AUTONOMOUS CONCEPTS TO EXPLORE THE SEAFLOOR IN OCEAN WORLDS.

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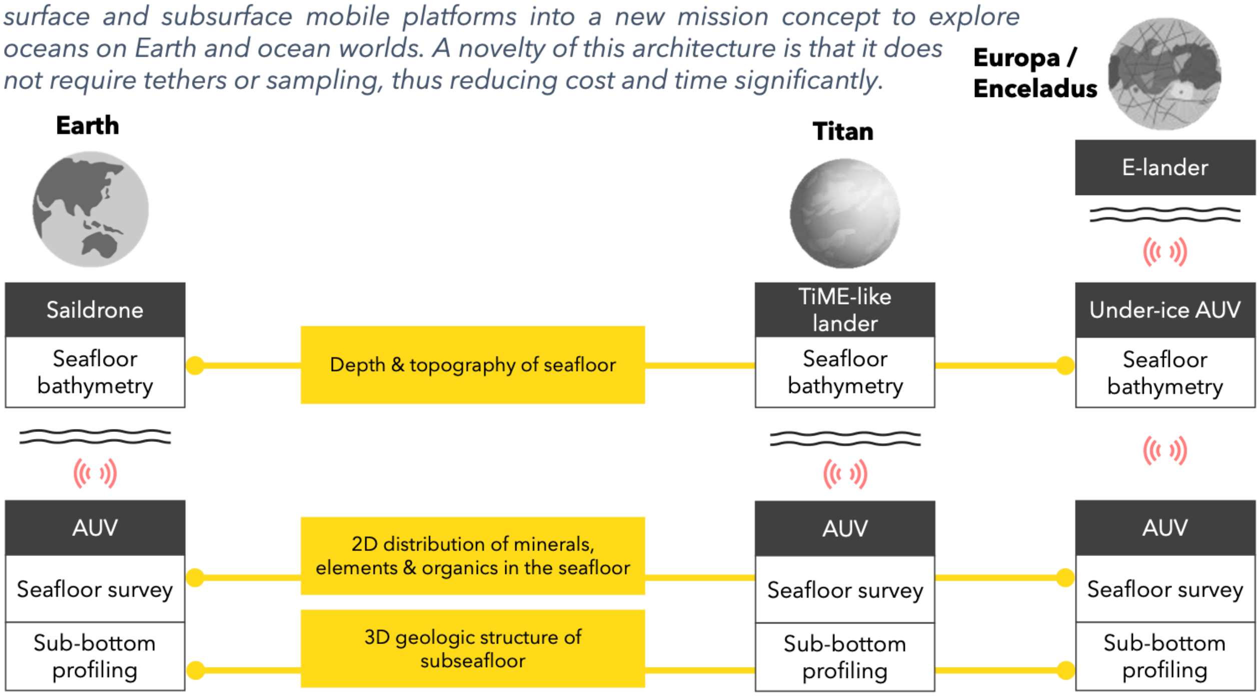
Figure 1. This concept combines leading-edge sensing technologies and state-of-the-art autonomous surface and subsurface mobile platforms into a new mission concept to explore oceans on Earth and ocean worlds. A novelty of this architecture is that it does not require tethers or sampling, thus reducing cost and time significantly.



The Mission: Our mission concept, STINGRAI—Seafloor Telepresence INvestigation of Geobiochemistry with Realtime Autonomous Intelligence—is a new way to explore the ocean seafloor on Earth and ocean worlds using state-of-the-art acoustic and optical sensing and at-the-edge computing technologies; that is, a mission that records, processes, and interprets new opto-acoustic data types in-situ, where the data is generated (Figure 1).

We define exploration as the acquisition and interpretation of comprehensive data and information needed to understand seafloor characteristics such as depth, topography, type, composition and distribution, and underlying geologic structure.

STINGRAI achieves expansive and cost-effective exploration of the seafloor using an innovative combination of high-endurance autonomous platforms: AUV (autonomous underwater vehicle) and USV (uncrewed surface vehicle), and a suite of high-performance stand-off sensing technologies: multi-beam echo sounder, laser spectroscopy suite, and acoustic sub-bottom profiler. We use a combination of proven commercial acoustic instruments and vehicles and a high-TRL optical instrument funded by NASA via path-to-flight technology development programs.

A new paradigm in seafloor exploration. Current methods to explore the seafloor are ex-situ, ship-based, requiring box-coring and dredging for hard-bottom substrate; shipboard sample split and return to on-shore labs for analysis and interpretation; AUV survey and identification of regions of interest that may be visited via ROV on subsequent dives to ground-truth locations of interest; and database creation and release.

The combination of vehicles and sensors we put forward with the STINGRAI mission concept will deliver 2D compositional maps and 3D structural maps in-situ with zero environmental impact stand-off and sample-less exploration surveys (Figure 2).

Based on known performance metrics of the technologies described below, we estimate that, with STINGRAI, 100 km^2 surveys can be completed in days, not months. This is the type of transformative innovation that our partnering agencies, BOEM, USGS, and NOAA, and other agencies and institutions require to advance ocean exploration goals. And the type of path-to-flight innovations NASA needs to move the Ocean Worlds Program forward. This is how the mission works:

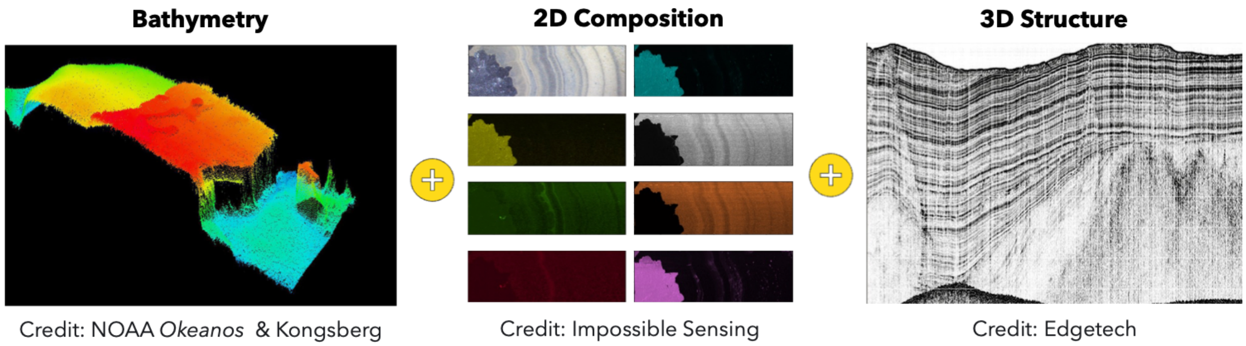


Figure 2. Examples of data products from acoustic and optical instruments that will be obtained with STINGRAI. Bathymetry and 3D structure maps are data from seafloor and sub-seafloor. 2D composition is data from our laser spectroscopy suite breadboard.

Expanded USV bathymetry: STINGRAI's USV performs multibeam bathymetric mapping at spatial resolutions between 0.9 to 31 m (at depths of 100 to 3600 m). The USV maps identify the location and distribution of seamounts and associated hydrothermal activity, if any.

AUV compositional surveys: Once seamounts are located through USV bathymetry, the STINGRAI AUV acquires: (a) sub-cm scale bathymetry of seamounts using SAS (synthetic aperture sonar); (b) Raman and fluorescence spectral datasets; and (c) profiles of sediment layers concurrently. The AUV carries out onboard processing and analysis of the data (at-the-edge computing) in real time and deliver 2D compositional maps and 3D structural maps of the seafloor (Figure 2). Variability of sediment thickness provides constraints as to how useful these techniques are for exploration as sediment cover.

Obtaining compositional maps of the seafloor *in-situ*. STINGRAI features this new capability, which is not yet available commercially. Impossible Sensing (IMS) has developed new hardware and software technologies that STINGRAI utilizes to identify mineral deposits, distal indicators of seafloor mineralization, and associated biological communities non-invasively and non-destructively from AUV. IMS developed these technologies under several NASA SBIR and MatiSSE awards. This project brings IMS's space exploration technologies to the seafloor, allowing, for the first time, rapid compositional mapping *in-situ* using a laser spectroscopy suite. Thus, we drastically improve functionality and sensitivity in exploration missions, deep ocean and deep space, with new, high-TRL technologies that are being developed for spaceflight.

Our laser spectroscopy suite (is an innovative combination of three technologies: real-time autofocusing, ultra-fast beam steering, and ultra-high sensitivity laser Raman and laser fluorescence spectroscopy. A shape-changing spherical lens allows for continuous tuning of the focal length/working distance to handle seafloor topography while maximizing signal return. IMS developed this under NASA SBIR Phase II (#80NSSC19C0312). The tunable lens is combined with an ultra-fast (kHz) mirror gimbal-less two-axis scanning mirror architecture optimized for optical beam scanning, also developed by IMS under NASA SBIR Phase II (#80NSSC19C0333). The optical arrangement of both tunable lens and ultra-fast scanning mirror allow mapping a 100 m^2 field of view with nearly arbitrary raster patterns at ultra-high resolution (<7 mm/pixel at 5 m distance) in under 60 min. Resolution can be adjusted for faster survey analysis that can yield high-throughput 100 m^2 spectral maps during AUV transects that are limited only by AUV speed.

Earth to Space. Advancing missions to determine the astrobiological potential of planetary oceans requires focused, ongoing efforts to characterize Earth's own seafloor using innovative technologies and building new exploration capabilities. That's why we plan to validate our new mission concept in terrestrial use cases first and demonstrate STINGRAI's ability to lower time and cost of exploration, thus filling a strategic capability gap in ocean exploration on- and off-earth.

In 2022 we will perform technology validations of IMS's NASA-funded optical sensing subsystem onboard an ROV (remotely operated vehicle) for geochemical vectoring-based critical mineral deposit localization and cataloguing of deep-sea habitats and benthic communities in priority areas of the Clarion-Clipperton Fracture Zones. This validation will de-risk critical technologies and concepts of operation of our mission concept, a critical step in the development of new autonomous sensor platforms and adaptive survey strategies for seafloor exploration, and advance both scientific and technological readiness of a new approach to explore oceans on- and off-planet.

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