DON'T INVENT THE WHEEL:
SEEKING LIFE IN THE SUBSURFACE OF MULTIPLE ICY OCEAN WORLDS BY 2050

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Icy ocean worlds such as Europa, Enceladus and Triton are compelling targets for the search for life. These planets present together a similar challenge for future exploration and the search for life. These worlds have different science questions, different engineering challenges, and different priorities than the Moon and Mars. Most importantly, the most critical and potentially impactful questions must be answered NOT at the surface, but deep within the subsurface in aqueous environments. We must not use our experience with Mars as an intuitive guide for how to approach their exploration. Rather, we require a holistic approach to the science of these bodies and the way that we envision exploring their subsurfaces.

Ocean Worlds present unique engineering challenges that need critical investments.

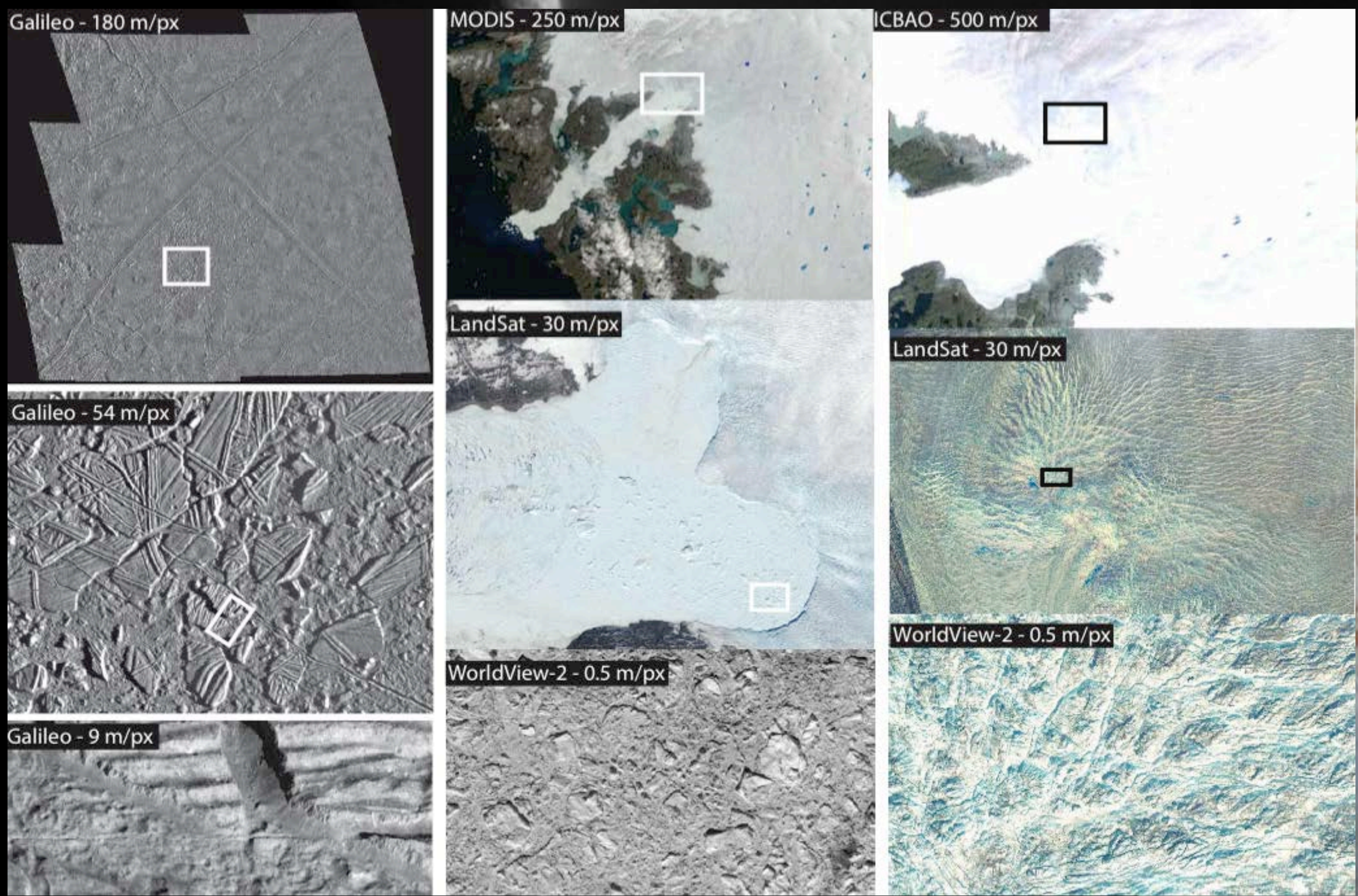
Steps needed to realize the goal of multiple moon subsurface exploration by 2050:

0) Adjusting terrestrial planet based intuition for exploration and science questions
The ocean worlds will not be host to surface biospheres—photosynthesis is inefficient and the temperatures and radiation environment are extreme. *They are not depositional or erosional.*

1) Dedicated Icy World technology programs are needed:
- -EDL, navigation, and subsurface access.
- -PSTAR (etc) as backbone and testbed, *background*
- -Competitive largeer scale programs, keep contractors and centers honest, *feasibility studies*
- -Mission competition and center innovation, *pre-phase A*

2) Dedicated life detection instrumentation programs ground tested on Earth & in space
- -New technology is at a disadvantage in MATISSE and PICASSO, *strategy*
- -COLDtech and Astrobiology instrument programs, *backbone*
- -Flight opportunities to qualify new life detection capability, *TRL 7 or better*

Icy World Surface Access

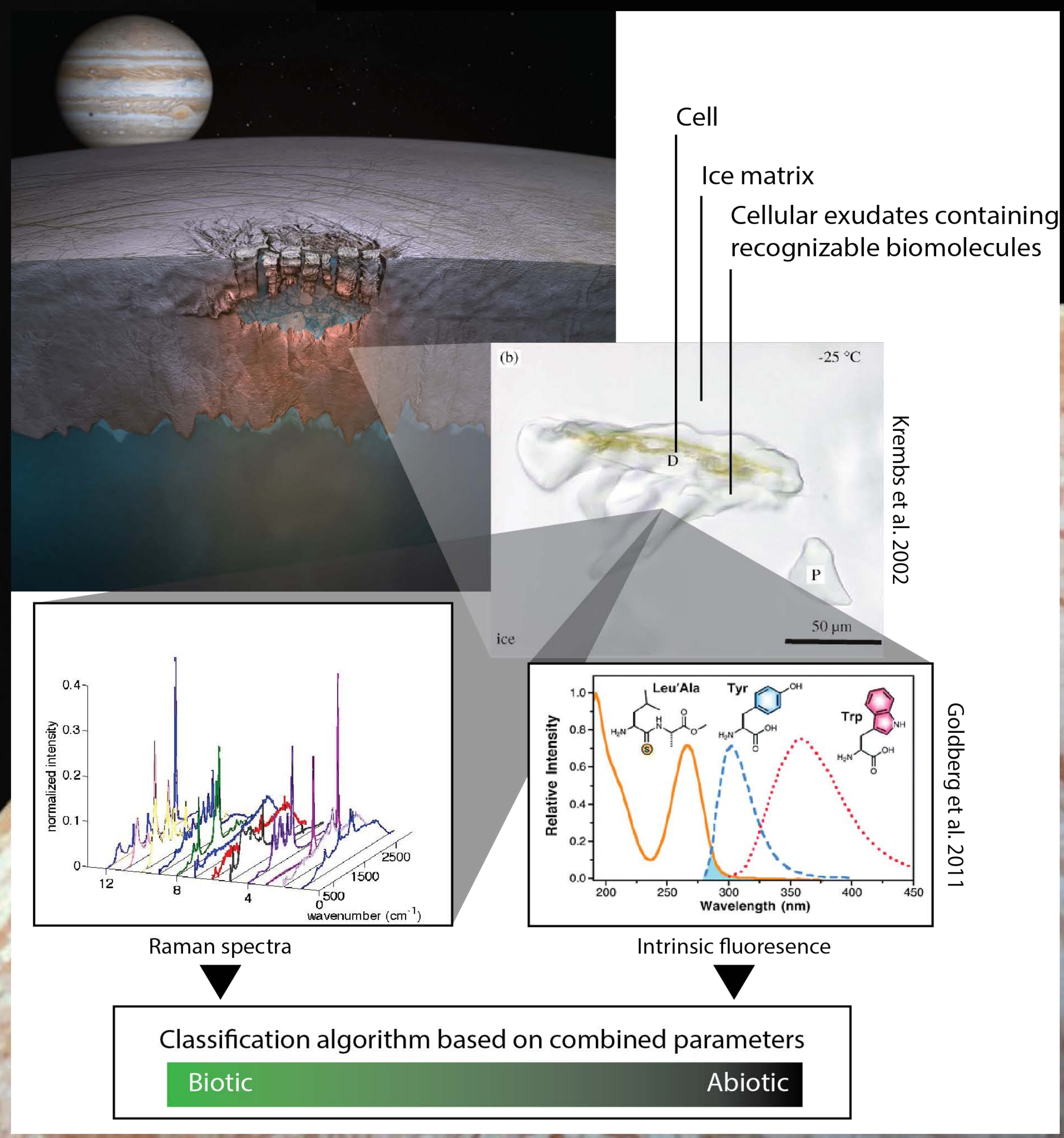


How Do We Scratch the Surface?
1) *We have to land with no atmosphere.* At present, landers to Europa or Enceladus are (nearly) prohibitively expensive since landing systems grow exponentially depending on landed mass. The existing landing systems for Mars, hybrids of the sky crane design, are the best solution currently available, but it is not clear that this is the optimum solution for bodies without atmospheres.
2) *Icy surfaces are unforgiving.* These surfaces require better landing technologies. The Europa Lander study was limited to a 25 kg science payload, constrained by the sky crane system. This is an insufficient payload to achieve science in the subsurface.

NASA Strategic Document Goals for Key Ocean Worlds

Study	Questions
Visions & Voyages Decadal Survey	Q4. What were the primordial sources of organic matter, and where does organic synthesis continue today? Q6. Beyond Earth, are there modern habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?
NASA Exploration Roadmap	Europa Explorer (Europa Multiple Flyby Mission) Neptune-Triton Explorer Europa Astrobiology Lander
NASA Astrobiology Roadmap	I. How Can We Assess Habitability on Different Scales? II. How Can We Enhance the Utility of Biosignatures to Search for Life in the Solar System and Beyond? III. How Can We Identify Habitable Environments and Search for Life within the Solar System? I. What are the Fundamental Ingredients and Processes That Define a Habitable Environment? IV. What are the Processes on Other Types of Planets That Could Create Habitable Niches? II. How Will We Know When We Have Found Life? IV. How Can We Account for "Weird Life" That May Have Alternative Biochemistry or Alternate Habitability Constraints?
OPAG Goals Document	Triton: Does it have an ocean? What is the current heat flow? Has cryovolcanism played a major role in renewing the surface? What does Triton's surface chemistry tell us about its origin? Is oceanic chemistry expressed on its surface? Enceladus: What is the composition of the ocean, sea, or liquid reservoir that apparently feeds the plumes erupting from the South Polar Terrain? Is Enceladus habitable? Europa: How does Europa's ice shell work? What is the distribution of water within Europa? What is Europa's surface, ocean, and interior composition? Is Europa habitable today? Was it ever? Has life arisen on Europa?

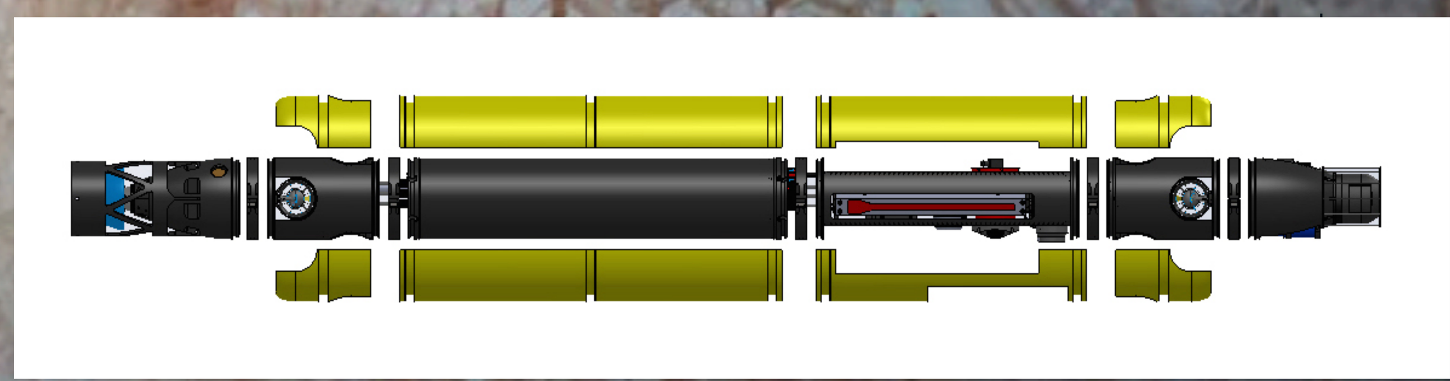
Real Life Detection Strategies



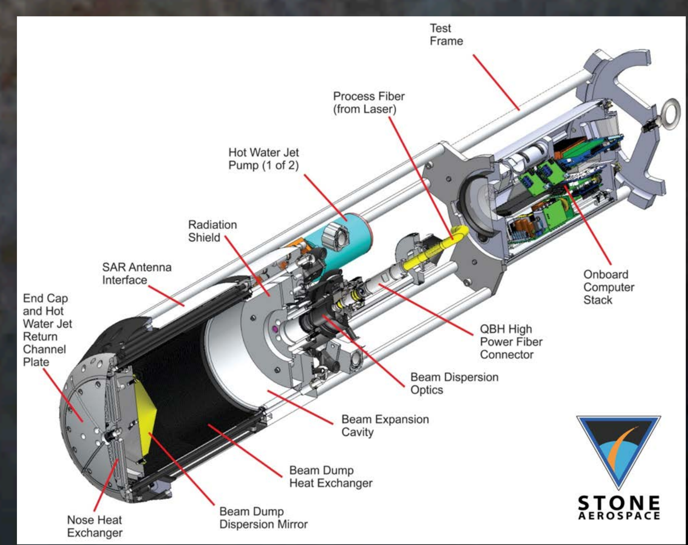
Life detection is a complex goal requiring multiple lines of corroborating evidence to make convincing detections. But discreet samples cannot easily be passed through multiple instruments. This is especially true when destructive techniques are used, i.e. GCMS. We must realize the capability to run many tests on a single source, and develop non-destructive techniques for more robust life detection. Information about organic molecules is crucial but not sufficient. Rather a range of potential biosignatures in ice or oceans must be identified to make a classification of the material as biotic or abiotic.

Scalable rovers exist for Mars, where science payload changes but the architecture remains constant, saving money and risk. Scalable landing and aerial systems exist that are shared between Venus and Titan. No such systems exist for sub-ice and ocean exploration. However, they could. Terrestrial oceanography does not drive towards small robotic systems because of boats and large-scale logistical capabilities. The planetary Science community will necessarily drive the miniaturization of ocean and ice technologies. Competition is needed early to ensure that no one intuitional response creates long-range loss of capability or cost growth that would impede progress in ocean world exploration within and below ice.

Scalable Ocean World Robotic Systems



Left: Icefin, Georgia Tech, an under ice AUV/ROV with swappable instrument bay.
Bottom: Left-Ice Shuttle, Bremen Univ./AWI melt probe for Eurex. Middle-Valkyrie, Stone Aerospace, melt probe. Right—LENG, Bremen Univ/AWI, Long-range UUV.



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