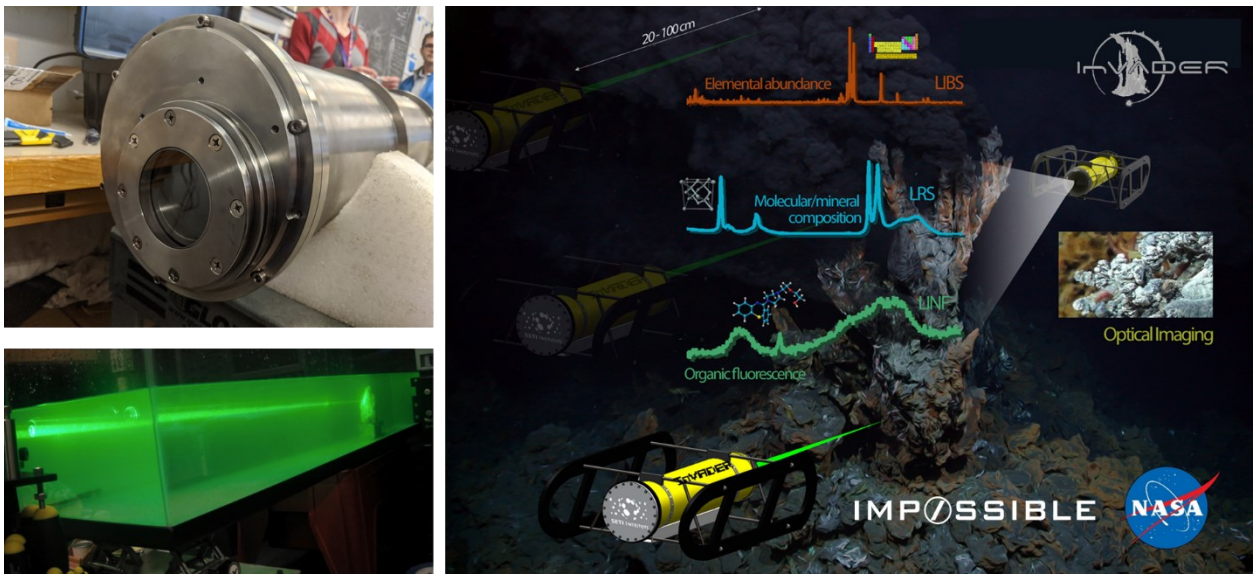

Figure 1. InVADER is fuly assembled and undergoing environmental qualification in early 2021. System performance has been verified and validated in laboratory environment and the system will launch in July 2021.

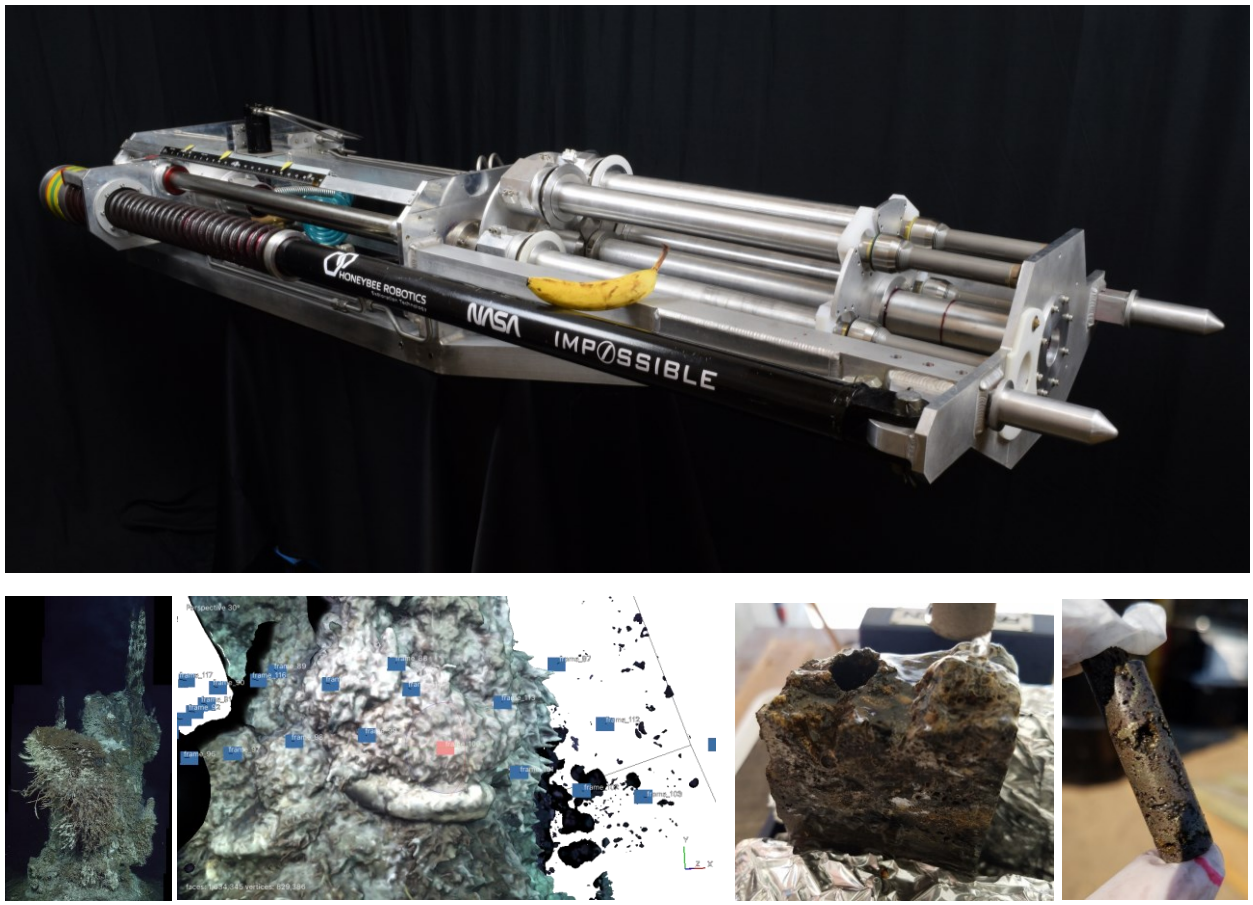

Figure 2. (Top) InVADER sample collection mechanism (Honeybee Robotics, see companion abstract in this issue). Bottom) target chimney for 2021 deployment (UW/APL/NSF) and 3D shape-from-motion reconstruction of chimney vents using image sequences taken from real dive video footage at vent sites (APL/JPL). The reconstruction faithfully capture many of the detailed features, including tube worms and limpets.

Second, we will advance adaptive multi-sensor data product acquisition with real-time integrated data management and extraction of scientific information.

By advancing operational strategies for a new payload and establishing a clear path-to-flight for planetary exploration, InVADER will provide valuable scientific, technological, and operational insights into the robotic exploration of hydrothermal vents. Thus, InVADER will lower the risks of planetary vent exploration through synergistic technology and science operations demonstrations and the optimization of InVADER's instruments.

InVADER features the first long-term-resident, real-time, combined imaging and spectroscopy payload for underwater sensing. Thus, InVADER will pave the way for future autonomous ocean/vent exploration efforts, with applications to ocean sciences and future targeted exploration of off- and on-world oceans.

Earth Oceans Application: Characterizing Deep Sea Habitats and Benthic Communities: A recent report entitled America's Oceans: A Decadal Vision by the National Science and Technology Council identifies pressing research needs within the ocean science and technology enterprise for the decade 2018–2028. One priority, Assessing Marine Critical Minerals, included the objectives to "*identify and quantify the location, size, and nature of important deep-sea minerals… and conduct basic and applied research to characterize the effects of deep-sea mining on vulnerable marine ecosystems, including documentation of deep-sea biodiversity, and improved prediction of the scale and extent of environmental impacts from deep-sea exploration*."

InVADER puts forward a zero environmental impact exploration platform service based on autonomous non-destructive and non-invasive mineral data and deepsea catalog of habitats and benthic communities characterization. In addition, InVADER can discover and evaluate seafloor deposits of critical minerals through expansive and cost-effective robotic surveys that will unlock marine resources at the speed that rapid decarbonization requires.

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